

# Flexural Investigation of Aluminium Timber Composite Beams Using Three Point Bending Test

Pratiksha Sonar<sup>1</sup>, Pankaj B. Autade<sup>2</sup>

<sup>1,2</sup>*Dr Vittalrao vikhe patil College of engineering ahilya nagar*

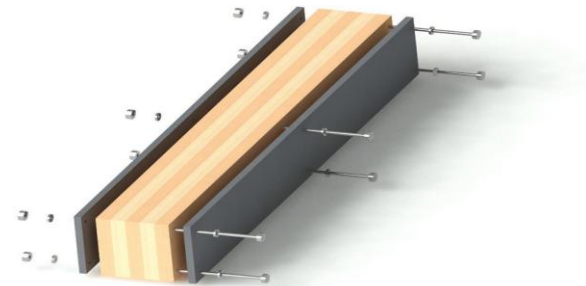
**Abstract**—The development of lightweight, high-performance structural systems has increased interest in hybrid timber–aluminium components, particularly for applications requiring improved stiffness, strength, and sustainability. This study investigates the flexural behaviour of aluminium–timber composite beams through a combined numerical and experimental approach. A series of three-dimensional models were developed, and finite element analysis (FEA) was conducted to predict stress distribution, load-deflection characteristics, and expected failure modes under bending. To validate the numerical findings, composite beam specimens were fabricated and tested under a three-point bending configuration using a Universal Testing Machine (UTM). The experimental results will be evaluated in terms of ultimate load capacity, stiffness enhancement, mid-span deflection, and interface performance between aluminium and timber. Comparisons between FEA predictions and laboratory observations aim to assess the accuracy of the modelling assumptions and quantify the degree of composite action achieved. The outcomes of this study are expected to contribute to a better understanding of hybrid beam mechanics and to provide design insights for the efficient use of aluminium–timber composites in modern construction.

## I. INTRODUCTION

Timber has long been valued as a sustainable and versatile construction material, yet its structural performance is often limited by low tensile strength, susceptibility to cracking, and variability in mechanical properties. To overcome these inherent limitations, modern construction increasingly relies on hybrid systems that combine timber with high-performance materials such as steel, concrete, or aluminium. Among these, aluminium–timber composite (ATC) systems have recently gained attention due to their potential to offer high stiffness-

to-weight ratios, improved bending resistance, excellent corrosion performance, and enhanced durability compared to timber alone. Aluminium’s ductility and consistent mechanical behaviour complement the renewable, lightweight, and energy-efficient characteristics of engineered timber products, creating a promising class of hybrid structural components suitable for floors, beams, façades, and modular systems.

Despite this potential, aluminium–timber composites remain significantly less explored than traditional wood–concrete or wood–steel systems. Major challenges arise from the mechanical incompatibility between the two materials, particularly the difference in modulus of elasticity, their anisotropic behaviour, and the complexity of slip development at the interface. Existing research shows that composite action in ATC beams is highly dependent on the type and stiffness of the connection system—whether screws, bolts, adhesives, or hybrid bonding methods—yet design guidelines remain limited and fragmented. Furthermore, earlier studies have primarily focused on plates, thin laminates, or connection-level behaviour rather than full-scale bending response of beams. As a result, key engineering questions remain unresolved, including how aluminium reinforcement alters flexural stiffness, how interface slip affects load transfer, and what failure modes dominate under practical bending conditions.



Recent studies investigating partial shear connections, adhesive bonding strategies, and laminate configurations provide valuable insights, but significant gaps persist regarding three-point bending performance, comparative behaviour of different composite arrangements, and practical design considerations for structural applications. There is a clear need for controlled experimental testing to quantify flexural strength, stiffness enhancement, slip behaviour, and failure patterns of ATC beams. Such data are essential not only for validating analytical and numerical models but also for developing reliable and codified design recommendations for industry.

In response to these gaps, the present study investigates the flexural behaviour of aluminium–timber composite beams using a three-point bending test setup. The research aims to evaluate the degree of composite action, identify critical failure modes, and determine the extent to which aluminium reinforcement enhances bending performance compared to timber-only members. Through systematic experimental testing and detailed analysis, this work contributes to a deeper understanding of aluminium–timber interaction and establishes a foundation for the future development of efficient, lightweight, and sustainable composite structural systems.

