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# Flexural Performance Investigation of Aluminium-Timber Composite Beam

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**Abstract- This research presents an investigation into the flexural behaviour of aluminium-timber composite beams, employing both numerical modelling and experimental evaluation. Finite Element Analysis (FEA) utilizing ANSYS Workbench was conducted to simulate and analyse the structural response of a monolithic timber beam and a composite configuration where timber was reinforced with an aluminium I-channel. Concurrently, physical specimens were subjected to three-point bending tests via a Universal Testing Machine (UTM) to ascertain their load-carrying capacity. FEA results indicated a substantial enhancement in force reaction capability for the composite beam (7145.9 N) compared to the timber-only specimen (5727.5 N). Experimental testing of the aluminium-timber composite beam yielded a maximum force reaction of 6980 N. The close correlation between FEA predictions and experimental outcomes, manifesting a discrepancy of approximately 2.38%, serves to validate the numerical model. This study substantiates the improved structural performance achieved through the synergistic interaction of aluminium and timber in composite construction.**

**Keywords: Aluminium-Timber Composite Beam, Three-Point Bending Test, Universal Testing Machine (UTM), Finite Element Analysis (FEA), ANSYS, Load-Bearing Capacity.**

## I. INTRODUCTION

The search for structurally efficient systems often dictates merging materials for each to work at its capability, a methodology which lies at the heart of composite building. While wood benefits from being sustainable and possessing an acceptable strength to weight ratio, reinforcement can refine its flexure capabilities. Steel has conventionally filled this role, but aluminium alloys have the attractive properties of a high strength-to-weight ratio and high corrosion resistance, which implies promise for lightweight but strong composite members. Nevertheless, detailed information on aluminium-timber composite beam behaviour, and especially flexural response, is less common than for steel-timber systems, and warrants specific study.

This research fills this void by examining the flexural behavior of an aluminium I-channel reinforced timber beam. Employing a dual approach of Finite Element Analysis (FEA) as numerical simulation and physical three-point bending tests to experimentally validate results, the research seeks to describe the

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structural behavior of these composite members. The primary goals are to measure the performance gain as a result of aluminium reinforcement and to confirm the predictive capability of the FEA model, thus aiding in a better understanding of this hybrid construction method.

## II. LITERATURE RIVIEW

Hsu et al. [1] investigated the performance of timber-steel composite beams, focusing on the Flitch beam concept and the influence of different steel core shapes on structural behaviour, optimizing geometry for load-carrying efficiency primarily through numerical methods. Chybiński and Polus [2, 7, 8] have conducted extensive research on aluminium-timber composite (ATC) beams, particularly those with bolted [2] and screwed [7, 8] connections between Laminated Veneer Lumber (LVL) and aluminium I-beams. Their work involved push-out tests to characterize connection shear properties and bending tests to evaluate beam capacity and failure, alongside the development and validation of 2D and 3D FE models incorporating orthotropic material properties and damage criteria. Salem [3] explored timber-to-timber composites (CLT to Glulam) using self-tapping screws, highlighting the importance of connection parameters. Early work by Saleh and Jasim [4] on ATC beams utilized plywood slabs and aluminium box sections with epoxy and screws, demonstrating basic feasibility and full interaction under three-point bending. Methodologically, Szewczyk and Szumigała [5] offered insights into strengthening steel-concrete beams using FE models and recoverable strain energy for optimization, an approach potentially adaptable to ATC systems. Šubic et al. [6] investigated hybrid wood beams with internal aluminium strips for slender applications, showing significant improvements in bending stiffness and capacity. Shabbar [9] explored natural fiber composites, offering a contrast in material systems but methodological relevance in I-beam testing. Comparative numerical analyses by Szumigała et al. [10, 11, 12] on various composite beam types (including ATC) assuming full shear connection provided insights into relative stiffness and highlighted the need for experimental validation for ATC systems, considering the lower elastic moduli of aluminium and timber compared to steel and concrete. These studies collectively underscore the critical role of connection behaviour, the utility of combined experimental-numerical approaches, and the emerging focus on understanding ATC systems.

### AIM

To analyze the flexural behavior of aluminum-timber composite beams under three-point bending test.

### OBJECTIVES

To Study the Concept and Significance of Composite Beam Systems in Construction.
To analyze the mechanical properties of aluminum and timber.
To fabricate composite beams with suitable bonding techniques and conduct three-point bending tests and record load-deflection behavior.
FEA simulation results with experimental test data and validate the accuracy of the FEA model for predicting composite beam performance.

