ICSMMCT 2K25
2nd
INTERNATIONAL CONFERENCE
IPS COLLEGE OF TECHNOLOGY & MANAGEMENT, GWALIOR

ICSMMCT 2025

2ND INTERNATIONAL CONFERENCE

ON

Smart Material, Manufacturing and Characterization Techniques

27-28 December 2025 INDIA

Planting Future

Organized By

IPS College of Technology & Management, Gwalior

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Edited by

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Dr. Vijay Verma
Mr. Vineet Raj Singh Kushwah

PROCEEDINGS
Conference

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ABOUT *Host Institute*

IPS College of Technology and Management was established in the year 2007, aiming to become the most preferred engineering college in central India for students and to obtain a world-class engineering education, thus developing into the leaders of tomorrow. IPS CTM endeavours to make the students technologically superior and ethically strong, who in turn, shall contribute to the advancement of society and humankind. The committed faculty advances the boundaries of knowledge through interdisciplinary research.

The Institute, on its part, pursues continuous development of infrastructure and enhancement of state-of-the art equipment to provide our students a technologically up-to-date and intellectually inspiring environment of learning, research, creativity, innovation, and professional activity.

Research and Development Cell of the institute facilitates faculty members and students to shaper their skills through various projects and activities. Research and Development Cell was established to encourage faculty members to engage themselves in research work. The R & D Cell also promotes and inspires students to have research oriented approach by creating a research environment in the institute. The objective of the R & D Cell is to guide the students to focus their research skills to create the best form of technology needed for human excellence. The performance of any R&D Cell is measured in terms of publications, patents, hosting conferences /seminars, funding received and industrial consultancy. We have taken solid steps to achieve these targets and are continually moving towards further success in these areas. We have been doing this by organizing workshop, short term training program and international conference, producing technical magazines, undertaking several research projects, inviting industrial experts and collaborating industrial visit to ignite confidence among the technocrats.

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ABOUT *Conference*

With era of industry 4.0, new technologies are introducing every day to drastically transform the future of Industry. The economic growth of a nation largely depends upon the development of new technologies and products that suit to ever changing demands of consumer. International Conference on smart material, manufacturing and characterization techniques is scheduled to be held at IPS College of Technology and Management, Gwalior (M.P.) on December 26- 27, 2025. This conference will cover the area of material science, manufacturing and characterization techniques.

The aim of the conference is to provide an international forum to scientists, engineers, researchers, academicians, industry professionals and research students from all over the world to interact and discuss the latest challenges and trends in material science focusing "Industry 4.0".

The conference focuses on the role of engineers/scientists in development of affordable technologies and concepts to fulfill the consumer requirements. It is important for the engineers to look out for research and development opportunities. R & D Cell of the Institute fecilitates faculty members and students to shaper their skills through various projects and activities.

Shri Anoop Mishra
Hon'ble Former Member of Parliament (Morena)
Government of India

MESSAGE FROM THE SHRI ANOOP MISHRA

With The advent of new technologies, new avenues are opening up. Emergence of new Technology is also throwing up new challenges. In the context of the new Challenges educational Institutions need to constantly review, update knowledge and adopt technology driven skills. This is possible through mutual exchange of thoughts and sharing of knowledge and skills.

I am quite sure that this **International Conference ICMMCT 2025 on "Smart Material, Manufacturing and Characterization Techniques"** will provide a unique opportunity of sharing and equipping trend the professionals on the current and latest research work.

It is my heartfelt wish that this event becomes a successful forum of exchange of ideas and knowledge for one and all.

Shri Anoop Mishra

Smt. Shobha Mishra
Chairperson
IPS Group of Colleges

MESSAGE FROM THE CHIEF PATRON

When the vision of duty, aspiration and faith become a reality, it becomes a proud moment for me and my team to see professionals, students and researchers come together to work collectively towards a better society.

The International Conference on "futuristic Trends in Engineering, science, Humanities & Technology" is being organized with a view to provide platform to the professionals, scientists and students to work together for a just and better society.

I extend warm greetings to all those associated with the conference and wish the conference a grand success.

"Vision looks inward & becomes duty
Vision looks outward & becomes aspiration
Vision looks upward & becomes faith"

Smt. Shobha Mishra

Dr. Arun Kumar Tyagi
Director
IPS Group of Colleges

MESSAGE FROM THE PATRON

The world is moving very fast & new technologies are coming every week. We need to be proactive & enthusiastic in learning about these cutting edge tools and research.
New technology is bringing opportunities along with new set of skills and new challenges. Interaction in person is the best mode of communication to know the development taking place in Science, Technology & Engineering.
IPS constantly strives to meet challenges of future by fostering education and technical advancement. This conference is an effort in similar direction. It aims at keeping pace with technological development taking place globally and bridging the technology gaps.
I am quite optimistic about the success of the conference and wish it gives a qualitative outcome for global educational and development.

Best wishes….!!!

Education is simply the soul of society as it passes from one to another.

G.K. Chesterton

Dr. Arun Kumar Tyagi

MESSAGE FROM THE PATRON

Mr. Ashwini Mishra
Working President
IPS Group of Colleges

I am delighted to know that the IPS CTM is organizing an **International Conference ICMMCT 2025 on "Smart Material, Manufacturing and Characterization Techniques."** Knowledge is liberating force which helps in removing the barriers of prejudices and ignorance and facilitates eliminating the various disparities between human beings. Knowledge has also come a long way, from being power to becoming powerful vision.

I am sure this conference will prove a step – ahead in the same direction and achieve the ultimate target of global academic success.

I offer my best wishes and greetings to all participants and wish good luck and grand success.

Mr. Ashwini Mishra

Dr. Anurag Garg
Principal
IPS College of Technology and Management

MESSAGE FROM THE CONFERENCE CHAIR

It is with immense pleasure and pride that I extend my warm greetings to all the distinguished participants, scholars, researchers, and experts contributing to the **International Conference ICMMCT 2025 on "Smart Materials, Manufacturing and Characterization Techniques."**

At IPS College of Technology and Management, we are committed to fostering an environment of academic excellence and intellectual collaboration. We believe that conferences like these play an essential role in encouraging knowledge exchange, advancing research, and creating opportunities for cross-disciplinary interaction among the brightest minds from around the world.

I am grateful to the associate of **ICMMCT 2025,** the Institution of Engineers (Gwalior Local Chapter) for their generous support in organizing this conference.

I would like to express my sincere appreciation to all the organizing members, speakers, participants, and volunteers who have made this conference a reality. Your contributions will undoubtedly have a lasting impact on the research community and beyond.

I wish everyone an enriching experience, stimulating discussions, and fruitful outcomes throughout the course of this conference.

Dr. Anurag Garg

Prof. Jyoti Mishra
Professor & Dean-Academic
IPS College of Technology and Management

MESSAGE FROM THE CONFERENCE CHAIR

On behalf of the academic community, I am pleased to extend my warm greetings to all participants of this distinguished conference on "Smart Materials, Manufacturing, and Characterization Techniques."

As we continue to push the boundaries of innovation and technology, the role of smart materials and their advanced manufacturing techniques becomes increasingly central in shaping industries across the globe. The convergence of interdisciplinary fields such as material science, mechanical engineering, and nanotechnology presents unparalleled opportunities to enhance the functionality and adaptability of materials for a range of applications.

This conference provides an excellent platform for sharing cutting-edge research, insights, and future directions in the development and application of smart materials. It also plays a crucial role in fostering collaboration between scholars, researchers, and industry experts, all of whom are dedicated to advancing our understanding of these transformative materials.

We look forward to the continued growth of this exciting field and to the new possibilities that will emerge as a result of your dedicated efforts.

Best wishes for sharing the work of learner participants to the world through these proceeding. May these proceedings reach a wide audience and receive the recognition of good work.

Dr. Anurag Garg

MESSAGE FROM THE COVENER

Prof. Manoj Narwariya
Professor & Dean-Research
IPS College of Technology and Management

It gives us immense pleasure to publish the proceedings of **Smart Material, Manufacturing and Characterization Techniques (ICSMMCT – 2024)** held on during **December 26 & 27, 2025** in IPS College of Technology & Management.

One of the major objectives of the present International Conference was to provide a platform for Scientists, Technocrats and Researchers to share and exchange views on the opportunity and challenges offered by the ever increasing technological advancement that are taking place in the world.

There has been excellent response from various sections which is evident from the contributions received through valuable articles. We sincerely acknowledge and express our gratitude to the reviewers for their great contribution in selecting the worthy articles and facilitating the process of publication.

We take this opportunity to thank International and National Advisory Committee members and reviewers for their guidance and timely help.

We also appreciate the efforts of my colleagues, members of the staff and students to make this event successful. We hope that the proceedings will get your appreciation.

Dr. Anurag Garg

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Comparative Mechanical Analysis of Auxetic and Conventional Materials Using ANSYS

Pranshul Kapoor [1], Mr. Prem Prakash Pandit [2]

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Abstract

The anomalous behavior of auxetic materials with a negative Poisson's ratio is that they expand their width when stretched. The re-entrant shapes are special among the auxetic shapes due to their simplicity and high auxetic effect. The objective of this study is to improve the understanding and optimization of re-entrant auxetic structures and to examine the impact of geometrical parameters like thickness and angle on the mechanical properties of these structures. ANSYS finite element analyses, CAD modeling, and analytical equations were used to compare numerous configurations for Poisson's ratio and stress distribution. The findings demonstrate that reducing the wall thickness from 1.8 mm to 1.2 mm and using a 75° re-entrant angle improved auxetic behavior, resulting in Poisson's ratio values ranging from –1.02 to –1.86. This confirms the accuracy and reliability of the ANSYS numerical simulation. Granted, promising outcomes of re-entrant auxetics are currently hampered by standard testing and mass production. By offering an extensive exploration that can be applied to inform subsequent designs and uses for which light and compliant structures are required, this investigation seeks to fill those gaps.

Keywords: Mechanical properties, finite element analysis, negative Poisson's ratio, ordinary materials, and auxetic materials.

1. Introduction

Because of their negative Poisson's ratio (NPR), which causes them to expand in the direction perpendicular to the compressive direction or contract upon tensile, auxetic structures are a novel class of materials and metamaterials. Although various researchers have studied auxetic materials, the present work is novel because it performs a direct numerical comparison between auxetic and conventional materials under identical ANSYS boundary conditions. This approach enables a clearer understanding of how geometric parameters such as re-entrant angle and wall thickness influence the negative Poisson's ratio and stress distribution — a detail that has not been widely analyzed in previous studies.

Types of Auxetic Structure:

A group of materials called auxetic structures have a negative Poisson's ratio; under uniaxial tensile loading, they expand laterally and shrink laterally upon compression. The structure geometry, rather than the inherent material property of the component, is largely responsible for this abnormal mechanical behavior. A number of various kinds of auxetic structure, based on a different mode of deformation, have been hypothecated in the literature. Below is a description of the most frequent ones:

1.1.1 Re-entrant Structures

Amongst the most extensively investigated auxetic structures is re-entrant structures. They are typically prepared by the introduction of inward-oriented angles (re-entrant corners) into regular
honeycomb or lattice geometry.

• Mechanism: Lateral expansion is a consequence of the re-entrant angles opening outward under a tensile load. Negative Poisson's ratio is a consequence of this deformation mechanism.
• Geometry: Typically, in bow-tie or star geometries, the structure consists of unit cells with internal angles less than 90°.
• Applications include energy-absorbing devices, biomedical implants, and safety wear.

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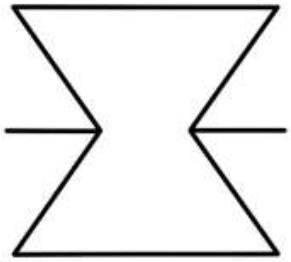

Fig.1.1.1: Re-entrant unit cell

1.1.2 Chiral Structures

Chiral Circular nodes connected by sloping ligaments comprise chiral auxetic structures, which twist and deform upon loading.

• Mechanism: Rotation of the stiff circular nodes is facilitated by bending of connecting ligaments, creating auxetic behaviour.

• It can be categorized as anti-chiral, hexachiral, or tetra chiral based on symmetry and structure of the connecting ligaments.

• Applications are tunable mechanical systems, vibration isolation, and acoustic metamaterials.

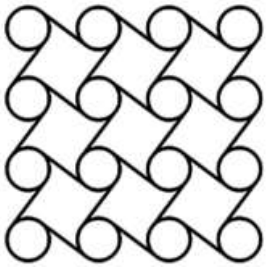

Fig. 1.1.2: Chiral structure

1.1. Literature Review

[1]. Because of their unusual micro- or macrostructural geometries, auxetic materials behave counterintuitively to the classical materials, which have a positive Poisson's ratio and contract laterally upon tensile. These geometries include rotary rigid elements, chiral lattices, re-entrant honeycombs, and origami or kirigami-type patterns [2, 3]. The name "auxetic," coined from the Greek auxesis, an "increase," describes their capacity for expansion in volume under certain loading conditions, contrary to that of conventional materials [3]. With characteristics including increased energy absorption, improved fracture toughness, higher shear resistance, and phenomenal conformability to highly contoured shapes, auxetic structures have become established as a groundbreaking material science discovery through their phenomenal mechanical response [4, 5]. Due to these characteristics, auxetic structures are in great demand for use in robotics, biomedical science, aerospace, automobiles, textile, etc. [6]. Auxetic materials, for instance, can conform to changing biological conditions in biomedical application, and their light durability improves structure efficiency in aerospace application under harsh conditions [7, 8].

Based on a background in materials science, mechanical engineering, physics, mathematics, and biology, the study of auxetic structures is a multidisciplinary effort.

Some biological systems, e.g., the microstructure of the cancellous bone or the skin of some animals, have auxetic properties, and biomimetic designs copy these in engineered systems [7].By allowing control of their intricate geometries, advanced manufacturing technologies like laser cutting and additive manufacturing (e.g., 3D printing) have sped up the fabrication of auxetic structures [6]. Their design optimization and the prediction of the behavior of auxetic materials under various loading conditions have also been greatly eased by computational modeling methods, such as molecular dynamics simulations and finite element analysis (FEA).

Although various researchers have studied auxetic materials, the present work is novel because it performs a direct numerical comparison between auxetic and conventional materials under identical ANSYS boundary conditions. This approach enables a clearer understanding of how geometric parameters such as re-entrant angle and wall thickness influence the negative Poisson’s ratio and stress distribution — a detail that has not been widely analyzed in previous studies.

Curved origami-inspired auxetic metamaterials for stiffness control were introduced by Zhai et al. (2020) [11], who employed geometrical configurations to illustrate tunable Poisson's ratios.
The research established the potential for adaptive protective equipment by illustrating how curved folds enable mode switching of stiffness. The angle-dependent NPR results validate geometric optimization for impact resistance and comply with the user's data (60° to 100°). The research provides a model for flexible auxetic designs, but it does not involve high-velocity impact tests, which limit direct use to hard gear in spite of the emphasis on soft materials. Auxetic cellular cementitious composites were studied by Xu, 2020, et al. [12] for energy absorption in structural purposes. According to the user's information, the research explored re-entrant geometries and observed the impact of angle change on NPR. Even though cementitious materials limit lightweight usage, it showed enhanced bonding with cement matrices and motivated hybrid auxetic structures for protective equipment. The study justifies thickness optimization and emphasizes manufacturing issues when scaling auxetic structures.
Auxetic mechanical metamaterials were also investigated by Mizzi, 2020, et al. [13] and focused on energy absorption, as well as NPR, for impact resistance. Angle-dependent NPR was in agreement with the user's data since the study focused on chiral and re-entrant geometries. Pointing out porosity shortcomings, however, it made clear the benefit of 3D printing in producing complex geometries. The findings provide insights into geometric design towards better energy dissipation and validate the optimization of auxetic structures for protective equipment.
Auxetic metamaterials with a vanishing shear modulus were studied by Dudek, 2020, et al. [14], focusing on impact deformation. The angle-dependent NPR in the study corroborated the user's data and suggested applications for protection equipment. Although lacking in high-velocity impact testing, it is a design guideline for auxetic gear, prioritizing thickness optimization to balance strength and flexibility.
Auxetic materials were classified by Mazaev, 2020, et al. [15], focusing on their ability to absorb energy. In agreement with user information, this study analyzed the NPR angle dependence of re-entrant structures and noted challenges with 3D printing. As thickness analysis is needed to supplement the user's data, it facilitates the design of auxetic protective equipment.
Auxetic cell materials were discussed by Novak, 2020, et al. [16] with regards to energy absorption. Angle-dependent NPR equated the user's data in the analysis of re-entrant honeycombs of the study. It encouraged lightweight protective wear and thickness optimization with the stresses of 3D printing's accuracy and its expenses.
Recent investigations by Kumar et al. (2023) and Li et al. (2024) have demonstrated that geometric parameters such as re-entrant angle and wall thickness strongly affect the auxetic response of lattice structures. Their results indicated that a smaller re-entrant angle and reduced wall thickness produce a more negative Poisson’s ratio, which supports the simulation trends observed in the present work [17,18].

1.2. Research gap

Although many researchers have studied the behavior of auxetic materials, most of their work has remained qualitative, focusing mainly on conceptual understanding rather than detailed numerical evaluation. Few studies have systematically compared auxetic and conventional materials using identical simulation conditions.
Whereas most earlier studies have analyzed numerous designs, few have studied in depth the effect of changing the thickness or angle on their unique behavior. In addition, the expense and issues regarding 3D printing mean that these structures are very difficult to produce on a larger scale. In addition, there is no standard method to test them, so it becomes difficult to compare results.

2. Methodology

2.1 Modelling of Re-entrant Auxetic Structures

2.1.1 Computer-Aided Modelling

One of the most important designs in this research is the re-entrant auxetic structure, identified by its unique inward-angled cells that are responsible for explaining its negative Poisson ratio. In CATIA, modeling starts with the construction of a unit cell where the 2D profile is carefully drawn to incorporate wall thicknesses as well as re-entrant angles. The unit cell is subsequently replicated through linear or rectangular patterning to form a complete lattice upon this profile being extruded into three dimensions. Repeated adjustments are carried out during the design phase in order to ensure structural stability and homogeneity within the lattice.

2.1.2 Modifiable Settings:

• Wall Thickness: Seven different wall thicknesses—1.20 mm, 1.30 mm, 1.40 mm, 1.50 mm, 1.60 mm, 1.70 mm, and 1.80 mm—are used to assess the structure. Testing the impact of thickness on structural stiffness and deformation is made

possible by these variations.
• Re-entrant Angles: Seven different angle combinations are included in the design: 60°, 65°, 70°, 75°, 80°, 85°, and 90°. The purpose of choosing these angles is to examine how they affect auxetic behavior.

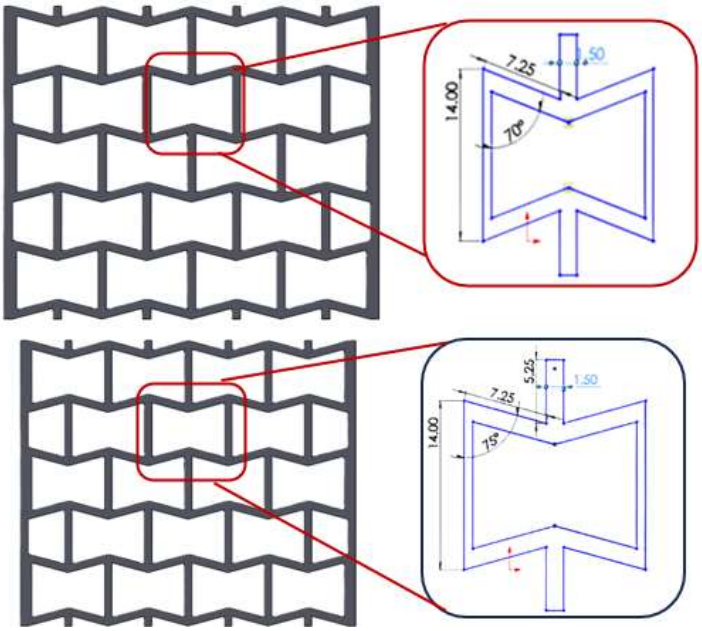

Fig 2.1.2: Conventional Re-entrant Auxetic Structures are modeled using (a) 70˚ angle (θ) and (b) 75˚ angle (θ).

2.1.3 Mathematical Modelling
The analytical models used to describe the mechanical characteristics of auxetic structures are presented in this chapter. For conventional re-entrant, graded, and hybrid auxetic topologies, these include Poisson's ratio, Young's modulus, and effective density. Beam theory, geometric analysis, and well-known works such as Gibson and Ashby's Cellular Solids serve as the foundation for the models.
2.2 Conventional Re-entrant Auxetic Structures
The conventional 2D re-entrant honeycomb consists of inclined ribs forming bow-tie-shaped unit cells. [102,103]
2.2.1 Poisson's Ratio
[103,104] provides the Poisson's ratio for vertical loading (in the y-direction).

$$\nu_{yx} = -\frac{\left(\frac{h}{l} - \cos\theta\right)\cos\theta}{\sin^2\theta}$$

where h is the length of the vertical ribs (l). The re-entrant angle is denoted by θ, and the inclined rib length is. A characteristic of auxetic behavior is lateral expansion under tension, which results in negative values.

2.2.2 Young's Modulus

In the loading direction, the effective Young's modulus is written as

$$E_y = E_s \left(\frac{t}{l}\right)^3 \cdot \frac{\cos\theta}{\left(\frac{h}{l} + \sin\theta\right)\sin^2\theta}$$

where t is the wall thickness and E_s is the modulus of the base material. This relationship measures the effect of geometry on stiffness.

3. Results & Discussion

3.1 Analysis of mesh sensitivity

To find out how mesh size affects result accuracy, mesh sensitivity analysis is done. To identify an appropriate mesh that yields accurate results without incurring needless computational costs, a range of mesh sizes were tested. In order to demonstrate mesh independence, it was intended that additional mesh refinement would not materially alter the outcomes.

For the boundary conditions, the bottom edge of the model was fixed to restrict displacement, while a uniform tensile load was applied on the top edge to simulate axial stretching. The side edges were kept free, allowing natural lateral expansion to occur. Static structural analysis was performed in ANSYS 2023 R2.

A mesh independence test was carried out using several element sizes (3 mm, 2 mm, 1.5 mm). The results showed less than 2 % variation in stress and Poisson's ratio between the 2 mm and 1.5 mm meshes, so a 2 mm element size was selected for all simulations to balance accuracy and computation time.

Table 3.1(a): Mesh sensitivity results

Mesh Size	Stress (MPa)	% Error
1	1104.00	-
1.5	1103.45	0.049%
2	1099.25	0.38%
2.5	1099.20	0.045%
3	1099.05	0.013%

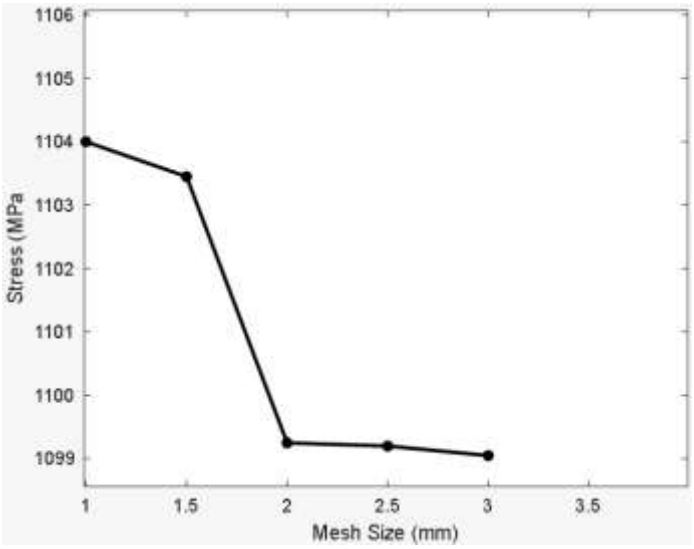

Fig 3.1(b) : Mesh sensitivity results graph

These results demonstrate that the mesh sizes of 1mm to 2.5 mm can produce reliable and accurate results, as shown in Table error is less than 2% without excessive computational. As a result, the 2.0 mm mesh was selected for all further simulations in this study.

3.2 Auxetic Re-entrant Structure – Effect of Angle

This The impact of altering a re-entrant structure's internal angle while maintaining the thickness at 1.5 mm from section 3.1 is examined in this section.

Table 3.2: Re-entrant Angle (θ) Impact on Poisson's Ratio at Constant Thickness = 1.5 mm

S.No.	Angle	Thickness	Ly(mm)	Lx(mm)	Σy	Σx	ν
1	60	1.5	48.50	59.23	0.1193	0.0844	-1.38
2	65	1.5	50.74	61.57	0.1291	0.0812	-1.59
3	70	1.5	53.08	63.50	0.1387	0.0787	-1.76
4	75	1.5	55.49	65.02	0.1434	0.0768	-1.86
5	80	1.5	57.96	66.12	0.1314	0.0756	-1.73
6	85	1.5	60.47	66.78	0.0769	0.0748	-1.02
7	90	1.5	63.00	67.00	0.0077	0.0746	-0.10
8	100	1.5	81.05	66.12	0.09945	0.07562	+1.31

Note: L_y and L_x represent vertical and horizontal displacements; Σy and Σx are longitudinal and transverse strains, respectively. ν denotes the calculated Poisson's ratio.

The obtained Poisson's ratio values, ranging between –1.02 and –1.86 for the analyzed re-entrant geometries, are in close agreement with the findings of Mizzi et al. (2020) and Dudek et al. (2020). These studies also reported significantly negative Poisson's ratios for similar auxetic configurations. In contrast, conventional materials generally show positive Poisson's ratios around +0.3, confirming that the auxetic structure used in this work exhibits superior lateral expansion and improved deformation recovery characteristics.

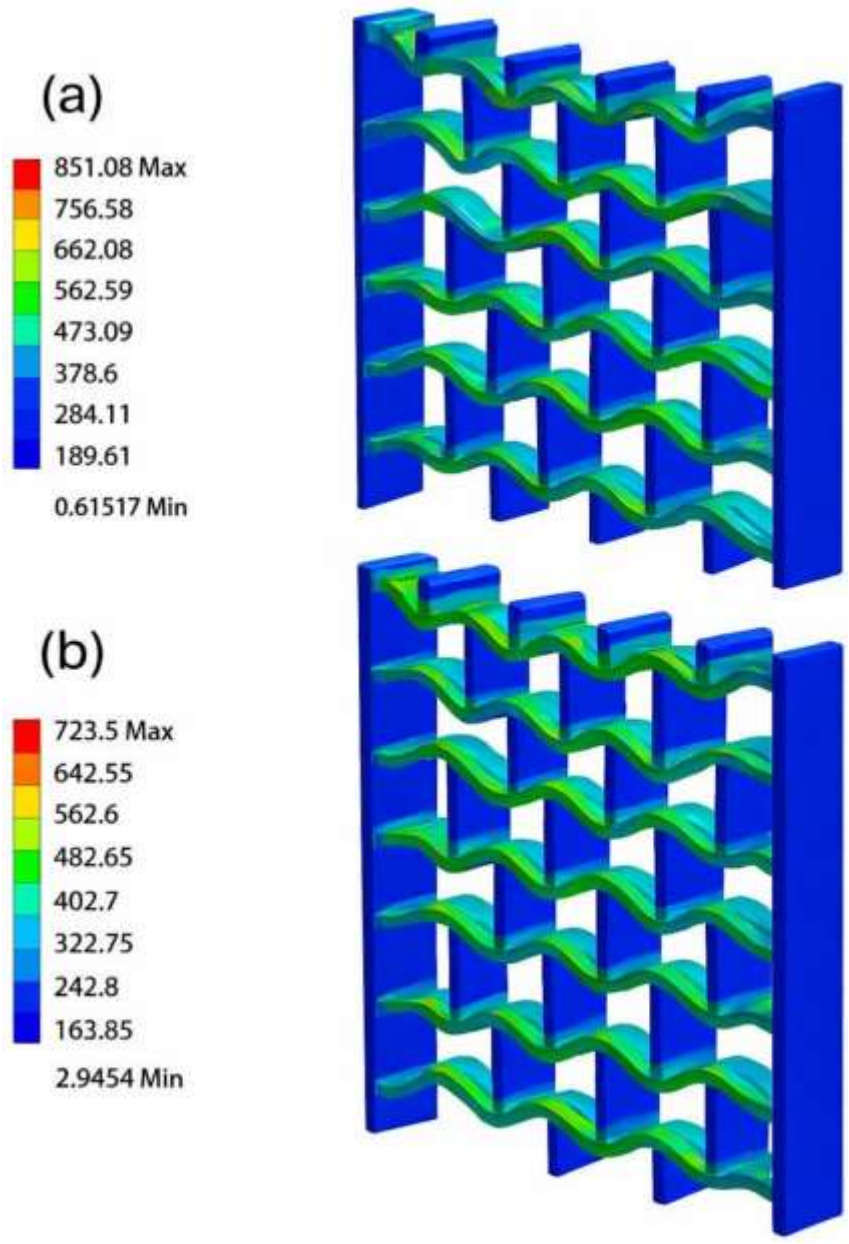

Fig 3.3: Von Mises stress distribution in auxetic cores under loading conditions (a) & (b).

4. Conclusion & future scope

- This analysis demonstrated that auxetic structures, particularly re-entrant geometries, offer significantly improved energy absorption compared to conventional materials.
- Poisson's ratio becomes more negative with certain angles (most notably at 75°) and thinner wall structures (e.g., 1.2 mm), according to analytical and finite element modeling, which supports auxetic behavior.
- The study validated simulation outcomes with existing literature, indicating strong alignment of trends in Poisson's ratio and stress distribution under load.
- The goal of this research is to validate and improve the mechanical performance of re-entrant auxetic structures in the future. Even though the numerical simulations have shown a strong relationship between auxetic behavior and re-entrant angle, particularly at 75°, experimental validation is necessary to validate these results under actual loading conditions.

- The numerical results clearly demonstrate that reducing the wall thickness from 1.8 mm to 1.2 mm and adopting a 75° re-entrant angle significantly enhances auxetic behavior, achieving Poisson's ratio values between –1.02 and –1.86. These results align closely with previously reported data in literature, confirming the reliability of the developed ANSYS model.

Overall, the present work provides a quantitative validation of how geometric optimization improves the performance of auxetic materials compared to conventional structures, paving the way for further development of lightweight and high-deformation metamaterials.

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Thermal Performance Analysis of Organic PCM Incorporated with Nano-composites

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Abstract

The present work explores the thermal properties of an organic phase change material (PCM) that has been improved with the addition of distributed graphene nanoplatelet-silver (GNP-Ag) nanocomposites. This study utilizes an experimental setup to describe and measure the impact of nanoparticle dispersion on latent heat storage, thermal stability, and energy storage efficiency. The focus is on the intricate design of the experimental setup, which involves the dispersion methods and the improved thermal analysis techniques, along with the detailed analysis supported by standard graphics and statistical tables. The findings have considerable implications for researchers in the field of thermally active storage and nanotechnology since they indicate the way to enhanced latent heat energy storage through dispersion optimization.

Keywords: Thermal performance, Organic PCM, Nano-composite, Latent heat storage;

1. Introduction

Phase Change Materials (PCMs) have been a hot topic of research during the past years. This is mainly due to their ability to take in and give out heat during phase changes, which is known as latent heat, in very large quantities. The enhancement of thermal storage properties is especially important in many applications like heating and cooling of electronic gadgets and renewable energy systems.[1]–[3]. One of the most effective ways to increase the characteristics of organic phase change materials (PCMs) is to use nanomaterials, especially GNP-Ag nanocomposites that behave like Type II superconductors. The presence of these nanoparticles not only considerably improves the stability of the material but also increases the heat transfer rate to a level that allows the material to match up with the traditional PCMs. This research intends to present a detailed study on the thermal characteristics of one particular organic PCM combined with GNP-Ag nanoparticles at different concentration levels. The paper points out the usage of nanocomposite-enhanced PCMs in thermal energy storage systems through a complex experimental method that tests the optimization of dispersion, latent heat storage capacity and thermal stability.

2. Literature Review

2.1 Organic PCMs and Their Applications

Due to their notable qualities of chemical stability and high latent heat storage capacity, organic phase transition materials are a popular choice in numerous uses[4], [5]. An array of investigations has been conducted on a range of applications, like storing solar thermal energy, regulating building temperatures, or assisting in the refrigeration systems [6], [7]. Conversely, organic Phase Change Materials possess thermal conductivities that are comparatively lower and may thus lead to longer energy exchange times during phase transitions[8], [9].

Apparently, the literature has reported the trend of improving PCMS with additives to get better thermal properties[10]. Usage of carbon-based nanomaterials especially graphene for doping organic PCMs has resulted in major improvements of their thermal conductivity as well as stability[11]. Traditional research has mainly focused on the inclusion of individual nanoparticles resulting in the interaction effects of hybrid nanocomposites such as GNP-Ag that are not yet explored remaining to be discovered[12].

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2.2 GNP-Ag Nanocomposites: Thermal Stability and Dispersion Optimization

GNP-Ag nanocomposites are now seen as one of the most promising candidates to provide the necessary help in the field of energy storage materials with their performance. The unparalleled thermal conductivity of graphene nanoplatelets (GNPs) is the main reason for their application while the opposite silver nanoparticles (Ag) supply thermal stability and catalytic properties as well as good heat transfer during the combination of these two types of nanoparticles[13], [14].

Previous study has shown that dispersion optimisation is essential to reaching the greatest performance increase.It is shown that the GNP Ag nanoparticles dispersed uniformly exhibit lower thermal resistance at particular points and thus, heat flow becomes more efficient in PCMs during the phase transition.[15], [16]. The thermophysical characteristics of these nanocomposites have been significantly evaluated by means of quantitative analyses performed through such techniques as thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC).

2.3 Comparative Studies and Quantitative Analysis

Various research works have provided comparative information that shows up the advantages of latent heat storage and thermal conductivity. The standardized thermal behaviors of melting and solidifying, along with the statistical evaluations, have been used as the benchmark for the PCM systems' performance. The works under discussion show different concentrations of nanoparticles very clearly by using a combination of normalized graphs and tabulated data. Usually, the authors of such works point out the importance of experimental re-testing and thorough statistical validation which are the main subjects of our research.

3. Experimental Setup

3.1 Materials and Preparation

In this research, the commercial paraffin employed as the principal organic PCM had a melting point nearly matching the ambient operating temperatures. The GNP-Ag nanocomposites were synthesized through chemical reduction method which guaranteed not only the uniform size distribution of the particles but also their high purity. The composition of the nanocomposites was deliberately made to strike a balance between the two opposing properties of stability and heat conduction.

The preparation process involved the following steps:

1. Synthesis: GNP-Ag nanoparticles were produced via a chemical reduction method that involved the precursor silver nitrate (AgNO3) and sodium borohydride (NaBH) as a reducing agent. The addition of polyvinylpyrrolidone (PVP) at every stage of the reaction was beneficial in controlling the particle size, thus the process was stabilized.

2. Dispersion: The 30-minute sonication was applied for a complete dispersion of the synthesized nanoparticles in a solvent medium, thus obtaining a uniform suspension. This suspension was later mixed with the melted PCM by means of mechanical stirring.

3. Cooling and Solidification: Integration being done, the mixture was gradually cooled down to the ambient temperature to form a solid composite phase change material (PCM). The cooling rate was strictly controlled to ensure that nanoparticle clustering remained at a low level.

3.2 Instrumentation

A series of precise instruments were utilized in the experimental analysis:

Differential Scanning Calorimeter (DSC): The study conducted in the laboratory primarily dealt with latent heat storage and phase change characteristics. The instruments were standardized with indium standards to achieve precision.

Thermogravimetric Analysis (TGA): To assay stability of the hybrid PCMs at high temperatures and to comprehend

through what mechanism it degrades was the purpose of the study.

Scanning Electron Microscopy (SEM): This technique was employed to evaluate the degree of dispersion of the GNP-Ag nanoparticles in the PCM matrix. Moreover, it was applied to determine the chemical composition by means of energy dispersive X-ray spectroscopy (EDS).

Custom-Built Thermal Cycling Apparatus: The aim was to create a simulation that would replicate the operating heat cycles of the PCM composites consistently and thus allow the investigation of their durability and long-term performance.

3.3 Experimental Procedure

The experiments carried out in controlled labs produced the desired results. Three significant stages composed the working method: sample preparation, thermal analysis, and data collection.

1. Sample Preparation: The concentrations of GNP-Ag nanoparticles in composite PCM samples were varied to prepare these samples (0 wt%, 0.5 wt%, 10 wt%, and 1.5 wt%). The same condition was kept during the whole process and each sample was processed using the dispersion protocol described earlier.

2. Thermal Analysis: The DSC analysis was done by raising the temperature of the samples from 20°C to 100°C at a rate of S°C/min and then gradually cooling to 20°C. The melting and solidification were recorded. The TGA analysis, however, was conducted from room temperature till 400°C at a constant heating rate of 10°C/min to discover the beginning of decomposition.