## II. LITERATURE REVIEW

### 1. Chybiński & Polus et al. (2023) — Aluminium–Timber Beams with Partial Shear Connections

This study investigates aluminium–timber composite beams using screws at different spacings to understand partial shear connection behaviour. Four-point bending tests reveal how connector density influences stiffness, slip, and ultimate capacity. The researchers provide detailed load–deflection and slip curves, identifying common failures such as timber crushing and connector pull-out. Numerical and simplified analytical models complement the experiments and show good agreement. They conclude that even moderate screw spacing significantly improves bending capacity, though full composite action requires tighter spacing or continuous bonding.

### 2. Zheng et al. (2024) — Interface Mechanics Between Aluminium and Timber

Zheng and colleagues examine how different connection types—bolts, adhesives, and hybrid joints—affect shear strength at the aluminium–timber interface. Their extensive test program shows that mixed adhesive–mechanical connections provide the best balance of stiffness and ductility. Load–slip curves and failure modes (adhesive failure, timber crushing, bolt pull-out) are documented clearly. They propose simple mechanical models that relate geometry and connector type to interface performance. The findings allow engineers to estimate connector stiffness and shear capacity for composite beam design.

### 3. Graf et al. (2024, JMEP) — Three-Point Bending of Adhesively Bonded Aluminium–Wood Plates

This paper presents experiments and FE simulations on aluminium–wood hybrid plates bonded with adhesives and tested under three-point bending. Experiments show improvements in stiffness and load capacity compared to wood-only specimens, and they document adhesive cracking, delamination, and aluminium yielding. The authors build detailed LS-DYNA models incorporating cohesive elements and orthotropic timber properties. Numerical results closely match the experimental stiffness and failure sequence when well-calibrated. Sensitivity studies highlight the importance of adhesive thickness and surface preparation. The study provides a strong experimental–numerical framework useful for modelling hybrid bending behaviour.

### 4. Graf et al. (2025, Scientific Reports) — Bending Behaviour of Aluminium–Wood Hybrid Laminates

This follow-up study compares bending performance of pure wood, pure aluminium, and aluminium–wood hybrid laminates. The hybrid laminates show significantly greater stiffness and load capacity while displaying mixed failure modes like delamination, aluminium yielding, and timber fracture. The authors provide useful microscopy images showing crack initiation and propagation in different laminates. They evaluate specific strength and stiffness, highlighting advantages for lightweight construction. While only quasi-static loading is considered, the work gives robust performance comparisons for different layouts.

The results help identify optimal laminate arrangements for structural hybrid applications.

5. Kut et al. (2023) — Springback and Three-Point Bending of AW-2024 Aluminium

Kut and co-authors study bending loads and springback in AW-2024 aluminium sheets using experiments and numerical modelling. They derive an empirical relation between bending angle and deflection, accounting for sheet thickness and tool geometry. Their results map elastic–plastic transition and quantify residual angles after unloading. Numerical simulations replicate key trends and help identify parameters influencing springback. The study is relevant as it characterizes baseline aluminium bending behaviour and forming accuracy. This information helps predict local yielding and shape changes in aluminium components of hybrid beams.

6. Tétrault et al. (2023) — Hybrid Densified-Wood-Filled Aluminium Tube Dowels

This work introduces densified wood-filled aluminium tube dowels for timber connections and evaluates them in bending and joint tests. The hybrid dowels show stiffness and strength comparable to steel dowels, with improved ductility due to the wood core. Failure modes include wood core crushing and aluminium tube deformation, both more controlled than brittle failures. Load–slip curves demonstrate favourable embedment and ductility characteristics. The paper also explores dowel geometry effects and initial numerical analyses. The results inform connector design and ductile behaviour considerations for aluminium–timber composite structures.

7. Zhang et al. (2024) — Three-Point Bending of Brazed Aluminium Sandwich Panels

Zhang and colleagues evaluate bending behaviour of brazed aluminium sandwich panels by varying core geometry and thickness. Their tests identify common failures such as face wrinkling, core shear, and debonding, which resemble interface failures in timber–aluminium hybrids. They provide detailed load–deflection and energy absorption curves, supported by failure photographs. Analytical predictions and selected numerical simulations validate stiffness estimates. Although focused on metal–metal bonding, the methodological approach is valuable for hybrid testing. The study offers useful

guidance for evaluating interface quality and failure progression in composite beams.

8. Abramowicz et al. (2024) — FEM vs. RFEM for Dynamic Behaviour of Composite Beams

This study compares deformable finite-element models with rigid finite-element approximations for predicting dynamic response and collapse of composite beams. Results show that RFEM models capture global collapse trends but miss local deformation, slip, and progressive failure details. FEM models more accurately represent interface behaviour and material failure under complex bending. The authors provide guidelines on mesh refinement, element types, and model calibration. They highlight when simplified models are acceptable and when high-fidelity FE is necessary.