## III. METHODOLOGY

### Material Selection

**Timber**: Pine Wood was selected as the primary beam material, valued for its renewability and ease
Aluminium: An aluminium alloy 6061-T6, specifically in the form of an I-channel profile, was chosen as the reinforcing material. This selection was based on aluminium's high strength-to-weight ratio and corrosion resistance, offering potential advantages for composite action.

### Specimen Fabrication

**Timber Beam**: A control specimen consisting solely of a timber beam with defined cross-sectional dimensions and length was fabricated. [Dimensions: 300 mm x 35 mm x 75 mm (L x W x H)]

**Aluminium-Timber Composite Beam**: A composite specimen was created using an identical timber beam section as the control. An aluminium I-channel was affixed to this timber beam. Care was taken to ensure consistent geometry between the timber components of both specimen types. [Dimensions: 300 mm x 75 mm x 75 mm (L x W x H)]

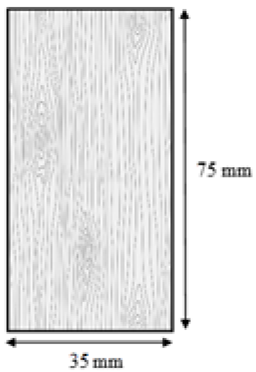



Fig 1: Cross Section of Timber

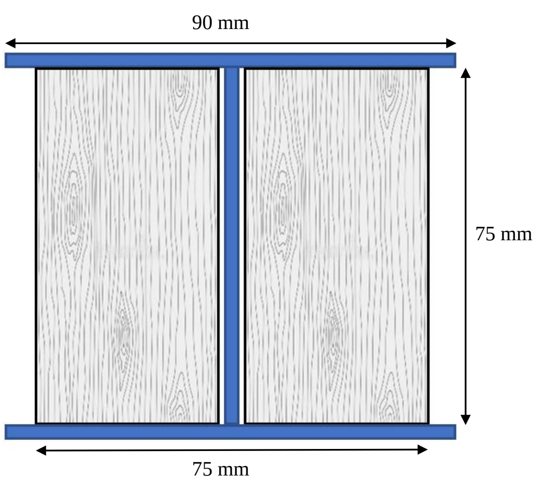



Fig 2: Cross Section of Aluminium I-section and Timber

**Experimental Testing**

Physical tests were conducted using a Praj Metallurgical Lab's Universal Testing Machine (UTM), with a 400 kN capacity.

Setup: Specimens were positioned on a standard three-point bending fixture with a span length of 200 mm between supports. Load was applied via a central loading pin. Testing photographs are provided.

**Loading Protocol**: Load was applied quasi-statically at a constant crosshead displacement rate of 10 mm/min.

**Data Acquisition**: Applied load (N) and corresponding vertical displacement (Deformation, mm) were continuously recorded, generating a load-deformation curve.