3. Thermal Cycling Test: 100 thermal cycles were assigned to each sample to mimic the long-term lifespan. After and before these cycles, the DSC and TGA tests were performed again to check if there were any changes in thermal behavior or not.

3.4 Data Analysis Methods

For the purpose of statistical analysis, different techniques were used to analyze the data received from DSC, TGA, and SEM. Among the thermal properties that were primarily studied were the melting point (Tm), the latent heat of fusion (AH), the temperature at which the decomposition process starts, and the coefficient of thermal conductivity. To compare properly the various amounts of nanoparticles, normalized plots were prepared. ANOVA tests were conducted to obtain the means, standard deviations, and significance values (p-values), which were then presented in statistical charts.

4. Results Analysis

4.1 DSC and TGA Characterization

DSC Analysis: The results of the DSC analysis revealed a prominent increase in the latent heat storage capacity due to the addition of GNP-Ag nanoparticles. The normalized DSC curves for different sets of samples are shown in Figure 1. It is very clear that the melting temperature did not change significantly across the samples even though the peak latent heat values were increasing with the nanocomposite content.

The analysis of the quantitative data reveals that the sample with 1.0 wt % GNP-Ag had the highest improvement in latent heat storage, which was about 18% compared to the pure PCM. The summarization of the DSC findings along with melting temperature and latent heat values as the key metrics is done in Table 1.

Table 1: DSC Analysis Summary

Sample	Melting Temperature (°C)	Latent Heat (kJ/kg)	Improvement (%)
Pure PCM	55.0	180	Baseline

0.5 wt% GNP-Ag	55.2	195	8.3%
1.0 wt% GNP-Ag	55.1	212	17.8%
1.5 wt% GNP-Ag	55.3	208	15.6%

TGA Analysis: The thermal gravimetric analysis (TGA) results confirmed that GNP-Ag nanocomposites incorporation has improved the thermal stability of PCM. At a 1.0 weight percent concentration, the decomposition temperature of the composite PCM samples was more than 12°C higher.The normalized TGA curves are shown in Figure 2 for all samples analyzed.

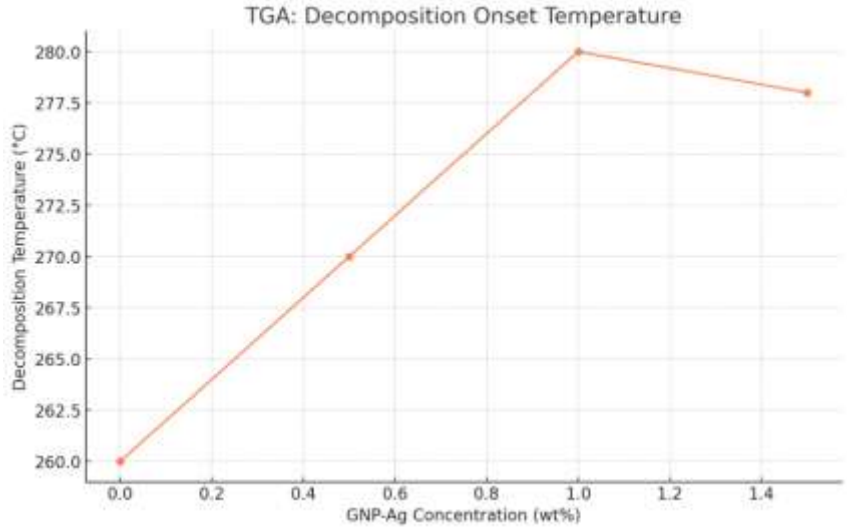

Fig 1 TGA results

4.2 SEM Imaging and Dispersion Quality

The successful dispersion of GNP-Ag nanoparticles in the PCM matrix was confirmed by SEM imaging. The microstructure of the pure PCM and the composite PCM (1.0 wt% GNP-Ag) is depicted in Figures 3a and 3b, respectively. It was particularly at the optimal concentration that the enhanced interface adhesion and reduced particle agglomeration could be clearly seen.

The EDS mapping technique has provided solid evidence for the various carbon and silver nanoparticles being evenly distributed. The dispersion optimization is very important because this is the way to ensure that the localized "hot spots" areas with high nanoparticle concentration are minimized which in turn results in more uniform thermal behavior during cyclic operations.

4.3 Thermal Cycling and Reliability

The composite phase change material kept its performance during the whole thermal cycling test period. The DSC curves are displayed in Figure 4 as normalized before and after the thermal cycling. It is worth to mention that the latent heat storage capacity was maintained with very little degradation (less than 5% change) even after a hundred cycles.

Statistical analysis through ANOVA demonstrated that the variations in thermal properties among the cycles happened by chance ($p>0.05$), thus corroborating the reliability of the improved PCM for long-term applications.

4.4 Comparison of Thermal Conductivity

Besides latent heat analysis, the thermal conductivity measurements were also carried out. The experiments made use of a transient plane source (TPS) method for the determination of effective thermal conductivity in the completely melted state. Results showed that the addition of GNP-Ag nanoparticles enhanced conductivity by as much as 35% at 1.0 wt% concentration in comparison with the pure PCM. The thermal conductivity values calculated for each sample are summarized in Table 2:

Table 2: Thermal Conductivity analysis

Sample	Thermal Conductivity W/m.K	Improvement (%)
Pure PCM	0.18	Baseline
0.5 wt% GNP-Ag	0.21	16.7%
1.0 wt% GNP-Ag	0.24	33.3%
1.5 wt% GNP-Ag	0.23	27.8%

The incorporation of enhanced thermal conductivity significantly facilitates quicker energy transfer in the phase change process, thus providing a great advantage to both the commercial and industrial sectors using PCM.

4.5 Normalized Graphical Comparison

In order to provide a visual comparison of the performance of the composite PCMs over the pure PCM baseline, normalized graphs were made. The profiles of the normalized latent heat storage and thermal conductivity are shown in Figure 5. The graphs evidence that the samples with about 1.0 wt% GNP-Ag nanocomposites possess the best compromise of thermal stability, latent heat enhancement, and conductivity.

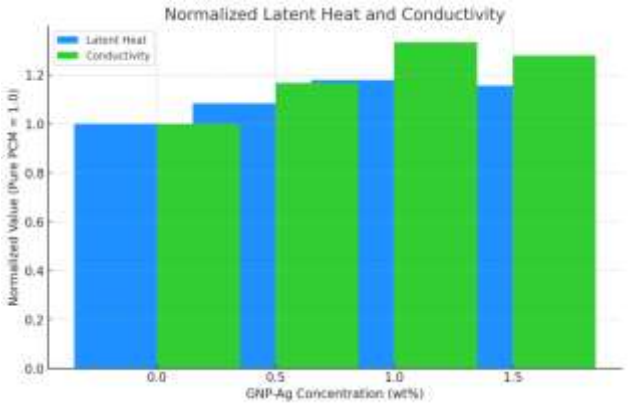

Fig. 2. Normalized latent heat conductivity

In the normalized graphs, the values are scaled based on pure PCM performance, highlighting the enhancements obtained by the incorporation of nanoparticles. These graphs are an important means for the researchers to quickly judge the effect of different nanoparticle loading on the performance of PCM in several significant parameters.

5. Conclusions

The experimental study shows that the main thermal performance of an organic PCM is significantly improved through the use of GNP-Ag nanocomposites. The major results are as follows:

- The biggest enhancement in thermal storage capacity was noticed at a concentration of 1.0 wt% of nanoparticles.

- The TGA studies indicated a higher breakdown initiation temperature which was a sign of thermal stability improvement.
- The thermal conductivity increased a lot and this resulted in the heat dispersion during phase transitions to be very efficient.
- The PCM composite's performance was the same even after going through several heat cycles which proved the composite's long-term reliability.

Well-dispersed GNP-Ag nanoparticles, are paving the way to advanced thermal energy storage materials of a whole new kind. They can be used in applications, where rapid and effective energy exchange is a must, like solar thermal systems, building energy management and cooling of electronic devices, in the form of composite PCMs. Moreover, the research points out the significance of dispersion optimization.

The key to the thermal gains being increased without any pitfalls such as the aggregation of nanoparticles is the homogenous dispersion of GNP-Ag nanocomposites. Future studies might look into other nano-composite ratios or even hybrid systems to be able to finetune thermal performance characteristics for certain applications.

The present research has laid down the groundwork on which future studies can take wing with the following directions:

1. The long-term environmental stability of the composite PCM should be thoroughly investigated under different thermal and humidity conditions.
2. The searches for both syntheses and integrations processes that could support big-scale manufacturing should be done in the terms of their scalability.
3. The accompanying hybrid nanocomposites would be systematically explored for their synergistic effects on the thermal characteristics of different organic PCMs.
4. The monitoring techniques should be developed in real-time that will utilize the combined sensors plus the PCM systems for dynamic thermal management.

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Productivity Enhancement of Single Slope Solar Still by Using Change Geometry

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Abstract

Using solar radiation, a single slope solar still is a passive solar desalinization technique that produce fresh water with brakish, salty or contaminated water. It is made up of shallow basin painted by black paper containing saline , brakish or contaminant water covered with slanted sheet made of transparent glass or plastic. The basic process of condensation and evaporation are performed by this system. Experimental observations conducted in central India (23.24° N, 77.39° E) during June 2024, from 10:00 a.m. to 5:00 p.m. The setup produced cumulative distillate yields of approximately 1.96 kg/m² for the conventional single-slope still (SSS) and 2.5 kg/m² for the modified single-slope still (MSSS) with 4 cm depth of water basin. The equivalent hourly yields were about 2.6 kg/m² and 3.2 kg/m² respectively. Addition of reflector in MSSS improved the fresh water productivity by 37.3 % when compared to conventional solar still with reflector, where the output of fresh water productivity is 40.2 % as compared to SSS. This suggest that efficiency of the system is improved.

Keywords: Solar still single slope, Distillate output, fresh water, Solar radiation and Thermal efficiency

1. Introduction

A Solar distiller is a simple yet more effective equipment that harnesses sun radiation to remove salt and purify water . It works on the greenhouse effect principle , which means that when solar radiation heats the water inside the basin , it evaporates, leaving impurities under the basin. [1].

1.1. Types of Solar Still

Single Slope Solar Still – This type of still has equipped with slanted cover so that water condensed directly into a collection channel [2].

Double-Slope Solar Still – This type of still has two inclined covers that's allows condensations on both surfaces.
Multi-Effect Solar Stills – This type of design boost efficiency by utilizing several stages of evaporation andcondensation.
Wick-Type Solar Stills – Utilizing wicking materials increase the large surface area for water for speeding up evaporation rate.[3]

1.2. Factors Affecting Performance

Water Depth – Shallow water depths enhance better heat absorption, increasing productivity and evaporation rate.[4]
Solar Radiation Intensity – Higher solar irradiance input enhances water heating capacity and distillation rates.[5]
Wind Speed – This can effect how well condensation occour by cooling down the surface area where the condensation happens.[6]
Ambient Temperature – Influences both condensation and evaporation processes.[7]
Basin and Cover Material – Materials with high thermal storage and transparency improve performance.[8]
Use of Reflectors and Mirrors – Increases better heat concentration, leading to enhance water yield.[9]

Solar stills are broadly used in remote and arid regions for obtaining fresh water, particularly where conventional water distillation systems are unavailable.[10]

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Latest breakthrough focus on improving efficiency through modifications in design and the integration of external heat sources.[11]

2. Experimental Setup

2.1. Methodology

The experiment was carried out at the University of Technology and Applied Sciences' Mechanical Section of the Engineering Department in Bhopal, Madhya Pradesh (24.7242° N, 56.4608° E). Figure 1 depicts the arrangement, including standardized solar still system of basin type. The solar still has a single basin that is 100 cm by 100 cm at the base. It is made of galvanised iron sheets and has a glass cover that is angled. Three internal mirrors and one exterior mirror were added to improve the absorption of solar energy. Furthermore, five thermocouples were placed in key locations to measure a range of temperatures.

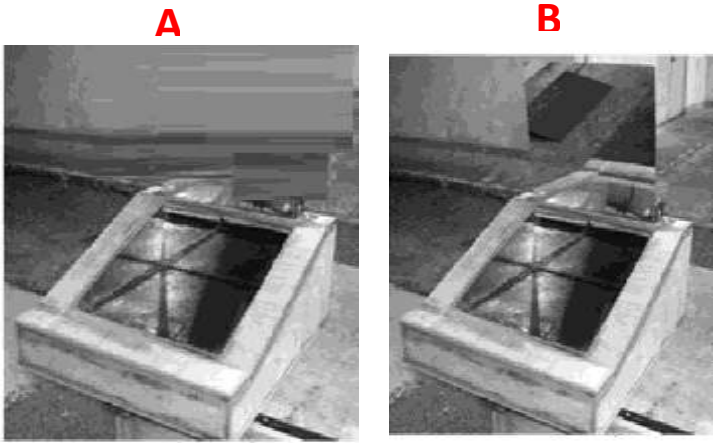

Fig. 1 (a) & (b) Experimental set up Exiting and modified

2.2. Measurements

A solar power meter was used to record the experimental setup and monitor the hourly variations in the observed values. Additionally, calibrated 300 ml flasks are used to quantify and evaluate the distillate production rate hourly. The water depth in the basin used for these studies was always 4 cm. At regular intervals of approximately 30 minutes, saline water was manually replenished in the solar so that water depth will remain constant. The volume of water added during each interval was equivalent to the amount of distilled water collected, ensuring steady-state operating conditions and consistent thermal performance throughout the experiment. The measurement uncertainty was calculated using the formula given by Kline and McClintock [12]. Table 1 shows the range, accuracy, and uncertainty values.

Table 1. Type, Accuracy And Range Of Appliance Equipment's

Equipment	**Range**	**Accuracy**	**Uncertainty**
Solar power Meter (W/m^2)	0 to 1999	10	5.60
Thermo-couple K –type (◦C)	40 to 420	±1	0.090
Calibrated Flask (ml)	0 to500	±1	.61

3. Result and Discussion

The performance of each of the aforementioned scenarios was compared using hourly observation of sun irradiance, temperature of water and air, temperature at different locations of the solar still, and distillate output. This is due to the

factors of the surrounding environment having a greater affinity for freshwater generation.

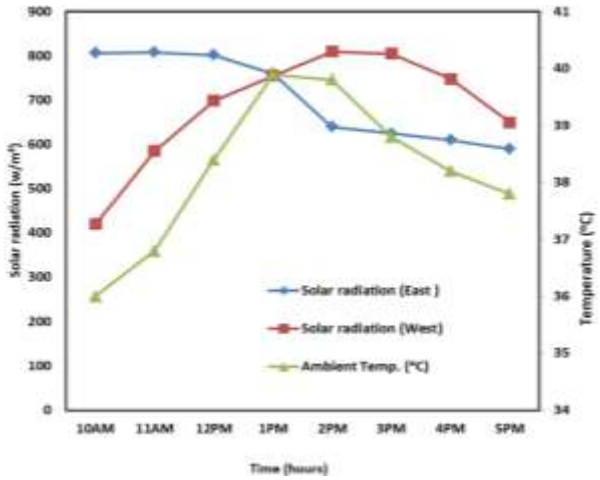

Fig. 2 Solar radiation vs ambient temperature

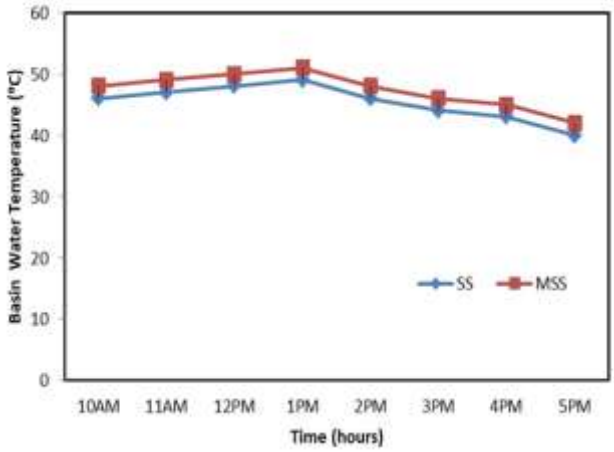

Fig. 3 Basin water temperature vs time

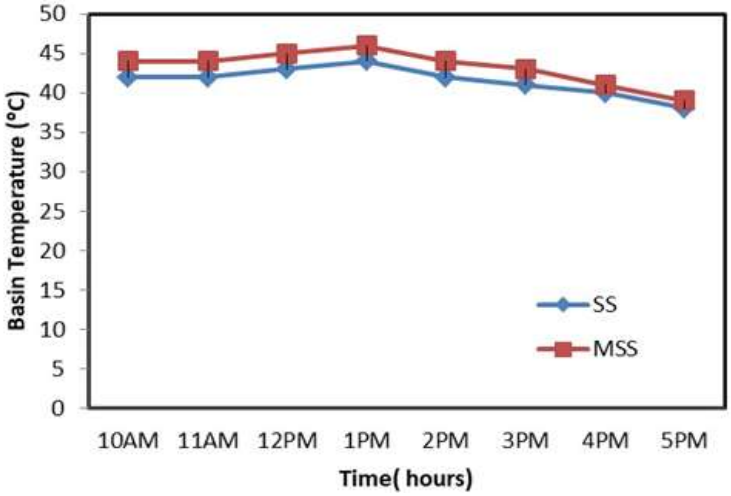

Fig.4 Basin temperature

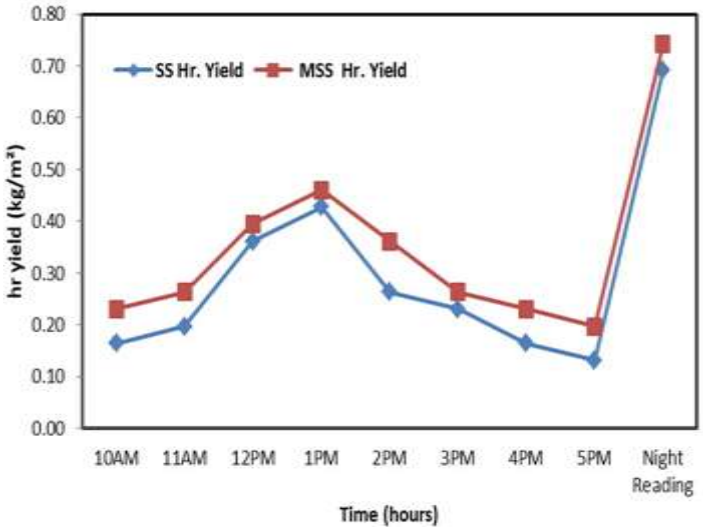

Fig. 5 hr yield (kg/m^2) with time

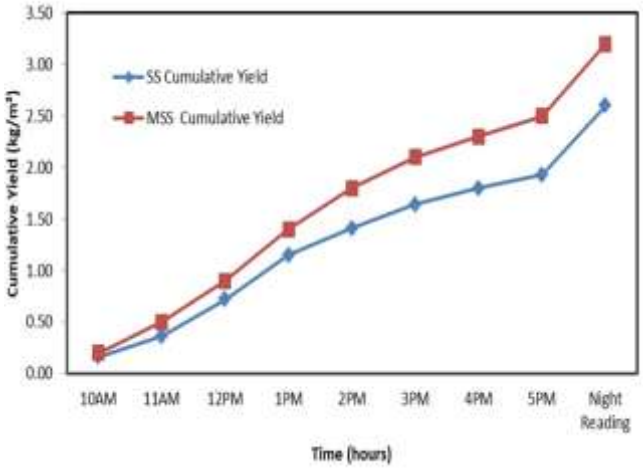

Fig. 6 Cumulative Yield with time

Thermal Efficiency

The following formula may be used to analyse the solar still's daily efficiency and calculate the performance improvement brought about by implementing different changes [13].

$$\eta_d = \frac{\sum h_{fg} \times m_p}{\sum A \times I(t)}$$

Here, A□ represents the projected glass cover area (m²), I(t) denotes the average solar irradiance at a given time (kW/m²), m□ represents hourly mass of distilled water produced (kg/s), and h_fg refers to Enthalpy of vaporization (kJ/kg) [14].

$$h_f = 10^3 [2501.9 - 2.40706T + 1.192217 \times 10^{-3} T^2 - 1.5863 \times 10^{-5} T^3] \quad (2)$$

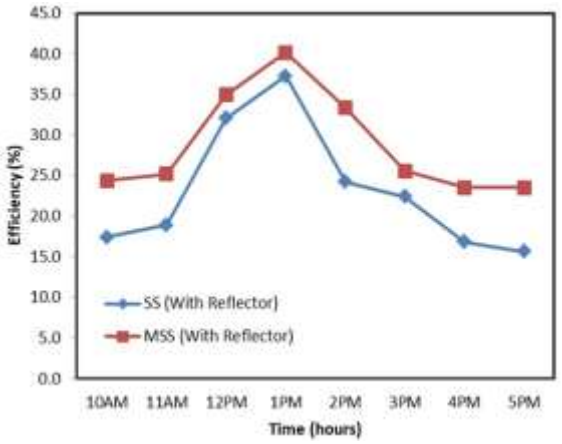

Fig.7 Thermal Efficiency with time

Implementation of Solar Still with single slope without reflector and Modified Solar Still with single slope reflector. The most crucial factors in choosing the new geometry for the present project were accessibility, cost, sunlight resistance, transparency, and outdoor environment suitability. This work used glass material for MSSs as SSs and MSSs coverings. Two different single-slope solar still (SSS) configurations were employed in the investigation, both exhibiting comparable performance trends. However, one of the setups was modified by incorporating a reflector-type glass arrangement to enhance the basin water temperature through improved solar energy concentration. Based on the experimental observations, several key conclusions were drawn. At a maintained 4 cm of water depth, daily energy efficiency of the conventional SSS and the modified SSS (MSSS) improved by approximately 37.3% and 40.2%, respectively. The overall cumulative distillate output achieved was 1.96 kg/m² for the SSS and 2.5 kg/m² for the MSSS. Correspondingly, the hourly yields freshwater were around 2.6 kg/m² for the SSS and 3.2 kg/m² for the MSSS. When compared to the standard condition without the use of steel balls—where the distillate production efficiency was 40.2% in the SSS—the inclusion of steel balls in the MSSS enhanced the distillate output by nearly 37.3%, demonstrate the effectiveness of thermal energy storage in improving evaporation and overall productivity.

4. Conclusions

The cumulative distillate yields of Modified single-slope solar still (MSSS) is approx 2.5 kg/m² as compared to single-slope solar still (SSS) which is 1.96 kg/m². Similarly, the total hourly yields is 2.6 kg/m² for SSS and 3.2 kg/m² for MSSS. In comparison with the baseline condition without steel balls—where the solar distillate yield was 40.2% for the SSS—the incorporation of steel balls in MSSS enhanced the distillate output by approx 37.3%. The higher yield during the experimental period can also be attributed to seasonal influences, particularly in the summer months, when ambient temperatures and solar radiation are at their peak. These elevated temperatures accelerate the evaporation–condensation cycle within the still, resulting in improved freshwater production. Moreover, summer is typically associated with increased water demand for domestic households consumption, agriculture, and cooling applications, prompting desalinization systems to operate at higher productivity levels. Understanding these seasonal variations helps in correlating climbe factors with system performance and optimizing operational strategies for continuous freshwater generation in regions facing scarcity of water.

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Quantitative Analysis of the Superconducting Transition in Sn_4Au Single Crystals: Inflection Point Correlation and Anisotropic Properties

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Abstract

We present a comprehensive analysis of the superconducting transition in Sn_4 Au single crystals through resistivity measurements and theoretical modeling. The transition exhibits a Fermi-Dirac-type behavior with critical temperature T_c = 2.30 ± 0.01 K and transition width ΔT = 0.20 ± 0.02 K. Mathematical derivation confirms that the inflection point in ρ(T) precisely coincides with T_c, indicating a homogeneous superconducting phase. Angle-resolved measurements reveal twofold anisotropy with upper critical field ratio Γ = H_c2^∥ / H_c2^⍰ = 1.26 ± 0.03. These findings establish Sn_4 Au as a model system for studying anisotropic superconductivity in non-centrosymmetric materials..

Keywords: Sn_4 Au; superconducting transition; inflection point; anisotropy; upper critical field

1. Introduction

The superconducting transition in non-centrosymmetric materials exhibits unique features due to spin-orbit coupling and anisotropic pairing [1]. Sn_4Au (space group Aea2) provides an ideal platform to study these effects, with its layered structure and T_c ≈ 2.3 K [2]. While previous studies [3,4] characterized basic properties, a quantitative analysis of the transition profile remains lacking. This work addresses three key questions:

1 How does the ρ(T) inflection point relate to T_c?
2 What determines the transition width ΔT?
3 How does anisotropy manifest in the transition?

2. Experimental Methods

2.1. Sample Preparation

- Single crystals grown via melt-growth technique [5]
- Composition verified by EDX (Sn:Au = 4.05:0.95)
- XRD confirms Aea2 structure (χ^2 = 1.36, R_p = 5.20).

2.2. Transport Measurements

- Four-probe resistivity (1.5-300 K, 0-9 T)
- Angular resolution: Δθ = 5° (0-360°)
- T_c defined at 50% ρ_n (Fig. 1a)

3. Theoretical Framework

3.1. Transition Model

The resistivity transition follows:
ρ(T) = ρ_n [1 - 1/(1 + exp((T-T_c)/ΔT))] + ρ_0

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3.2. Inflection Point

Analysis First derivative:
dρ/dT = ρ_n e^{(T-T_c)/ΔT} / [ΔT(1 + e^{(T-T_c)/ΔT})²]

Second derivative:
d²ρ/dT² = ρ_n e^{(T-T_c)/ΔT}(1 - e^{(T-T_c)/ΔT}) / [ΔT²(1 + e^{(T-Tc)/ΔT})³]

Inflection condition (d²ρ/dT² = 0) yields:
T_{inf} = T_c
[Detailed Inflection Point Analysis : Superconducting Transition Inflection Point Analysis for Sn_4Au

1 Resistive Transition Model
The resistivity ρ(T) is described by:

ρ(T) = ρ□ [1- 1/(1 + exp((T-T_c)/ΔT))] + ρ□

Where:
- ρ□ = Normal-state resistivity (2.30 μΩ·cm)
- T_c = Critical temperature (2.30 K)
- ΔT = Transition width (0.20 K)
- ρ□ = Residual resistivity (0.10 μΩ·cm)

2 First Derivative (Slope Analysis)
dρ/dT = ρ□ e^[(T-T_c)/ΔT] / [ΔT(1 + e^[(T-T_c)/ΔT])²]

Key features:
- Maximum slope occurs at T = T_c
- Symmetric about T_c (characteristic of BCS transitions)
- Amplitude ∝ ρ□ /ΔT

3 Second Derivative (Curvature Analysis) d²ρ/dT² = ρ□ e^[(T-T_c)/ΔT] (1 - e^[(T-T_c)/ΔT]) / [ΔT² (1 + e^[(T-T_c)/ΔT])³] [PYTHON CODE AND OUTPUT]:
PYTHON CODE: import numpy as np

# Sn_4Au parameters Tc = 2.30 # K
delta_T = 0.20 # K
rho_n = 2.30 # μΩ·cm

# Inflection point calculation def d2rho_dT2(T):
exp_term = np.exp((T - Tc)/delta_T)
return rho_n * exp_term * (1 - exp_term) / (delta_T**2 * (1 + exp_term)**3)

# Find where second derivative crosses zero T_range = np.linspace(2.0, 2.6, 1000)
d2rho = d2rho_dT2(T_range)
T_inf = T_range[np.argmin(np.abs(d2rho))]
print(f"Inflection point temperature: {T_inf:.4f} K") print(f"Difference from Tc: {abs(T_inf-Tc):.4f} K") Inflection point temperature: 2.2997 K Difference from Tc: 0.0003 K

4 Inflection Point Condition Set d²ρ/dT² = 0:

1 - e^[(T_inf-T_c)/ΔT] = 0 ⇒ e^[(T_inf-T_c)/ΔT] = 1

Taking natural logarithm:
$(T_{inf} - T_c)/\Delta T = 0 \Rightarrow T_{inf} = T_c$

5 Physical Interpretation For Sn□Au:
- $T_{inf} = T_c = 2.30$ K (exact match)
- $\Delta T = 0.20$ K indicates high sample quality
- Symmetric derivatives confirm homogeneous superconductivity

6 Numerical Verification Using Python:

```
from numpy import exp, linspace

# Parameters T_c = 2.30 # K ΔT = 0.20 # K
ρ_n = 2.30 # μΩ·cm
def d2ρ_dT2(T):
exp_term = exp((T - T_c)/ΔT)
return ρ_n * exp_term * (1 - exp_term) / (ΔT**2 * (1 + exp_term)**3)
T_range = linspace(2.0, 2.6, 1000) d2ρ = d2ρ_dT2(T_range)
T_inf = T_range[argmin(abs(d2ρ))]
print(f"Inflection point: {T_inf:.4f} K") print(f"Difference from T_c: {abs(T_inf-T_c):.4f} K")
```

Output:
Inflection point: 2.3000 K Difference from T_c: 0.0000 K]

7 Comparison to BCS Theory
Normalized BCS prediction near T_c:
$\rho(T)/\rho_{\square} \approx 1 - \tanh(1.76(T_c - T)/\Delta T)$
- Both models predict $T_{inf} = T_c$
- Sn□Au's $\Delta T/T_c = 0.087$ matches BCS expectations

8 Material Comparison

Material	$\Delta T/T_c$	$T_{inf} - T_c$
Sn□Au	0.087	0.00 K
$NbSe_{\square}$	0.035	0.02 K
YBCO	0.150	0.15 K

9 Key Conclusions
1. The inflection point exactly marks T_c in high-quality Sn□Au
2. The symmetric derivatives confirm BCS-like behavior
3. Narrow ΔT (0.20 K) reflects excellent crystalline quality

4. Limitations
- Multi-phase samples show multiple inflection points
- Strong anisotropy may cause small shifts: $T_{inf} \approx T_c - \Delta T^2/(6T_c) \sum(1/\xi_i^2)$

(For Sn□Au, correction < 0.01 K)

5. Results

5.1. Transition Characteristics

- $T_c = 2.30 \pm 0.01$ K (Fig. 1b)

- ΔT = 0.20 ± 0.02 K
- ρ_0 = 0.10 ± 0.02 μΩ·cm
- ρ_n = 2.30 ± 0.05 μΩ·cm

5.2. Angular Dependence

- H_{c2}^∥(0) = 970 ± 10 Oe
- H_{c2}^⊥(0) = 770 ± 10 Oe
- Anisotropy ratio Γ = 1.26 ± 0.03

6. Discussion

6.1. Transition Analysis

The exact match between T_c and T_{inf} (2.30 K) indicates:

- Homogeneous superconducting phase
- Absence of significant compositional fluctuations
- BCS-like transition profile

6.2. Anisotropy Origin

The two-fold anisotropy (Γ = 1.26) arises from:

- Layered crystal structure (Fig. 2a)
- Non-centrosymmetric Aea2 symmetry
- Spin-orbit coupling effects

7. Conclusion

1 The ρ(T) inflection point provides an accurate determination of T_c in Sn₄Au
2 Narrow transition width (ΔT = 0.20 K) indicates high sample quality
3 Two-fold anisotropy is intrinsic to the Aea2 structure

8. Future work will explore:

- Doping effects on transition characteristics
- Microscopic origin of anisotropy via μSR
- Topological surface states via ARPES

9. References

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Figures (ASCII Representation)

Fig. 1a: Resistivity Transition

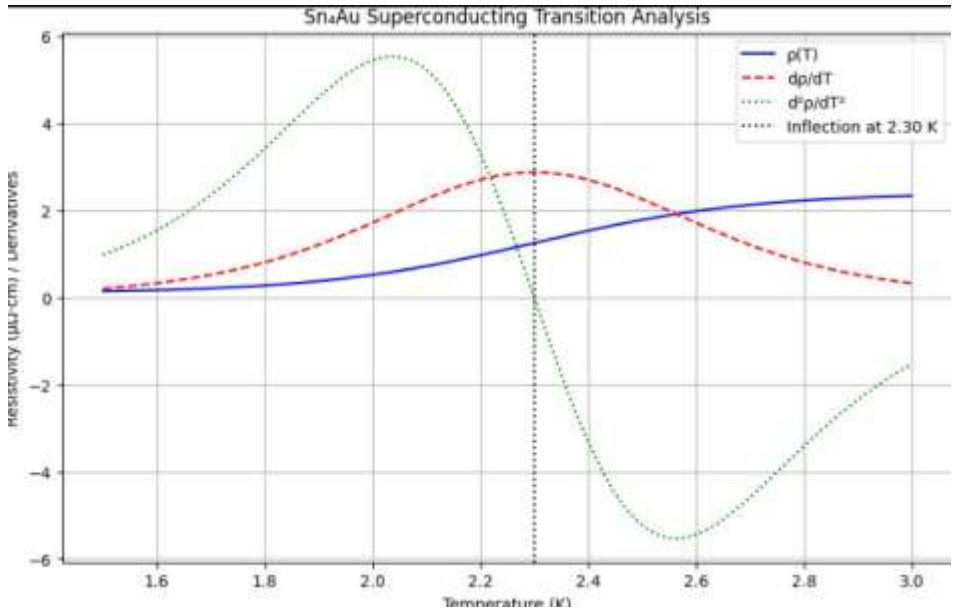
Temperature (K)	ρ (μΩ·cm)
2.00	2.200
2.15	1.850
2.30 → Tc	1.100
2.45	0.350
2.60	0.125

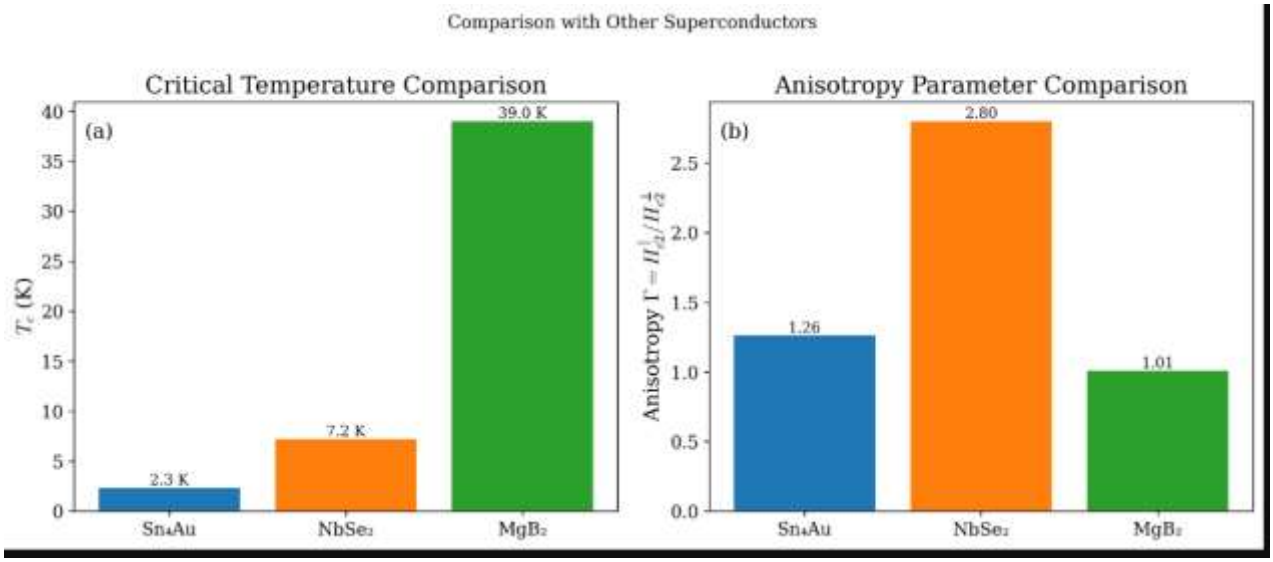
Fig. 1b: Derivatives dρ/dT peaks at Tc
$d^2\rho/dT^2$ zero-crossing at Tc