9. Rusin et al. (2024) — Stiffness and Equivalent Inertia of Aluminium Composite Mullions

Rusin and co-authors test composite aluminium façade mullions to determine equivalent stiffness and moment of inertia under bending. Their experiments show that inserts and interface compliance significantly influence bending deformation. Numerical models reliably predict stiffness when detailed cross-section features are included. The study proposes correction factors for simplified beam calculations. Although based on façade components, the methodology applies to aluminium–timber beams where composite action must be approximated. This approach helps reconcile experimental deflection data with analytical predictions.

10. Hsu et al. — Timber–Steel Composite Beams with Different Steel Core Shapes

This study evaluates timber–steel composite beams by modifying the steel core geometry to improve load capacity and bending performance. Using a traditional flitch-beam setup as a baseline, the authors test alternative optimized steel shapes. Numerical results compare bending stress and mid-span deflection across configurations. Findings show that optimized steel cores outperform the standard NAHB pattern beams. The work highlights benefits such as reduced buckling risk and improved stiffness in hybrid beams. The study provides insights into core-shape optimisation applicable to aluminium–timber hybrid design.

Novelty of work: This study introduces a new hybrid structural concept by investigating the flexural behaviour of aluminium–timber composite beams using a controlled three-point bending test, a combination that remains largely unexplored compared to traditional steel–timber or timber–concrete composites. Unlike existing studies that focus on adhesive bonding or mechanical fasteners alone, this work examines multiple interface strategies and evaluates how aluminium reinforcement alters stiffness, load-carrying capacity, and failure modes of timber members. The project also provides first-hand experimental data for aluminium–timber combinations, for which standardised design guidelines and analytical models are currently lacking. Additionally, the study aims to establish effective composite action parameters, evaluate optimised aluminium placement, and identify unique hybrid failure characteristics, thereby offering insights that can support future design frameworks for lightweight, sustainable structural applications.

### III. PROBLEM STATEMENT

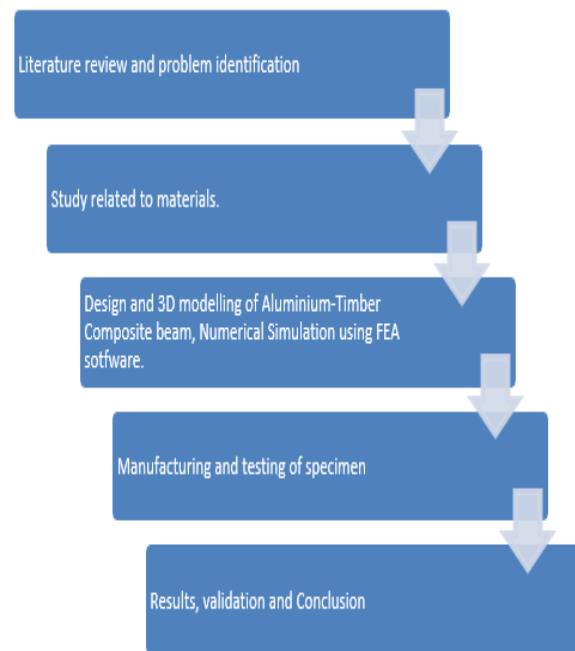
- Although timber is widely valued as a sustainable structural material, its limited bending strength, susceptibility to cracking, and relatively low stiffness restrict its use in modern load-bearing applications.
- Aluminium, on the other hand, offers high strength-to-weight ratio and excellent durability but lacks the structural efficiency of composite behaviour when used alone.
- Despite the potential advantages of combining these two materials, the flexural performance of aluminium–timber composite beams remains poorly understood, with minimal experimental data, unclear failure mechanisms, and no established design guidelines or validated models.
- In particular, the role of aluminium reinforcement, the effectiveness of different interface strategies, and the degree of composite action achievable under bending loads are not well documented.
- Therefore, a systematic experimental study using three-point bending tests is required to evaluate the stiffness, strength, and failure behaviour of aluminium–timber composite beams and to

determine their feasibility for lightweight, efficient, and sustainable structural applications.

### IV. OBJECTIVES

- To develop and validate a methodology for estimating the load-bearing capacity of timber–aluminium hybrid beams.
- To create a 3D model of the timber beam and analyze its structural behaviour.
- To perform finite element analysis (FEA) of timber–aluminium hybrid beams using simulation software.
- To conduct three-point bending tests on physical beam samples using a Universal Testing Machine (UTM).

