Structural Analysis and Optimization of Truss using ANSYS

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Abstract: **Trusses are widely used in civil construction due to their efficient load distribution capabilities and ability to span large distances with minimal material usage. However, trusses are prone to various failures, including tensile failure, joint failure, corrosion, and buckling, particularly in slender members under critical loads. Metal Matrix Composites (MMC) offer an improved alternative, providing superior strength, fracture toughness, ductility, thermal resistance, and corrosion resistance, along with an excellent strength-to-weight ratio.**

This research focuses on enhancing roof truss strength by employing high-stiffness MMC materials and optimizing the truss design. Using Finite Element Method (FEM) analysis, the reaction forces on the left support of the MMC truss were found to be 65.5% lower than those of a steel truss, indicating more efficient load distribution. Additionally, deformation in the MMC truss was 81.3% lower, showcasing its superior stiffness and rigidity, resulting in a more stable structure. The axial force in the MMC truss was 66.6% lower than in a steel truss, reflecting its higher durability and reduced failure risk. Furthermore, the combined stress in the MMC truss was 68.18% lower than in steel, highlighting its ability to sustain higher loads without yielding or failure, thus providing greater resilience.

Optimization using Response Surface Optimization involved three variables: truss height, baselength1, and baselength2. For combined stress, truss height had the highest sensitivity, indicating its dominant effect, while baselength2 had the lowest sensitivity. Baselength1 exhibited an intermediate influence at 32.326%. Similarly, for direct stress, truss height showed the highest sensitivity, while baselength2 was the least influential, with baselength1 displaying an intermediate sensitivity of 22.666%. These findings underline the critical role of truss height in determining the structural performance of MMC trusses.

Keywords: ANSYS, Bending Stress, Deformation, FEM, Metal Matrix Composites (MMC) Response Surface Optimization, Truss Structure.

I. INTRODUCTION

Trusses are structural frameworks characterized by a lattice configuration, composed of interconnected small components. The weight of the truss depends on the angle and size of the roof. The dimensions and configuration of the truss are critical, similar to the strength of its individual components. Furthermore, there exist alternative design options. In the industrial sector, trusses represent the optimal selection for roofing applications. This method demonstrates a notable increase in cost-effectiveness compared to R.C.C. construction. Truss structures exhibit a lower weight compared to reinforced cement concrete (RCC) buildings. Trusses serve as a prevalent structural solution for buildings characterized by significant heights and extended roof spans. In comparison to reinforced concrete structures, trusses exhibit enhanced visual elegance and operational efficiency over prolonged durations. The economic viability of an industrial building's structure depends on the design, the type of roof truss and portal frame used, the forces acting on the building, and the choice of steel sections according to the applied forces.

Response Surface Optimization (RSO) is a mathematical and statistical method used to optimize processes or systems by modeling the relationship between input variables (factors) and output variables (responses). It helps identify the optimal combination of inputs to achieve desired outcomes, such as minimizing stress or maximizing performance. RSO involves constructing a response surface, often using regression models, to approximate the behavior of the system based on data collected through Design of Experiments (DOE). This approach allows researchers to explore input-output relationships, visualize trends using contour and response surface plots, and pinpoint optimal conditions.

Response Surface Optimization (RSO) with truss structures using ANSYS involves systematically varying design parameters like truss height and base length, simulating their effects on responses such as stress and deformation, and constructing a predictive response surface. ANSYS employs optimization algorithms to identify the best configurations for improved load-bearing performance, reduced stress, and enhanced durability, streamlining the design process and ensuring optimal structural efficiency.

Objective of Study

- Assess the structural performance of truss models, including stress distribution, deformation, and load-bearing capacity.
- Develop and analyze truss structures using the ANSYS to understand their behavior under various conditions.
- Utilize the Response Surface Optimization (RSO) technique to identify the best design parameters for enhanced performance.

II. LITERATURE REVIEW

Recent research emphasizes the significant potential of Response Surface Optimization to study truss structures to maximize their structural performance.