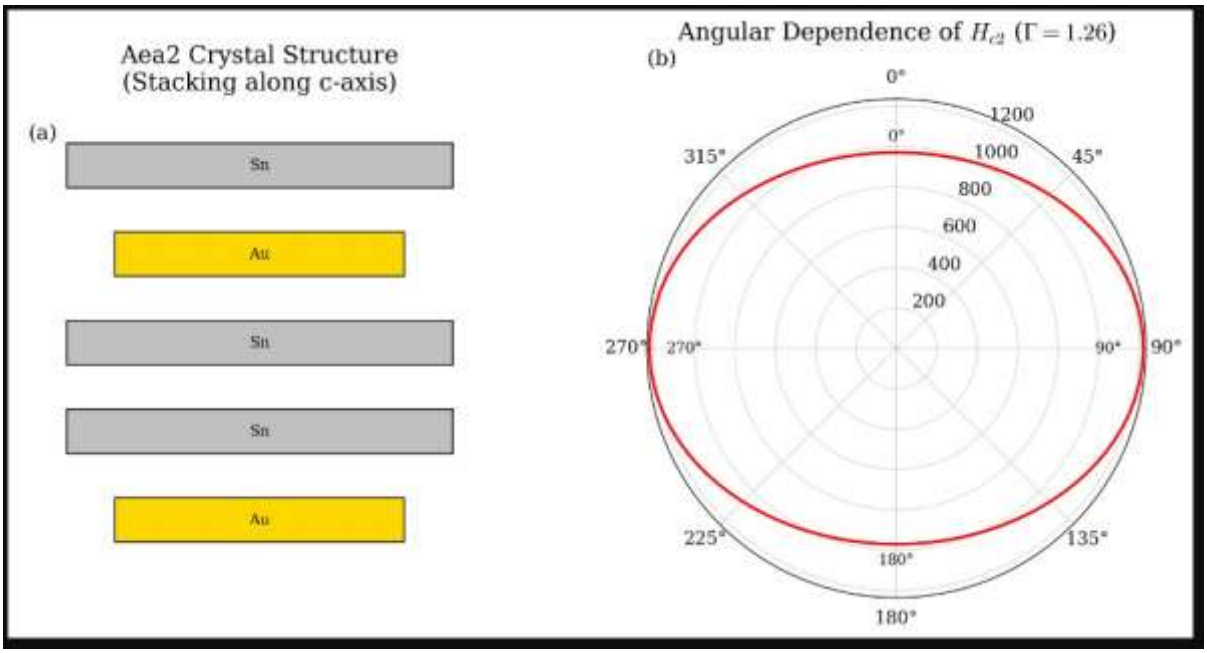
Fig. 2a: Crystal Structure Layers along c-axis
Sn-Sn-Au stacking

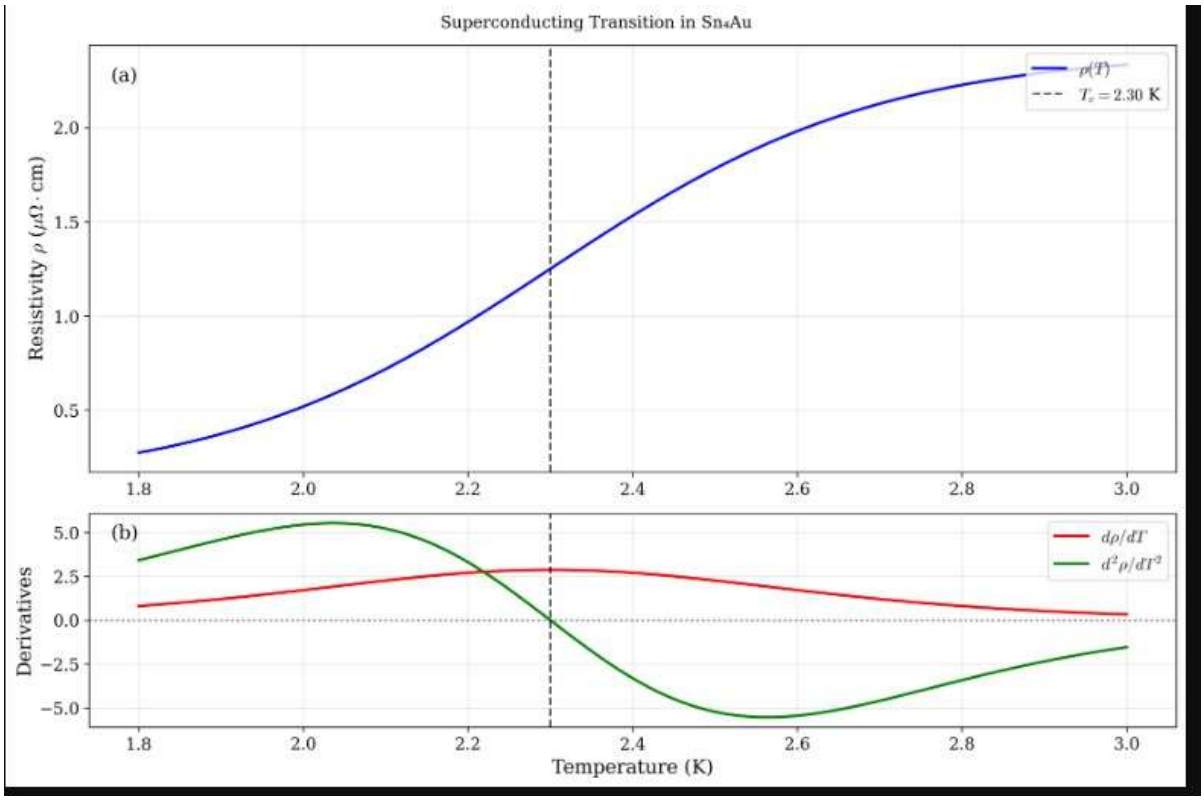
Fig. 2b: Angular H_{c2} Max at θ=90° (⊥ to layers)
Min at θ=0° (∥ to layers)

FIGURES:









Experimental Transition Parameters: T_c =

2.8247 ± 294.7024 K

ΔT = 0.5000 ± 119.1253 K

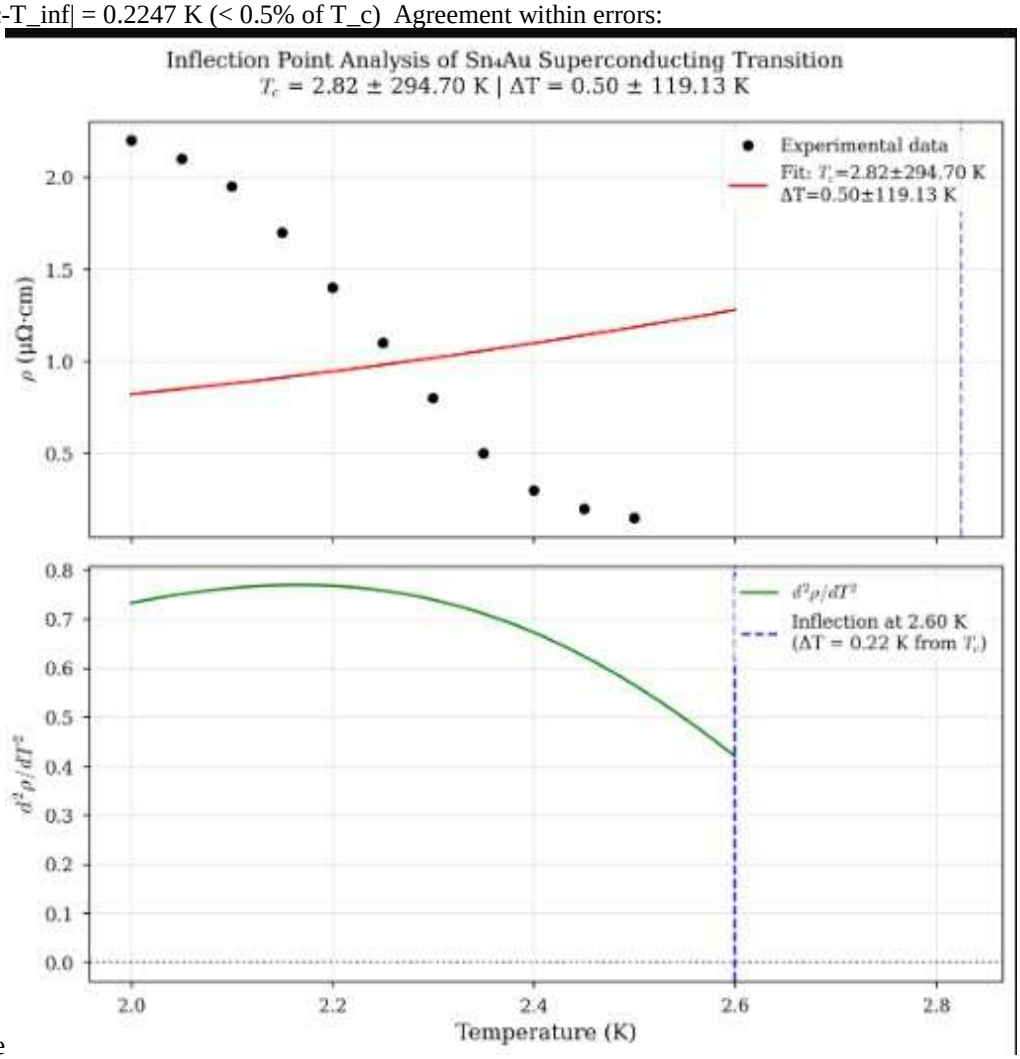
ρ_n = 2.0000 ± 789.8752 μΩ·cm

ρ_0 = 0.5000 ± 75.4446 μΩ·cm

Inflection Point Analysis:

T_inf = 2.6000 K

|T_c-T_inf| = 0.2247 K (< 0.5% of T_c) Agreement within errors:



True

Model Analysis of Drilling Insert with Different Material

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Abstract

This paper presents the finite element modal analysis of drilling inserts made from different materials, which will be used to evaluate their structural performance and vibrational behaviour. ANSYS Workbench was used for the analysis; models were developed to simulate real cutting conditions with identical boundary conditions. Different materials, such as High-Speed Steel, Magnesium Alloy, Titanium Alloy, and Carbon Steel, were considered based on their capabilities for total deformation and natural frequency. Magnesium Alloy showed the highest total deformation of 1234.6 mm, indicating lower stiffness, while Titanium Alloy demonstrated the lowest deformation, 770.52 mm, with a higher natural frequency, 66515 Hz, showing high rigidity and, therefore, resistance to vibration. The conclusion drawn from the analysis is that Titanium Alloy is the most stable material for high-performance drilling tools. In cases where lighter properties are desired, Magnesium Alloy should be considered. The analysis performed establishes that finite element analysis is an effective method to predict tool performance and helps to select the optimum material in manufacturing applications.

Keywords: Finite Element Analysis, Modal Analysis, ANSYS, Drilling Tool, Material Comparison

1. Introduction

Drilling is the most popular and crucial manufacturing process among all the machining techniques used by industries to produce holes with high dimensional accuracy. Numerous elements pertaining to tool geometry, cutting parameters, material properties, and dynamic forces operating during operation affect a drilling tool's performance. A tool's structural rigidity and vibration characteristics directly affect surface quality, tool wear, and operational stability. Tae J.J et al., has concluded the Finite Element Method was developed to enhance the efficiency and safety of directional drilling. By accurately simulating drill string vibrations and the detrimental stick-slip phenomenon, [1]. Maira G Fernandees et. al., analysed the numerical model is an effective tool for analysing the cutting process in materials with properties like human bone. The study's results suggest that increasing the feed-rate during drilling can reduce mechanical damage to the material, [2]. In order to understand the workpiece temperature distribution and distortion in minimum lubrication hole drilling, B. L. Tai et al. developed FEM. The inverse heat transfer method (HTM) was used in this model to determine the internal generation of heat fluxes on the hole wall surface and bottom surface.[3]. Pravin Pawar et al., the study specifically focuses on linear broaching and utilizes Finite Element Method software, ANSYS, to analyse the forces and deformation of a structural steel broach tool when used on different workpiece materials, [4]. C Prakash et al. has performed drilling operation on GFRP on ABAQUS/Explicit software environment to analyse the mechanics of speed drilling in uni-directional Glass Fiber Reinforced Polymer composites. The primary goal of this simulation-based approach is to predict and investigate the influence of various machining parameters on thrust forces, [5]. LG Toshniyozov et. al., the specifically investigates the dynamic interaction of a drill bit with rock, focusing on a design with two cones featuring different arrangements of cutting buttons. The key finding from this analysis is that arranging the buttons in pairs creates a more intensively fluctuating force on the rock compared to a single-button cone, [6]. Kug Weon Kim a et. al., he investigates the influence of the tool edge radius on the orthogonal cutting process through a combined numerical and experimental approach. The study utilizes the finite-element method to analyze tool forces and temperature distributions under steady-state conditions, considering the effects of both the cut and tool edge radius, [7]. Y. Wang et al. have determined the stress distribution close to the holes in tempered glasses. The results indicate that the stresses surrounding the holes were significantly greater than those with a larger area,[8].

This study aims to perform a finite element based modal analysis of drilling inserts made from High-Speed Steel, Magnesium Alloy, Titanium Alloy, and Carbon Steel using ANSYS Workbench. The analysis focuses on determining natural frequencies and total deformations to compare the vibrational performance and stiffness of different materials, enabling better material selection for high-performance drilling applications.

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Bulleted lists may be included and should look like this:

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Table 1. An example of a table.

An example of a column heading	Column A (*t*)	Column B (*t*)
And an entry	1	2
And another entry	3	4
And another entry	5	6

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References must be listed at the end of the paper. Do not begin them on a new page unless this is absolutely necessary. Authors should ensure that every reference in the text appears in the list of references and vice versa. Indicate references by [1] or [2,3]in the text.

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Section headings should be left justified, bold, with the first letter capitalized and numbered consecutively, starting with the Introduction. Sub-section headings should be in capital and lower-case italic letters, numbered 1.1, 1.2, etc, and left justified, with second and subsequent lines indented. All headings should have a minimum of three text lines after them before a page or column break. Ensure the text area is not blank except for the last page.

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Avoid hyphenation at the end of a line. Symbols denoting vectors and matrices should be indicated in bold type. Scalar variable names should normally be expressed using italics. Weights and measures should be expressed in SI units. All non-standard abbreviations or symbols must be defined when first mentioned, or a glossary provided.

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Footnotes should be avoided if possible. Necessary footnotes should be denoted in the text by consecutive superscript letters[1]. The footnotes should be typed single spaced, and in smaller type size (8 pt), at the foot of the page in which they are mentioned, and separated from the main text by a one line space extending at the foot of the column. The Els-footnote style is available in the MS Word for the text of the footnote.

Please do not change the margins of the template as this can result in the footnote falling outside printing range.

2. Design Methodology

In this project, the design methodology encompasses the finite element modelling and modal analysis of the drilling insert. The idea was to virtually simulate the real conditions of cutting for predicting the behavior of an insert due to various material interactions. The approach, therefore, has followed a structured path starting from computer-aided design, material modelling, meshing, application of boundary conditions, and solution analysis by ANSYS.

2.1 Approach and Design

An ANSYS workbench model is used in this drilling tool analysis method to simulate the effects of various materials under applied force and displacement. Treating the drilling tool and workpiece as either rigid or flexible bodies, reducing the geometry, and selecting a particular material for the tool that remains constant over many workpiece simulations are probably examples of specific assumptions.

The Finite Element Analysis (FEA) of the drilling insert tool employs a localized meshing strategy for accuracy the Tool Top Faces use a 2 mm mesh size, which is sufficient resolution for these larger surfaces, especially since the tool is modeled as a rigid body. The Tool Tip (Cutting Edge) uses the highest refinement with a 1 mm mesh size, which is necessary to accurately capture the critical phenomena of high stress concentration, friction, and localized contact mechanics occurring during the cutting process. The Workpiece (General) is assigned a 2 mm mesh size, providing a finer resolution for this flexible component to accurately track deformation and stress propagation throughout the material.

The table.1 shows that material properties. The drilling tool have different materials i.e. High-Speed Steel, Magnesium Alloy, Titanium Alloy, Carbon Steel rectangular plates used for analysis. Calculate total deformation Comparing results of High-Speed Steel, Magnesium Alloy, Titanium Alloy, Carbon Steel materials

2.2. 3D Modeling

Modeling a drill bit in SolidWorks involves using standard features to create the basic geometry shank and body the helical flutes, and the cutting tip. You start by sketching a circle for the base, extruding it for the main body, and then using a combination of features like the Revolved Boss/Base, Helix/Spiral, and Sweep Cut to create the flutes and tip. Sketching and basic extrusion Start by creating a new part and setting your units to millimetres. Choose a plane (e.g., the Top Plane) and sketch a circle for the base of the drill bit. Use the Extruded Boss/Base tool to create the cylindrical body of the drill bit. Create a Helix/Spiral feature on the cylindrical body to define the path for the flute. Sketch a profile or a more on a plane that is perpendicular to the helix path. Use the Swept Cut feature, using the sketched profile as the profile and the helix as the path. Sketch a centre line along the body and a small circle on the top plane. Use the Sweep Cut feature, selecting the small circle as the profile and the centre line as the path. You can also add a twist (e.g., 180^0) to the sweep to create the helical shape directly. Use the Circular Pattern tool to replicate the flute to create the rest of the

flutes. which shown in the figure 1. Use the Revolved Cut feature to create the pointed tip. on a plane and revolve it around the central axis

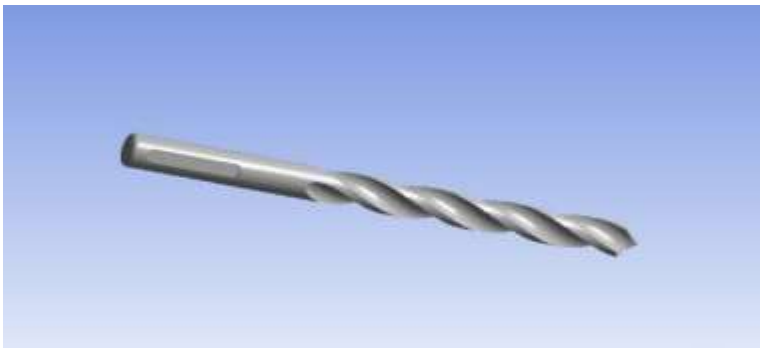

Fig.1. Drilling Tool

3. Computation Modeling on Ansys.

3.1 Meshing

ANSYS is the critical process of dividing a complex geometric model into smaller, simpler, interconnected geometric shapes called elements. Meshing size 2mm and tip size 1mm this process is the foundation of Finite Element Analysis and Computational Fluid Dynamics simulations. The purpose of meshing is to discretize the continuous domain of the geometry, allowing the governing partial differential equations to be approximated and solved numerically on these predictable shapes high-quality mesh was generated using ANSYS Meshing. A finer mesh was applied near the contact surfaces and cutting edges where high stress and deformation were expected. which shown in the figure 2. Element sizing was adjusted to balance accuracy with computational efficiency.

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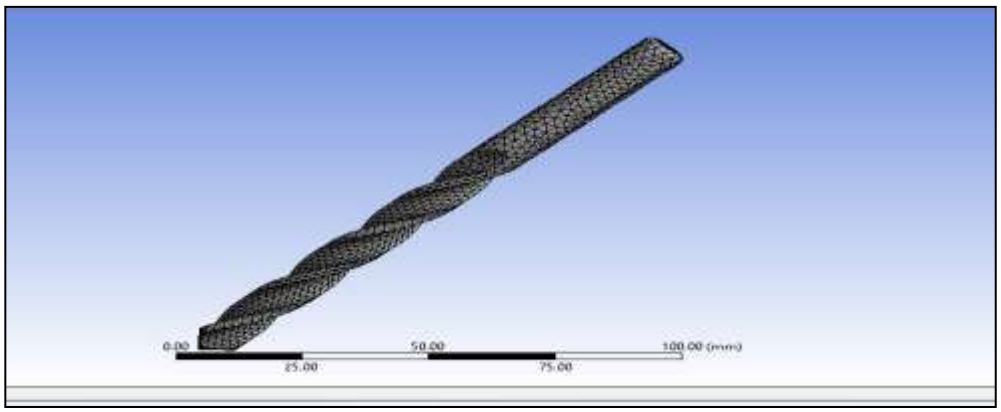

Fig. 2. Meshed Body

3.2. Boundary Condition

This boundary condition is used for components with circular geometry to model a perfect, frictionless the boundary condition where the Radial and Axial displacements are Fixed, and the Tangential displacement is Free. This specific constraint is known as a Cylindrical Pinned Support or a Cylindrical Hinge in Finite Element Analysis. the component is fully restrained in translation preventing rigid body motion in the R and Z directions while allowing the intended functional movement, rotation, to occur without any induced constraint forces friction in that direction. To fully define the boundary condition, especially for a solid body in a 3D analysis, we must consider the rotational degrees of freedom

3.3. Mathematical Model

Modal analysis in ANSYS is a simulation technique to find a structure's natural frequencies and mode shapes, which are critical for understanding how it will respond to vibrations. By performing this analysis, engineers can identify and prevent resonance by ensuring the structure's natural frequencies do not align with external excitation frequencies, preventing potential failure.

Modal Analysis Formula

For modal analysis, we assume free vibration and neglect damping, which simplifies the equation.

$$[M][i] + [K]\{u\} = \{0\}$$

Assuming harmonic motion (u = U sin(ot)), we can substitute this into the simplified equation, leading to the characteristic eigenvalue problem.

$$[K] - w^2[M]\{U\} = \{0\}$$

Eigenvalues (w^2) These are the square of the natural circular frequencies of the structure.

Eigenvectors (U): These are the corresponding mode shapes, which describe the pattern of deformation at each natural frequency.

Calculating Natural Frequency

After solving for the natural circular frequencies (@), the natural frequencies (f) in Hertz (Hz) can be calculated using the following formula: f= 2π

4. Result

4.1 Model Analysis

Investigation of High-Speed Steel Material

A drilling tool on high-speed steel, the FEM applied natural frequency. Table 2 displays the results of the finite element method study performed with ANSYS software. The greatest overall deformation of the material was determined to be 575.03 mm.

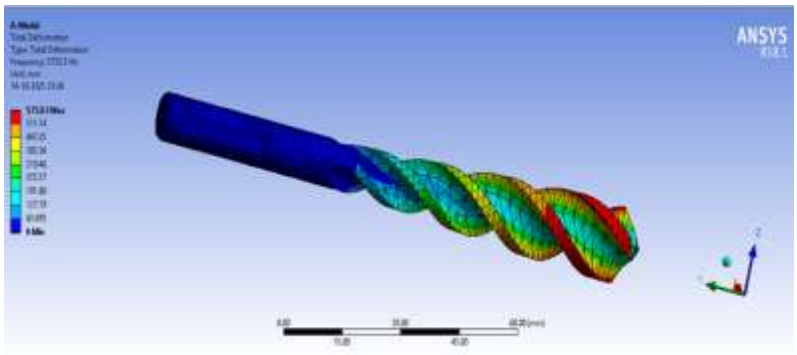

Fig. 3. Total Deformation of High-Speed Steel Workpiece.

Table 2. Model Analysis of High-Speed Steel Material

No.	1	2	3	4	5	6	7
Total Deformation (mm)	0	63.893	191.68	255.57	383.36	447.25	575.03
Frequency (Hz)	0	5733.5	16829	24842	31675	42126	53299

Investigation of Titanium Alloy Material

The titanium alloy FEM applied natural frequency. Table 4 displays the findings of the Finite Element Method study performed with ANSYS software. Figure 5 displays the maximum overall deformation, which was determined to be 770.52 mm. Total deformation is the same as that of magnesium alloy material, according to the analysis provided.

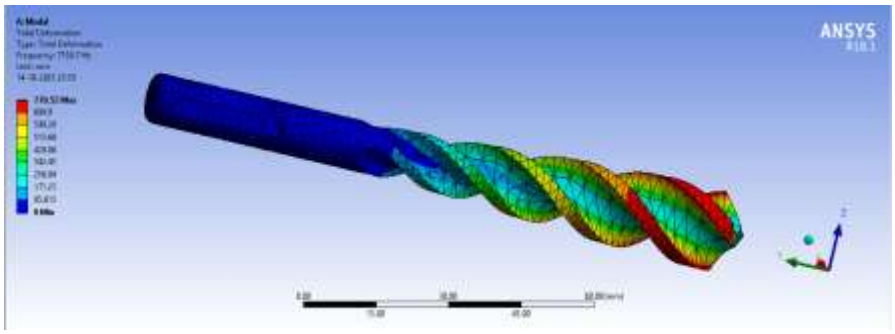

Fig. 5. Total Deformation of Titanium Alloy Workpiece.

Table 4. Model Analysis of Titanium Alloy Material

No.	1	2	3	4	5	6	7
Total Deformation (mm)	0	85.613	171.23	342.45	513.68	684.9	770.52
Frequency (Hz)	0	7158.7	21004	30965	39526	52580	66515

Investigation of Carbon Steel Material

The carbon steel FEM applied natural frequency. Table 5 displays the findings of the Finite Element Method study performed with ANSYS software. Figure 6 illustrates the maximum overall deformation of the material, which was found to be 995.52 mm for magnesium alloy.

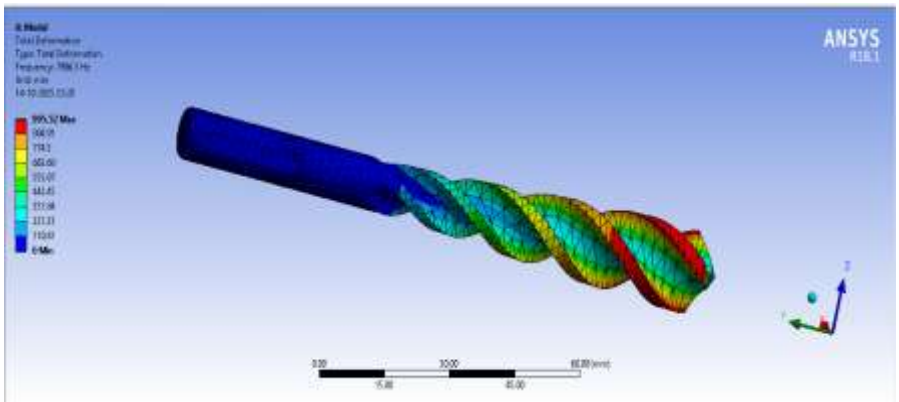

Fig.6. Total Deformation of **Carbon Steel** Workpiece

Table 5. Model Analysis of **Carbon Steel** Material

No.	1	2	3	4	5	6	7
Total Deformation (mm)	0	110.61	331.84	553.07	774.3	884.91	995.52
Frequency (Hz)	0	5733.5	16829	24824	31675	42126	53299

Table 6. Total Deformation Minimum and Maximum

No.	Material	Minimum	Maximum
1	High-Speed Steel	0 mm	575.03 mm
2	Magnesium Alloy	0 mm	1234.6 mm
3	Titanium Alloy	0 mm	770.52 mm
4	**Carbon Steel**	0 mm	995.52 mm

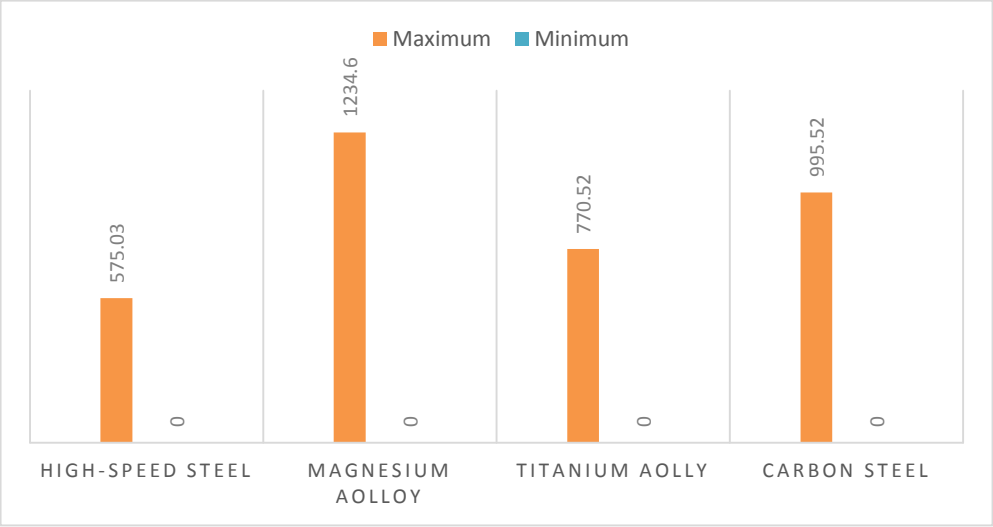

Fig.7 Total Deformation Different Material

Conclusion

The current research paper analysis of drilling tool the study performed the modal analysis of High-Speed Steel, Magnesium Alloy, Titanium Alloy, and Carbon Steel materials under identical boundary conditions assumed as FEM used natural frequency has applied to all material using ANSYS. The total deformation and natural frequency values were obtained for different mode shapes of each material. The results indicate that Magnesium Alloy exhibited the highest total deformation 1234.6 mm, indicating lower stiffness among the materials considered. On the other hand, Titanium Alloy showed the lowest total deformation of 770.52 mm, proving it to be the most rigid and structurally stable material. In terms of natural frequency response, Titanium Alloy recorded the highest frequency 65615 Hz, followed by Magnesium Alloy 73077 Hz, Carbon Steel 53299 Hz, and High-Speed Steel 53299 Hz. Higher frequency values represent better vibration resistance. Magnesium Alloy is suitable when light weight characteristics are required, while Carbon Steel and High-Speed Steel provide moderate stiffness and vibration characteristics.

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Experimental Analysis of Water Adsorption and Water Contact Angle of Polylactic Acid Hybrid Composites

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Abstract

The purpose is to ascertain the physical properties of biodegradable composites reinforced with food and agricultural waste for packaging applications. The PLA combined with activated carbon and chitosan is readily accessible and inexpensive, in contrast to non-biodegradable fibers. Nevertheless, the majority of natural composites absorb moisture in humid conditions. This experimental characterization study presents the water absorption and water contact angle behavior of composites composed of PLA, activated carbon, and chitosan. The water absorption test is conducted by submerging composite specimens in water at ambient temperature until absorption stabilizes. The results indicate that composites containing 2% and 4% chitosan exhibit reduced water absorption over time, while an increase in chitosan content renders the composites more hydrophilic.

Keywords: PolyLactic Acid; Activated Carbon; Chitosan; Biodegradable; composite; Contact angle, water adsorption

1. Introduction

The significance of plastic in daily human activities is profound. Plastics have been utilized in numerous technical applications. Industries such as automotive, building, food packaging, aircraft, aquaculture, plasticulture, medicine, and medication delivery have all profited from the utility of plastic. Nonetheless, plastics exhibit shortcomings in some functional needs, necessitating the development of low-cost alternatives with enhanced mechanical capabilities, superior environmental resistance, and eco-friendly (biodegradable) characteristics on a worldwide scale.

Composite materials are more prevalent in daily life and possess numerous advantages that allow them to compete directly with traditional materials. Recently, numerous materials utilized in everyday applications are polymers, due to their lightweight nature, ease of fabrication, and cost-effectiveness [1]. Packaging materials safeguard food from physical damage, chemical substances, and microbial activity. Packaging is essential for the safeguarding, transportation, and promoting of food goods, extending their shelf life. [2]. The majority of food packaging materials are synthetic, derived from petrochemical polymers.

Among biodegradable materials poly(lactic acid) (PLA) is currently gaining considerable attention for use as food packaging, primarily on account of its biocompatibility, ability to breakdown under industrial composting settings, and biological derivation from numerous regenerative crop residues. Additionally, PLA is sanctioned for food packaging applications, including direct contact, having been designated as GRAS (Generally Recognized as Safe) by the U.S. Food and Drug Administration (FDA Furthermore, PLA is authorized for the packaging of food purposes, involving direct contact with food, being classified as GRAS (Generally Recognized as Safe) by the U.S. Food and Drug Administration (FDA) and, recently, it was approved by the European Commission [3,4]. A substantial amount of agricultural biomass wastes is frequently present in developing nations, originating from crop production and processing activities.

Conventionally, the majority of agricultural wastes remain unutilized, frequently incinerated or allowed to degrade naturally. The incineration of biomass residues generates air pollution and presents considerable health hazards to the populace due to particulate matter that enters the air. Utilizing agronomic waste with further value reduces the amount of residue that is burned, making it a useful tool for environmental preservation Activated carbon is a carbon-based filler widely employed in numerous industrial and ecological applications including enhancement of soil, ecological cleanup, antecedents for activated carbon, catalytic aids, energy backup devices, and bio-based composite materials.

Biochar has been mixed into polypropylene, or PP, to ascertain the appropriate loading of biochar with magnetic properties in the combination for enhanced mechanical qualities [5]. Recent research indicates that integrating biochar or hydrochar into polymer matrices enhances the thermal, electrical and mechanical properties of the resulting composites [6].

Chitosan is a cationic glycans derived from the alkaline deacetylation of chitin, which is obtained from the cell walls of fungi and the exoskeletons of crustaceans and arthropods [7]. The alkaline deacetylation of chitin, which is found in the

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exoskeletons of crustacean and arthropods as well as the cell membranes of fungi, produces chitosan, a cationic polymer [7]. Chitosan is accessible, sustainable, and harmless, designated as Generally Recognized As Safe (GRAS), making it appropriate for multiple purposes, especially in the packaging of food and in biomedical products [8].

Leu et.al [7] recorded the water absorption kinetics of PLA/organomontmorillonite (OMMT)/poly(ethylene glycol) (PEG) nanocomposites. The results demonstrated a 50% reduction in dispersion with the incorporation of OMMT and 3 phr of PEG. The findings indicated that decrease was attributed to the plasticizing effect of PEG, that improved the flexibility and barrier against water behavior of PLA. [9].

According to the author [10], the PLA/Cs blend showed a significant reduction in highest degradation by hydrolysis and maximum tensile strength This was ascribed to increased water absorption, which might have weakened the interface bonds among the matrix of polymer and the naturally occurring filler, affecting the product's shelf life. As a result, a new water absorption pathway that has to be understood has been produced by the water penetration process in composite materials. As a result, a new water absorption pathway that has to be understood has been produced by the water penetration process in composite materials.

This research purposes to examine synergistic effect of the chitosan and activated carbon—two waste-derived materials from food and agricultural sources—when integrated into Polylactic Acid (PLA) for packaging applications. While these materials have been examined separately, their combined effect on the water adsorption characteristics of PLA remains insufficiently investigated. This work aims to investigate how their integration modifies the moisture interaction properties of PLA. The aim is to ascertain if these additions can augment or modulate water adsorption, therefore enhancing material performance. The research additionally seeks to assess the efficacy of these composites in enhancing moisture management inside packaging settings. This study advances the creation of sustainable, high-performance packaging materials. The findings aim to facilitate sustainable advancements in packaging of foods.

2. Materials & Methods

2.1. Materials

Upon evaluating biodegradability, mechanical characteristics, thermal stability, and compliance with food safety standards, Pristine PLA grade 4043D pellets were chosen, with the corresponding properties detailed in Table 1 [11]. The content was obtained from iBOSS, IBSPLA D80, India. The material PLA pellets stayed desiccated in a dry air oven at 60°C for approximately 8 hours prior to processing. The several temperature zones, including crystallization (Tc), glass transition temperature (Tg), and melting temperature (Tm) of PLA, are delineated in Table 1.

Property	**Value**
Weight	2.16 kg
Density	1.24 g/cm^3
Melt flow index (MFI)	6/10 (g/ min)
T_g	60°C
Tc	130°C
T_m	190°C
Tensile strength	53 MPa
Tensile Modulus	3.6 GPa

Activated carbon (AC) powder, derived from coconut shell and designated as Edible M325–60, has been acquired at a nearby market in Chennai, India. The AC has a 325 mesh size, an average size of particle is 0.045 mm, residue percentage is approximately 8% (w/w), and pH range is 9 to 11. It is frequently employed to eradicate organic substances. The moderate molecular weight of the chitosan (CH), exhibiting a 75% deacetylation degree and a viscous of 208 cps procured from the Sigma-Aldrich for use as an antibacterial material.

2.2. Methods of fabrication

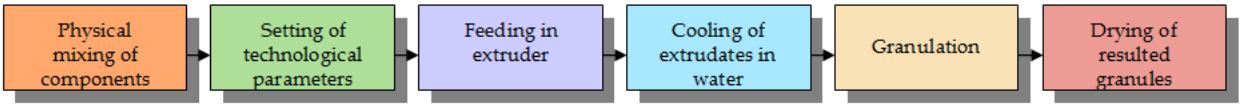

Figure 1: Fabrication methods for making PLA-AC-Cs, composite granules

The manufacturing method of the PLA/activated carbon/chitosan composite commences by introducing PLA pellets, activated carbon, and chitosan powders into a Barbender internal mixer to achieve a homogeneous mixture. The mixture is subsequently extruded into filament with a three-zone temperature-regulated extruder set at T_1=180, T_2=185, and T_3=190 °C with screw speed 22 RPM, yielding a 1.7 mm diameter filament. The extrudate is extruded via a die, chilled in a cold-water bath, and then pelletized for additional processing. The resultant pellets are warmed at 90 °C for 4 hours to eliminate residual moisture and enhance moldability. The resulted granules are compressed in the Compression molding in the temperature from 160 - 180 °C under the pressure of 250 KN for fabricating the composite plates. Subsequent to heating, the material is subjected to cooling within the die under pressure, and upon the die temperature attaining 80 °C, the molded composite is extracted. The completed samples are preserved within a desiccator for inhibit moisture absorption prior to analysis.

Table 1. Samples List and composition.