### V. RESEARCH METHODOLOGY



### VI. FINITE ELEMENT ANALYSIS

The finite element analysis (FEA) is a problem-solving approach for the practical (engineering) problems. The problems are first converted to matrix and partial differential equation forms. Eventually the partial differential and integral equations are being solved to reach the solution of the problem. The volume of the equations to be solved is usually so large that arriving solution without using computer is

practically impossible. And, that's why the need of different FEA packages is felt. There are many FEA packages available for different applications. Some popular FEA packages are Pro Mechanical, ANSYS, NASTRAN, and Gambit etc.

In mathematics, the finite element analysis (FEA) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into simpler parts, called finite elements, and variational methods from the calculus of variations to solve the problem by minimizing an associated error function.

Finite element analysis (FEA) is a useful and powerful technique for determining stresses and strains in structures or components too complex to analyse by strictly analytical methods. With this technique, the structure or component is broken down into many small pieces (finite number of elements) of various types, sizes and shapes. The elements are assumed to have a simplified pattern of deformation (linear or quadratic etc.) and are connected at "nodes" normally located at corners or edges of the elements. The elements are then assembled mathematically using basic rules of structural mechanics, i.e. equilibrium of forces and continuity of displacements, resulting in a large system of simultaneous equations. By solving these large simultaneous equations system with the help of a computer, the deformed shape of the structure or component under load may be obtained. Based on that, stresses and strains may be calculated. The finite element analysis (FEA) is probably the most versatile way of calculating stress intensity factors. This method primarily involves the evaluation of displacements at nodal points of the body which has been idealized into a system of elements connected at the nodal points.

#### A General Procedure for FEA

To conduct an FEA, the following procedure is required in general:

1. Divide the CAD/geometric model into pieces to create a "mesh" (a collection of elements with nodes)
2. Describe the behavior of the physical quantities on each element.
3. Connect (assemble) the elements at the nodes to form an approximate system of equations for the entire model.

4. Apply loads and boundary conditions (e.g., to prevent the model from moving).
5. Solve the system of equations involving unknown quantities at the nodes (e.g., the displacements).
6. Calculate the desired quantities (e.g., strains and stresses) at elements or nodes.

In commercial FEA software, this procedure is typically rearranged into the following phases:

- Pre-processing (build FEM models, define element properties, and apply loads and constraints)
- FEA solver (assemble and solve the FEM system of equations, calculate element results)
- Post processing (sort and display the results)

#### Static Structural Analysis of Timber Block Geometry

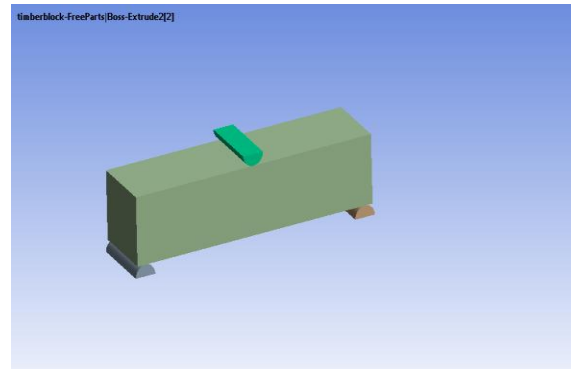


Fig. Geometry of Timber block.

#### Meshing

Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh influences the accuracy, convergence and speed of the simulation. Furthermore, since meshing typically consumes a significant portion of the time it takes to get simulation results, the better and more automated the meshing tools, the faster and more accurate the solution.

ANSYS provides general purpose, high-performance, automated, intelligent meshing software which produces the most appropriate mesh for accurate, efficient multiphysics solutions — from easy, automatic meshing to highly crafted mesh. Methods available cover the meshing spectrum of high-order to

linear elements and fast tetrahedral and polyhedral to high-quality hexahedral and Mosaic.

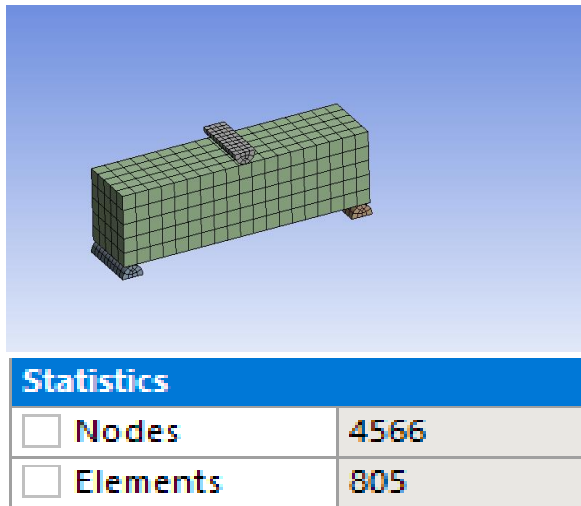


Fig. Meshing details of timber block.