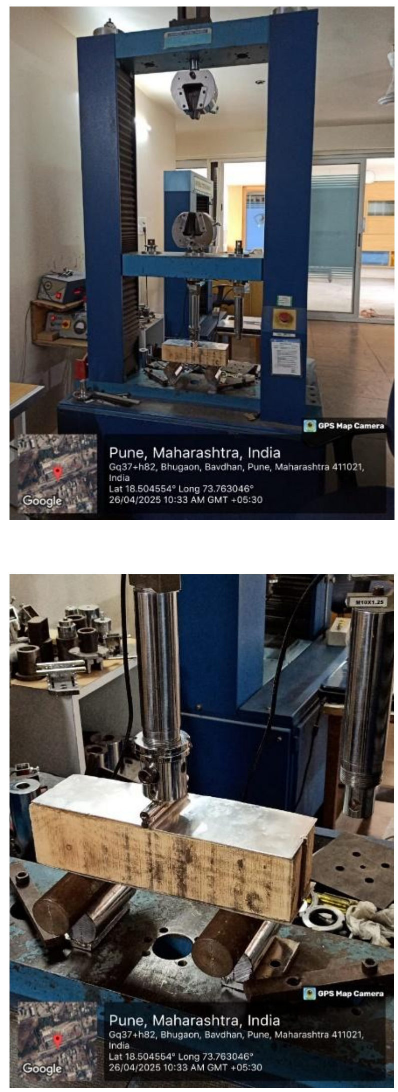



Fig 3: Three Point Bending Test

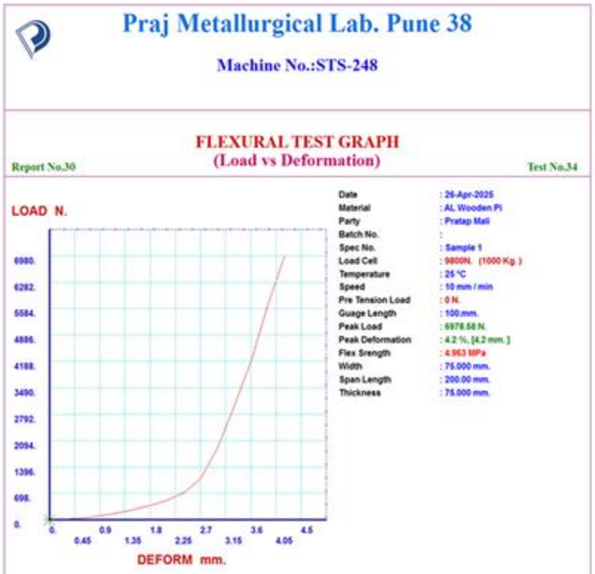



Fig 4: Flexural Test Graph (Load vs Deformation)
The above fig. shows the graph of displacement v/s load for Aluminium I channel and timber. Displacement is taken on X-axis and Load in N is taken on Y-axis. The max force reaction 6980 N is taken by the Aluminium I channel and timber specimen (ATC Beam) under three point bent test.

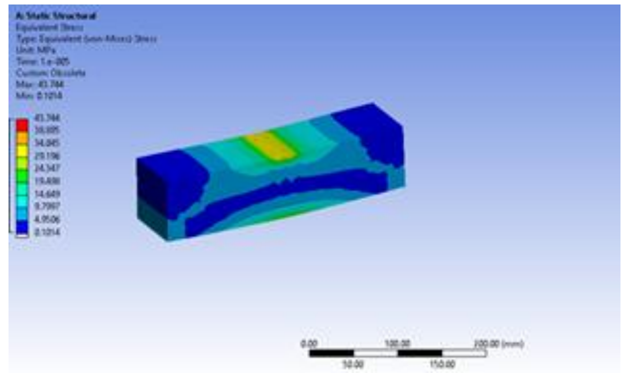
**Finite Element Analysis (FEA)**
Numerical simulations were performed using ANSYS Workbench to predict the structural response.

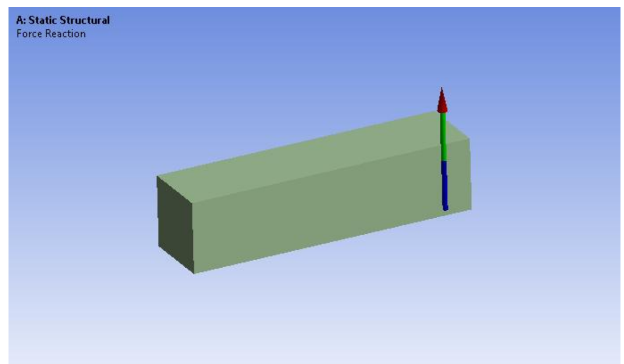
**Geometric Modelling:** 3D solid models of both the plain timber beam and the aluminium-timber composite beam were developed.

**Meshing:** The geometric models were discretized into a finite element mesh. For the timber model, this resulted in 4566 nodes and 805 elements. For the composite model, the mesh comprised 10253 nodes and 1630 elements.

**Boundary Conditions and Loading**: The three-point bending test scenario was replicated. Fixed supports were applied to the bottom edges of the beam models corresponding to a span length of 200 mm. A controlled displacement was applied vertically downwards at the mid-span of the top surface of the beam or aluminium channel.

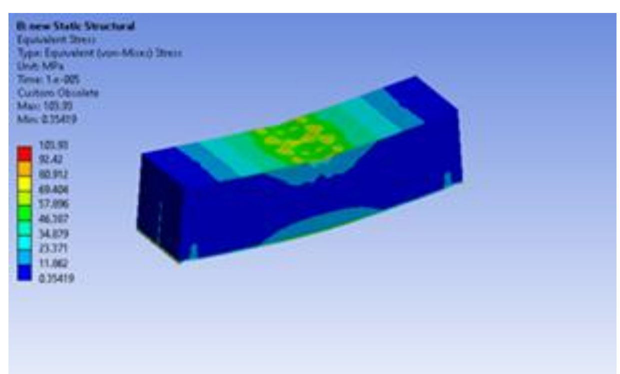
**Analysis Type:** A Static Structural analysis was conducted.