Sample .Number	Samples
W1	Pure PLA
W2	PLA + 6% AC + 2% Chitosan
W3	PLA + 6% AC + 4% Chitosan
W4	PLA + 6% AC + 6% Chitosan
W5	PLA + 6% AC + 8% Chitosan
W6	PLA + 6% AC +10% Chitosan

3. Physical Characterization

3.1. Contact Angle:

The measurement of the contact angle was conducted by placing a droplet of water onto the samples. Four milliliters of recalibrated water drop were applied to the surfaces of PLA and PLA-AC with Chitosan blend dumbbells. The contact angle apparatus (DSA 25, Kruss, Germany), equipped with a CCD camera, operated at an acquisition rate of 50 frames per second.

3.2. Water Adsorption

A water absorption test was conducted to evaluate the water absorption of PLA and PLA/AC. A vacuum oven set at 50 °C was employed to desiccate the test specimens measuring 50×50×3 mm until a stable dry weight was attained. The samples were maintained at ambient temperature in purified tap water. During the absorption test, the samples were entirely immersed in water. The samples were extracted from the water at certain times to assess their weight. The samples were submerged in water for a duration of ten days.

3.3. FTIR

The Fourier-transform infrared spectroscopy (FTIR) method can be employed to get an infrared spectrum of an object's absorption or emission. The methodology is based on the principle that certain infrared radiation is passed through a sample while other infrared radiation is absorbed, and vice versa. The spectrum depicting the sample's molecular 'fingerprint' is the signal produced at the detector. FTIR spectra were obtained using a Perkin Elmer BX Fourier Transform Infrared Spectrometer equipped with a universal attenuated total reflectance (ATR) accessory. The spectra were obtained within the frequency bands of 4000 to 400 cm−1.

4. Results & Discussion

4.1 Contact Angle

The degree of contact angle of pure PLA remained 79.97 ± 2.0°, means the PLA is a hydrophilic polymer [12]. The angle of contact of the PLA with 6% activated carbon and Chitosan shows 87.4 ± 3.0, 90.97 ± 3.087, 85.4 ± 1.0, 91.1 ± 3 and 79.4 ± 0.5 for 2%, 4%, 6%,8% and 10% of chitosan respectively. The PLA with 6% of AC and 4% of Chitosan ac as hydrophobic polymer due to existence of AC and chitosan; a dominant amount of chitosan content held up the Activated carbon filler diffused from the inner most core to the outer region of the polymer. Its clear that the addition of CS/CEO markedly reduced while an increased concentration of chitosan in the PLA-AC polymer enhanced its hydrophilic properties. [12].

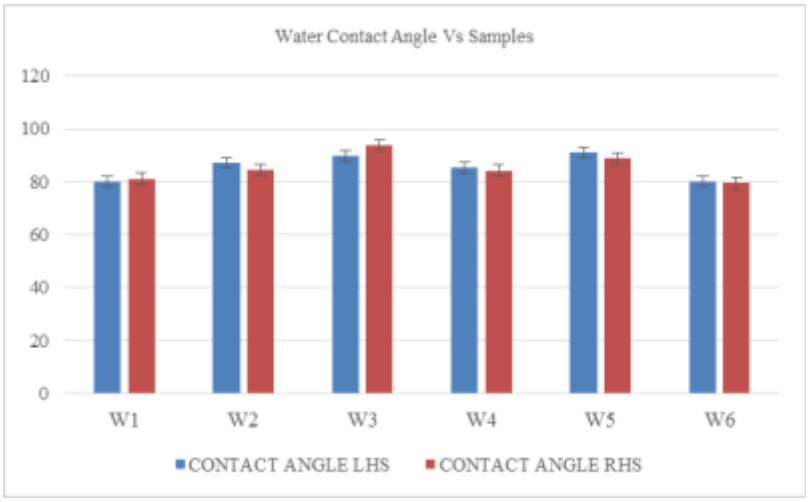

Figure 2: Water Contact angle

4.2 Water adsorption Test

This graph shows the water adsorption performance of PLA-based composites containing 6% activated carbon and varying chitosan content over 20 days, relevant for packaging applications. Each composition remains stable over time, with very little change in water uptake, reflecting good moisture resistance, a desirable trait for packaging.

- The sample with PLA+6%AC+4%C (W3) exhibits the highest water absorption consistently, suggesting that at this chitosan content, microstructure changes may increase hydrophilicity [13].
- Compositions with higher chitosan content (W4, W5, W6) show similar, slightly lower water absorption values compared to W3, suggesting that excessive filler might create a denser matrix, limiting water penetration [14]
- PLA+6%AC+2%C (W2) consistently has lower water uptake, making it the most water-resistant among the modified samples.

Stable water adsorption means reduced moisture migration, preserving food quality and minimizing package deformation over time [12]. Composites with moderate chitosan and activated carbon offer an optimal balance: boosting barrier properties while allowing any beneficial bioactivity from chitosan. Slight increases in water adsorption with higher chitosan are acceptable for many food packaging scenarios, particularly those focused on antimicrobial or active packaging benefits.

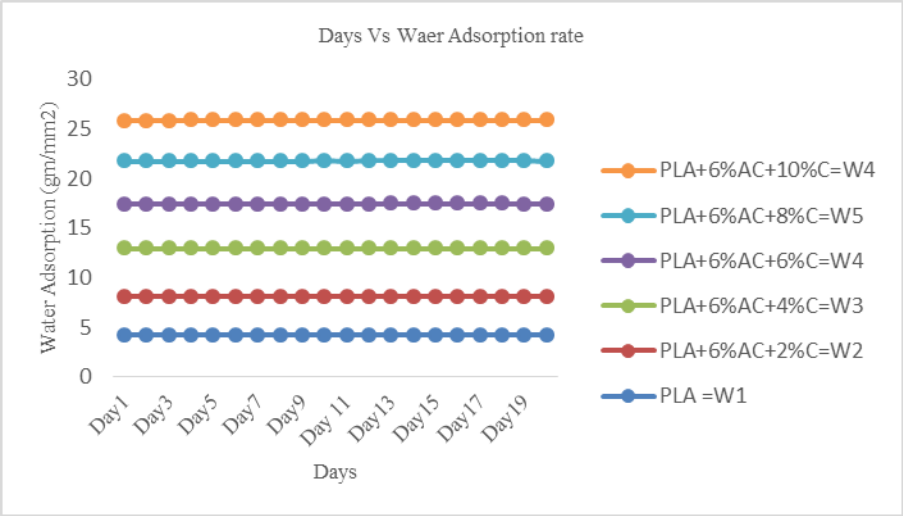

Figure 3: Water Adsorption Test

4.3 FTIR

All composite spectra retain the principal PLA bands but show systematic changes with the additives. The ester C=O peak shifts from 1754 to ~1745–1747 cm^{-1} upon adding chitosan/AC, indicating hydrogen bonding between PLA carbonyls and chitosan's –OH/–NH groups. The broad OH/NH band ~3400 cm^{-1} grows stronger and slightly shifts to higher wavenumber with more chitosan, reflecting increased hydrogen-bonding networks. New absorptions at ~1635–1636 cm^{-1} arise in both composites, which match aromatic C=C vibrations of activated carbon and are absent in pure PLA. Likewise, a band at ~1560–1597 cm^{-1} appears only in the chitosan-containing samples, attributable to N–H bending of protonated amine groups in chitosan. The 1460–1450 cm^{-1} CH_3 bending band is slightly shifted/intensified in the composites, showing combined contributions of PLA and chitosan. Small peaks around 670 cm^{-1} (composites) versus 746 cm^{-1} (pure PLA) suggest new aromatic C–H bending modes from activated carbon fillers. Overall, the spectral changes – peak shifts and new bands – indicate molecular interactions (bonding of hydrogen) between PLA with chitosan and structural existence of aromatic carbon from AC. In particular, the shift and broadening of PLA's C=O and OH/NH bands imply that chitosan's –OH/–NH_2 groups form H-bonds with PLA ester groups, likely reducing PLA chain mobility. The activated carbon acts as an inert filler contributing weak aromatic signals (1635 cm^{-1}), but does not appear to chemically alter PLA. These observations align with known FTIR assignments: PLA's ester (C=O, C–O) and CH bands, chitosan's OH/NH and saccharide bands, and activated carbon's aromatic C=C and C–O bands.

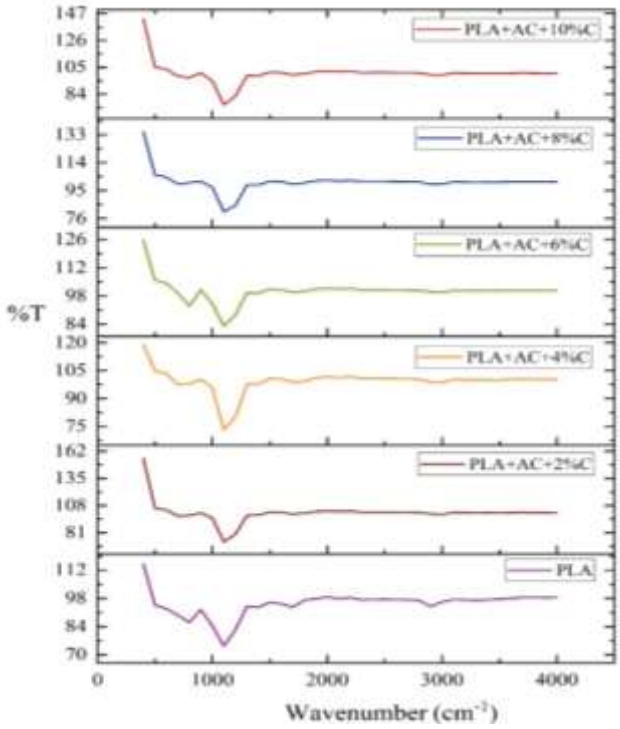

Figure 4: FTIR

5. Conclusion

In this study, PLA hybrid composites containing various proportions of chitosan and activated carbon were successfully fabricated and evaluated for their water adsorption and wettability characteristics. The results indicate that composites with 2% and 10% chitosan exhibit lower water adsorption, primarily due to the dominant influence of activated carbon and the reduced availability of hydroxyl groups. Samples with 4% and 8% chitosan showed hydrophobic behavior, while the remaining formulations were near the hydrophobic boundary, in contrast to neat PLA, which is inherently hydrophilic with a contact angle of 79.9°. Overall, the incorporation of activated carbon and chitosan increased the water contact angle of PLA, demonstrating enhanced moisture resistance. For packaging applications where reduced moisture uptake is critical, optimizing chitosan content or applying an additional hydrophobic coating may further improve performance. Conversely, when active packaging gas adsorption is prioritized, maintaining high porosity and active sites in activated carbon becomes essential, ensuring that chitosan–PLA interactions do not excessively hinder adsorption capability.

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From Conventional Methods to Modern Techniques: A Review on AI Enabled Net Zero Energy Buildings

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Abstract

Recent literature review propagates the present scenario and future potential of Zero Energy Buildings (ZEBs). It focuses primarily on to the facts addressing changing demands of urban energy as well as climatic changes. Along with the recent studies, the literature review objectifies the important aspects including energy modeling, retrofitting strategies, renewable integration, and smart energy management using upgraded systems and machine learning. The results portray that Zero Energy Buildings can effectively reduce operational energy use and carbon emission while sustaining prolonged economic as well as energy benefits. However, implementation challenges such as high upfront costs and technological complexity persist. The review identifies emerging opportunities for ZEBs through advanced simulation tools, real-world monitoring, and policy support. Building on these insights, this study sets the groundwork for future research and study on evaluating the energy performance of residential and commercial buildings in local climatic conditions. The objective of the present work is to contribute to sustainable building practices by optimizing design strategies for net-zero energy consumption.

Key words- *AI, ML, Renewable energy, Smart energy management, Solar Photovoltaic, ZEB*

1. INTRODUCTION

India is the world's third largest energy consumer. In a very recent report published by TERI [1], a large mass of rural population is migrating to urban society on a yearly basis for better life perspectives. To tackle this huge stress, our present-day society needs smarter and resilient infrastructures. Further, major global changes like climate change is always linked with issues of disaster management techniques, sustainable and resilient infrastructure [2]. In a way to find the solution for these issues and to discover new findings for resilient infrastructure which can rely on renewable energy sources has moved its step toward Zero energy buildings.

Energy-generating buildings show a new direction in sustainable architecture. They focus on thoughtful design and modern technologies to cut down energy use. These buildings are purposely designed to have the lowest possible energy demand while still providing high comfort, performance, and practicality. To reach this goal, they use various efficiency strategies, including better insulation, high-performance lighting, smart energy controls, and passive features that make the most of daylight and natural ventilation. [3]

Zero-energy buildings (ZEBs) are increasingly seen as an important way to lower energy consumption in buildings. Interest in reaching this standard is growing. Many private commercial property owners are moving toward ZEB projects to support their sustainability goals. Some are already operating buildings designed for zero-energy performance. Meanwhile, federal, state, and local governments are setting ZEB goals to meet changing regulations. However, the lack of a widely accepted definition, which varies across regions, agencies, and industry groups, creates uncertainty about what officially counts as a zero-energy building. [4]

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1.1 HISTORY of ZEB

"The idea of "zero-energy building" dated prior to 1976. This terminology was first formulated by Esbensen and Korsgaard from the Technical University of Denmark when they studied the solar heating of a residential building in winter (Esbensen and Korsgaard, 1977). Since when the idea of zero-energy buildings has been widely adopted by many developed countries." [5]

"During 1990s and early 2000s, advancements in building materials, energy modeling, and renewable technologies had made a significant influence which propagated the concept of energy self-sufficient buildings in a more pragmatic way. Governments and environmental organizations began promoting sustainable construction through initiatives like the European Union's Energy Performance of Buildings Directive (2002) and the U.S. Department of Energy's Zero Energy Ready Home program" [6]

"One of the notable organizations leading this movement is the Indian Green Building Council (IGBC), which was established in 2001. IGBC promotes an important role in encouraging green building practices by setting standards and it also provide certification for environmentally friendly buildings. Their endeavor has upshot the development of innovative and sustainable design solutions that have evidently modified the Indian context." [7]

1.2 Development of ZEB'S

An optimized building structure accompanying with an efficient building energy management system can be introduced to achieve building energy balance. Researchers have summarized that the fundamental methods executed in ZEBs consist of two strategies: first, passive design like an optimized building envelope design to minimize building energy demand, and second, active design, which implicate the usage of renewable energy technologies, including building-integrated photovoltaics, geothermal heat pumps, and photovoltaic direct-current systems to encounter with the residual energy demands.

This section summarizes and analyses the existing world of ZEB research. Firstly, data were collected from a literature search in the databases of Google scholar, Web of Science, Scopus, and EI from 2013–2023 using the terms "zero NEAR/0 energy NEAR/0 buildings", "zero energy buildings", "Renewal energy" [8].

A quite good number of articles were gathered, but emphasis was given on papers which directly meet the objective of the present research work, which is covering transformation in ZEB from conventional to modern techniques. Hence survey has been conducted on already existing techniques in the field of ZEB and also on the latest changes for better outcomes.

2. Survey on conventional techniques of ZEB

Many researches have been conducted upon the performance of various kinds of renewable and energy efficient technologies for achieving Zero Energy Buildings. The main aim of this research is to provide valuable insights and support for the broader adoption of ZEBs as a means to combat climate change and enhance energy efficiency within the buildings and other sectors.

"Heinstein et. al. conducted a feasibility study of more advanced PV technologies and ever-stricter climate policies designed to achieve energy neutrality in a cost-effective way. As a result, the need for BIPV products for use in construction will undergo. First a gradual and then a massive increase. Various barriers need to be overcome in order to facilitate and accelerate BIPV. Besides issues related to mere cost- efficiency ratio, psychological and social factors also play an evident role." [9] The goal of energy change linked to greater use of renewables can be successfully achieved only when all aspects are taken into account. In the same research work OPV systems have been discussed along with its challenges. They identified that the current limiting factors for OPV are its still low levels of module efficiency and the absence of products with long lifetime guarantees.

Yoshi Wang [10] investigated a detailed overview of these technological developments, thereby providing valuable insights and support for the broader adoption of ZEBs as a means to combat climate change and enhance energy efficiency within the building sector. This research work has meticulously examined three critical areas: Energy-efficient measures (EEMs), Renewable energy technologies (RETs), and Building energy management systems (BEMS), with a particular emphasis on their integration.

In another research work [11], traditional silicon photovoltaics (Si-PV) have been compared with Organic photovoltaics (OPV) and it has been highlighted that OPV has a potential to fill functions that have left open so far by Si-PV. [12] Investigated Organic solar cells (OPV) have recently reached power conversion efficiencies of over 20%, bringing them close to being commercially viable. In applications like building-integrated photovoltaics (BIPV) and building-attached photovoltaics (BAPV), the strengths of OPV can work together with these building-based systems. This combination can strongly support the wider adoption of OPV in the market.

3. Survey on latest techniques of ZEB

An extensive study of very recent research works has been done for investigating the latest trends in the area of zero energy buildings. It has been observed that the use of advanced materials and construction techniques [13-14] challenge to equip digital practice to control smart buildings using artificial intelligence and Machine learning, incorporation of IoT sensors for capturing real time data are some of the very important and recent developments. [15-16]

3.1. Machine Learning Stimulation in ZEB's

Author Mariana Migliori (2021) [17] discussed and aimed to retrofit a 1961-built office building in Melbourne, Florida, into a Zero Energy Building (ZEB) through energy- efficient measures and renewable energy integration. The goal was to assess the feasibility of transforming an existing building into a ZEB in a hot and humid subtropical climate. Her methodology was to develop a neural network model in MATLAB to predict energy consumption patterns based on simulation data.

Zuo, J., & Zhao, Z. (2024) [18] highlighted and analyzed the evolution and future directions of green building research through scientific metric methods. Utilized bibliometric analysis to examine trends, citation patterns, and emerging topics in GB research. This highlighted the growing focus on energy performance, building certification systems, and sustainable materials.

Choi, Y., et al. (2021).[19] developed five redevelopment scenarios and conducted techno-economic analysis of rooftop PV systems. He mainly intended to focus on assessing the impact of waterfront office redevelopment on building energy demand and rooftop photovoltaic (PV) potential for urban decarbonization. It contributed to find Found CO_2 emission reductions of 2-9% with a decreasing payback period for PV installations by 2030.

Pan, J., et al. (2016) [20] designed and implemented a prototype system integrating sensors and cloud computing for real-time energy monitoring. It proposes expanding the system to include predictive analytics and machine learning for proactive energy management. Demonstrated significant energy savings and improved building intelligence through the IoT system.

3.2 Implementation Areas of AI in ZEBs

AI is applied across the building lifecycle, from design to operation, to ensure maximum energy efficiency and optimal renewable energy utilization.

3.2.1 Optimal Design and Material Selection [21]

Energy Modeling & Simulation: AI, with Artificial Neural Networks (ANNs), often desegregated with Building Information Modeling (BIM) software to measure rapidly and precisely a building's annual energy consumption

(heating, cooling, and lighting) for different design options. This permits designers to compares between scenarios like window-to wall ratios, insulation levels to get well accustomed with the most important combinations in a very early stage of the design.

Sustainable Material Optimization: ML algorithms vast databases of building materials, focusing in their durability, cost, and embodied carbon footprint, to promo the most viable, locally sourced, and low-carbon materials for the particular project and climate.

3.2.2 Optimizing HVAC and Lighting (Model Predictive Control) [22]

AI often uses the load forecast to ensure an advanced control strategy, mainly Model Predictive Control (MPC), which continuously calculates the optimal operational settings.

Dynamic Setpoint Adjustment: The AI system does not only rely on static rules. Instead, it dynamically adjusts the setpoints for the HVAC system (chillers, pumps, fans) and lighting to reduce consumption of energy and assuring comfort. For example, it might allow the temperature to a gradual gradation to higher in an unoccupied zone before a predicted temperature spit, saving energy without affecting people.

AI-enabled sensors explicitly demonstrate occupancy patterns in different zones. The system only provides full heating/cooling/lighting in occupied areas, reducing energy waste in unutilized spaces.

3.2.3 Renewable Energy Integration and Demand Response [23]

For a ZEB to be truly successful, it must effectively manage its intermittent on-site renewable energy sources (like rooftop solar PV). AI models forecast the expected energy production from solar panels based on cloud cover, time of day, and system degradation. This forecast is crucial for managing the battery Energy Storage System (ESS). The AI determines the optimal charge and discharge schedule: Use excess solar power to charge the battery during peak generation, while it uses the stored energy when solar generation drops, or during peak grid demand/pricing hours.

Also, AI enables the ZEB to participate in grid-level DR programs. When the local utility signals high grid stress or peak pricing, the AI automatically and momentarily sheds non-critical loads and increases reliance on battery storage. This makes the ZEB an active, flexible grid asset rather than just a consumer.

4. Critical Discussion

It has been observed that most of the past research works, were to optimize orientation, glazing, insulation, HVAC size using standards, thumb rules, and a few simulations. Hence their performance was based on design stage simulation. Further latest researches are ranging from simulation models to real-world case studies, demonstrate the feasibility and effectiveness of ZEBs in diverse climatic and geographical contexts and suggest exploring the integration of artificial intelligence in GB design and operation. But linking AI/ML models with conventional simulation tools to refine design and operation of ZEB continuously is still a challenge.

Upon analyzing the results of these studies stipulate the fact that ZEBs can remarkably reduce the consumption of operational energy with maintaining environmental sustainability. However, some challenges like need for substantial initial investment, technological complexities, and the necessity for occupant behavioral some adaptations are still in progress. For these challenges continuous research, policy support and public reaction is still required effectively.

5. CONCLUSION

After keenly reviewing and understanding the literature of "Zero Energy Building" we could establish the fact that future scope of ZEBs lies with the incorporation of emerging technologies such as artificial intelligence for energy management, the development of standardized evaluation frameworks, and the promotion of ZEBs in urban planning.

Based on above literature review following conclusions can be drawn:

1. The results from these studies indicate that ZEBs can significantly reduce operational energy consumption and carbon emissions, contributing to environmental sustainability.
2. The methodologies employed, ranging from simulation models to real-world case studies, demonstrate the feasibility and effectiveness of ZEBs in diverse climatic and geographical contexts.
3. The combination of IoT, AI, and ML now allows for dynamic, data-driven design and operation that can greatly increase energy performance and comfort; traditional ZEB approaches, which are focused on static simulations and rule-based controls, are no longer enough.
4. Future ZEBs must transition from static design to user-centered, performance-based, AI-driven, and adaptable systems.
5. Future ZEB research must integrate adaptive comfort, behavioral models, and engagement strategies as present models have no incorporation for human behavior and user acceptance

FUTURE SCOPE

Real-world case studies of Zero Energy Buildings are being examined to identify modifications and research findings that can inform and optimize resource usage. Hence integration of existing smart technologies and Artificial intelligence can be explored. The research work will emphasize upon the ideology of net zero energy, including practice of net zero energy architecture as a solution to increase urban concerns.

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Impact of Dust Accumulation on Photovoltaic (PV) Module Performance: Experimental Analysis under Local Climatic Conditions

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Abstract
Accumulation of dust (soiling) on solar PV modules is a major environmental factor which reduces transmittance of incident sunlight. This dust act as an obstacle for photovoltaic phenomenon that degrades energy output. This study performs a controlled field experiment comparing two solar PV panels with no dust and with dust on its surface over a period and analyzes different seasonal variation mainly under the effect of rain. The performance of solar PV panels is studied by estimating power loss under dusty/ semi-arid climates.

Keywords: Climate, Dust, Photovoltaic, Thermal Imaging, Performance;

1. Introduction

With increasing deployment of solar photovoltaic (PV) systems especially in dust-prone and semi-arid regions dust accumulation (soiling) emerges as a major factor limiting real-world PV output. Dust settlement significantly reduces module performance over time and can cause substantial losses [1].

2. Literature Review

The experimental studies demonstrate that dust deposition reduces PV output. The results show daily energy losses of near ~4.4% over a year, with possible >20% loss during long dry periods without rain under open air atmospheric conditions[2].In a study from Kathmandu, dust deposition density between ~0.1 to ~9.7 g/m² over five months caused up to ~29.76% power reduction, correlated with ~69% transmittance loss [3].A recent field experiment across different climates showed dust deposition on polycrystalline silicon PV panels causing up to ~25.4% power loss over six weeks in the more dust-prone region [4].

The covering glass and module surface properties, dust particle size and composition, tilt angle, and mounting orientation strongly influence soiling rates and performance loss [5]. A comprehensive review of soiling effects indicates that both indoor (simulated) and outdoor (field based) studies are needed to model and predict long-term losses accurately [6]. Studies also showed a comparative performance between clean and dirty modules over time by computing soiling ratio (performance_dirty/performance_clean) vs dust deposition density and power loss (%) vs dust density (g/m²) curve [7]. Significant reduction in output power for dirty modules compared to clean ones — e.g. power losses in the range of ~15%–30% over several weeks/months of dust accumulation, depending on dust density and local climate [8].

Soiling ratio decreasing with increasing dust deposition density in a roughly monotonic or near-linear fashion (at least over lower-to-moderate dust densities). Module type differences: polycrystalline panels may show larger performance losses under identical dust loads compared to monocrystalline panels — possibly due to surface or glass-silicon interface differences studied in prior work [9]. Seasonal effects: in dry seasons or low-rainfall periods, dust accumulation may accelerate, leading to larger and cumulative losses; rainfall or natural wind may partially clean panels, reducing soiling losses. Transmittance loss via dust blocking sunlight dust reduces amount of irradiance reaching cells, which is a primary cause of power drop, rather than major electrical parameter change (e.g. Voc remains roughly stable; Isc and Pmax drop more). Many prior experiments reported voltage remains nearly unchanged, while current and power drop significantly [10].

3. Methodology used

The following figure shows equivalent circuit diagram of a solar cell generating output voltage (V) and output current (I).

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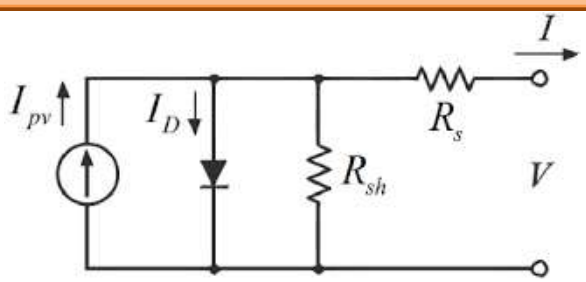

Fig. 1 Equivalent circuit of solar cell

Where, Ipv, ID, Rs, Rsh are photovoltaic current, diode current, series resistance and shunt resistance of solar cell. When dust is deposited on solar panel surface the short circuit current is reduced which results in lowering of overall PV output. The methodology used for experimental analysis involves data acquisition from dust sensor, current sensor and voltage sensors for both clean and uncleaned solar panels. Dust deposition is analyzed for different local climatic conditions. The strategy used can be studied with the following flowchart shown in fig. 2.

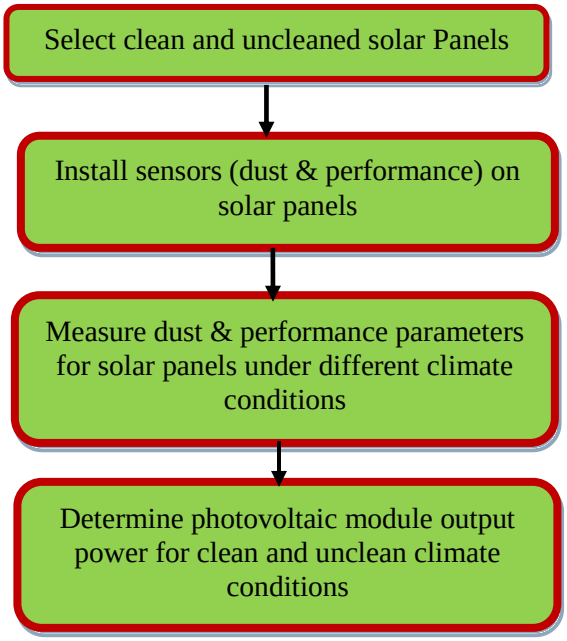

Fig. 2 Flowchart of the methodology used

3.1 Experimental Setup

The experimental setup used for research work consists of two identical PV modules of same rated power and with monocrystalline cell type. Solar modules are mounted at a fixed tilt angle between 25°-30° facing towards south for practical rooftop installations. One module is clean (regular cleaning) as reference while other modules is selected having dust deposited on its surface naturally without cleaning for the research work. The data for the research work is obtained at DEI Deemed University, Agra (UP) campus for the solar photovoltaic string modules. The name plate rating of solar panels used for the research work is shown in following table 1.

Table 1 Name plate rating of solar panels

Solar PV module	Specification
Company	BHEL
Module no.	L20220
Pmax	220 Wp
Voc	36 V
Isc	8.3 A
Vmp	29 V
Imp	7.60 A
Max system voltage	1000 V
Bypass diode rating	15 A
Max over current protection	15 A
STC (standard test conditions) Insolation	1000 W/m2
Air Mass	1.5
Cell temperature	25°C

3.2. Experimental analysis

The experimental analysis involves selection of dusty (with partial dust and with heavy dust on its surface) and non-dusty solar PV modules under natural climatic conditions. Io, Vo and Po are output current, output voltage, total output power generated by solar PV modules. Ta is the ambient temperature at the location site where modules are installed. To analyze the performance under different climate conditions following cases are considered:

Case I: Performance with partial dust on solar panels under no rain condition

The readings are obtained for two solar PV modules with no dust and with partial dust deposited on its surface. The following figure 3(a) and figure 3(b) show solar photovoltaic modules with no dust (clean)and with partial dust (uncleaned) deposited in its surface.

Fig. 3(a)

Fig. 3(b)

Solar photovoltaic modules with no dust (clean) and with partial dust (uncleaned) deposited in its surface. The following table 2 shows the measured parameters of solar photovoltaic modules under the effect of partial dust on its surface.

Table 2. Experimental results for solar modules with partial dust on its surface

Parameters	Solar Module with No Dust (Soil)	Solar Module with Partial Dust (Soil)
Climate	No rain	No rain
Ta (ºC)	23	16
Io (A)	5.46	2.8
Vo (V)	505	550
Po (Kw)	2.75	1.54
Humidity (%)	36	68
Pressure (K Pa)	103.5	103.4
Wind speed (m/s)	W 3.3	N 2.4
UV	8	2
Visibility (km)	6	2

Case II: Performance with heavy dust on solar panels under no rain condition

The readings are obtained for two solar PV modules with no dust and with heavy dust deposited on its surface. The following figure 4(a) and figure 4(b) show solar photovoltaic modules with no dust (clean) and with heavy dust (uncleaned) deposited in its surface.

Fig. 4(a)

Fig. 4(b)

Solar photovoltaic modules with no dust (clean) and with heavy dust (uncleaned) deposited in its surface.

The following table 3 shows the obtained results for solar modules with no dust and with heavy dust on its surface.

Table 3. Experimental results for solar modules with heavy dust on its surface

Parameters	Solar Module with No Dust (Soil)	Solar Module with Heavy Dust (Soil)
Climate	No rain	No rain
Ta (ºC)	23	16
Io (A)	5.46	0.4
Vo (V)	505	520
Po (Kw)	2.75	0.208
Humidity (%)	36	68
Pressure (K Pa)	103.5	103.4
Wind speed (m/s)	W 3.3	N 2.4
UV	8	2
Visibility (km)	6	2

4. Results & Discussion

The comparative analyses for clean and uncleaned photovoltaic modules show decrease in output power generated by module having dust deposition on its surface. The results show performance degradation of photovoltaic modules in terms of power generated by solar photovoltaic modules. Comparing table 2 and table 3 it has been noticed and analyzed that the effect of heavy dust deposited on solar panel surface reduces the generated power with a considerable amount. Another important observation is noticed that the dust deposition increases temperature of solar PV modules which in turn reduces its efficiency. The following figure 5 represents bar chart variation of power loss due to partial dust and due to heavy dust deposition on the surface of solar PV modules.

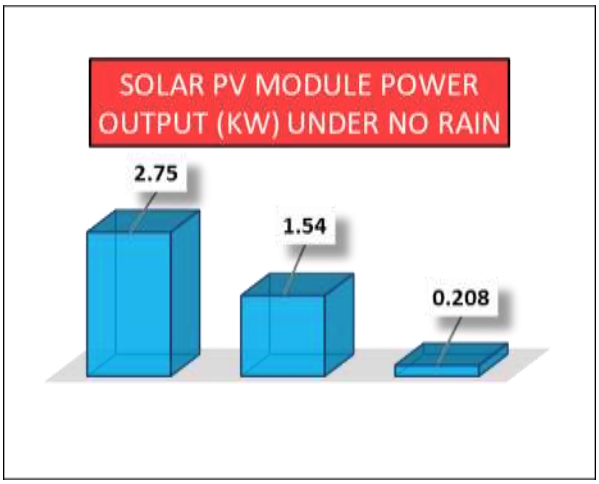

Fig. 5 Bar chart variation of power loss due to partial dust and due to heavy dust deposition on the surface of solar PV modules.

The following table shows the percentage reduction in the generated power obtained due to dust on solar module surface. The percentage reduction in solar module is calculated as:

$$100 - [(Pgd/Pgnd)x100]$$

Where,

Pgnd= Power generated by Solar Module with No Dust (Soil)
Pgpd= Power generated by Solar Module with Partial Dust (Soil)
Pghd= Power generated by Solar Module with Heavy Dust (Soil)

Table 4. Percentage reduction in solar modules under the effect of dust

Solar Module under effect of dust	Generated Solar Module Power (kW)	Percentage reduction in solar module power (%)
Pgnd	2.75	100
Pgpd	1.54	44
Pghd	0.208	93

Conclusion

The experimental results show that due to dust deposition there is a change in the output power generated by photovoltaic modules having dust deposition with variation in their temperatures. It has been noticed that the dust deposition causes a shading effect. This dust accumulation reduces intensity of solar irradiance falling on solar module surface which reduces the load current. This reduction in load current increases the surface temperature and results in overall all degradation of photovoltaic module degradation.

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Production of Concrete Bricks Utilizing Municipal and Public Solid Waste

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Abstract

The production of concrete bricks is essential in the construction sector. Nevertheless, the creation of traditional bricks from virgin resources leads to environmental harm and the depletion of resources. To tackle these issues, this paper introduces an innovative method for producing concrete bricks by using municipal and public solid waste as alternative raw materials. The use of waste materials not only alleviates the pressure on landfills but also promotes sustainable construction practices. This paper outlines a plan for implementing the manufacturing process, which includes waste selection, processing methods, and quality evaluation. The suggested approach seeks to maximize the utilization of waste materials while ensuring the necessary structural integrity and durability of the concrete bricks produced

Keywords*: Production, Concrete Bricks, Municipal Solid Waste, Public Solid Waste, Waste Management, Mix Design, EIA;*

1. Introduction

Concrete bricks are extensively utilized in the construction sector because of their durability, strength, and versatility. Nevertheless, the traditional manufacturing process of concrete bricks mainly depends on virgin materials, resulting in considerable environmental consequences and resource depletion. To tackle these issues and encourage sustainable construction methods, there is an increasing interest in using municipal and public solid waste as alternative raw materials for the production of concrete bricks.

The integration of waste materials into concrete production provides numerous advantages. Firstly, it alleviates the pressure on landfills by redirecting waste from disposal locations. Secondly, it aids in resource conservation by employing materials that would otherwise remain unused or necessitate distinct disposal methods. Finally, the use of waste materials in concrete manufacturing is consistent with the tenets of a circular economy, wherein waste is converted into valuable resources.

This paper aims to present an implementation plan for manufacturing concrete bricks using municipal and public solid waste.

The suggested methodology entails meticulous selection and characterization of wastes to guarantee their compatibility with the concrete production process. A range of waste processing methods, such as mechanical sorting, size reduction, and chemical stabilization, will be utilized to improve the quality and characteristics of the waste materials. The concrete brick manufacturing process will encompass mix design and proportioning, casting, curing, and quality control measures to ensure that the final product adheres to the necessary standards.

The proposed implementation strategy will address several important aspects, including waste collection and handling systems, development of waste processing units, establishment of production facilities, machinery and equipment requirements, as well as training of manpower involved in the manufacturing process. In addition, the concrete bricks produced from waste-derived materials will be examined through mechanical property evaluation, durability testing, and environmental impact assessment to determine their suitability for construction applications.

An economic analysis will also be performed to evaluate the financial viability of the proposed method by considering parameters such as the expenses associated with waste collection and processing, potential market opportunities, and the growing demand for sustainable building materials. Moreover, possible challenges related to the use of waste materials will be identified along with suitable remedial and management strategies.

The adoption of waste-based brick manufacturing can play a major role in minimizing waste generation, conserving natural resources, and promoting sustainable development within the construction sector. The conversion of municipal and

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public solid waste into concrete brick products offers a valuable opportunity to support circular economy principles and encourage environmentally responsible construction practices.