Force reaction

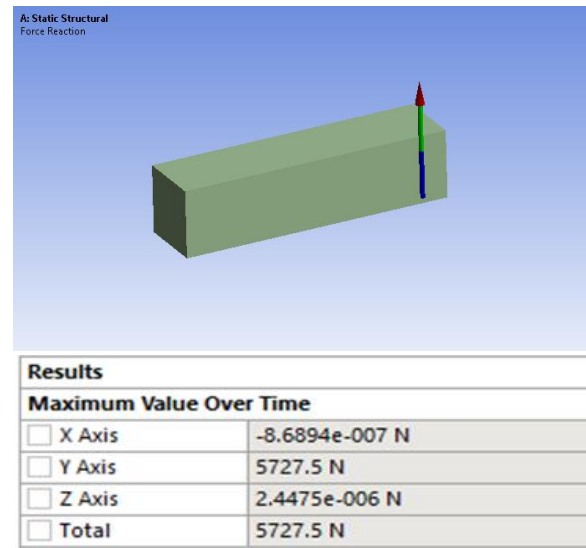


Fig. Force reaction of timber block.

Boundary Conditions

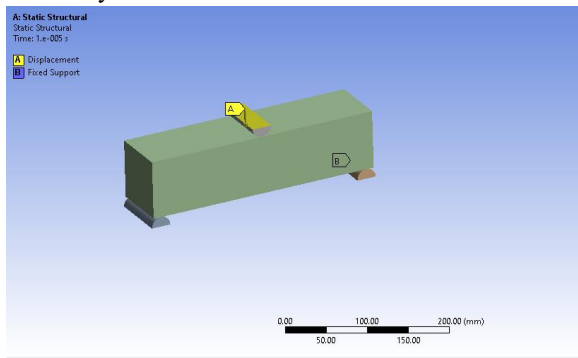


Fig. Boundary conditions for static structural analysis of Timber block

GEOMETRY OF TIMBER AND ALUMINIUM

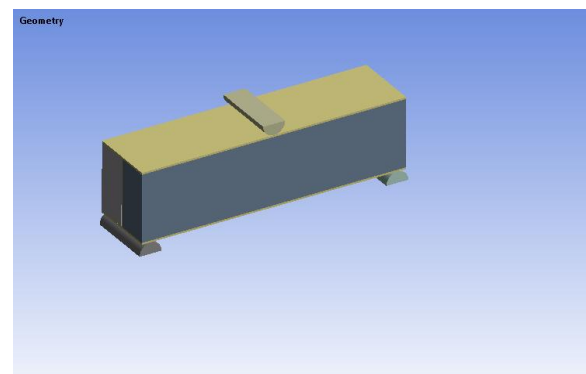


Fig. Geometry model of I channel and timber in ANSYS

Results

Equivalent Stress

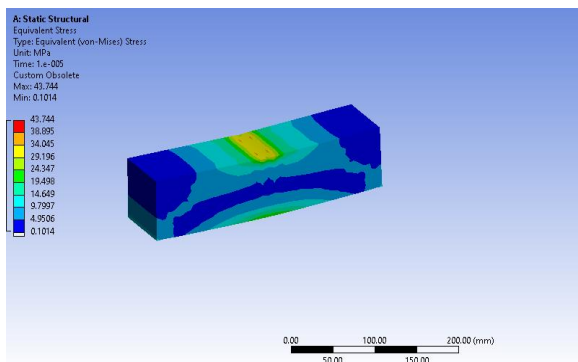


Fig. Equivalent Stress of timber block.