Xiangmin et al. (2025) conducted a study on roof structures made from timber materials in an Australian city, focusing on the impact of roof-to-wall connections (RWC) on the structural stability of trusses under heavy windstorm conditions. The research examined construction defects, such as missing nails, found in over six roof trusses, which significantly reduced the capacity and stiffness of these connections under wind loads. Damian et al. (2025) investigated solid roof trusses following EN 1993-1-1 guidelines. The study analyzed truss bracing types, including vertical and transverse configurations, and evaluated the effects of geometric imperfections on structural performance. A 1:50 scale model of a truss with imperfect girders was tested, with results closely aligning with analytical predictions. Ngoc et al. (2025) investigated truss bars using both experimental and numerical methods, employing elastic-plastic analysis through Finite Element Analysis (FEA) to assess the strength and stiffness of trusses. The study used a nonlinear problem formulation with an iterative solver and found that deformation in trusses analyzed with nonlinear techniques was greater compared to linear formulations. Alessia et al. (2025) studied high-rise building structures with roof trusses, analyzing their performance using hysteretic dampers. The research explored the feasibility of an optimal design method for evaluating truss strength and found that incorporating dampers reduced the structural cost of the building. Vagelis et al. (2025) conducted experimental research on steel roofs under seismic loading conditions. Their analysis evaluated the inter-story drift and lateral deformation of the building structure, providing insights into the roof's seismic performance. Hoa et al. (2024) performed a 3D nonlinear seismic analysis of steel frame buildings with trusses, focusing on a magnitude 7.9 earthquake in the San Andreas fault zone. The study revealed that redesigning buildings with new trusses could significantly enhance structural stability. Chen et al. (2024) researched steel roofs using experimental and numerical techniques, analyzing the capacity of trusses to distribute loads. The study evaluated the inelastic behavior of cold-formed steel trusses, including their critical buckling capacity and energy absorption under quasi-static loading. Findings highlighted the significant impact of truss geometry and loading conditions on stress and deformation. Ananda et. al. (2024) conducted research on 3 bar truss and 10 bar truss using experimental and numerical techniques. The numerical analysis is conducted using improved convergence and interior penalty function. The descent method is used which has shown improved accuracy and higher convergence speed. Zhang et. al. (2024) researched on steel planar truss structures using numerical techniques. The connections used in the trusses are of column-beam type connections. The truss structure is of semi-rigid type and results have shown that connection type has significant effect on deformation and stresses induced on trusses. Davison and Birkemoe et al. (2022) performed experimental testing on trusses, analyzing residual stress along the longitudinal direction and bending stress along the perpendicular direction. The research evaluated variations in residual and mean longitudinal stresses in different directions. Qing et al. (2021) investigated the design and analysis of trapezoidal trusses using numerical techniques, evaluating stresses, strain, and deformation. The findings showed that trapezoidal trusses have higher strength compared to rectangular trusses. Zihan et al. (2021) studied the design and development of industrial roof trusses made from steel. Analytical evaluation using the limit state method demonstrated greater accuracy compared to the working stress method. The study also found that tubular sections were more economical than other truss designs. Vaibhav et al. (2019) conducted research on constructing cost-effective structures using square and rectangular tubular sections. These tubular sections, used in trusses, help reduce structural weight and material usage, making the design more economical, with cost savings of up to 45%.

III. METHODOLOGY

The methodology process involves modeling of truss in design modeler of ANSYS software. The developed model of truss is shown in Figure 2. The model of truss is developed in sketch tool of ANSYS design modeler. The model is developed using points and sketch tools. The model of truss is discretized using linear elements, shown in Figure 3. The model is meshed with medium element sizing, generating 580 elements and 1039 nodes. Structural loads and boundary conditions are applied, including fixed support at the base (indicated by dark blue arrows) and a downward force of 965N at points E and D. Following the application of boundary conditions, solver settings are configured, and the simulation is executed.