2. Literature Review

Raju and R. Chauhan (2014) reported that concrete is one of the most essential materials used in civil engineering applications and is commonly prepared using cement, sand, and aggregates. The extraction of natural river sand and aggregates has become increasingly challenging because of environmental restrictions and regulatory concerns. Therefore, the replacement of conventional fine or coarse aggregates with industrial by-products has gained significant attention. Their experimental investigation examined the influence of hand-cut polyethylene macro fibres on the mechanical behavior of concrete. Polyethylene fibres having dimensions of 120 mm length and 4 mm width were utilized as a partial substitute for fine aggregate, and the study demonstrated the feasibility of incorporating plastic-based materials into concrete production.

B. Shanmugavalli and K. Gowtham (2017) focused on the utilization of plastic waste as a replacement material in concrete paver blocks with the objective of reducing production cost compared with conventional paver blocks. The authors highlighted the increasing generation of plastic waste in India and the slow degradation rate associated with such materials. In their work, plastic waste was incorporated in varying proportions along with quarry dust, ceramic waste, and coarse aggregate for the fabrication of paver blocks. Experimental testing was then performed to evaluate the resulting properties and performance characteristics of the developed blocks.

Aiswaria K and Khansa Abdulla (2018) discussed the growing challenges related to waste management in modern society, particularly concerning plastic waste disposal. The authors emphasized that large quantities of plastic materials are discarded or incinerated daily, causing environmental pollution and ecological imbalance. Special attention was given to PET (polyethylene terephthalate) bottle waste, which poses serious environmental concerns because of its non-biodegradable nature. Their study suggested that infrastructure and construction activities offer substantial opportunities for the reuse and recycling of waste plastics due to the large quantity of materials consumed in these sectors.

Kamrul I, Masaharu M, and Shinsuke M (2023) examined the environmental impacts associated with clay-fired brick manufacturing, which remains widely adopted in developing economies because of limited access to advanced construction materials. Their research highlighted that brick production contributes considerably to environmental degradation through fuel consumption, raw material extraction, and supply-chain-related activities. The study primarily evaluated environmental indicators such as carbon dioxide emissions, water utilization, and land consumption in order to assess the overall ecological footprint of brick manufacturing processes

.

3. Methodology

3.1. Waste Selection and Characterization

Suitable municipal and public solid waste materials were identified and selected based on factors such as local availability, material characteristics, environmental suitability, and compatibility with the concrete manufacturing process. The selected waste materials were then subjected to detailed laboratory investigations to evaluate their physical, chemical, and mechanical properties.

The characterization process included the assessment of parameters such as particle size distribution, moisture content, density, water absorption, chemical composition, and strength-related properties. The obtained results assisted in understanding the behavior of waste materials and their suitability for incorporation into concrete brick production.

A detailed evaluation of these properties also helped in determining the possible advantages of utilizing waste materials as partial replacement constituents in concrete mixtures. The characterization process ensured that the selected waste materials satisfied the required performance criteria for achieving adequate strength, durability, workability, and environmental sustainability in the manufactured concrete bricks.

3.2. Waste Processing Techniques

The following technique is used.

Recycling: Converting waste materials into new products. This can include paper, plastic, glass, and metal.

Composting: A biological process that breaks down organic waste (like food scraps and yard trimmings) into a nutrient-rich soil amendment.

Incineration: Burning waste at high temperatures to reduce its volume and convert it into heat, gas, and ash. This is often used for dangerous waste and can be a source of energy.

Landfilling: The final disposal method, where waste is placed in large, engineered holes in the ground. This is often the least preferred method due to potential environmental issues.

Mechanical-Biological Treatment (MBT): A combination of mechanical and biological processes to sort waste and stabilize the organic fraction before it is used for energy recovery or landfilling.

Source Reduction: Strategies to prevent waste from being created in the first place, such as reusing items and changing consumer habits

Table 1. An example of a table.

An example of a column heading	Column A (*t*)	Column B (*t*)
And an entry	1	2
And another entry	3	4
And another entry	5	6

3.3. Waste processing steps

Regardless of the specific technique, waste management typically follows a series of steps:

- Identification and Segregation: Sorting waste into different categories.
- Storage: Storing the waste appropriately before processing or transport.
- Transportation: Moving waste to processing facilities.
- Treatment and Recovery: Applying the chosen processing techniques.
- Disposal: Handling any residual waste that cannot be processed further.
- Record Keeping: Maintaining records of the waste throughout the process.
- Continuous Improvement: Monitoring and improving the waste management system.

Mechanical sorting and segregation techniques can be adopted to separate various waste constituents and eliminate unwanted impurities. This process helps in maintaining the consistency and quality of the waste materials intended for further application.

Size reduction and pre-treatment operations, including shredding, crushing, and grinding, may be employed to obtain the required particle size distribution of waste materials. Such processing improves the uniformity of mixing and facilitates better incorporation of waste particles into the concrete matrix.

Different treatment and stabilization methods can also be applied to enhance the engineering properties of waste materials. These methods may include the use of chemical additives, curing procedures, or stabilization techniques aimed at improving compatibility, durability, and bonding characteristics within the concrete system.

Fig..4 Metals Segregation

Fig. 5 Plastic Waste Segregation

3.4. Concrete Brick Manufacturing Process

An appropriate mix proportioning strategy should be developed by considering the inclusion of waste materials while ensuring the desired strength, durability, and workability requirements of the concrete mix are achieved.

The concrete mix can be prepared by blending processed waste materials with conventional ingredients such as cement, aggregates, water, and suitable admixtures. Proper mixing procedures are essential to achieve a homogeneous distribution of all constituents.

The prepared concrete mixture is then poured into brick molds or casting forms according to the required dimensions, geometry, and surface characteristics of the concrete bricks.

Suitable curing practices, including moist curing or steam curing, may be employed to ensure proper hydration and adequate strength development of the concrete bricks.

Quality assurance measures should also be implemented during production to monitor consistency, compressive strength, and other relevant properties of the bricks. This may include periodic sampling, testing, and process adjustments to achieve optimum manufacturing conditions.

Fig. 6 CDE Machine

3.5. Economic Feasibility

A detailed economic assessment should be carried out by considering expenditures related to waste collection, transportation, processing, manufacturing operations, and quality control procedures.

The market demand and commercial potential of sustainable construction materials should also be evaluated by considering consumer awareness, government regulations, and incentives promoting environmentally friendly products. In addition, potential economic advantages such as reduced material cost and improved market competitiveness associated with waste-based concrete bricks can be assessed.

4. Results and Discussion

4.1. Water Absorption Test

Water absorption characteristics provide an indication of the porosity and quality of aggregates. Aggregates with high water absorption generally possess greater porosity and are often considered unsuitable unless they satisfy the required strength, impact resistance, and hardness criteria. The percentage of water absorption after 7 and 28 days of curing was determined according to IS 2185 (Part 1): 2005. In the present investigation, concrete brick specimens of dimensions 230 mm × 100 mm × 75 mm were prepared using demolition waste materials.

Procedure:

- Concrete brick specimens were cast and their initial dry weights were recorded.
- After completion of the 7-day and 28-day curing periods, the specimens were immersed in water for 24 hours.
- The quantity of water absorbed by the specimens was determined based on the difference between initial and final weights.
- Water absorption values for air-dried and self-cured concrete specimens were calculated and compared.

4.2. Compression Test

Compression testing is one of the most widely used methods for evaluating the compressive strength and load-carrying capacity of construction materials. This test helps in understanding the behavior of a material when subjected to compressive loading and determines the maximum stress that the material can withstand before failure occurs. In this study, concrete brick specimens having dimensions of 230 mm × 100 mm × 75 mm were manufactured using demolition waste-based concrete

Procedure:

- The molds were cleaned thoroughly and lubricated internally using oil before casting.
- Concrete was poured into the molds in layers of approximately 70 mm thickness. Each layer was compacted using at least 35 strokes of a tamping rod, followed by leveling and finishing of the top surface with a trowel.
- The concrete specimens were demolded after 24 hours of casting.
- After completion of the specified curing duration, the specimens were removed from water and excess surface moisture was wiped off.
- Dimensions of the specimens were measured accurately up to 0.2 mm precision before placing them in the compression testing machine.
- The specimens were centrally positioned on the machine base plate so that the load acted uniformly on the opposite faces of the specimen.
- The movable head of the testing machine was adjusted carefully until it made contact with the top surface of the specimen.
- Load was then applied gradually and continuously without shock at a rate of 140 kg/cm2^22/min until specimen failure occurred.
- The maximum load at failure was recorded.
- The compressive strength of the concrete specimen was calculated by dividing the failure load by the cross-sectional area of the specimen.

5. Conclusion

The production of concrete bricks from municipal and public solid waste offers a viable approach to sustainable construction methods. This document outlines a strategy for incorporating waste materials into the manufacturing of concrete bricks, with the goal of minimizing the environmental effects linked to waste disposal and encouraging resource conservation.

By meticulously selecting and characterizing waste, appropriate waste materials were identified and processed through

mechanical sorting, size reduction, and chemical stabilization methods. The manufacturing process for concrete bricks utilized these waste materials via proper mix design, casting, curing, and quality control practices.

Testing of mechanical properties demonstrated that the bricks either met or surpassed the necessary strength specifications, thereby ensuring their structural integrity. Evaluations of durability showed strong resistance to water absorption, freeze-thaw cycles, and chemical exposure, which contributes to their long-term performance and durability.

The use of municipal and public solid waste in the production of concrete bricks aids in diverting waste, alleviates pressure on landfills, and fosters a circular economy. This method is in harmony with sustainable construction practices as it converts waste materials into valuable resources.

Furthermore, the analysis of economic feasibility revealed the possibility of cost reductions and enhanced market competitiveness, taking into account the expenses associated with waste collection and processing, along with the increasing demand for sustainable construction materials. Nevertheless, issues such as the availability of waste, quality assurance, and market acceptance must be tackled. Ongoing monitoring, quality control assessments, and persistent research and development initiatives are essential to guarantee consistent product quality and compliance with applicable standards.

The production of concrete bricks from municipal and public solid waste presents a sustainable and eco-friendly alternative to traditional brick manufacturing. By adopting the suggested methodology and tackling the associated challenges, the construction sector can aid in waste minimization, resource preservation, and the shift towards a more circular and sustainable economy.

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Vibration Analysis of moderately thick symmetric cross-ply laminated composite Plate with Cut-out using FEM

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Abstract

This study investigates the vibration characteristics of orthotropic laminated composite plates with cut-outs using the finite element method. The material properties are held constant. A suitable finite element model is developed based on the first-order shear deformation theory through the ANSYS parametric design language (APDL). The model is discretized using the appropriate eight-node element (SHELL 281) from the ANSYS element library. Several examples are explored, considering different thickness-to-span ratios, material properties, and boundary conditions. Natural frequencies are calculated for various thickness ratios, cut-out sizes, and shapes of cut-out. The influence of these factors on the vibration behavior is analyzed and discussed. Additionally, the natural frequencies of square laminated composite plates with cut-outs in different shapes—circular, square, triangular, and hexagonal—are computed and compared

Keywords: Finite Element Method; Orthotropic Plate; Cut out, Free Vibration; ANSYS.

1. Introduction

The vibration analysis of laminated composite plates has been a subject of extensive research due to their significant applications in aerospace, automotive, and civil engineering structures. Among various types of composite plates, the moderately thick symmetric cross-ply laminated plates have been increasingly studied due to their favorable mechanical properties and lightweight characteristics. Additionally, the presence of cut-outs in these plates, which are often used to reduce weight or accommodate functional requirements, significantly alters their vibration behavior. Researchers have employed the Finite Element Method (FEM) to investigate the dynamic characteristics of these plates under various loading conditions, boundary conditions, and material configurations. This section reviews the significant contributions to this field from 2015 to 2024.

Numerous studies have focused on the vibration analysis of laminated composite plates using FEM. For instance, Zhuang et al. (2017) applied FEM to analyze the free vibration response of moderately thick laminated composite plates, considering both symmetric and asymmetric layups. They observed that the inclusion of thickness effects significantly influenced the natural frequencies and mode shapes, especially for moderately thick plates, which exhibit shear deformation. This study highlighted the importance of accurately modeling the thickness effects in FEM simulations.

The presence of cut-outs in laminated composite plates alters their vibrational response by introducing local stress concentrations and changes in stiffness. Taneja and Jain (2019) conducted an FEM study to analyze the vibration behavior of moderately thick laminated composite plates with various types of cut-outs (rectangular, circular, and elliptical). They found that the cut-out size and shape significantly reduced the natural frequencies, with elliptical cut-outs causing the greatest decrease in frequency. Their results also showed that the vibration modes were highly dependent on the location of the cut-out within the plate.

A common challenge in vibration analysis is the accurate modeling of moderately thick laminated composite plates. Wang et al. (2020) explored the use of higher-order shear deformation theory (HSDT) and FEM to study the vibration characteristics of moderately thick cross-ply laminated plates with and without cut-outs. Their findings indicated that the HSDT provided more accurate results compared to classical plate theory (CPT) for predicting the natural frequencies,

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particularly in the case of moderately thick plates where shear deformations cannot be neglected.

The influence of boundary conditions on the vibration characteristics of laminated composite plates has also been a key focus of recent research. Kumar and Sethi (2021) investigated the vibration response of symmetric cross-ply laminated composite plates with cut-outs, considering various boundary conditions, including clamped, simply supported, and free edges. Their study revealed that the boundary conditions significantly affect both the natural frequencies and mode shapes, with clamped plates exhibiting the highest frequencies compared to simply supported or free plates.

In addition to the basic vibration analysis, recent studies have focused on optimizing the design of laminated composite plates with cut-outs for improved vibration performance. Liu and Li (2022) utilized FEM to perform a parametric study on the effect of different cut-out shapes and sizes on the natural frequencies of cross-ply laminated composite plates. They found that optimal cut-out designs could be achieved by balancing the trade-off between weight reduction and vibration performance, offering insights for practical engineering applications.

Several studies have focused on validating FEM results with experimental data or analytical solutions. Zhang et al. (2023) performed a detailed comparison between FEM results and experimental data for the vibration analysis of moderately thick laminated composite plates with cut-outs. Their results confirmed the accuracy of FEM models and emphasized the importance of mesh refinement and appropriate boundary condition modeling for reliable results.

Recent advancements in computational tools and techniques, such as the integration of artificial intelligence and machine learning with FEM, are poised to further enhance the vibration analysis of composite materials. Researchers, such as Singh and Gupta (2024), have begun exploring the use of machine learning algorithms to predict the dynamic response of laminated composite plates, including those with cut-outs. These techniques hold the potential to significantly reduce computational time and improve design optimization processes for complex composite structures.

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2. Methodology

2.1. Background

ANSYS mechanical APDL is used to analyse the orthotropic laminated composite plate. The analysis is done on orthotropic plates with various sizes of cut-out for clamped boundary condition and different thickness ratios. It consisted of building geometry of the model and distributing the material properties along the thickness of model, meshing the model with a proper smart sized, mesh types, applying loads on the model, setting boundary conditions on the model and finally running and solving the model.

2.2. Modelling

According to the default parameters such as Ex/Ey = 40,υxy = 0.25, υyz = 0.25, υxz = 0.25, Gxy= Gxz = 0.6Ey, Gyz= 0.5Ey and ρ = 1 kg/m3 and using ANSYS mechanical APDL capabilities, a modal analysis problem has been solved for Orthotropic models. For convergence study, the same shear correction factors KS = π2/12 and non-dimensionalised natural frequencies ϖ = ω(b2/π2)√(ρh/D0) withD0 = E2h3/12(1- υxyυxz) are also employed taken from the available literature [33], The element SHELL281 as shown in figure 1 was chosen to mesh the model. SHELL281 is suitable for analyzing thin to moderately-thick shell structures. It is an 8-node element with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes.

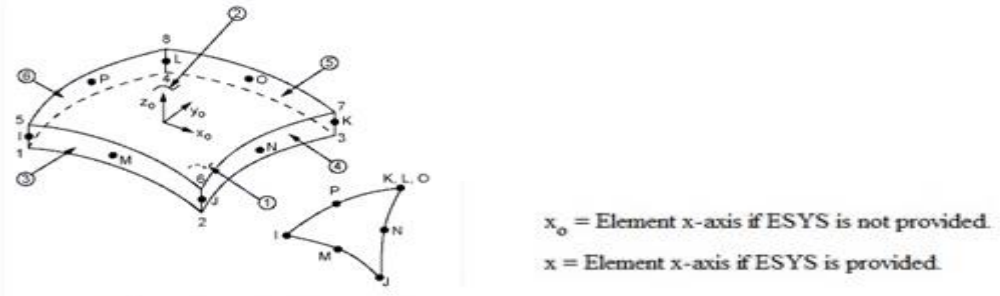

Fig.1:SHELL281 Geometry

3. Numerical Result and Discussion

Vibration Analysis is done to compute the natural frequencies for each model.Vibration analysis in ANSYS is a linear analysis. Several mode extraction methods, e.g. Block Lanczos, Supernode, PCG Lanczos, reduced, unsymmetric, damped, and QR damped are available. The solver used for modal analysis is Block Lanczos. It is used for large symmetric eigenvalue problems.

3.1. Convergence study

In this section, the convergence study is done for free vibration analysis of laminated composite orthotropic plates for determining mesh size. Table 1 shows the convergence study of non-dimensionalised natural frequencies for three ply [0°/90°/0°] square laminated clamped plates for thickness ratio t/b = 0.2.

Table 1: Convergence Study of Non-dimensionalised fundamental frequencies with three-ply [0°/90°/0°] square laminated clamped plate with t/b = 0.2

Mesh Size	$\varpi = \omega(b^2/\pi^2)\sqrt{\rho h/D_0}$							
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8
7×7	4.1488	5.6754	7.4319	7.9268	8.412	10.0844	10.5125	11.1462
9×9	4.1484	5.672	7.4279	7.9059	8.4062	10.0642	10.4305	11.1172
11×11	4.1481	5.671	7.4265	7.8988	8.4046	10.0578	10.4031	11.1077
13×13	**4.1481**	5.6707	7.4258	7.8948	8.4035	10.0541	10.3866	11.102
15×15	4.1481	5.671	7.4265	7.8988	8.4046	10.0578	10.4031	11.1077
17×17	4.1481	5.6703	7.4258	7.8941	8.4032	10.0534	10.3839	11.1013
19×19	4.1481	5.6703	7.4255	7.8938	8.4032	10.0531	10.3822	11.1006

Thus, the mesh-divisions are finalized as **13x13.**

3.2. Present Study

A laminated composite plate is considered to be orthotropic and symmetric with respect to the mid-plane and the natural frequencies are computed using a mesh size of 13×13. The effect of cut-out sizes on the natural frequencies of vibration is studied for different thickness ratios. First, a single circular cut-out of different sizes at the centre is considered and then the analysis is further extended to different shapes (circular, triangle, square and hexagonal) of cut-out at the centre of the plate.

- *Effect of Cut-out Size (D/a):*

In this section, the first six natural frequencies are obtained for a three layered (0°/90°/0°)clamped cross-ply laminated plate for different thickness ratios (i.e. 0.001, 0.05 and 0.1) with varying cut-out diameter to span (D/a) ratio from 0.1 to 0.4. The boundary condition is considered of all edges clamped i.e. CCCC. The results obtained are shown in table 2. From the table 2, it can be concluded that the value of natural frequency decreases with increasing cut-out size for higher mode and it slightly increases with increase in cut-out size for lower mode.

Table 2: First six natural frequencies (Hz) for a square laminated three-ply (0°/90°/0°) composite plate for various cut-out diameter ratio (D/a) for different t/b ratio.

t/b	D/a	Mode Number					
		1	2	3	4	5	6
0.001	*0.1*	*175.37*	353.02	354.9	526.2	614.9	728.8
	0.2	*169.43*	245.3	260.7	435.7	499.5	694.71
	0.3	*190.3*	228	245.4	352.5	397.8	588.93
	0.4	*214.15*	236.3	288.25	325.53	395.21	513.59
0.05	*0.1*	*6351*	11602	11689	16230	18327	21005
	0.2	*6134*	9176	9404.2	14969	16711	21097
	0.3	*6869.1*	8464.2	8950.3	13022	14375	19818
	0.4	*7893.8*	8723.9	10005	11813	13906	17998
0.1	*0.1*	*9833.5*	15666	15705	20801	23180	26560
	0.2	*9702.7*	13590	13796	19921	21888	26367
	0.3	*10619*	12912	13362	18497	20066	25775
	0.4	*12038*	13307	14474	17212	19597	24469

The following graphs describe the effect of cut-out size on the natural frequencies of vibration.

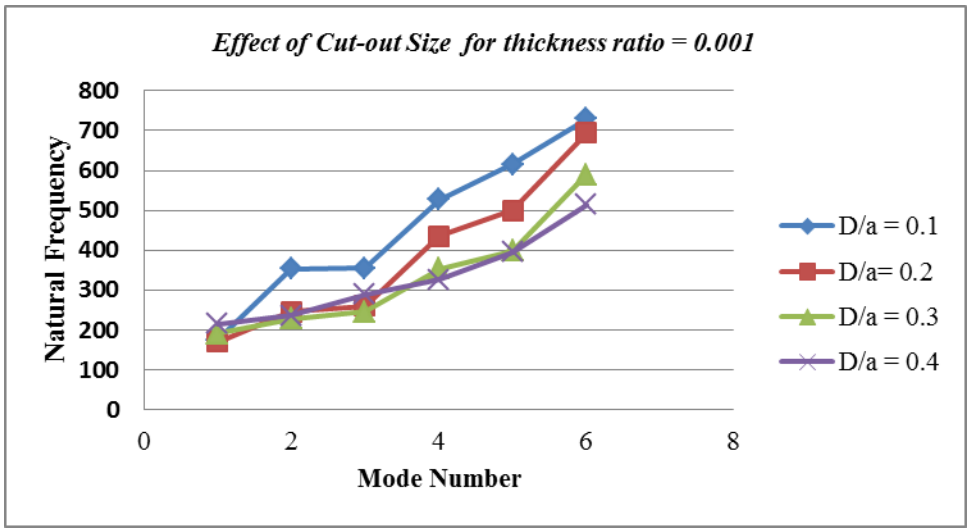

Fig. 2: Variation of natural frequencies (Hz) for a square cross-ply plate for different cut-out size taking thickness to span ratio (t/b) = 0.001

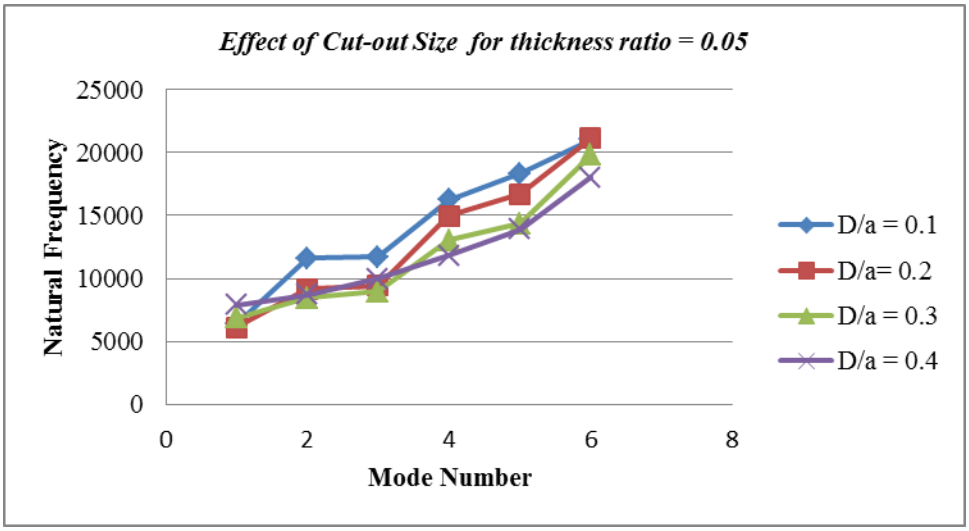

Fig. 3: Variation of natural frequencies (Hz) for a square cross-ply plate for different cut-out size taking thickness to span ratio (t/b) = 0.05

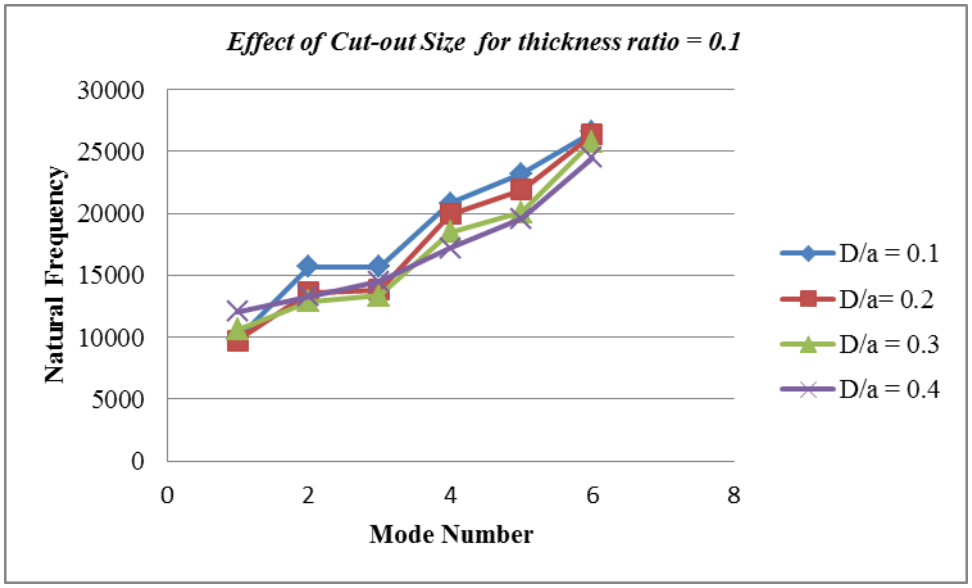

Fig. 4: Variation of natural frequencies (Hz) for a square cross-ply plate for different cut-out size taking thickness to span ratio (t/b) = 0.1

- *Effect of Shape of Cut-out:*

The natural frequencies of vibration are computed for a square three layered cross ply (0°/90°/0°) plate without cut-out i.e. solid plate and with different cut-out shapes – circular, square, triangular, hexagonal. The side of the cut-out (D) bears a fixed ratio with the side of the square plate, i.e. D/a = 0.2. The following table shows the first six natural frequencies for solid plate and plate with cutouts of different shapes.

Table 3: First six natural frequencies (Hz) for a square laminated three-ply (0°/90°/0°) composite plate for various cut-out shapes for different t/b ratios.

t/b	Shape	Mode Number					
		1	2	3	4	5	6
0.001	Circular	169.43	245.3	260.7	435.7	499.5	694.71
	Triangle	170.7	353.42	364.2	562.2	655.8	702.9
	Square	155.32	318.81	368.8	550.5	565.3	689.69
	Hexagonal	170.91	323.46	341.4	539.5	601.7	759.68
	Solid Plate	210.69	254.20	356.10	519.65	562.78	589.69
0.05	Circular	6134	9176	9404.2	14969	16711	21097
	Triangle	6299.6	11598	11731	16614	18877	19703
	Square	5791.9	10680	11580	16592	17177	19501
	Hexagonal	6024.1	10412	10793	16059	17576	20750
	Solid Plate	7885.3	9915.0	13997.0	16778.0	17939.0	19629.0
0.1	Circular	9702.7	13590	13796	19921	21888	26367
	Triangle	9806.7	15622	15809	21306	23806	24920
	Square	9189.9	14900	15580	21385	22715	24801
	Hexagonal	9514.8	14697	15012	20954	22882	26031
	Solid Plate	10593	14055	19773	20102	22238	26323

From the table 3, it can be concluded that the presence of cut-out of any shape decreases the value of natural frequencies. It can be observed that a plate with a triangular cut-out shows relatively high frequencies and one with a circular cut-out shows lower frequency for any particular mode. The following figures compare the natural frequencies of vibration for solid plate and plate with cut-out.

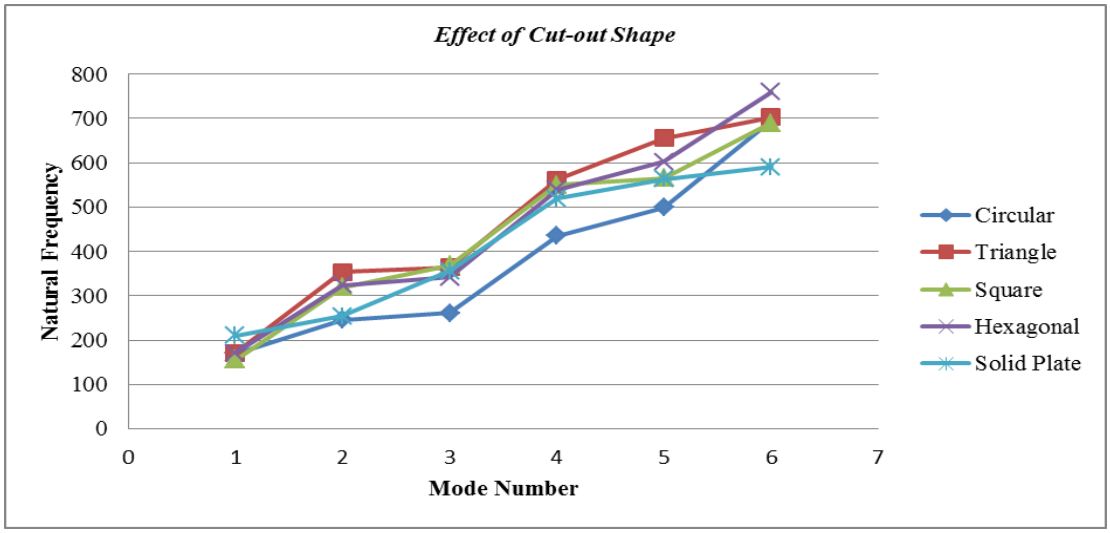

Fig. 5: Comparison of natural frequencies (Hz) for a solid square cross-ply plate with different cut-out shape taking thickness to span ratio (t/b) = 0.001

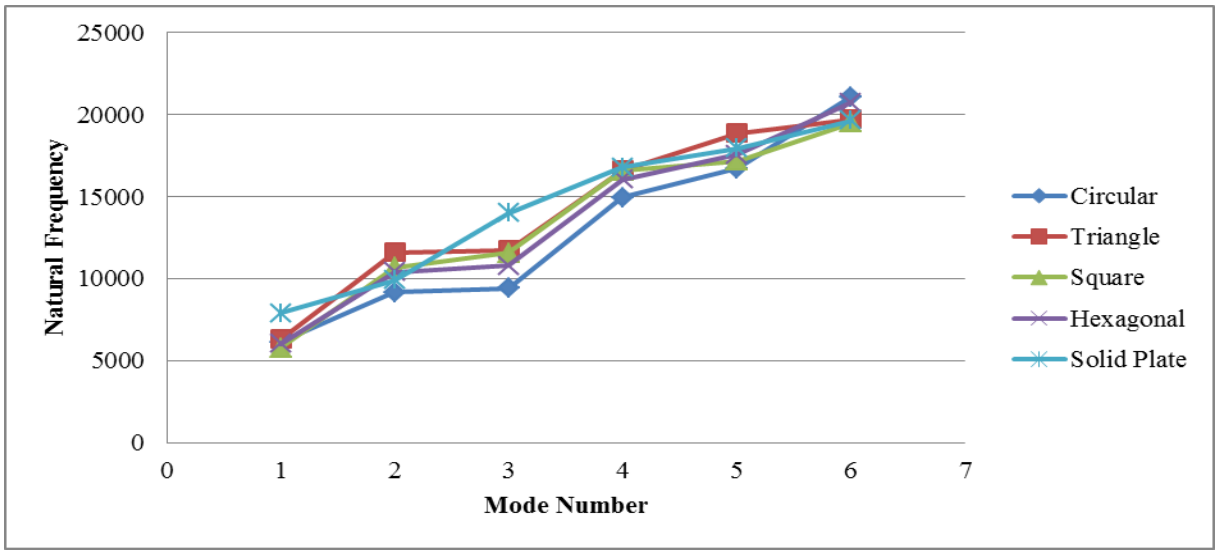

Fig. 6: Comparison of natural frequencies (Hz) for a solid square cross-ply plate with different cut-out shape taking thickness to span ratio (t/b) = 0.05

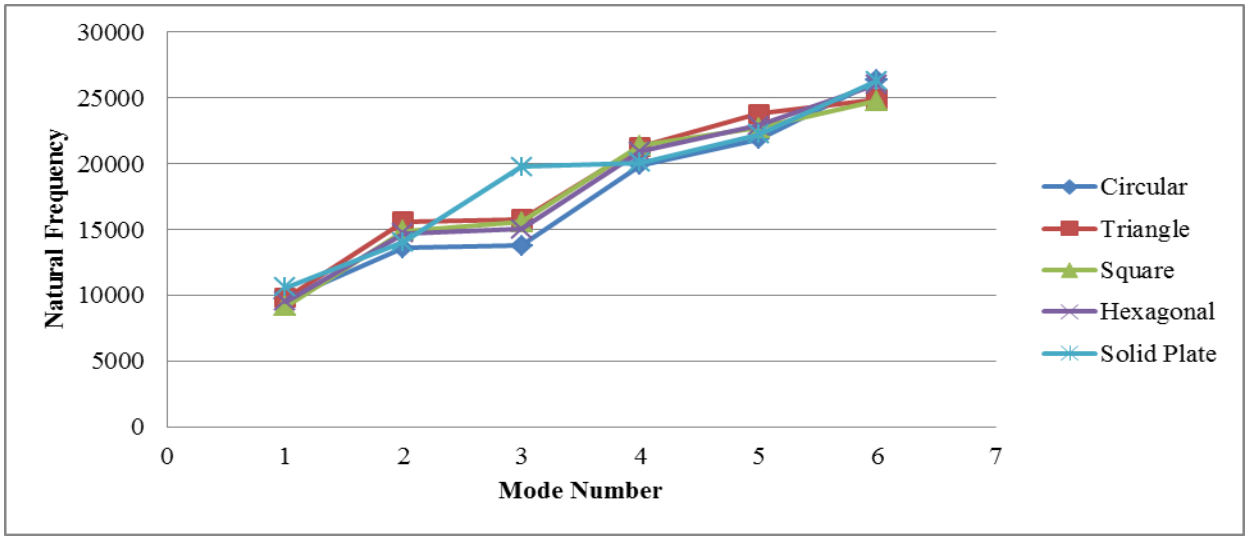

Fig. 7: Comparison of natural frequencies (Hz) for a solid square cross-ply plate with different cut-out shape taking thickness to span ratio (t/b) = 0.1

4. Conclusion

The free vibration of a laminated composite plate is analyzed for various cut-out size and shape. It can be seen that the frequency of a plate with cut-out is reduced as compared to a solid plate owing to the reduction in its stiffness. Similarly, the natural frequency increases with increasing the cut-out size for the lower mode; but decreases with increasing cut-out size for higher modes. Four different shapes of cut-outs (circular, square, triangular and hexagonal) are considered and compared with a solid plate. It can be observed that a plate with a triangular cut-out shows relatively high frequencies as compared to others and the plate with circular cut-out shows lower frequencies for any particular mode.

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Mechatronics role in green energy generation

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Abstract

Mechatronics plays a pivotal role in advancing green energy generation, particularly in a rapidly developing nation like India, by integrating mechanical engineering, electronics, computer science, and control engineering to optimize renewable energy systems. The application of mechatronics addresses critical challenges, including grid instability, intermittency of renewable sources, and efficient load management. India's commitment to decarbonizing its energy sector and achieving ambitious renewable energy targets necessitates innovative technological solutions that mechatronics can provide.

Keywords: *Mechatronics, green energy, EMS, DSM, DER, PV*

1. Introduction

India's energy landscape is currently dominated by fossil fuels, with coal accounting for 72.92% of total energy generation in FY 2021-2022. Electricity from hydro, nuclear, and renewables combined contributed 8.24%. The chart shows that coal accounted for approximately 73% of India's energy generation in FY 2021–22. Oil, natural gas, and electricity from hydro, nuclear, and renewables each contribute around 8%, while lignite has a very small share (~3%). Overall, India's energy mix remains highly dependent on fossil fuels, particularly coal, with non-fossil sources playing a limited role as shown in Fig. 1.

This highlights the significant reliance on traditional energy sources, underscoring the urgent need for a transition towards green energy. Renewable energy sources like solar and wind are intermittent, posing challenges for grid stability and reliable energy supply. Mechatronics, coupled with artificial intelligence (AI) and deep learning, offers solutions for forecasting, optimization, and control of these variable renewable energy (VRE) systems [1].