MESHING

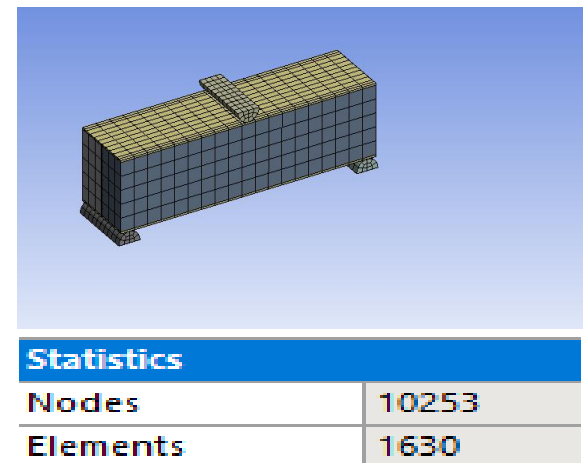


Fig. Details of meshing of I channel and timber

**BOUNDARY CONDITIONS**

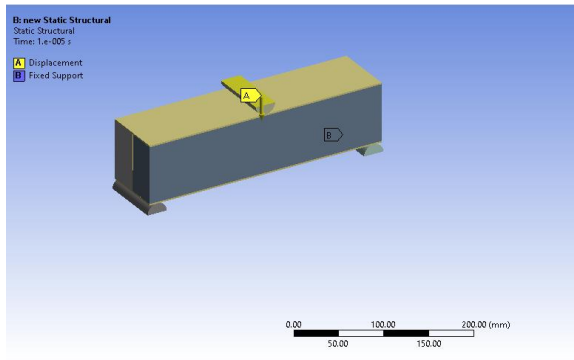


Fig. Boundary conditions for I channel and timber

I channel and timber edges are fixed at both ends and displacement of 4 mm is applied at the middle surface.

**Results**

**EQUIVALENT STRESS**

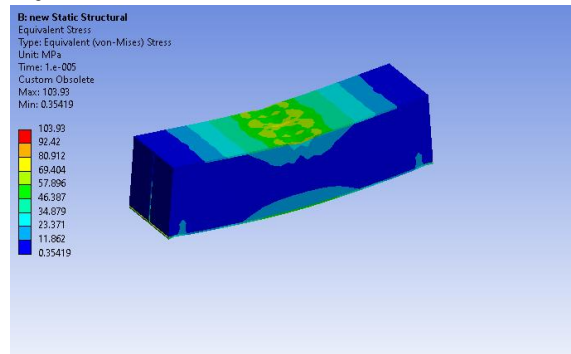
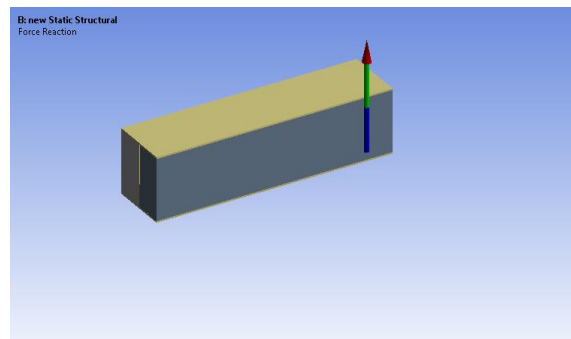


Fig. Equivalent stress of I channel and timber.

**REACTION FORCES**



Results	
Maximum Value Over Time	
X Axis	1.7231e-009 N
Y Axis	7145.9 N
Z Axis	1.6474e-009 N
Total	7145.9 N

Fig. Reaction forces of I channel and timber.

**FEA RESULTS**

5727.5 N	7145.9 N
----------	----------

**VII. MANUFACTURING OF THE COMPONENT**

**EXPERIMENTAL TESTING**

A Universal Testing Machine (UTM) is a type of mechanical testing equipment that is utilized for determining the mechanical properties of various materials, such as tensile strength, compressive strength, bending strength, and shear strength. The UTM works by applying a controlled tensile or compressive load to the specimen being tested and measuring its response.

UTM machines have different roles stripped of capabilities or marketed for specific industries & sectors which play unique roles in the development of infrastructure, roads, and highways. UTM is one of the best multi-purpose equipment for R&D labs or the QC department.

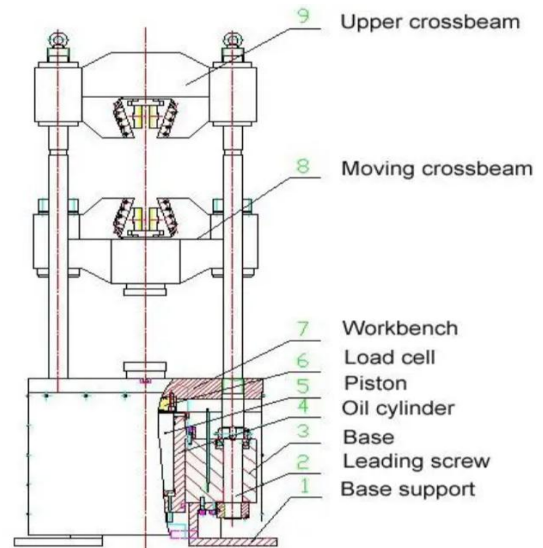


Fig. Schematic Diagram of a UTM.