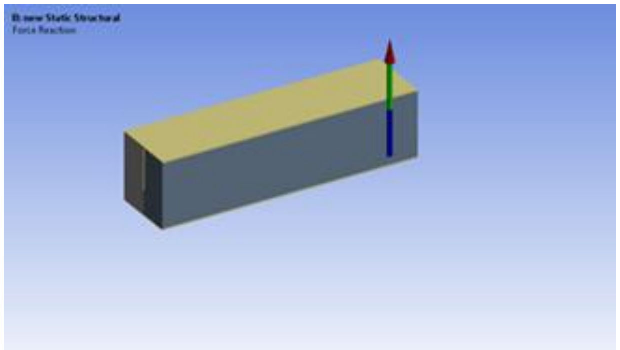





| Results | |
|---|---|
| Maximum Value Over Time | |
| X Axis | -8.6894e-007 N |
| Y Axis | 5727.5 N |
| Z Axis | 2.4475e-006 N |
| Total | 5727.5 N |

Fig 5: Equivalent Stress and Force Reaction (Wooden Specimen)





| 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 6: Equivalent Stress and Force Reaction (Aluminium I channel and Timber)

## IV. RESULTS

**Experimental Results**

**Peak Load:** The maximum load sustained by the aluminium-timber composite specimen was 6980 N.

**Flexural Strength:** Based on this peak load, the specimen dimensions (width = 75 mm, depth = 75 mm, span = 200 mm), the calculated apparent Flexural Strength (Modulus of Rupture, MOR) for the composite section was 4.963 MPa.

The standard formula for flexural strength (σf) in a three-point bending test for a rectangular cross-section is:

$$\sigma_f = \frac{3PL}{2bd^2}$$

**Where:**

P = Peak Load applied at the center (N) = 6980 N
L = Span length between supports (mm) = 200 mm
b = Width of the beam (mm) = 75 mm
d = Depth (or height) of the beam (mm) = 75 mm

$$\sigma_f = \frac{3 \times 6980 \times 200}{2 \times 75 \times 75^2}$$

$$\sigma_f = \frac{4188000}{843750}$$

$$\sigma_f = 4.963 \text{ MPa}$$

**Finite Element Analysis (FEA) Results**

**Timber Beam Simulation**: The FEA simulation of the plain timber beam indicated a maximum Equivalent (von Mises) stress of 43.74 MPa. The simulation predicted a total force reaction at the supports of 5727.5 N.

**Aluminium-Timber Composite Beam Simulation**: For the composite beam, the FEA showed a maximum Equivalent (von Mises) stress of 103.93 MPa, primarily concentrated within the aluminium I-channel. The predicted total force reaction at the supports for this configuration was 7145.9 N.

**FEA Comparison:** The FEA results demonstrated a predicted increase in load-carrying capacity of approximately 24.8% for the composite beam relative to the plain timber beam.

**Comparison and Validation**: FEA vs. Experimental

A direct comparison of the load-carrying capacity for the aluminium-timber composite beam is presented:

FEA Predicted Force Reaction: 7145.9 N

Experimental Peak Load (UTM): 6980 N

The absolute difference (7145.9 N - 6980 N) is 165.9 N. The percentage difference, relative to the experimental value, is

$$\%\ Difference = \frac{165.9}{6980} \times 100\%$$

$$\%\ Difference = \frac{165.9}{6980} \times 100\%$$

$$\%\ Difference = 0.0238 \times 100\% \approx 2.38\%$$

## V. CONCLUSION

This research was able to successfully describe the flexural behavior of aluminium-timber composite beams using both Finite Element Analysis and experimental three-point bending tests. The research was able to validate that strengthening timber beams with an aluminium I-channel greatly increases their load-carrying capacity, with FEA estimating a force reaction of 7145.9 N for the composite beam versus 5727.5 N for plain timber. This is due to the aluminium being able to absorb a large part of the flexural stresses.

Experimental testing achieved a peak load of 6980 N for the composite sample, showing an excellent correlation (about 2.38% deviation) with the FEA solution. This close proximity confirms the FEA model as a credible predictor of the flexural behavior of these aluminium-timber composite beams. The observations highlight the synergistic advantages of this hybrid construction, affirming improved structural performance and reaffirming the viability of aluminium-timber composites for applications demanding optimized strength and stiffness.

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