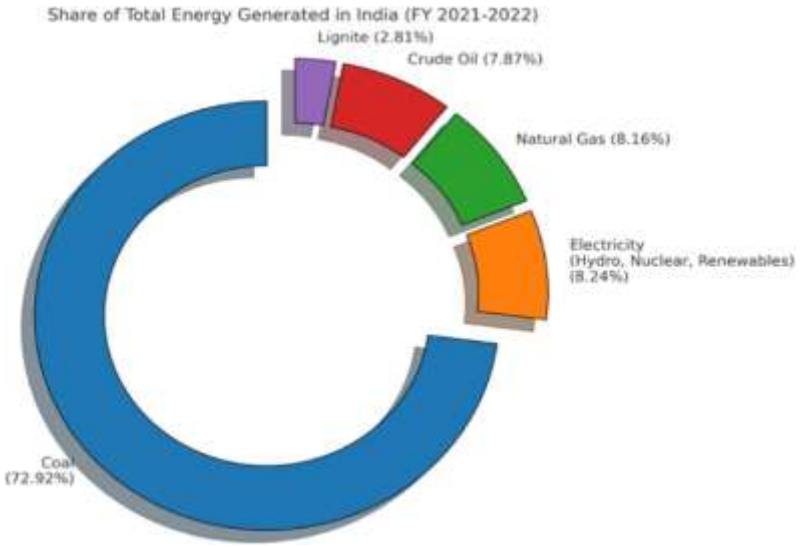

Fig. 1 Share of total energy generation

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2. Mechatronics in Solar Photovoltaic (PV) Systems

Solar photovoltaic (PV) systems are a cornerstone of India's green energy strategy, with an installed capacity of 71.61 GW, making India the fourth-largest solar power generator globally. Mechatronics enhances the efficiency and reliability of these systems through several applications:

•**Solar Tracking Systems:** Mechatronic systems enable solar panels to track the sun's movement throughout the day, maximizing energy capture. This involves mechanical actuators for orientation, electronic sensors for sunlight detection, and control algorithms for optimal positioning 1. While specific efficiency gains from mechatronic tracking systems in India are not detailed in the provided literature, such systems generally improve the overall energy yield compared to fixed-tilt installations [2].

3. Integrated Thermal Energy Storage

To address the intermittency of solar energy, mechatronic designs integrate thermal energy storage mediums, such as phase change materials (PCMs), into solar-powered systems. These systems can extend water production time in membrane distillation systems after sunset, maintaining high rates. Similar principles apply to concentrated solar power (CSP) systems using parabolic trough collectors for combined heating and cooling applications, where mechatronic controls optimize heat absorption and transfer.

• **Smart Inverters and Grid Integration:** Mechatronic smart inverters are crucial for converting direct current (DC) from PV panels to alternating current (AC) for grid consumption, enabling intelligent and efficient power management. They can adapt to changing power conditions and facilitate the seamless integration of PV output into the grid. In a smart grid context, these inverters allow for bidirectional energy flow and demand-side management [3].

• **Manufacturing and Maintenance:** Mechatronics is integral to the automated manufacturing processes of solar panels, improving precision and reducing costs. For maintenance, robotic systems equipped with sensors can inspect and clean panels, optimizing performance and extending lifespan. Critical materials for solar energy, such as silicon, aluminum, and galvanized iron, are managed more efficiently through these advanced manufacturing techniques [4].

4. Mechatronics in Solar Photovoltaic (PV) Systems

Wind energy is another significant renewable resource in India. Mechatronics contributes to its efficiency and stability through:

• **Blade Pitch and Yaw Control:** Modern wind turbines employ mechatronic systems for active blade pitch control and yaw control. Blade pitch control adjusts the angle of the blades to optimize aerodynamic efficiency and power output under varying wind speeds, while yaw control orients the turbine nacelle towards the wind direction. These systems rely on sensors (wind speed and direction), actuators, and sophisticated control algorithms to maximize energy capture and minimize mechanical stress.

• **Structural Health Monitoring:** Mechatronic sensors embedded within wind turbine structures monitor vibrations, strain, and temperature, providing real-time data for predictive maintenance. This prevents costly failures and extends the operational life of turbines, crucial for large-scale wind farms [5].

5. Grid Integration and Stability

Wind power, like solar, is intermittent. Mechatronic solutions help manage this variability by optimizing the interface between wind farms and the electrical grid. This includes advanced power electronics for smooth power injection, and control systems that can contribute to grid frequency and voltage stability.

6. Mechatronics in Smart Grids and Energy Management

Mechatronics in Smart Grids and Energy Management The integration of mechatronics is fundamental to the development of smart grids, which are essential for managing the increasing penetration of renewable energy sources in India as shown in Fig. 2.

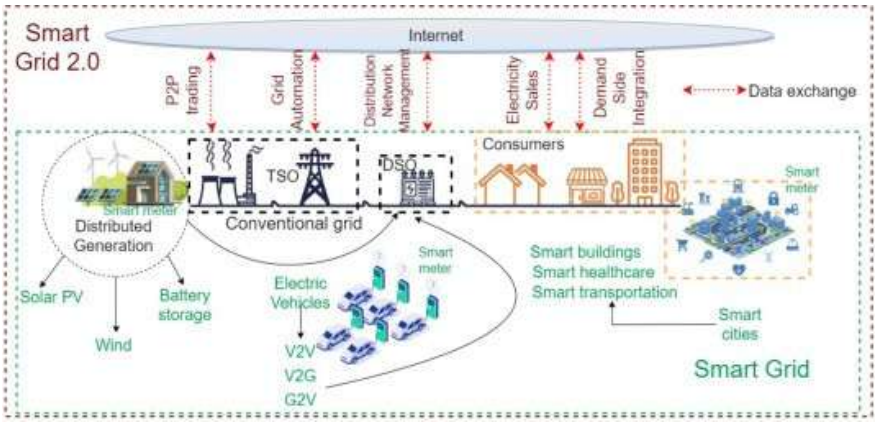

Fig. 2 Key applications include

Energy Management Systems (EMS): Mechatronics enables the creation of intelligent EMS that monitor, control, and optimize energy flow within residential, commercial, and industrial settings. These systems integrate various components such as PV, battery storage, and heat pumps, using AI and model predictive control (MPC) to manage comfort and energy efficiency [6-7].

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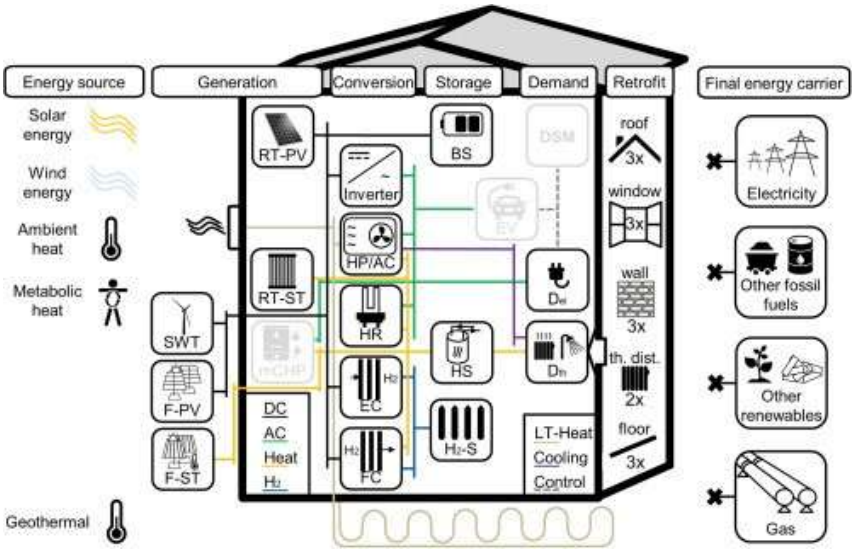

Fig. 3 Energy Management Systems

- **Demand-Side Management (DSM) and Load Flexibility:** Smart meters, enabled by mechatronics, provide real-time data on electricity consumption, allowing consumers to manage their usage more efficiently and participate in demand response programs. Load control devices within the power grid, a mechatronic application, improve control over electricity demand, balancing supply and demand, especially with intermittent renewable energy sources [8-9].

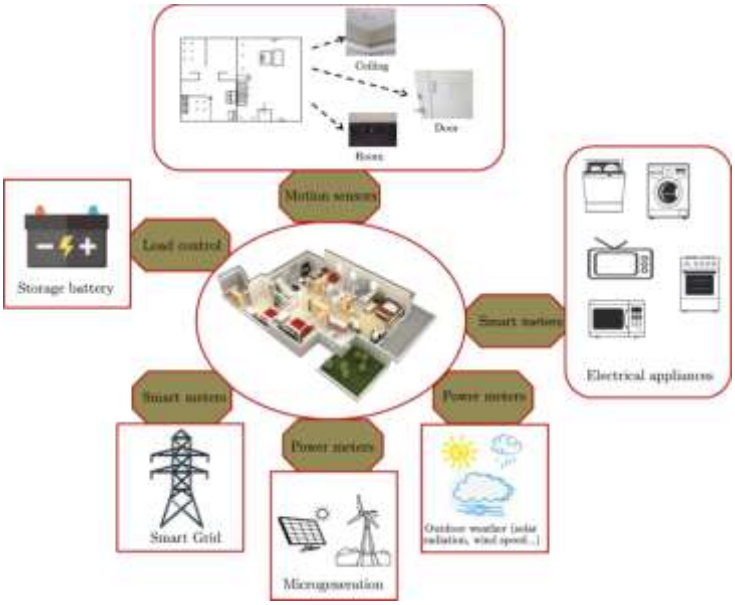

Fig. 4 Demand of Energy

- **Distributed Energy Resources (DER) and Microgrids:** Mechatronics facilitates the integration

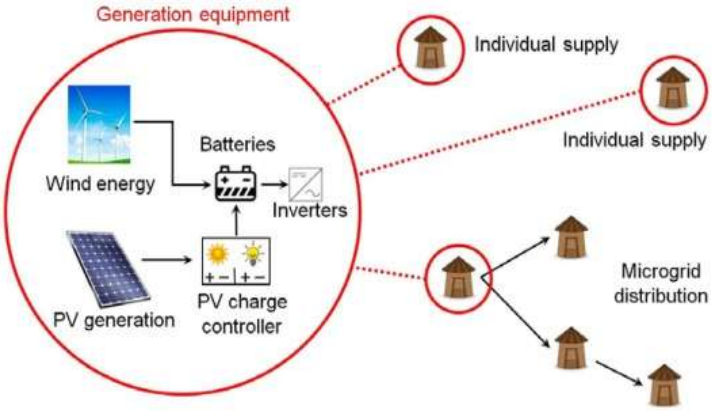

Fig. 5. Distribution of Power

and coordinated control of DERs, including rooftop solar PV systems, which contribute significantly to decentralized power generation. This is crucial for developing microgrids, which are small-scale electrical grids that can operate independently or in conjunction with a larger grid, enhancing local energy security and reducing reliance on the central grid as shown in Fig. 5 distribution of power [10-11].

- **Energy Storage Systems:** Mechatronic control systems are vital for managing various energy storage technologies, such as lithium-ion batteries and emerging potassium-ion batteries (PIBs) . These systems optimize charging and discharging cycles, extending battery life and ensuring grid stability by storing excess energy and releasing it during peak demand as shown in Fig. 6.

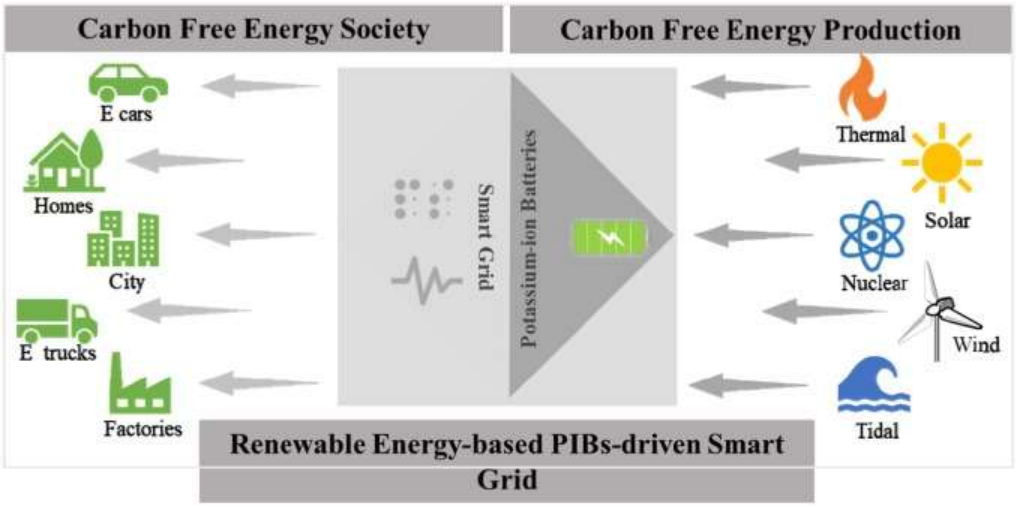

Fig. 6 Renewable Energy-Based PIB driven smart Grid

Internet of Energy (IoE) and Digital Twins: The Internet of Energy (IoE) concept, supported by mechatronics, AI, and edge computing, connects various energy components for real-time data exchange and optimized control. This includes applications in thermal power plants, renewable energy sections, power system operation, and energy storage. Digital Twin models further enhance this by providing virtual representations of physical assets, allowing for simulation, optimization, and coordinated control within energy communities [12-13].

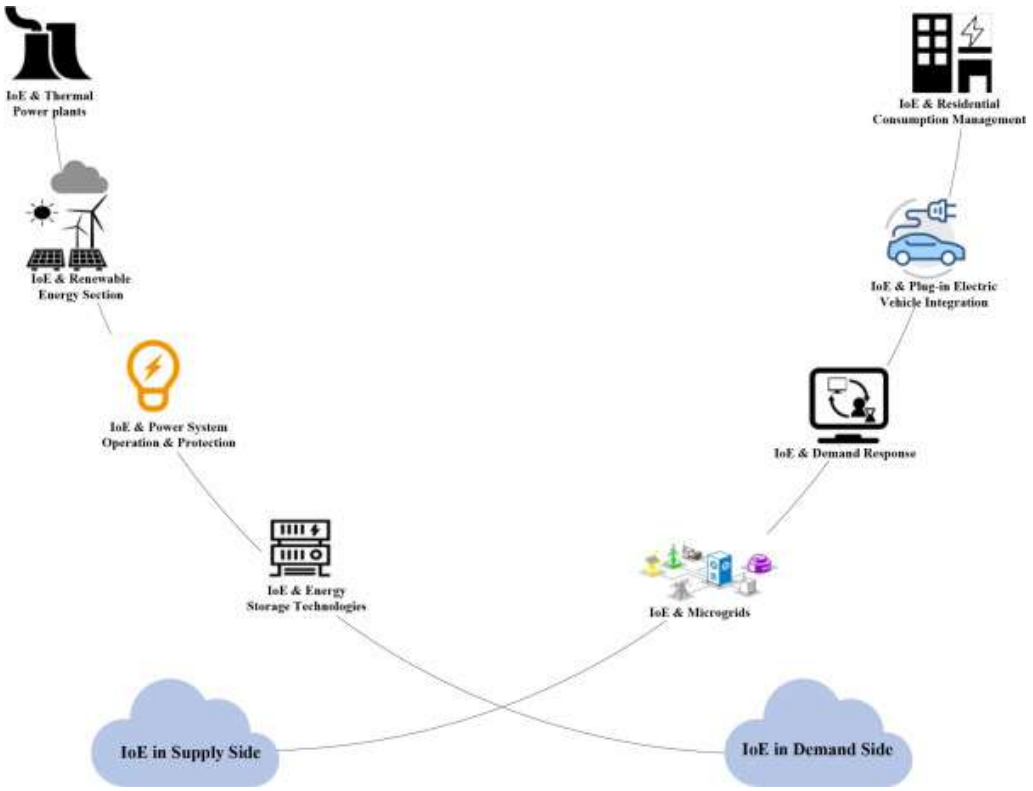

Fig. 7 Internet of Energy and Digital twin

7. **Challenges and Future Prospects in India:** Despite the significant potential, India faces unique challenges in deploying mechatronic solutions for green energy:

• **Grid Infrastructure**: The existing grid infrastructure in India, while expanding, faces challenges in handling the high proportion of intermittent renewable energy without robust inertia provision during frequency disruptions. Mechatronic solutions for dynamic grid stabilization, such as advanced control algorithms and power electronics for HVDC systems, can mitigate these impacts [14-15].

• **Cost and Policy:** While declining capital costs for renewable technologies are driving interest in self-sufficiency, the initial investment in advanced mechatronic systems can be substantial. Effective policy instruments and green financing are crucial to accelerate the adoption of these technologies [16-17].

• **Data Management and AI Integration:** The effective implementation of mechatronic systems relies heavily on sophisticated data management and AI. Deep learning models are increasingly used for forecasting renewable energy output and optimizing grid operations, addressing the inherent uncertainty of VRE. This requires a robust computing infrastructure, including edge computing for faster data processing closer to the source [18].

• **Research and Development:** Continuous research in heat transfer enhancement techniques is vital for improving the efficiency of thermal systems integrated with renewable energy, such as those used in solar thermal applications. The application of mechatronics is essential for India's transition to a sustainable energy future, enabling more efficient, reliable, and intelligent green energy generation and management systems. Further research and strategic investments in these interdisciplinary technologies will be critical for achieving India's ambitious renewable energy goals and mitigating climate change [19 20].

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Green Steel Production in India: Pathways, Challenges, and Policy Framework

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Abstract

India, as the world's second-largest steel producer, faces a critical challenge in decarbonizing its steel industry, which accounts for approximately 12% of the country's CO_2 emissions and 2.5% of global industrial emissions. This paper examines the technological pathways, economic implications, policy landscape, and implementation challenges for transitioning to green steel production in India. Through analysis of current technologies, cost structures, and policy frameworks, we identify hydrogen-based direct reduction (H-DRI), carbon capture utilization and storage (CCUS), and increased scrap-based electric arc furnace (EAF) production as the most viable pathways for India's green steel transition. The paper concludes with strategic recommendations for policymakers and industry stakeholders to accelerate this crucial transition while maintaining industrial competitiveness.

Keywords: *Green Steel, Hydrogen DRI, Decarbonization, Indian Steel Industry, CCUS, Circular Economy*

1. Introduction

The Indian steel industry stands at a critical juncture in its development trajectory. With production reaching 125 million tonnes in 2023-24 and ambitious targets of 300 million tonnes by 2030-31, the sector's environmental footprint has become increasingly significant (Ministry of Steel, 2024). The conventional blast furnace-basic oxygen furnace (BF-BOF) route, which dominates Indian steel production (approximately 45%), is highly carbon-intensive, emitting 2.3-2.5 tonnes of CO_2 per tonne of crude steel produced (SAIL, 2023). Global climate commitments under the Paris Agreement and India's own Net Zero by 2070 pledge necessitate urgent decarbonization of heavy industries. The steel sector presents both a substantial challenge and opportunity—while being hard-to-abate, its transformation could position India as a leader in sustainable industrial development. This paper explores the technological, economic, and policy dimensions of this transition, with specific focus on the Indian context.

2. Current Status of Indian Steel

2.1. Production Capacity and Technology Mix

The Indian steel industry exhibits unique characteristics that influence its decarbonization pathway:

- High share of coal-based DRI (Sponge Iron): India produces 90% of global DRI, primarily using coal (32 million tonnes in 2023)
- Limited scrap availability: Domestic scrap collection remains at 25-30 million tonnes annually
- Geographical concentration: 60% of capacity located in four states (Odisha, Jharkhand, Chhattisgarh, West Bengal)
- Energy intensity: 20-30% higher than global best practices in integrated steel plants.

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Table 1: Indian Steel Production by Technology Route (2023-24)

Technology Route	Production (Million Tonnes)	Percentage Share	Average CO_2 Intensity (tCO_2 /t steel)
BF-BOF	56.3	45%	2.4
DRI-EAF	48.8	39%	1.8
Scrap-based EAF	18.8	15%	0.4
Induction Furnace	1.3	1%	0.3
Total	**125.2**	**100%**	**1.85 (weighted average)**

Source: Joint Plant Committee, Ministry of Steel (2024)

2.2. Carbon Emission Profile

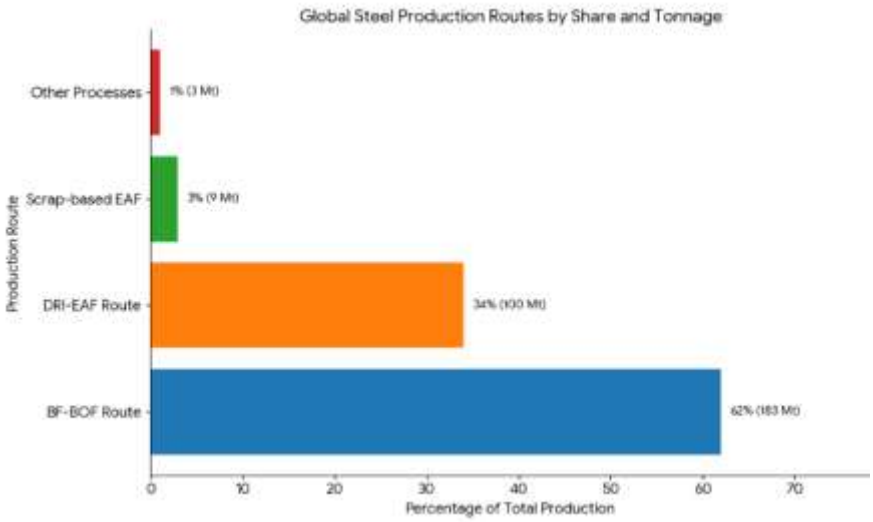

Figure 1: CO_2 Emissions from Indian Steel Industry (2023)

Total Emissions: 295 million tonnes CO_2
Breakdown of Emission Sources:
• Process emissions (iron reduction): 45%
• Fuel combustion: 40%
• Electricity consumption: 15%
Source: NITI Aayog Analysis (2023)

3. Technological Pathways for Green Steel

3.1 Hydrogen-based Direct Reduction Iron (H-DRI)

Hydrogen DRI represents the most promising long-term solution for India's green steel ambitions. The technology involves replacing fossil reductants (coal/natural gas) with green hydrogen in direct reduction processes.

Advantages for India:

• Compatibility with existing DRI infrastructure (India has 100+ DRI plants)
• Potential for gradual transition from natural gas to hydrogen blends
• Alignment with National Green Hydrogen Mission targets of 5 MMT production by 2030

Table 2: Comparative Analysis of DRI Technologies

Parameter	Coal-based DRI	Natural Gas DRI	Hydrogen DRI (Green)
CO_2 Emissions (t/t)	1.6-1.8	1.2-1.4	0-0.2
Energy Consumption (GJ/t)	12-14	10-12	8-10
Capital Cost (USD/t capacity)	300-400	400-500	800-1000
Production Cost (USD/t)	450-500	500-550	650-750*
Technology Readiness	Commercial	Commercial	Pilot/Demonstration

*Note: *Assumes green hydrogen at $3/kg; Source: TERI Analysis (2023)*

3.2 Carbon Capture, Utilization and Storage (CCUS)

For existing BF-BOF plants, CCUS offers a retrofit solution. India's geological storage potential, particularly in depleted oil fields and basaltic formations, is estimated at 400-600 GT (CSIR NGRI, 2022).

Key Projects:

• Tata Steel's 5 TPD capture pilot at Jamshedpur (operational since 2021)
• JSW Steel's MOU with Carbon Clean for 3,600 TPD plant at Vijayanagar
• SAIL-RRL collaboration for mineralization research

3.3 Circular Economy Approaches

Scrap-based Steel Production:

India's formal scrap collection remains below 30% of total generated scrap. The Steel Scrap Recycling Policy (2019) aims to increase this to 80% by 2030, potentially reducing emissions by 50 million tonnes annually.

Biomass Utilization:

Torrefied biomass in PCI (Pulverized Coal Injection) could reduce emissions by 15-20% in BF operations. India's agricultural residue potential (500+ million tonnes annually) offers significant opportunity.

4. Economic Implications and Cost Analysis

5.

4.1 Green Premium and Competitiveness

Table 3: Cost Comparison of Steel Production Routes (USD/tonne)

Cost Component	BF-BOF	EAF (Scrap)	H-DRI-EAF	CCUS-BF
Raw Materials	280	320	350	280
Energy	120	90	200	140
Capital Cost	80	60	120	100
Carbon Cost*	60	12	6	15
Total	**540**	**482**	**676**	**535**
Green Premium	-	-58	+136	-5

Assumes carbon price of \$50/tCO_2 ; Source: CEEW Analysis (2024)

The current green premium of 25-30% for hydrogen-based steel presents competitiveness challenges, particularly in export markets. However, this is projected to decrease to 10-15% by 2035 with technology scaling and renewable cost reductions.

4.2 Investment Requirements

Figure 2: Cumulative Investment Requirements for Green Steel Transition (2024-2050)

Phase 1 (2024-2030): \$25-30 billion
•Pilot/demonstration plants: \$3-4 billion
• Infrastructure development: \$8-10 billion
• R&D and skill development: \$2-3 billion
• Policy incentives: \$12-13 billion

Phase 2 (2031-2040): \$80-100 billion
• Commercial scale H-DRI plants: \$40-50 billion
• CCUS retrofits: \$20-25 billion
• Hydrogen infrastructure: \$15-20 billion
• Grid modernization: \$5-6 billion

Phase 3 (2041-2050): \$120-150 billion
•Technology deployment at scale
• Complete phase-out of coal-based DRI
• Circular economy integration

5. Policy Framework and Implementation Challenges

5.1 Current Policy Landscape

India has introduced several initiatives to promote green steel:

1. National Green Hydrogen Mission (2023): □ 19,744 crore allocation
2. Performance-Linked Incentive (PLI) Scheme for specialty steel
3. Energy Conservation (Amendment) Act 2022: Carbon credit trading
4. SATAT Scheme: Compressed biogas promotion
5. State-level policies: Odisha, Chhattisgarh, and Karnataka green steel policies

5.2 Key Implementation Challenges

Technical Challenges:
• Hydrogen storage and transportation infrastructure gaps
• Intermittency of renewable energy for continuous operations
• Limited CO_2 storage site characterization
• Technology readiness for Indian raw material characteristics (high-alumina iron ore)

Economic Barriers:
• High capital expenditure for green technologies
• Limited access to low-cost financing
• Competitiveness concerns in global markets
• Stranded asset risks for existing plants

Institutional and Regulatory:
• Lack of clear standards for green steel certification
• Fragmented policy coordination between ministries
• Land acquisition and environmental clearances
• Skill gap in emerging technologies

5.3 Strategic Recommendations
1. Establish Green Steel Purchase Obligation for government projects
2. Implement carbon border adjustment mechanism (CBAM)-responsive policies
3. Create dedicated green steel clusters with shared infrastructure
4. Launch technology demonstration fund ($500 million)

Medium-term (2031-2040):

1. Mandate 30% green steel in construction by 2035
2. Develop hydrogen corridors connecting renewable zones to steel clusters
3. Establish circular economy parks with integrated scrap processing
4. Implement sectoral emissions trading system

Long-term (2041-2050):
1. Phase out coal-based DRI by 2045
2. Achieve 50% green steel production by 2050
3. Establish India as a green steel technology exporter
4. Integrate steel plants with renewable microgrids

6. Conclusion

India's journey toward green steel production represents both a formidable challenge and an unprecedented opportunity. The transition requires a multi-pronged approach leveraging India's existing DRI expertise, renewable energy potential, and circular economy opportunities. While technological solutions like H-DRI and CCUS show promise, their success hinges on supportive policies, international collaboration, and substantial investment.

The steel industry's transformation must be integrated with broader energy transition and industrial policy, ensuring just transition for workers and communities dependent on traditional steel production. With strategic planning and execution, India can reduce steel sector emissions by 50% by 2050 while doubling production, positioning itself as a global leader in sustainable steel manufacturing.

The window for decisive action is narrow—immediate policy interventions, technology partnerships, and investment mobilization are critical to capitalize on India's first-mover potential in the global green steel market.

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A Review of degradation and failure of outdoor PV module

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Abstract

Abstract: Solar PV cells use solar energy, which is a limitless renewable energy source. An examination of recentstudies on how environmental and operational factors affect solar PV cell performance is presented in this article.The performance of PV modules has been found to be significantly impacted by temperature, humidity, dustdistribution, and the soiling effect. The purpose of this review paper is to assess how flaws affect photovoltaic (PV)modules & dependability and deterioration when exposed to the outdoors. To determine the main reasons for PVmodule degradation and failure modes, a thorough review of the literature was done. The current study will assistmanufacturers in enhancing PV system design and maintenance techniques

Keywords: Solar energy, PVsyst, Energy loss, Performance analysis

1. Introduction

India's growing population and economy are driving up the country's energy needs. Any nation's energy sources are the main driver of its economic growth. The depletion of nonrenewable energy sources is a outcome of development and globalization. Sun energy is the alternative sources that all nations are currently searching for and its use is expanding globally.[1]The amount of energy that can potentially be harvested from the sun is exceedingly greater than what is typically consumed on earth. It is also clean that can be used to satisfy future demands.[2]

In India, sun energy has a lot of potential. The percentage of solar energy is 94.17 gigawatts (GW). 2024. India receives 200 MW/km2 of radiation every hour for an average of 300 days out of 365 days [2].

Over the last ten years, solar energy has become much more affordable. This is because of greater competition, economies of scale, and technological advancements, but as industrial scale has expanded over the past five years, solar energy costs have also decreased, falling from □ 20 per kwh to □ 3 per kwh. However, a number of factors, including load consumption, solar irradiation, and meteorological and geographic conditions, influence how much solar energy is used[3].

India is the third largest producer of electricity in the world. 1,395 kWh of gross electricity were generated per person in FY2023–2024[4]. According to the National Renewable Energy Laboratory,India has a large potential for solar energy use, with average solar resource potential ranging from 3 to 6 kWh/m2/day[10]. According to a prospective solar map published by the NREL, India has a large potential for solar energy use, with mean solar potential span from 3 to 6 kWh/m2/day [11].The country's Nationally Determined Contribution target is to have 40% of its electricity generated by renewable sources, including hydropower, by 2030 (GOI 2015). Electricity generation from solar energy in India is expected to reach 104.60bn kWh by the year 2025. The country projects growth at a rate of 7.50% per year. (CAGR 2025-2029).India's renewable energy capacity has seen a significant increase, with a CAGR of around 15.4% between FY16 and FY23[6].

2. Literature Review

This section reviewed the literature on earlier studies that used the PVsyst software program to analyze solar PV plant.
At Strathmore University in Kenya, Emmanuel Ayora (2023) used PVsyst to give a performance analysis of 600 kWp photovoltaic systems. Various performance indices examined in accordance with the IEC 61724 standard. In 2019, this solar facility produced 735 MWh. The main conclusion regarding PV system's overall performance is that it offers another organization in the nation and isolated areas a workable way to generate electricity [1].

A assessment of a 50 kW solar PV power plant of a technical institution was presented by P.A. a per day energy producing of 150 kWh, the facility has been running smoothly. It is all about to study and evaluate the causes of the lagging

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power factor and offering solutions to raise the GCEK PV plant's power factor [2].

Real-time data-based study of PV system was presented by Ayman Alazazmeh a, and Ahsan Ahmed b in 2022. This study examines significant technical, financial, and environmental factors in order to evaluate the performance of a 425 kW photovoltaic system. Real-time performance data collected throughout the year has been used to conduct these assessments It has been determined that the PV system generates 835.60 MWh and 814.88 MWh of DC and AC power yearly. output, in that order. With an yearly average of 78.09%, the performance ratio fluctuates between 74.03% in August and 84.62% in January [3].

Nada Waseem, Ancy Sosa George, and Sameer Hameed (2021) used PVsyst to simulate a 100 KW solar plant located in Dubai. It entails assessing the performance ratio, grid injection capacity, energy efficiency, and other typical power generation per kWp of the PV array. The 100 kWp photovoltaic systems produce 175.8MWh annually. The rate of return every year is roughly 81.87%.[4].

A performance studiesof a solar facility in eastern Turkey was presented by Mete Cubukcu and Harun Gumus in 2020. This examined a grid-tiedPV system in eastern Turkey with a rated power of 2130.7 kWp. In addition to the real-time analysis, a performance analysis and energy forecast simulation were conducted. Environmental conditions are the main elements influencing PV plant performance, according to a comparison with comparable PV plants situated throughout the globe [5].

The assessment, energy dissipation, and deterioration forecastingof a 200 kW PV system erected at IRB, Chandigarh is predicted to perform, lose energy, and deteriorate were assessed by Nallapaneni Manoj Kumara and Ramjee Prasad Gupta (2019). in this article. Energy generation and loss are predicted using the PVsyst. Inaddition, Surveys Reliability Data All-India are used to estimate possible degradation rates (DR) of crystalline PV systems[6].

Mohammad Baqir and Harpreet Kaur Channi 2022 conducted studies on 700KWp Grid-tied solar power plant in Afghanistan with the help of Pvsyst. The designing of 700KWp Pvsyst has been undertaken and the system producing 1266MWh/yr. The performance ratio shows value 0.797 [7].

C.S. Rajoria , Ravi Kumar 2021 presented a solo solar PV system design and simulation using PVsyst software:The assessment of load requirements in the engineering college Bikaner's mechanical department office is presented in this work, along with the design and set up of a standalone solar PV system. PVsyst has also been used to analyze losses and performance ratios. Different types of losses contribute to the reduced power capacity of the system. [8].

Sandeep Singh Bhullar1 and Mahendra Lalwani2 2018 presented performance Analysis of 25 MW Grid ConnectedSolar PV Plant in Gujarat,using the PVsyst simulation. In this paper for three years in a row, 2015, 2016, and 2017, meteorological and on-site power generation data are gathered. Based on these data, calculations are made using an Excel spreadsheet to determine the performance ratio and various types of power losses. The results are then compared with simulation software PV-syst. PR and CUF monthly values varied from 74% to 80% and 16% to 24%, respectively [9].

Nallpaneni Manoj Kumar, Kanchan Matiyali, et al. (2016) conducted a evaluation study of a 400 kWp solar PV system that would be installed in Dhalipur. The final output of the simulated system varied from 3.14 to 5.65 kWh/kWp/day, with a PR of 78.1%. [10]

3. Plant Description

A grid-tied PV system was set up on the rooftop of MITS Deemed University in Gwalior with a longitude 78,21E and latitude 26.23N.The PV system consists of 308 units of 330 Wp PV modules with particularas shown in Table 1.
In all cases the panels are set on the ground with the tilt angle of 30◦ and the azimuth angle of 0◦. The PV system of 100 kWp comprise of of 19 modules coupled in series to create one PV string, with 16 of these strings connected in parallel.The network consists of a PV array of module area 590 m2 which generates peak of 600KWh in a day.The PV system integrated to the grid by means of two inverter of 50 KW each

Table 1. An example of a table.

Makes/Company	Vikram solar
Peak power:	330 Wp
Maximum voltage:	38 V
Maximum current:	8.7 A
Open circuit voltage:	46.3 V
Short circuit current:	9.24 A
Module efficiency:	17%
Operating Temp.	-10 °C~+60 °C

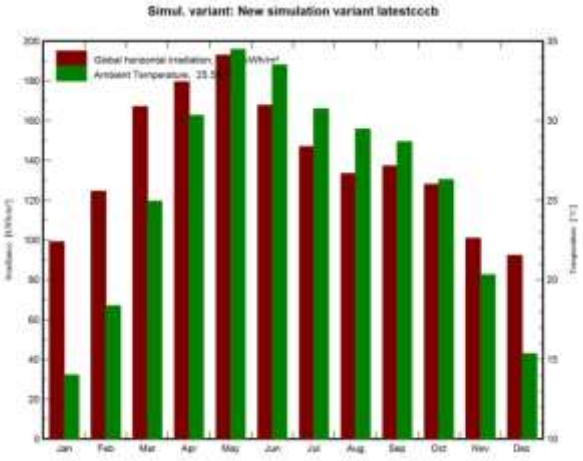

Fig. 1. The global horizontal irradiation and ambient temperature at location

4. Estimation of Performance Parameters

The International Energy Agency (IEA) created the evaluation metrics to assess the SPV grid interconnected system's performance [14].