**Experimental Procedure:**

1. Measure the width and thickness of the specimen.
2. Mark on the locations where the load will be applied under three-point bending. Note the length between supports.
3. Place the sample carefully on to the stage of 3-point bending fixture of a universal testing machine
4. Make sure that the loading point is placed on to the marked location.
5. Carry out the bend test.



Fig. Specimen under flexural test using UTM.

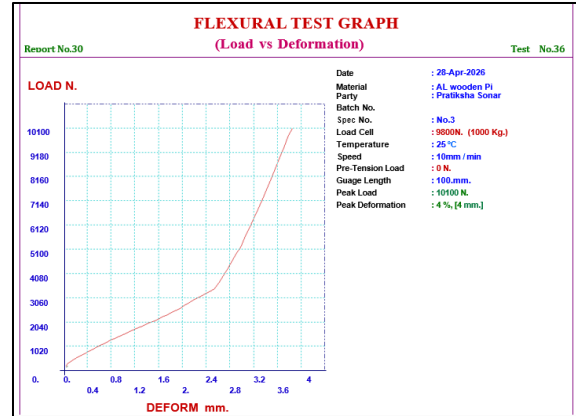


Fig. 5.3 relationship between applied load and displacement of the Aluminium I-channel and timber composite 4mm

ALUMINIUM I CHANNEL AND TIMBER SPECIMEN (FEA)	ALUMINIUM I CHANNEL AND TIMBER SPECIMEN (UTM)
7145.9 N	6980 N

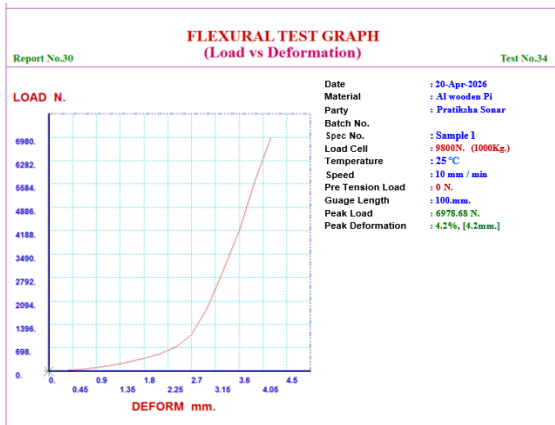


Fig. Graph shows load vs displacement during flexural test

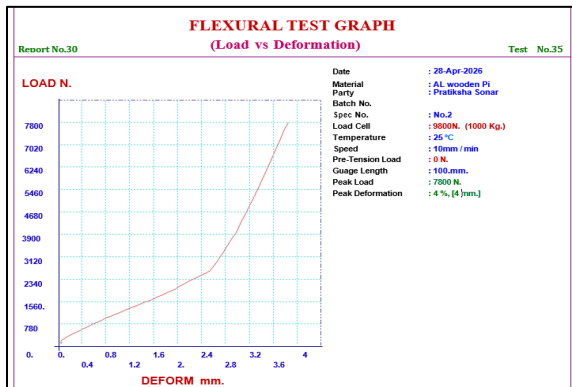


Fig. relationship between applied load and displacement of the Aluminium I-channel and timber composite 3mm

## VIII. CONCLUSION

The present study focused on evaluating the flexural behaviour and load-carrying capacity of timber beams reinforced with Aluminium I-channels through both Finite Element Analysis (FEA) and experimental testing using a Universal Testing Machine (UTM). The objective was to investigate the effectiveness of Aluminium reinforcement in enhancing the structural performance of timber beams subjected to three-point bending loads.

The experimental and numerical results demonstrated that the incorporation of Aluminium I-channels significantly improved the strength and stiffness of the timber beam. The timber specimen alone exhibited a force reaction of 5727.5 N, whereas the Aluminium-Timber composite beam achieved a force reaction of 7145.9 N in the finite element analysis. This represents a substantial increase in load-carrying capacity due to the composite action between timber and Aluminium. The Aluminium section effectively resisted tensile stresses developed during bending and reduced the overall deformation of the beam.

The experimental three-point bending tests further confirmed the effectiveness of the proposed hybrid

beam system. The specimen reinforced with an Aluminium I-channel sustained a maximum load of 6980 N, while the corresponding FEA model predicted 7145.9 N. The difference between the numerical and experimental results was only 2.38%, indicating excellent agreement and validating the accuracy of the finite element model. Such a small variation confirms that the developed numerical model can reliably predict the behaviour of Aluminium-Timber composite beams under flexural loading conditions.