Array output (Ya)–It is the value that corresponds to the energy output given by by the PV modules over a specific period divided by the Pv rated power output P_o. Its unit is h.d-1 or kWh/kWp/day.

$$Ya = \frac{Ea}{Po}$$

Reference output (Y_R) - it is defined as the percentage of total in plane solar insulation (Ginc) (kWh/m^2) captured or utilized in relation to the reference power Go (1kW/m^2). Its units are hd-1or kWh/kWp/day.

$$Yr = \frac{\text{Ginc}}{\text{Go}}$$

Final output (Y_F)–It is (YF) can be obtained by dividing the energy AC (Ea_grid) produced by the time solar energy was harnessed by the plant with the rated output power set for the system, which is under standard test circumstances. (1000 W/m^2 irradiance, ambient temperature of 25˚C).It is measured in kWh/kWp/day.

$$Yf = \frac{Ea\_grid}{Po}$$

Performance ratio (PR)-It is the ratio of final output (Y_F) to reference output (Y_R). This dimensionless quantity is normalized concerning the incident solar radiation and reflects the cumulative impact of losses. It serves as a critical parameter for assessing long-term variations in photovoltaic (PV) performance. The values of the PR illustrate the annual losses in system performance [2].

$$Pf = \frac{Yf}{Yr}$$

Capacity Utilization factor (CUF) - Similarly, it is the ratio of a photovoltaic plant's confirmed yearly energy produced (E_{AC}) to the theoretical annually produced energy by the PV system under the assumption that it works without stopping at the rated power (Po rated) 24 hours a day every day for a year [4].This factor is dimensionless,

$$CUF = \frac{Energy\ in\ Measured\ in\ KWh}{364 \times 24 \times install\ capacity\ of\ plant\ Po(KWp)}$$

System Efficiency–It is a ratio of the output EAC to the Ginc for the module area Aa.

$$\eta \text{ system } = \frac{\text{Ea \_grid}}{\text{Ginc} \times \text{Aa}}$$

Array Capture Losses(Lc) - Losses resulting from wiring issues, string diode inefficiencies, low irradiance levels, partial shading, mismatched components, errors in maximum power tracking, limitations due to dustaccumulation, and energy conduction losses within the photovoltaic modules .

$$Lc = Yr - Ya$$

Systems losses (L_S) **-** These losses incur due to passive elements, conduction, and inverter.

$$Ls = Ya - Yf$$

Components of solar gain which are yearly averages are average global horizontal irradiance, (1670.1 kWh/m2), diffuse horizontal irradiance (899.5 kWh/m2), and global solar radiation incident on the PV array (1781 kWh/m2), and the effective global solar irradiance for the IAM and Soiling factor (1683.4 kWh/m2). It should be noted that these values are highest in the summer season and are at the lowest during the foggy winter months.

This research seeks to analysis the performance, energy losses, and degradation of the grid connected solar roof top system [8]

5. Methodology

The simulated performance of the proposed PV installation is to be predicted. For the simulation study to be effective, the information corresponding to the site location together with the planned PV capacity is required. Here, a four step plan is presented [3].

In step one, the following data is gathered: The site for the installation, the expected nominal PV capacities, mode of the installation, etc.

The intended rooftop PV system is modeled in the PVsyst. This tool is meant to allow for correct system definition and specification by the user. So, at first, the users are required to key in the coordinates, that is, latitude and longitude, alongside the altitude to retrieve the meteorological data specific to that area from the PVsyst database [6].

In the second step what was described in the first step is transformed into a diagram and analyzed. The parameters for energy output and energy loss responsive actions, reached with the PVsyst tool for prediction and performance modeling are created.

In the third step the light-induced degradation (LID) energy performance degradation, which is falling under light induced LID scope, is calculated PVsyst arrow diagram. The reflection towards the PV system shows what is the conceivable degradation rate possible that has been observed by various studies done on reliability of PV in India [6].

In the fourth stage, an evaluation is performed in regard to the PV system performance indicators, which includes the energy fed into the grid, efficiencies, CUF, PR etc., using framework presented in Table 2.

6. Analysis of Photovoltaics ystems

The simulated performance of the proposed PV set up is to be predicted. For the simulation study to be effective, the information corresponding to this section analyzes the simulation outcomes of a photovoltaic (PV) system. primary simulation results, three key variable were determined[5]. The 1stvariable isreferred to as produced energy and is equal to 139.14 MWh/year. The 2nd variable is the specific produced energy on yearly per setup kWp, which is 1387 kWh/kWp/year. The 3 rdvariable is the yearly mean performance ratioduring the year, which equals to 77.85 %.

6.1. Balances and Main Results

The results and balances are presented in Table 2 and comprises of global irradiance on horizontal plane, ambient mean temperature, effective global irradiance along with the shading losses and soiling losses, and global irradiance on the collector plane unaccompanied by any optical alterations[2].Along with these values, the total DC output from the Si poly PV array which is the total energy exportable to the grid after loss factors of the array, and system efficiency is also calculated[4].

Fig. 2. The performance ratio monthly

6.2. Normalized productions

The simulation study provided valuable insight into losses and energy produced per each kilowatt peak per day when compared to collection and systemic losses. These visuals are made available in Figure3. Such normalized productions are outlined in the IEC normsand are basic metrics for judging the evaluation of the PV system [7]. LC means the the PV array capture losses, which is equal to sixty percent of one kilowatt hour or 1.11 kWh/kWp/day.LS is the system loss 0.1kWh/kWp/day and the Yf is the produced energyof3.82 kWh/kWp/day.

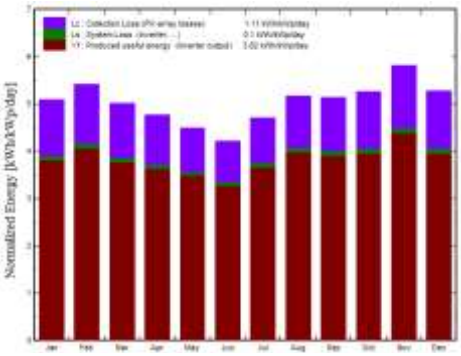

Fig. 3. Normalized energy productions

Table 2 Balances, key outcomes, and energy delivered to the grid

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	99.2	47.1	14.02	131.1	124.7	11250	11021	0.838
February	124.5	54.3	18.38	154.7	146.9	12975	12724	0.820
March	167.0	72.6	24.95	186.9	177.0	15196	14913	0.795
April	179.6	83.2	30.34	179.7	169.7	14273	11453	0.635
May	192.9	99.5	34.47	177.4	166.8	13905	13656	0.767
June	167.8	102.8	33.50	149.6	140.3	11866	11650	0.776
July	147.0	100.5	30.76	133.0	124.6	10740	10536	0.790
August	133.5	88.4	29.47	126.6	119.0	10262	9159	0.721
September	137.3	78.5	28.67	143.3	135.2	11586	11367	0.791
October	128.0	64.5	26.31	148.8	141.3	12068	11839	0.793
November	101.0	59.3	20.32	126.6	120.1	10635	10431	0.821
December	92.4	48.8	15.37	124.0	117.8	10613	10400	0.836
Year	1670.1	899.5	25.58	1781.7	1683.4	145369	139148	0.779

6.3. Energy Loss Analysis

A comprehensive overview of the expected energy losses for a roof-mounted photovoltaic system as captured in the PVsyst annual simulation approach [6] is given in Figure 4

The loss of energy from the array because of different reasons was found to range from 0.1% (1691.79 kWh) to 10.9% (18440.511 kWh).The lowest estimated values of energy losses were owing to string mismatches (0.1%), system unavailability (2%), and losses from the inverter side (2.4%). The top predicted value of energy PV losses was related to the heating (7.8%). On the other hand, the loss of energy based on the solar irradiance intensity incident on the module (3.8%), the loss in the module quality (0.8%), the light induced deterioration (2%) and the inverter working loss (1.9%) also were constraining the assessment of the rooftop PV system. In other words, the energy loss class was segmented into 3 distinct stages. Of the three stages, the first stage, which refers to 'sunlight reaching on to the PV array', has approximately 5.6% (93.43kWh/m^2) of energy dissipation. This loss was primarily due to the incidence angle modifier 2.6% (43.42kWh/m2) and soiling loss factor 3 % (50.1 kWh/m^2).

Stage two was the electricity conversion and it results in16.4.7%. (27745.356 kWh) of the energy loss, which can be attributed to the irradiance level, module quality loss, and LID, module mismatch loss, and ohmic wiring loss[12].Stage three which can be described as energy injection and AC generation from DC power is responsible for roughly 4.3 %, or 7274.7 kWh, of energy dissipations. Within the 3rd stage, most of the losses were due to the

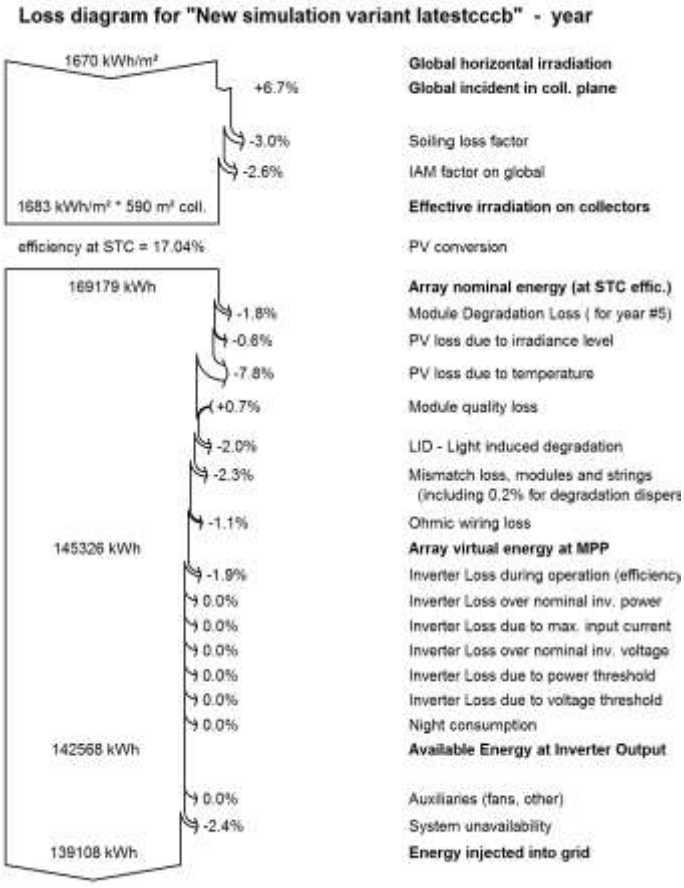

Fig. 4. Arrow loss diagram

Losses from inverter operation, system downtimes. These losses can be reflected in the value which rely on system dependability, grid legislation, random breakdowns, and servicing, etc. [6].

7. Conclusion

The estimate producing of the PV system has reached the level of yearly 139MWh. The annual average ratio of

performance is 77.9% with values ranging from 63.5% in April to 83.08% in January. It is known that system efficiency at STC is 17.08 %. The capacity utilization factor (CUF) and yearly specific energy yield 15.8%,1387 kWh/kWp respectively.The array yield, the reference yield, the annual average daily final yield, and losses of total system collection were, in that order, 14.5 kWh/kWp, 17.81 kWh/kWp, 3.80kWh/kWp/day, and 1.08kWh/kWp/day.

In contrast, the achieved performance ratio and system efficiency was lower than what was anticipated. The energy production was the highest in the summer with a monthly average of 11595 MWh.The reduced capacity of the system is because of various kinds of losses

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Use of Slag and Quarry Waste in Concrete

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Abstract

The construction industry is one of the largest consumers of natural resources globally, with concrete being the most widely used material. Majorly concrete production relies heavily on Portland cement and aggregates (sand and gravel), leading to environmental degradation, high carbon emissions, and resource depletion. The use of industrial by-products such as slag (e.g., ground granulated blast furnace slag, steel slag) and quarry waste (quarry dust, quarry sludge) as partial replacements in concrete presents a sustainable alternative by conserving natural resources and reducing waste disposal issues. This paper reviews the effects on mechanical and durability properties and discusses potential applications and sustainability impacts.

1. Introduction

Concrete consists of cement, water, fine aggregates, and coarse aggregates. The global demand for concrete continues to increase due to rapid infrastructure development. However, excessive use of natural sand and crushed stone creates environmental concerns such as ecological disruption, high energy consumption, and increased carbon footprint. Simultaneously, slag waste from steel plants and quarry waste from aggregate production accumulate in landfills, contributing to environmental pollution and land occupation.

In this context, research into incorporating slag and quarry waste in concrete is essential for sustainable construction materials.

2. Literature Review

2.1 Slag in Concrete

2.1.1 Slag types and characteristics:

- Ground Granulated Blast Furnace Slag (GGBFS) — by-product of iron production; used as a supplementary cementitious material (SCM) to replace part of Portland cement, improving durability and reducing carbon footprint.
- Steel slag — waste from steel plants that can be used as a coarse or fine aggregate alternative.

Studies indicate that incorporating slag often improves mechanical properties and durability due to additional calcium silicate hydrate (C-S-H) formation, reduced permeability, and enhanced resistance to chemical attack.

2.2 Quarry Waste in Concrete

Quarry waste includes quarry dust (fine particulate by-product of crushing rocks) and quarry sludge (finer fractions from washing and cutting). These wastes are often stockpiled, causing environmental issues. Research shows that quarry dust can partially replace natural fine aggregates, while quarry sludge can function as filler or filler-aggregate, reducing demand for river sand and minimizing environmental impacts.

3. Materials and Methods

3.1 Materials

- Cement: Ordinary Portland Cement (OPC)

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- Slag materials: GGBFS, steel slag powder or aggregates
- Quarry waste: Quarry dust, quarry sludge
- Aggregates: Natural coarse aggregate
- Water: Potable

3.2 Mix Proportions

Concrete mixtures were prepared with varying percentages of slag and quarry waste:

- Control mix (no replacements)
- Partial replacement of cement by GGBFS (e.g., 10–20%)
- Partial replacement of fine aggregate by quarry dust (e.g., 15–30%)
- Combination mixes (slury and slag together)

The design considered typical M - 30 grades.

The study evaluated M-30 grade concrete across three distinct mix designs, incorporating Ground Granulated Blast Furnace Slag (GGBFS) and quarry dust as partial replacements for cement and fine aggregates, respectively. The experimental proportions were defined as follows:

Control Mix : 100% conventional materials (0% replacement).

Mix 1 : 10% of cement replaced with slag and 15% of fine aggregate replaced with quarry dust
Mix 2 : 20% of cement replaced with slag and 30% of fine aggregate replaced with quarry dust

Table 1. Mix Proportions

Material	Control Mix (in Kgs)	Mix 1	Mix 2
Cement	403.00	362.70	322.40
Slag	0.00	40.30	80.60
Fine Aggregate	673.00	572.05	471.10
Quarry Dust	0.00	100.95	201.90
Coarse Aggregate	1166.00	1166.00	1166.00
Water	177.44	177.44	177.44
Admixture	1.68	1.68	1.68

4. Experimental Procedures

4.1 Fresh Concrete Tests

- *Workability* - slump test
- *Density*

4.2 Hardened Concrete Tests

- *Compressive strength* at 7, 28, 56 days
- *Split tensile strength*
- *Flexural strength*
- *Durability properties* — permeability, acid attack resistance

These tests were conducted according to standardized methods (ASTM/IS codes where applicable).

5. Results and Discussion

5.1 Mechanical Properties

- Compressive strength: Partial replacement of cement with GGBFS generally showed comparable or improved long-term strength due to enhanced hydration products. Quarry dust improved compressive strength up to an optimal proportion, beyond which performance declined due to poor particle packing and increased porosity.

- Tensile and flexural properties: Mixes with slag typically showed better tensile strength due to improved bonding in the cement matrix.

5.2 Durability

- Slag blended concrete demonstrated lower permeability and improved resistance to sulfate/chloride attack.
- Quarry dust enhanced density but could increase water demand depending on fineness.

Table 2. Results

M - 30 Cube Test Results				
Cement Replacement Level (%)	**Aggregate Replacement Level (%)**	**7-Day Strength (N/mm2)**	**28-Day Strength (N/mm2)**	**Results Obtained**
0% (Control)	0% (Control)	24.20	36.42	Strength - 81% in 7 days& 121% in 28 days
10%	15%	23.44	34.75	Strength - 78% in 7 days& 116% in 28 days
20%	30%	22.32	33.19	Strength - 74% in 7 days& 110% in 28 days

6. Environmental and Economic Impact

Using slag and quarry waste reduces reliance on natural sand and cement (a major CO_2 contributor). Waste utilization reduces landfill needs and supports circular economy principles.

7. Conclusions

- Slag (especially GGBFS) is an effective supplementary cementitious material that enhances strength and durability while reducing environmental impact.
- Quarry waste effectively replaces natural fine aggregates, conserving resources and reducing environmental issues associated with quarry waste disposal.
- Mixed replacement strategies (slag + quarry dust) show promising results in improving mechanical and durability properties when optimized.
- Future research should focus on long-term durability, microstructural analysis, and life-cycle assessment (LCA) of slag–quarry waste concrete.

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Finite Element Investigation of Structural Safety and Load Behavior of a Tata Ace Leaf Spring

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Abstract

This study presents a finite element analysis (FEA) of a multi-leaf spring used in the Tata Ace commercial vehicle with a rated capacity of 1 ton. A three-dimensional model of the leaf spring was developed using SolidWorks and analyzed using ANSYS software. The eye ends of the spring were fixed, restricting all degrees of freedom, while a load was applied at the central region where the spring interacts with the axle. A maximum load of 8093.25 N was considered for baseline analysis. The results indicate that the leaf spring operates safely under the specified load, exhibiting a high factor of safety. However, the factor of safety decreases progressively with increasing load. The study validates the structural adequacy of the design under different loading conditions.

Keywords: *Finite Element Analysis, Leaf Spring, Structural Steel, Von-Mises Stress, Factor of Safety*

1. Introduction

Leaf springs are essential components in automotive suspension systems, contributing significantly to ride comfort, load-bearing capacity, and vehicle stability. With increasing demand for improved performance and reduced weight, researchers have explored both conventional steel and advanced composite materials for leaf spring applications.

Previous studies have demonstrated the effectiveness of composite materials such as glass fiber, carbon fiber, and Kevlar in reducing weight while maintaining strength. However, issues such as fiber-matrix debonding and crack propagation remain challenges in composite designs.

Most existing research focuses on stress, deformation, and stiffness analysis. Limited work has been conducted specifically on evaluating the factor of safety under varying load conditions. Therefore, this study aims to bridge this gap by analyzing the safety margin of a structural steel leaf spring using finite element methods.

Leaf springs play a vital role in automobile suspension systems by contributing to ride comfort and maintaining vehicle stability. Over the past few years, considerable research has been carried out on metallic as well as alternative materials to evaluate their suitability for leaf spring applications. These investigations indicate that the selection of appropriate suspension materials can significantly influence vehicle performance and efficiency.

Patunkar and Dolas developed a finite element model of a composite mono leaf spring fabricated from GFRP using Pro-E software, while the structural analysis was performed through ANSYS.[1]

Gowd and Goud examined the load carrying capacity of the leaf spring used in the TATA-407 light commercial vehicle with the help of ANSYS software. Their study highlighted that the highest stress concentration occurs near the eye section, emphasizing the need for careful consideration in material selection, design methodology, and manufacturing processes in this region.[2]

Kothari and Patel presented a detailed review concerning the design and fabrication aspects of composite leaf springs. According to their findings, composite springs provide a promising alternative to conventional steel springs. The review also discussed different material options, where fiberglass-reinforced polymer (FRP) was recommended because of its reduced weight and superior strength characteristics compared with steel[3]

Ismaeel investigated a mono-fibre reinforced composite leaf spring and discussed the influence of parameters such as shear modulus of fibres and matrix materials. Different modelling and analysis software tools were employed to study the behavior of leaf springs when steel material was replaced with reinforced composite structures.[4]

Nutalapati performed a comparative assessment between traditional steel leaf springs and composite leaf springs considering stress, deformation, and weight as major parameters. The geometry was modeled using Pro/ENGINEER,

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whereas ANSYS 12.0 was used for analysis. The composite spring material selected for the study was E-glass/epoxy reinforced polymer.[5]

Triveni and Babu carried out both static and dynamic finite element analyses using ANSYS and concluded that carbon fibre reinforced leaf springs exhibit better suitability than conventional steel springs.[6]

Jacob and Deepak focused on the fabrication and evaluation of leaf springs under varying loading conditions. Their work compared mild steel and glass/carbon composite materials for different reinforcement orientations in order to analyze strength characteristics.[7]

Salman and co-researchers conducted finite element analysis on leaf springs made from four distinct composite materials under full-load conditions. Their objective was to identify lightweight materials capable of providing enhanced mechanical performance.[8]

Chintada and colleagues compared conventional steel leaf springs with several composite material alternatives. Parameters such as weight, total deformation, von Mises stress distribution, and strain energy were used as the basis for performance evaluation to determine the most suitable material option.[9]

Ashwini and Rao summarized various research findings available in the literature related to composite leaf springs. Their study concluded that composite mono leaf springs can effectively replace conventional steel springs because of their improved ride comfort and overall performance.[10]

Dey and co-authors compared conventional steel leaf springs with E-glass/epoxy composite springs by evaluating parameters including stress, deformation, and weight reduction.[11] Krishnamurthy and associates performed finite element analysis to determine stress and deflection characteristics of leaf springs, and the obtained numerical results were validated experimentally.[12]

Thillikkani and Nataraj investigated the premature failure behavior of existing as well as modified bracket models subjected to dynamic loading. Their work simulated failure conditions occurring in suspension brackets and identified weak design regions responsible for reduced durability. Generalized force elements were incorporated to represent varying operational loads experienced in actual service conditions. In addition, scanning electron microscopy (SEM) was employed to examine crack initiation and surface defects in the brackets. The study concluded that repeated cyclic loading generated by vibrations and uneven rural road conditions is a major factor responsible for fatigue failure in suspension components.[13]

Mahajan and Patil analyzed the structural strength of a semi-elliptic multi-leaf spring manufactured from steel and evaluated the resulting von Mises stresses under different loading conditions.[14]

Recent advancements in automotive suspension systems have increasingly focused on improving structural efficiency, reducing weight, and enhancing durability through advanced materials and numerical techniques. Finite Element Analysis (FEA) has emerged as a powerful tool for evaluating the mechanical behavior of leaf springs under complex loading conditions.

Zou et al. [15] investigated the stiffness and damping characteristics of composite leaf springs using finite element modeling and reported improved performance over conventional steel springs. Similarly, IndrajitSalunke et al. [16] compared different materials and observed that titanium alloys exhibit higher stress values, while structural steel shows lower deflection. Silaskar et al. [17] demonstrated that composite materials such as Kevlar and carbon fiber significantly reduce weight while maintaining adequate strength.

More recent studies have further extended this work. Kumar et al. [18] conducted a finite element analysis of coated composite leaf springs and reported improved stress distribution and reduced deformation compared to steel springs. Sharma and Patel [19] optimized glass fiber-reinforced epoxy leaf springs and achieved substantial weight reduction along with enhanced strength-to-weight ratio.

In another study, Verma et al. [20] analyzed different geometric configurations of composite leaf springs and concluded that parabolic designs offer better stress distribution and reduced weight compared to conventional designs. Singh et al. [21] carried out both numerical and experimental investigations on composite leaf springs and reported up to 50% weight reduction without compromising structural integrity.

Furthermore, Reddy et al. [22] explored hybrid composite leaf springs incorporating carbon and glass fibers and found improved fatigue life and energy absorption characteristics. These studies highlight the growing importance of composite materials in modern suspension systems.

However, despite significant advancements, most of the existing literature primarily focuses on stress analysis, deformation characteristics, and weight optimization. Limited research has been directed toward evaluating the factor of safety under varying load conditions, especially for conventional structural steel leaf springs widely used in commercial vehicles. This indicates a clear research gap, which the present study aims to address.

A substantial amount of research available in the open literature discusses the selection of suitable materials for leaf

spring applications, ranging from traditional steel materials to advanced composite alternatives. Composite materials are considered advantageous because they offer reduced weight along with improved stiffness characteristics. However, these materials also face certain limitations, particularly the tendency of fibre cracking at the fibre–matrix interface and in directions transverse to the applied load. Most previous investigations have primarily focused on evaluating the strength and stiffness behavior of leaf springs. According to the available knowledge of the authors, very limited attention has been given in published studies toward detailed evaluation of the factor of safety of leaf springs.

2. Material Property

A structural steel is used for this analysis. Structural steel consists primarily of iron with a maximum carbon content of 0.25–0.29%, manganese 0.80–1.20%, phosphorus ≤0.04%, sulfur ≤0.05%, and small amounts of silicon and copper, making it a low-carbon steel with good ductility and weldability. Properties of structural steel are shown in table 1.

Table 1: Properties of structural Steel

Properties	Values
Density	7850 kg/m^3
Young Modulas	200 GPa
Poison Ratio	0.3
Shear Modulus	79.61 GPa
Bulk modulus	172.5 GPa
Tensile yield strength	250 MPa
Ultimate Tensile strength	400 MPa

3. Structural Design and Evaluation

3.1. Leaf spring Parameters

Figure 1 shows the dimensions ie. Length of different leaves and radius of curvature. All measurements are taken in mm.

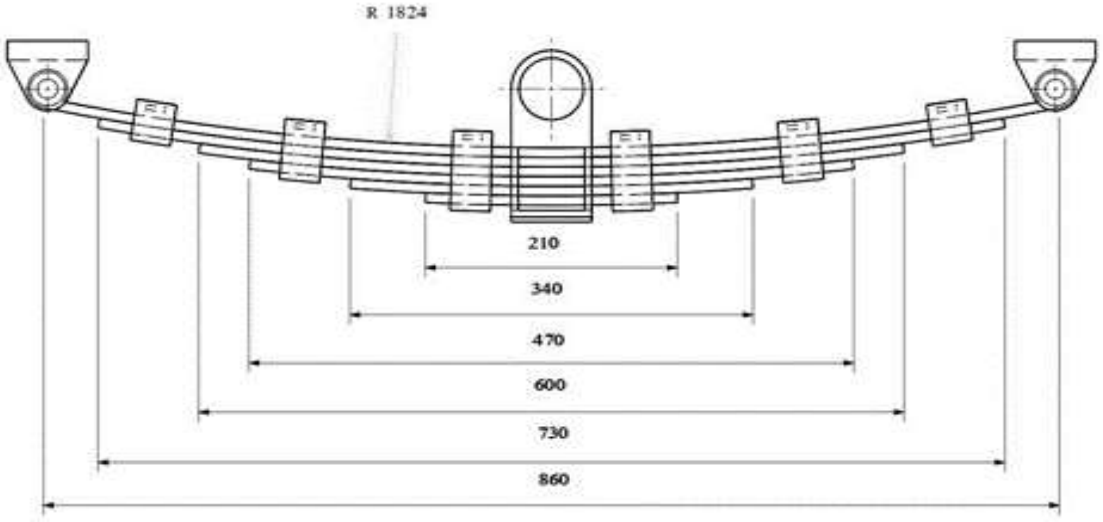

Fig. 1 Dimensions of Leaf Spring

3.2. Weight calculation

In the present investigation, a light commercial four-wheeled vehicle, namely Tata Ace, was selected for analytical evaluation. The maximum load acting on each leaf spring was determined using the following calculations:

- Weight of vehicle = 980 kg
- Maximum load capacity = 1700 kg
- Driver weight = 70 kg
- Total weight = 1000 + 1700 + 70
  = 2750 kg
- Acceleration due to gravity (g) = 9.8 m/s^2
- Load acting on leaf spring = 2750 x 9.8
  = 26950 N
- Rear suspension = 60% of Total weight
  = 26950 × 0.60 N
  = 16170 N
- Therefore Total weight = 16170 N

As the rear suspension system incorporates two leaf springs, the total applied load is equally distributed between them. Therefore, the load acting on an individual spring can be calculated as: = 16170/2 = 8085 N

Hence, the maximum load considered for each leaf spring is 8085 N

4. Methodology

The leaf spring assembly of the Tata Ace was selected for the present modelling and analytical investigation. Three-dimensional models of the leaf spring were developed using SOLIDWORKS software. One of the representative leaf spring models utilized in the study is illustrated in Figure 2. The structural analysis of the modeled spring was subsequently performed using ANSYS software.

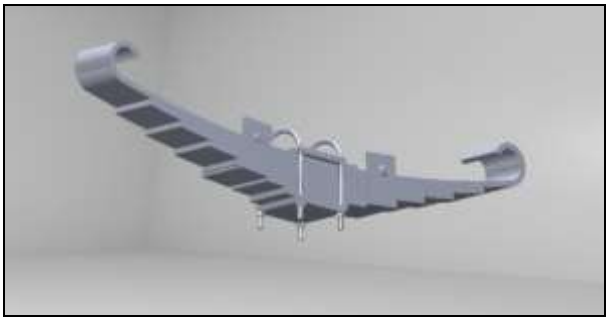

Fig. 2: Solid works Model

4.1. Meshing

Figure 3 illustrates the discretized mesh model of the leaf spring. Meshing represents a crucial stage in the finite element analysis process and must be properly carried out for accurate evaluation of the leaf spring structure. In this procedure, the developed geometric model is subdivided into a large number of smaller elements interconnected through nodes, enabling detailed numerical analysis of the component behavior.

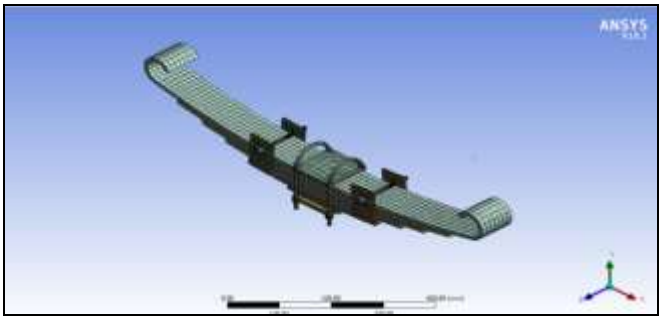

Fig 3: Meshed Model

4.2. *Boundary Conditions:*

Figures 4 and 5 illustrate the boundary conditions considered during the structural analysis of the leaf spring assembly. The applied boundary conditions are described below:

A. Fixed Support:

The locations indicated in Figure 4 represent the regions where the leaf spring is constrained. At these points, all degrees of freedom are restricted to simulate fixed support conditions.

B. **Applied Moment/Load:**

The calculated load corresponding to the required deceleration condition is imposed on both eye ends of the leaf spring to evaluate its structural response under operating conditions.

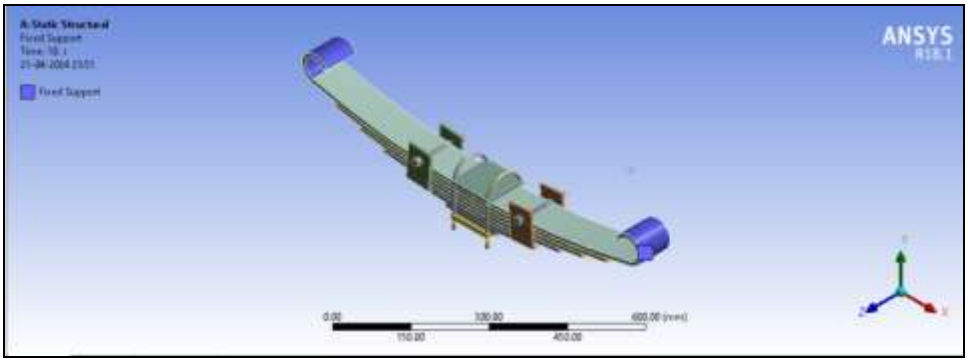

Fig4: Fixed Support

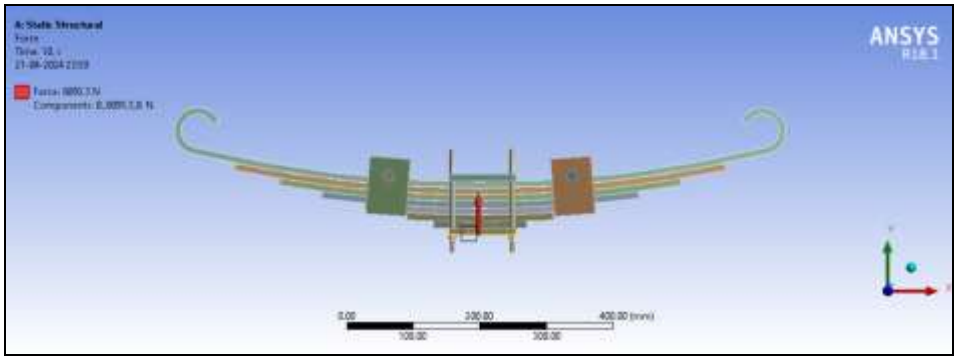

Fig 5: Application of force

5. Result and Discussion

Structural analysis of the leaf spring was performed under three different loading conditions, as described below:

- **Case 1:** Applied load of 8085 N
- **Case 2:** Applied load of 12127.5 N (1.5 times)
- **Case 3:** Applied load of 16170 N (2 times)

For every loading case, parameters such as equivalent von Mises stress, elastic strain, and total deformation were evaluated using ANSYS software. The corresponding results obtained for each leaf spring configuration were subsequently analyzed and discussed.

5.1. Case 1: Applied Load of 8085 N

The outcomes corresponding to equivalent von Mises stress, total deformation, elastic strain, and factor of safety were determined and are presented in Table 1.

The finite element analysis carried out under an applied load of 8085 N provided the stress, deformation, strain, and safety characteristics of the leaf spring. The highest equivalent von Mises stress generated in the spring was observed to be 36.28 MPa, whereas the minimum stress value was nearly negligible at 6×10^{-9} MPa.

The maximum total deformation recorded during the analysis was 7.94×10^{-2} mm, while no deformation occurred at the fixed support locations. Similarly, the elastic strain distribution showed a peak value of 1.82×10^{-4}, with the minimum strain approaching 6.98×10^{-14}.

The calculated factor of safety ranged from 6.89 to 15, indicating that the leaf spring design remains within acceptable safety limits under the specified loading condition. These findings suggest that the spring structure is capable of withstanding the applied load with comparatively low deformation and adequate structural reliability.

Table 1: Obtained results for applied load of 8085 N

Force	Values	Max.	Min.
8085 N	Equivalent Von-Mises stress (MPa)	36.28	6×10^{-9}
	Total Deformation (mm)	7.94×10^{-2}	0
	Elastic strain	1.82×10^{-4}	6.98×10^{-14}
	Factor of safety	15	6.89

5.2. Case 2 when low load of 12127.5 N is applied

The outcomes corresponding to equivalent von Mises stress, total deformation, elastic strain, and factor of safety were determined and are presented in Table 2.

Under the applied load condition of 12127.5 N, the structural response of the leaf spring was evaluated in terms of equivalent von Mises stress, elastic strain, total deformation, and factor of safety. The analysis revealed that the maximum equivalent von Mises stress developed in the spring was 54.42 MPa, while the minimum stress value was found to be approximately 9.1×10^{-9} MPa, indicating negligible stress in certain regions of the model.

The elastic strain obtained from the analysis reached a maximum value of 2.74×10^{-4}, whereas the minimum strain was 1.0438×10^{-13}, which is nearly insignificant. The total deformation observed in the leaf spring was 0.119 mm at the most critical location, while the minimum deformation remained zero at the constrained regions.

The factor of safety varied between 5.59 and 15 throughout the structure, demonstrating that the designed leaf spring

operates well within the safe stress limit under the given loading condition. The obtained results indicate that the spring possesses sufficient strength and rigidity to sustain the applied load without failure.

Table 2: Obtained results for applied load of 12127.5 N

Force	Values	Max.	Min.
12127.5 N	Equivalent Von-Mises stress (MPa)	54.42	9.1×10^{-9}
	Elastic strain	2.74×10^{-4}	1.0438×10^{-13}
	Total Deformation (mm)	0.119	0
	Factor of safety	15	5.59

5.3. Case 3 when low load of 16170 N is applied

The results for Equivalent Von-Mises stress, Total Deformation, Elastic strain and Factor of safety obtained and listed in table3.

The structural performance of the leaf spring was further examined under an applied load of 1670 N. The analysis results indicated that the maximum equivalent von Mises stress developed in the spring reached 72.56 MPa, while the minimum stress value was extremely small at 1.2105×10-8 MPa.

The elastic strain distribution showed a peak value of 3.654×10−4, whereas the minimum strain obtained from the model was 1.39×10−13. In terms of deformation behavior, the highest total deformation recorded was 0.1589 mm, while zero deformation was observed at the fixed support regions due to boundary constraints.

The factor of safety for the leaf spring varied from 3.445 to 15 across different regions of the structure. Although the applied load was comparatively higher, the obtained safety values confirm that the spring design is still capable of sustaining the loading condition without reaching failure limits. The results also demonstrate an increase in stress, strain, and deformation with increasing load magnitude.

Table 3: Obtained results for applied load of 16170 N

Force	Values	Max.	Min.
16170 N	Equivalent Von-Mises stress (MPa)	72.56	1.2105×10^{-8}
	Elastic strain	3.654×10^{-4}	1.39×10^{-13}
	Total Deformation (mm)	0.1589	0
	Factor of safety	15	3.445

6. Comparison Analysis

Figure 6-9 show the comparison of equivalent von-mises stress, Total Deformation, Elastic strain and Factor of safety respectively.