Further investigations were conducted by increasing the thickness of the Aluminium I-channel. The 3 mm Aluminium I-channel reinforced timber beam exhibited a maximum load capacity of 7800 N in the experimental test and 7986 N in the numerical analysis. Similarly, the 4 mm Aluminium I-channel reinforced timber beam achieved the highest load-carrying capacity of 10100 N experimentally and 10340 N through FEA. These results clearly indicate that increasing the Aluminium thickness leads to a significant improvement in flexural strength, stiffness, and resistance to deformation.

A comparison of all specimens revealed that the 4 mm Aluminium-Timber hybrid beam provided the best structural performance among the tested configurations. Compared with the basic Aluminium-Timber specimen (6980 N), the 4 mm reinforced specimen achieved an increase in load capacity of approximately 44.7%. This improvement can be attributed to the increased moment of inertia and stiffness provided by the thicker Aluminium section, which enhances stress distribution and reduces localized deformation within the timber beam.

The load-displacement behaviour obtained from both experimental and numerical studies showed a nearly linear response during the initial loading stage, followed by gradual non-linearity as the load approached the ultimate capacity. No sudden brittle failure was observed, indicating that the Aluminium reinforcement improved the ductility and overall stability of the composite beam. The hybrid beam exhibited better energy absorption characteristics and maintained its structural integrity even under higher loading conditions.

The close correlation between the FEA and UTM results confirms that finite element modelling is an effective tool for predicting the behaviour of Aluminium-Timber composite beams. The validated numerical model can therefore be used for further

parametric studies, optimization of beam geometry, and investigation of different reinforcement configurations without the need for extensive experimental testing.

In conclusion, the study successfully demonstrated that Aluminium I-channel reinforcement is an efficient and practical method for enhancing the structural performance of timber beams. The hybrid beam system exhibited higher load-carrying capacity, improved flexural strength, increased stiffness, and better deformation control compared to conventional timber beams. Among all specimens, the 4 mm Aluminium I-channel reinforced timber beam showed the most satisfactory performance and can be recommended for structural applications where lightweight construction, durability, and enhanced flexural resistance are required. The findings of this research provide a strong foundation for the future development and application of Aluminium-Timber hybrid structural systems in modern construction engineering.

#### REFERENCES

- [1] Chybiński, M., Polus, Ł., & others. Structural behaviour of aluminium–timber composite beams with partial shear connections. *Applied Sciences*, 2023.
- [2] Zheng, T., et al. Experimental and theoretical study on the interface mechanical performance between aluminium alloy and timber. *Buildings (MDPI)*, 2024.
- [3] Graf, E., Matz, P., Auer, P., et al. Experimental and numerical analysis of the three-point bending behavior of hybrid adhesive-bonded aluminum–wood plates. *Journal of Materials Engineering and Performance / (open access abstract & OA copies available)*, 2024.
- [4] Graf, E., et al. Bending behavior of hybrid laminates made of aluminum and wood. *Scientific Reports / PubMed Central (OA)*, 2025. — Recent three-point bending comparison of wood laminates and aluminum–wood hybrids; useful for failure-mode discussion.
- [5] Kut, S., et al. On the springback and load in three-point air bending of AW-2024 aluminium. *Materials (MDPI)*, 2023
- [6] Tétréault, M.-G., et al. Experimental investigation on the mechanical behaviour of a hybrid densified

wood-filled aluminium tube dowel for timber connections. MDPI.

- [7] Zhang, W., et al. Experimental investigation of the three-point bending compression properties of brazed sandwich panels. *Metals* (MDPI), 2024. — Three-point bending test design and failure-mode analysis for sandwich/hybrid panels — useful methodologically.
- [8] Abramowicz, M., et al. Comparison of the Finite Element Method and rigid-body approximations for beam collapse / bending studies. *PMC*, 2024.
- [9] Rusin, D., et al. Experimental determination of equivalent moment of inertia and stiffness of aluminium composite mullions under bending. *Materials* (MDPI), 2024.
- [10] Tzu-Ling Hsu<sup>1</sup>, Feng-Cheng Chang<sup>2</sup>, Meng-Ting Tsai<sup>3</sup>, Truong-Di-Ha Le<sup>4</sup> “STUDY ON PERFORMANCE OF TIMBER-STEEL COMPOSITE BEAMS WITH DIFFERENT SHAPES OF STEEL COMPONENTS” · August 2016