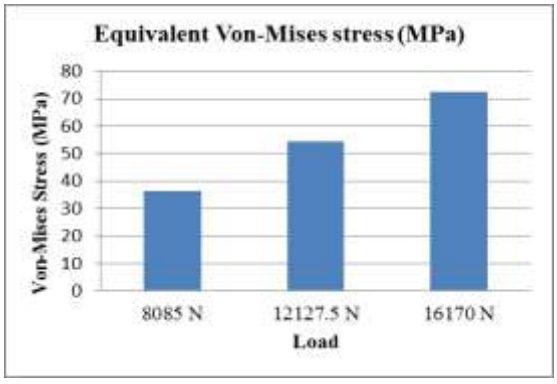

Fig. 6 Graph shows the comparison of Equivalent von-mises stress with increase in load

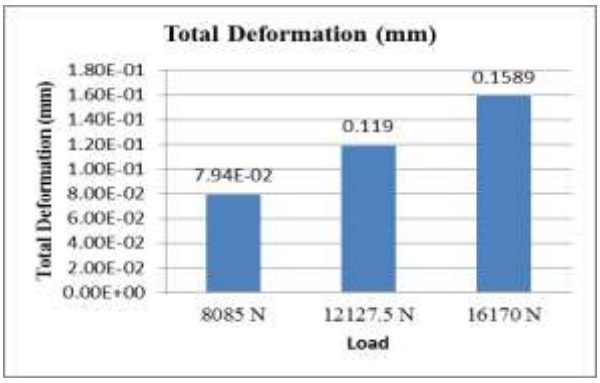

Fig. 7 Graph shows the comparison of total deformation with increase in load

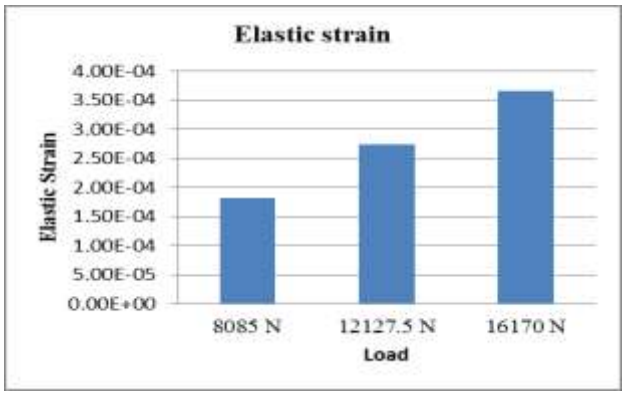

Fig. 8 Graph shows the comparison of equivalent elastic strain with increase in load

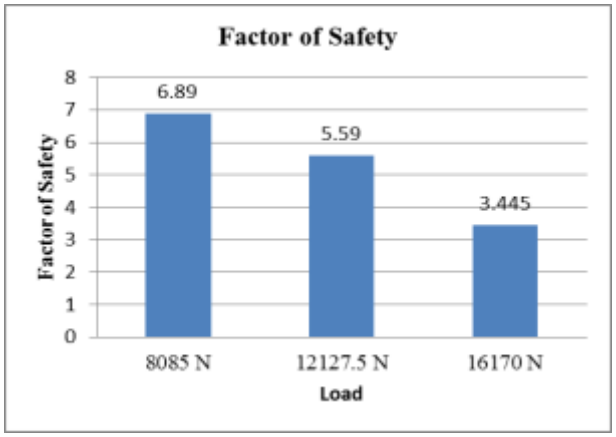

Fig. 9 Graph shows the comparison of Factor of Safety with increase in load

The comparative results obtained from the structural analysis of the leaf spring under different loading conditions are presented in the table. It can be observed that the equivalent von Mises stress, total deformation, and elastic strain increase continuously with the increase in applied load, whereas the minimum factor of safety decreases.

For the load condition of 8085 N, the leaf spring experienced a maximum equivalent stress of 36.28 MPa along with a deformation of 7.94×10^{-2} mm and an elastic strain of 1.82×10^{-4}. Under this loading condition, the minimum factor of safety was found to be 6.89, indicating highly safe operating conditions.

When the applied load increased to 12127.5 N, the equivalent stress increased to 54.42 MPa. Correspondingly, the deformation rose to 0.119 mm and the elastic strain reached 2.74×10^{-4}. The factor of safety reduced to 5.59, which still represents a stable and secure design condition.

At the maximum load of 16170 N, the leaf spring developed the highest stress value of 72.56 MPa. The total deformation also increased to 0.1589 mm, while the elastic strain became 3.65×10^{-4}. In this case, the minimum factor of safety decreased to 3.445 due to the higher load intensity. Even though the safety factor reduced, the value remained above the acceptable limit, confirming that the spring can safely withstand the applied load without structural failure.

The graphical trend clearly indicates an approximately linear relationship between the applied load and the induced stress in the leaf spring. This behavior confirms that the structural response of the spring remains stable and predictable within the considered loading range. Although the stress values rise with increasing load, all obtained stresses remain within the permissible limit of the material, indicating safe operation under the analyzed conditions.

The results further demonstrate that the designed leaf spring possesses sufficient load carrying capability and structural integrity. However, the maximum stress concentration becomes more significant at higher loading conditions, suggesting that critical regions of the spring should be carefully considered during design optimization to improve durability and fatigue life.

Overall, the comparison indicates that the mechanical response of the leaf spring follows a proportional trend with increasing load. Higher loading conditions result in greater stress, strain, and deformation, while simultaneously reducing the safety margin. Nevertheless, all analyzed cases demonstrate satisfactory structural performance and acceptable safety characteristics for the selected material and design configuration.

7. Conclusion

The present study aims to develop a leaf spring design capable of maintaining stress, elastic strain, deformation, and factor of safety within permissible limits. To achieve this objective, the geometry of the leaf spring was modified to obtain improved performance characteristics. A structural steel leaf spring was selected in this investigation because of its superior strength and lower deflection under identical loading conditions.

- A semi-elliptical multi-leaf spring for a four-wheel automobile was designed and analyzed under three different loading cases while maintaining similar operating conditions.
- The highest values of stress and deflection were recorded when the spring was subjected to the maximum applied load, which was twice the design load.
- Considerable variation in stress distribution and deflection behavior was observed in the leaf springs under identical static loading situations. However, the structural steel leaf spring exhibited comparatively lower stress and deflection even with increased load intensity.
- Based on the analytical results, it can be inferred that structural steel leaf springs containing a greater number of leaves provide better efficiency and performance than conventional springs having fewer plates.[13 & 17]

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Experimental Investigation and Analysis of Nanoparticles in PCM-Based Energy Storage Systems

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Abstract

The integration of oxide-based nanoparticles into paraffin-based phase change materials (PCMs) holds significant promise for enhancing the thermal performance of energy storage systems. This study experimentally investigates the influence of nanoparticle concentration on the latent heat storage capacity and thermal diffusivity of PCM composites. Utilizing ultrasonic dispersion methods, Al_2O_3 oxide-based nanoparticles with defined size distributions were incorporated into the PCM to ensure homogeneous distribution, as confirmed by scanning electron microscopy (SEM) imaging. Results indicate that while nanoparticle addition improves thermal conductivity, an increased concentration may lead to reductions in latent heat capacity due to the displacement of active PCM material by non-phase-changing particles. Reported latent heat reductions in the literature vary between 2% and 15%, with extreme cases reporting reductions of up to 68% for higher nanoparticle loadings. However, selected low concentration levels, such as 3 wt.%, have been associated with marginal improvements in latent heat. Enhanced heat transfer rates observed in the nanoparticle-infused PCMs are primarily attributed to improved conduction pathways facilitated by the nanoparticles. This paper discusses the critical balance required between enhancing thermal conductivity and preserving latent heat capacity, providing insights into optimizing nanoparticle loadings in PCM-based energy storage applications.

Keywords: phase change materials, nanoparticles, latent heat capacity, thermal conductivity, ultrasonic dispersion, SEM analysis

1. Introduction

Phase change materials (PCMs) are integral to modern thermal energy storage systems due to their ability to store and release large amounts of latent heat [1]. The incorporation of nanoparticles (NPs) into PCMs has been proposed as an effective strategy to enhance thermal conductivity and overall heat transfer rates. Al_2O_3 oxide-based nanoparticles, in particular, have garnered attention for their thermal stability and ease of dispersion when integrated with paraffin-based PCMs. However, an inherent challenge lies in maintaining latent heat capacity while achieving improved dispersion and heat conduction.

Previous studies have shown that while the addition of NPs may result in significant gains in thermal conductivity, it is often accompanied by a reduction in the effective latent heat capacity—this is partly due to the replacement of the PCM mass with non-phase-changing materials [2], [3]. This study aims to examine the effect of varying nanoparticle concentrations on both the latent heat storage capacity and the thermal diffusivity of PCM composites.

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Emphasis is placed on the experimental method of ultrasonic dispersion to ensure nanoparticle homogeneity, as verified by scanning electron microscopy (SEM) analyses. Through this investigation, the research seeks to elucidate the complex interactions between the nanoparticle additives and the PCM matrix to inform the development of optimal design strategies for enhanced thermal energy storage systems.

2. Experimental Methodology

2.1 Materials

The nanoparticles selected for this study were Al_2O_3 (aluminum oxide) nanoparticles with an average particle size in the range of 20–50 nm and a purity greater than 99%. This size range was chosen to achieve an optimal balance between enhanced thermal conductivity and dispersion stability within the paraffin-based PCM. The nanoparticles exhibited a thermal conductivity of approximately 25–35 W/m·K, significantly higher than that of the base PCM, thereby facilitating improved heat transfer. Spherical morphology was preferred to promote uniform dispersion and minimize viscosity increase. Additionally, the nanoparticles possessed a high specific surface area (30–150 m^2/g), which enhances interfacial heat transfer between the nanoparticles and the PCM matrix. Ultrasonic dispersion was employed to ensure stable suspension and to minimize agglomeration and sedimentation effects during preparation. The choice of Al_2O_3 oxide-based nanoparticles aligns with previous research, which indicates that such materials are effective in enhancing thermal conductivity without excessive chemical reactivity [6].

2.2 Nanoparticle Integration and Dispersion

Nanoparticles were integrated into the PCM using ultrasonic dispersion. Ultrasonication was conducted to prevent agglomeration and to ensure uniform distribution of nanoparticles within the PCM matrix. This method has been validated in previous studies [4], [5] for its effectiveness in dispersing nanoparticles, thereby enabling consistent thermal properties and reproducibility of results.

2.3 Characterization Techniques

The prepared nanoparticle-enhanced PCM composites were characterized using a combination of morphological and thermal analysis techniques to evaluate their structural uniformity and thermophysical properties.

2.2.1 Scanning Electron Microscopy (SEM): It was employed to investigate the dispersion and morphological distribution of Al_2O_3 nanoparticles within the PCM matrix. SEM analysis provided high-resolution images that enabled the identification of particle distribution, agglomeration behavior, and interfacial interaction between the nanoparticles and the base material. The micrographs were analyzed to assess the degree of homogeneity achieved through ultrasonic dispersion and to compare dispersion quality at different nanoparticle concentrations.

2.2.2 Differential Scanning Calorimetry (DSC): It was used to determine the latent heat storage capacity and phase change temperatures of the PCM composites. DSC measurements were conducted under controlled heating and cooling cycles to evaluate the melting and solidification behavior. The latent heat values were obtained from the area under the DSC curves, while peak temperatures provided insights into phase transition characteristics. This analysis was essential for quantifying the impact of nanoparticle addition on energy storage performance.

2.2.3 Thermal Conductivity Measurement: It was carried out using an appropriate technique such as the transient hot-wire method or guarded hot plate method. These measurements enabled the evaluation of heat transfer enhancement due to the incorporation of nanoparticles. The results were compared across different nanoparticle concentrations to identify trends and optimal loading conditions.

2.2.4 Thermal Diffusivity Analysis: It was performed to assess the rate of heat propagation within the PCM composites. Techniques such as laser flash analysis (LFA) were utilized to determine thermal diffusivity values. This parameter is critical in understanding the dynamic thermal response of the material during phase change processes.

Additionally, **visual observation and stability assessment** were conducted to evaluate sedimentation and phase separation over time. The stability of nanoparticle dispersion within the PCM matrix was monitored to ensure the reliability and repeatability of experimental results.

Collectively, these characterization techniques provide a comprehensive understanding of the structural, thermal, and stability aspects of nanoparticle-enhanced PCM systems, enabling the correlation between microstructural features and macroscopic thermal performance.

3. RESULTS

The experimental results demonstrated that the incorporation of Al_2O_3 oxide-based nanoparticles enhanced the thermal conductivity of the PCM composites. However, a critical observation was the trade-off between enhanced thermal conductivity and latent heat capacity. In particular, latent heat capacity was found to decrease with increasing nanoparticle concentrations, consistent with literature reports indicating reductions ranging from 2% to 15% depending on the concentration [2].

Scanning electron microscopy (SEM) analysis was conducted to examine the dispersion characteristics and morphological distribution of Al_2O_3 nanoparticles within the paraffin-based PCM matrix. The SEM micrographs revealed that at lower nanoparticle concentrations (≤3 wt.%), the nanoparticles were uniformly dispersed throughout the PCM, forming a relatively continuous and homogeneous structure. This uniform dispersion can be attributed to the effectiveness of ultrasonic treatment, which generates cavitation forces that break down particle clusters and promote even distribution.

At optimal concentrations, the nanoparticles appeared well embedded within the PCM matrix without significant clustering, indicating strong interfacial interaction between the nanoparticles and the base material. This homogeneous distribution facilitates the formation of effective thermal conduction pathways, thereby enhancing heat transfer performance.

However, at higher nanoparticle loadings (>3 wt.%), SEM images showed noticeable agglomeration and clustering of nanoparticles. These agglomerates arise primarily due to increased van der Waals attractive forces between nanoparticles at higher concentrations, which overcome the dispersive effects of ultrasonication. Additionally, the high surface energy of nanoscale particles further promotes particle–particle interaction, leading to the formation of clusters.

The presence of agglomerates disrupts the uniformity of the PCM matrix and reduces the effective surface area available for heat transfer. Moreover, these clusters can act as thermal resistance sites and hinder efficient phase change behavior. Agglomeration also contributes to localized non-uniformity, which may explain the observed reduction in latent heat capacity at higher nanoparticle concentrations.

Overall, SEM analysis confirms that nanoparticle dispersion is highly dependent on concentration, with lower concentrations promoting homogeneity and higher concentrations leading to agglomeration. These findings highlight the importance of optimizing nanoparticle loading to achieve a balance between improved thermal conductivity and stable morphological characteristics.

Panel (a): 1-3 wt.% - Uniform distribution

Panel (b): 5 wt.% - Good dispersion

Panel (c): 10 wt.% - Agglomeration clusters

Fig. 1. SEM analysis showing nanoparticle distribution at different concentration levels with scale bars indicating 1 µm or 500 nm magnification.

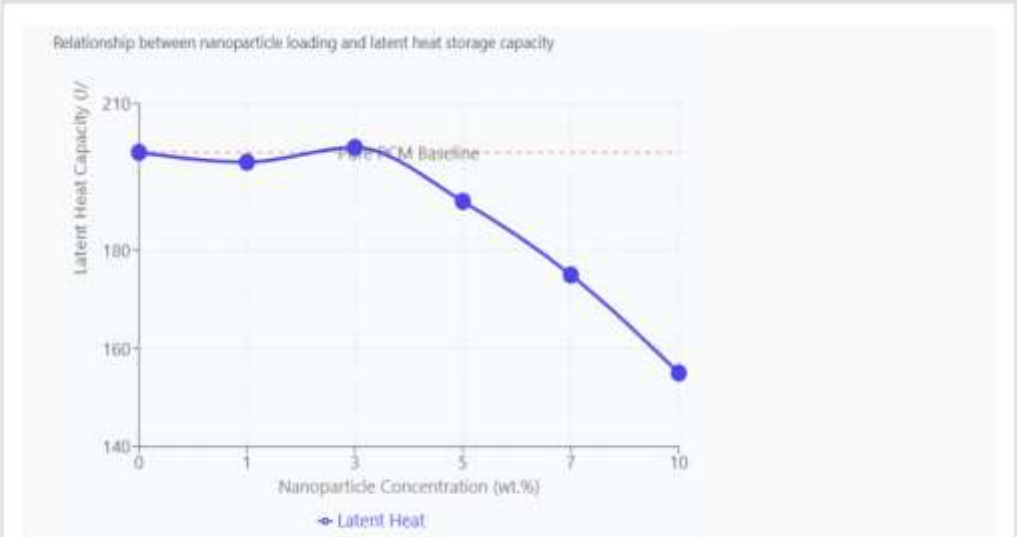

Fig. 2. Effect of nanoparticle concentration on latent heat capacity showing 2-15% reduction at moderate concentrations with annotation at 3 wt.% point.

Thermal diffusivity measurements revealed that moderate nanoparticle concentrations optimized the balance between heat conduction and latent heat storage. These improvements were statistically significant when compared to PCM systems without nanoparticle enhancements underscoring the role of nanoparticle concentration as a critical factor in the performance optimization of PCM-based energy storage systems [3], [6].

4. DISCUSSION

The experimental findings highlight the dual nature of nanoparticle integration in PCMs. On one hand, enhancements in thermal conductivity via Al_2O_3 oxide-based nanoparticles facilitate faster heat transfer during phase transitions. On the other hand, the displacement of PCM material by nanoparticles leads to reductions in the latent heat capacity—a phenomenon that must be carefully managed in system design [2].

The use of ultrasonic dispersion proved to be an effective method for ensuring uniform NP distribution, as corroborated by SEM imaging, which revealed significant improvements in the microstructural homogeneity of NP-PCM composites [4], [5]. These observations suggest that an optimal nanoparticle concentration exists, wherein the thermal conductivity is sufficiently enhanced while the latent heat reduction remains within acceptable limits.

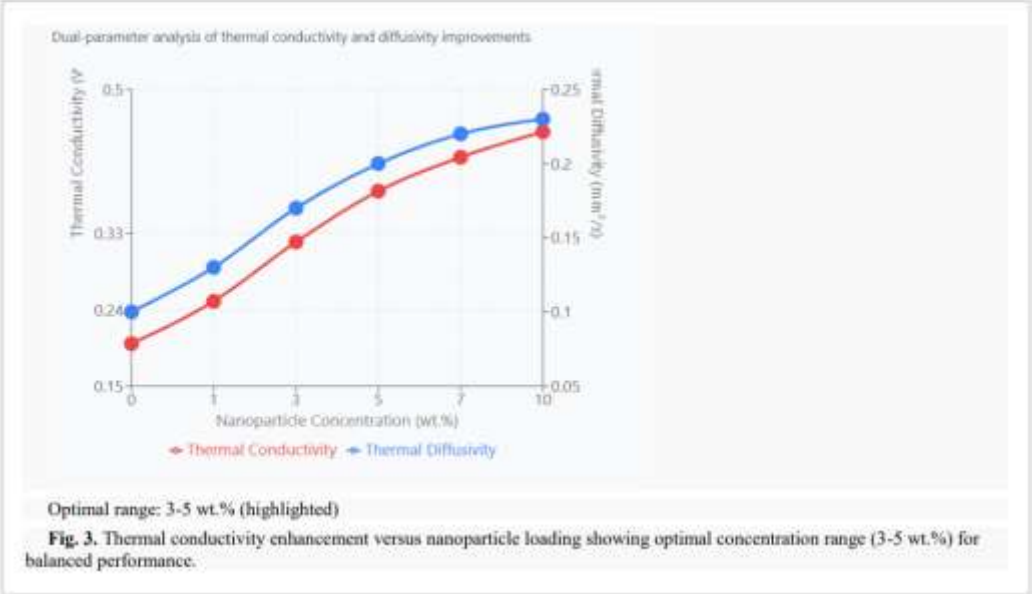

Fig. 3. Thermal conductivity enhancement versus nanoparticle loading showing optimal concentration range (3-5 wt.%) for balanced performance.

These observations suggest that an optimal nanoparticle concentration exists, wherein the thermal conductivity is sufficiently enhanced while the latent heat reduction remains within acceptable limits. Future research should focus on pinpointing this optimal concentration range for various PCM systems and expanding the study to include different types of nanoparticles. Such research is essential for developing advanced thermal energy storage systems that harness the benefits of nanoparticle integration without compromising energy storage efficiency.

5. CONCLUSION

In conclusion, this study demonstrates that the integration of oxide-based nanoparticles into paraffin-based PCMs significantly influences the thermal performance of energy storage systems. While improvements in thermal conductivity are evident, careful consideration must be given to the concomitant reduction in latent heat capacity at higher nanoparticle loadings.

The experimental approach—employing ultrasonic dispersion and SEM analysis—provides a reliable methodology for ensuring nanoparticle homogeneity and elucidating the underlying microstructural changes. The balance between enhanced heat transfer and latent heat maintenance is crucial for the optimal design of PCM-based energy storage systems. Further investigation into nanoparticle concentrations and types is recommended to further refine these systems and maximize their thermal storage capabilities.

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Non-Destructive and Destructive Test Results of Jute Fiber Reinforced Concrete: A Comparative Analysis

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Abstract

The need to reduce environmental impacts like carbon footprint and to conserve natural resources added to the demand for sustainable materials, especially in the field of construction. Addition of natural fibers like jute, coconut or sisal is seen as a better alternative for enhancing certain mechanical behaviors of concrete. However, to confirm this with details, further investigation is needed. Till date no IS code has any standardization for these natural fibers. This fact further intensifies research work requirements in the case of natural fibers. In present research work, investigation has been done on concrete modified with jute fibers- a material which is available in plenty, cost effective, bio-degradable and non-toxic. Testing on quality and material integrity, without causing any kind of damage or destruction to the component or structure, is very important according to IS:13311 Part 1 and Part 2 (1992), which covers ultrasonic pulse velocity and rebound hammer tests on concrete. This study mainly highlights the non-destructive evaluation of jute-fiber-reinforced concrete (JFRC) incorporating four fiber contents (0%, 1%, 2%, and 3%), to different concrete grades (i.e, M20, M25, M30), and two water–binder ratios (0.35 and 0.45). Ultrasonic Pulse Velocity (USPV) and Schmidt Rebound Hammer tests were conducted on all specimens prior to destructive compressive strength testing. The objective was to observe how jute fiber percentage and mix parameters influence NDT responses and to compare these readings with the corresponding compressive strengths. The collected data was plotted to examine the trends and correlations between USPV values, rebound numbers, and the measured strengths. The study reports the variations in NDT results across different mixes and provides graphical relationships that may support future interpretation of jute-reinforced concrete using non-destructive techniques.

Keywords: Concrete; Destructive testing; Durability; Non-destructive testing; Ultrasonic pulse velocity, Schmidt rebound hammer.

1. Introduction

To meet the demand of the growing population, construction is also increasing and hence the wide application of concrete is also increasing [1]. But the negative impact of concrete on the environment is (high emitter of CO2) very adverse, [2]. Also, from previous research work [3-4], it is very clear that brittleness and poor tensile strength of concrete is liable to easy cracking and eventual deterioration. This enforces investigation on alternative materials which can be used for preparation of “Green concrete” [5]. Mechanical properties of concrete can be enhanced using natural fibers like Jute. Jute is available in plenty, at the same time it is cheap, non-toxic and biodegradable. Due to these properties it has less negative impact on the environment. According to IS 667 [6], Jute has been classified under Bast fiber category, with high lignin content which is advantageous for improving durability. It also helps in protection against thermal degradation [7]. Various research works have been done related to the impact of jute content, aspect ratio [8-9] on mechanical properties of concrete modified with jute fiber. However, these reports have very limited information regarding long-term durability properties.

In a recent work [10], authors have validated results of compressive strength of concrete using non-destructive tests like the rebound hammer test. But, tests results of other NDT tests like ultra sonic pulse velocity test are not present in this report, which is essential for understanding actual quality of concrete members. Recent experimental studies on normal concretes show strong correlation between UPV and compressive strength. For example, Murali and Reddy’s [11] study of concrete cubes (grades M20, M25, M30, M35) reported R2 values exceeding 0.9 for linear fits. Estévez et al. [12] measured cement mortars and found linear regression yielded very high R^2 (0.97–0.99) between UPV and strength. However, combining Rebound Hammer test values with USPV have shown to increase the predictive performance. For example, Angiulli et al. [13] found combined use of USPV and rebound hammer values (SonReb) “are more accurate than

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the individual USPV and RH methods". Similarly, Thapa et al [14] reported high accuracy using SonReb fits for M20–M30 concretes using different percentage of recycled brick aggregate.

Nondestructive tests are very important for Jute fiber reinforced concrete, as these tests can predict the actual behavior of JFRC without breaking the sample or depending on destructive tests, which are again a costly affair. Due to lack of detailed information on jute fiber reinforced concrete, more investigation is required using NDT on JFRC, so that these results can be utilized to predict the correct behavior of concrete with amount of jute inclusion.

In the present research work concrete with jute fibers has been developed. Strength gain behavior of JFRC has been studied using both destructive and non-destructive test results. These outcomes have been compared to get a full insight into the actual behavior of JFRC. Focus has also been given that how NDT outcomes can be utilized for compressive strength prediction of green concrete which has been developed with inclusion of jute fibers in the present research work.

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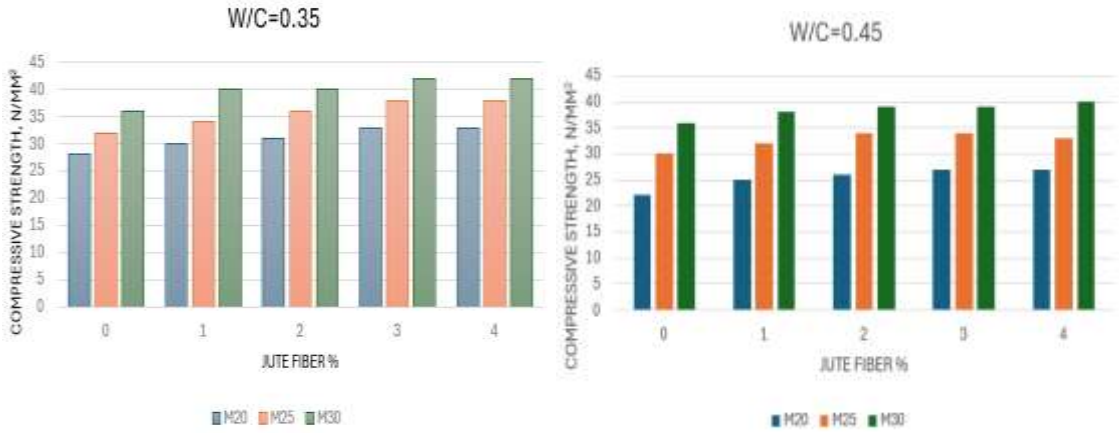
2. Methodology

Jute fibers were collected and cut into 5–10 mm lengths, then pre-soaked in water for 24 hours. Ordinary Portland Cement (OPC-53 grade) was used as the binder. Locally sourced river sand, washed and screened, served as fine aggregate. Coarse aggregates of 10 mm and 20 mm sizes were cleaned before use. Clean potable water, conforming to IS 456:2000 guidelines, was used for mixing. All materials were weighed using an electronic balance and mixed manually on a watertight platform. The pre-soaked jute fibers were first blended with cement, after which the fine and coarse aggregates were gradually incorporated. Water was added in stages to obtain a workable and uniform mix. The fresh concrete was placed into moulds and compacted using a needle vibrator to reduce air voids and prevent honeycombing. After 24 hours, the specimens were demoulded and cured in a water tank at ambient temperature for 7, 14, and 28 days. After 28 days of curing, compressive strength, rebound hammer, and ultrasonic pulse velocity (USPV) tests were conducted.

Fig. 1. (a) JFRC Cube moulds (b) Rebound hammer testing in laboratory

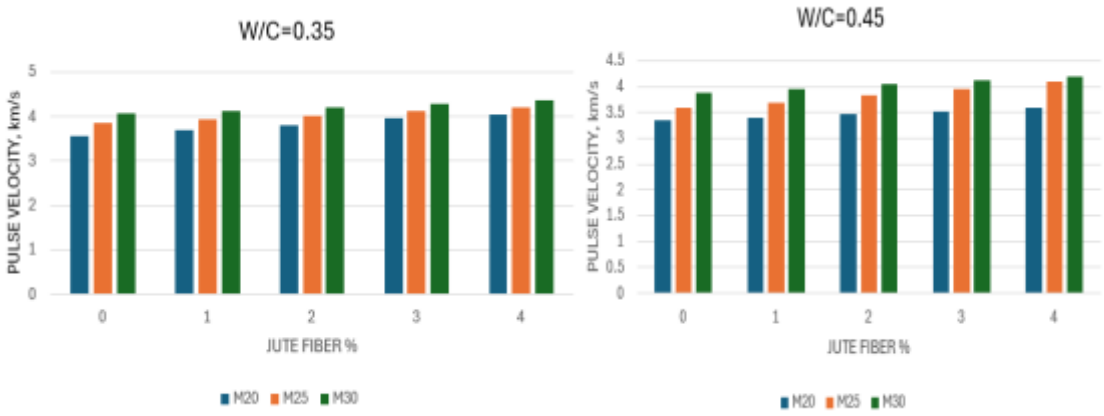
3. Results and discussion

JFRC cube moulds were casted in laboratory and then these were tested for destructive compressive strength after 28 days of curing. Simultaneously some non destructive tests like Schmidt rebound hammer and ultrasonic pulse velocity tests were performed on these samples.



(a) (b)

Fig. 2. Rebound hammer test results for JFRC with (a)-W/C=0.35 and (b) W/C= 0.45



(a) (b)

Fig. 3. Ultrasound pulse velocity test results for JFRC with (a) W/C = 0.35 and (b) W/C= 0.45

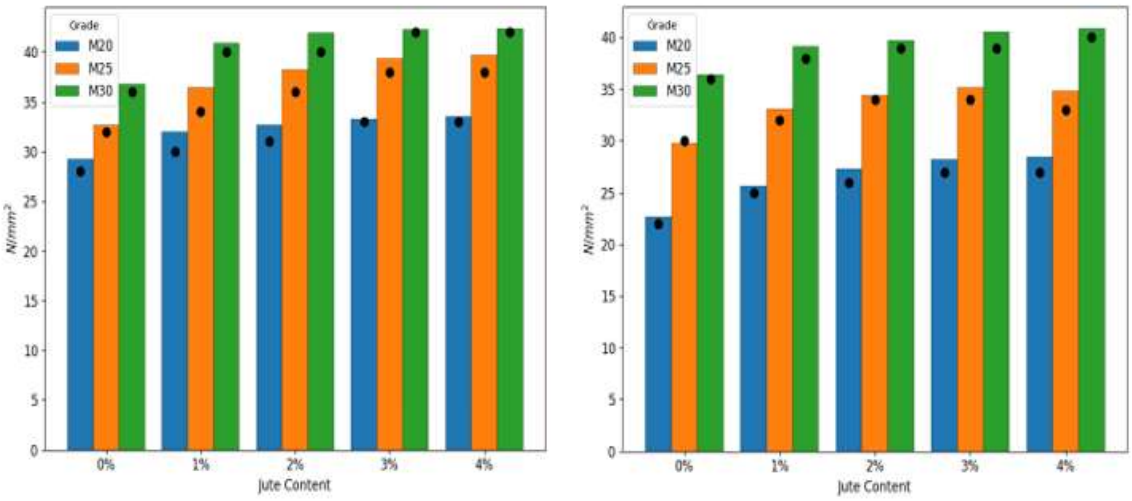
3.1. Rebound hammer test results

Test results of rebound hammer have been displayed using graphs in Fig. 2-(a) and 2(b). Both graphs show a clear indication of increase in rebound hammer value with increase in jute fiber content, thus increasing the compressive strength as well. RBH test actually predicts the behavior of top layers of concrete; hence it is also important to check the inner quality of concrete. For this second type of NDT examination has been conducted, that is, ultrasonic pulse velocity test.

3.2. USPV test results

It is very clear from outcomes of Fig 3(a) and Fig 3(b), that with increase in jute fiber content, pulse velocity in km/s has also increased. This increase is not very prominent for 2%-3% jute fibers. This reveals that jute incorporation has a good impact on concrete inner quality, making it more compact and impermeable. According to IS:13311-1992 clauses for grades of concrete less than M25, average pulse velocity should be between 3.5-4.5 km/s, that means quality of concrete considered here is good. From Fig. 3 it is clear that M20 and M25 grade of concrete specimens fall under good quality of concrete. This also holds good for M30 grade concrete, which has an average output of 3.75-4.5 km/s (as per IS code).

3.3. Comparison of destructive and non-destructive test results

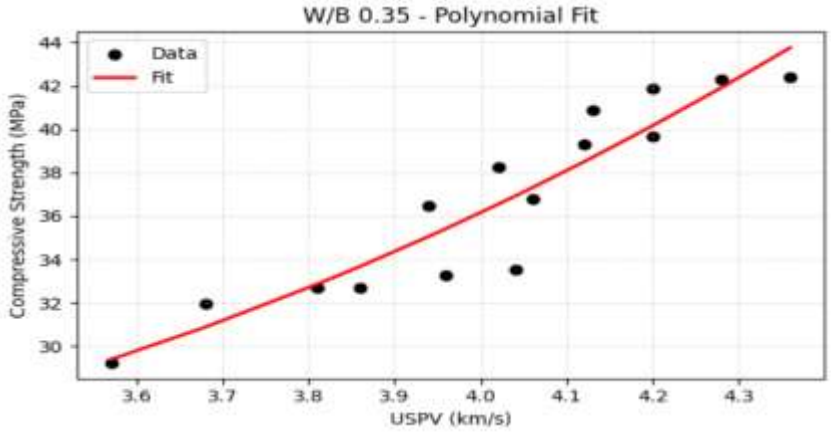


(a) (b)

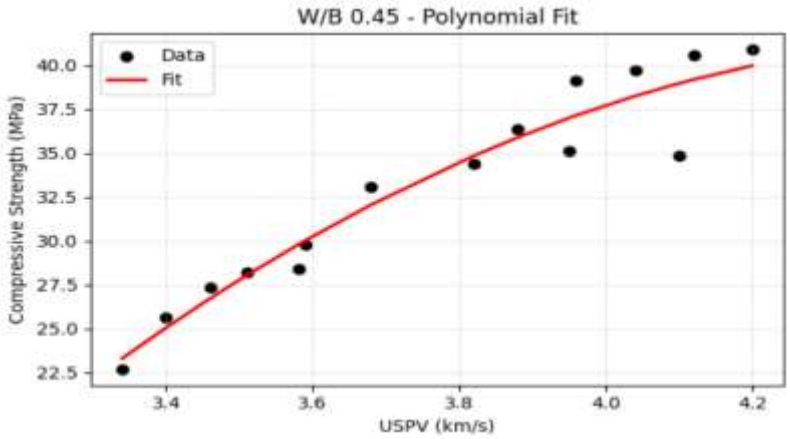
Fig 4. Plots for Rebound Hammer Test and destructive Compressive Strength Test for different concrete grades at different jute contents (for (a) W/C ratio = 0.35 and (b) W/C ratio = 0.45). The bars represent the values of destructive Compressive Strength Test while the black dots represent the values of Rebound Hammer Test.

In the above graphs, results of destructive and non-destructive tests have been compared and displayed. For both the W/B ratios it is very clear that RB hammer prediction for compressive strength is very close to the actual compressive strength data (that is the outcome of destructive compressive strength test). In almost all the cases taken up here, RB hammer compressive strength is slightly less than the actual compressive strength values. This finding is in agreement with Hossain et al's [10] results that NDT strength estimates were on average slightly lower (~5.5%) than their destructive counterparts. Hence it can be concluded that in absence of actual test data, Rebound hammer testing can be done to know the compressive strength of jute fiber reinforced concrete. This agrees with Yesmin & Islam's [15] conclusion that "the rebound number method was more efficient in predicting the strength" of jute-fiber concrete.

Again, to corelate compressive strength results with that of ultrasonic pulse velocity outcomes, regression analysis of outcomes of USPV test has been done using polynomial model. From the results of Fig. 5(a) and (b), it is clear that, this model has best fit with coefficient of determination R^2 = 0.8675 and R^2 = 0.9276; for W/B = 0.35 and 0.45 respectively. This is in line with previous literature [11, 12] that report strong correlation between USPV and Compressive strength values. This gives a clear remark that in absence of actual or destructive test results of JFRC specimens, compressive strength can be predicted with sufficient accuracy using only the test results obtained from USPV nondestructive test results.



(a)



(b)

Fig. 5. (a) Regression analysis results of JFRC for W/B =0.35 (b)-Regression analysis results of JFRC for W/B = 0.45

However, as a continuity of research work, noises present in model can be reduced further considering other influencing parameters for USPV results, such that future prediction of actual compressive strength will be more accurate. Particularly, SonReb method combined with different machine learning algorithms as well as including various other parameters (such as concrete grade, curing period, WB ratio etc) can be explored as future work to improve the predictive accuracy.

4. Conclusions

Following final conclusions have been made after analysing the outcomes of all the research work done in this present case:

1. Inclusion of Jute fibers has a good impact on internal quality of concrete.
2. Compressive strength of concrete increases with increase in jute fiber content. This observation has been found more predominating for 2%-3% of jute fiber content.
3. Jute fiber content also improves the inner quality of concrete thereby making it more compact.
4. Nondestructive tests (RB hammer) predict the correct behavior of mechanical properties of JFRC, hence it can be used in place of lack of destruction or direct test results. But this should be always supplemented with another set of NDT results.
5. Also, USPV outcomes can be utilized to predict the correct compressive strength of JFRC, with very marginal errors.
6. For more accurate correlation between NDT results and actual laboratory test results, other influencing factors like age of concrete, curing condition, moisture content etc. must be considered while designing regressing model.

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