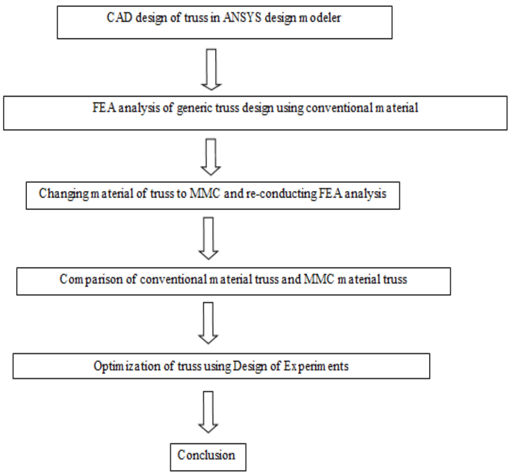

Fig. 1 Workflow for Truss Optimization Using Finite Element Analysis (FEA) and Material Modification

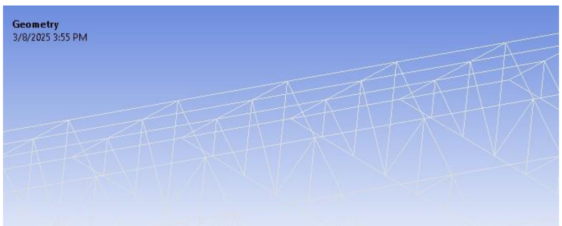

Figure 2: Developed model of truss in ANSYS design modeler

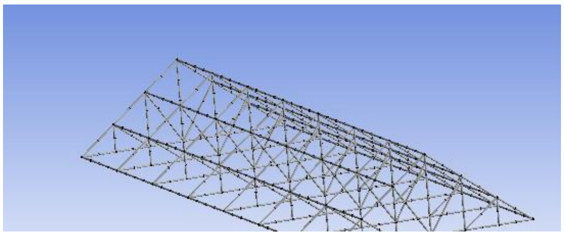

Figure 3: Discretized Model of Truss

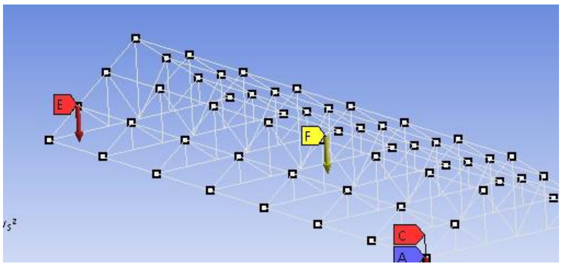

Figure 4: Loads and boundary conditions

IV. RESULTS AND DISCUSSION

This section presents the results obtained from the experimental investigations and their analysis. The findings are systematically organized to provide clarity and insight into the study's objectives.

Table 1. Comparison table for different materials

Material	Ra (N)	Rb (N)	Deformation (mm)	Axial force (N)	Max. Combined Stress (MPa)
Structural steel	50061	49716	0.9102	7346.7	5.8647
MMC	17260	17147	0.1694	2448.7	1.8675

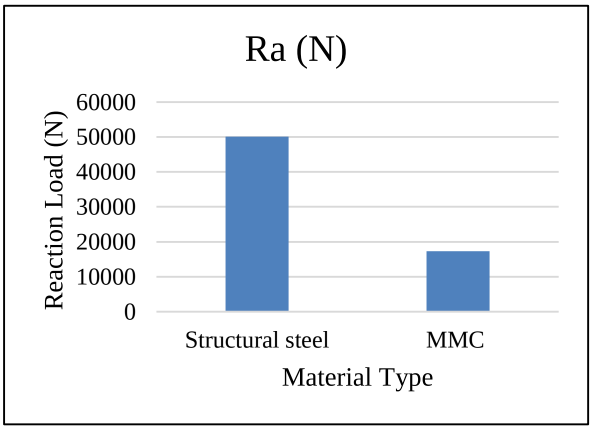

Fig. 5 Reaction load comparison at point A

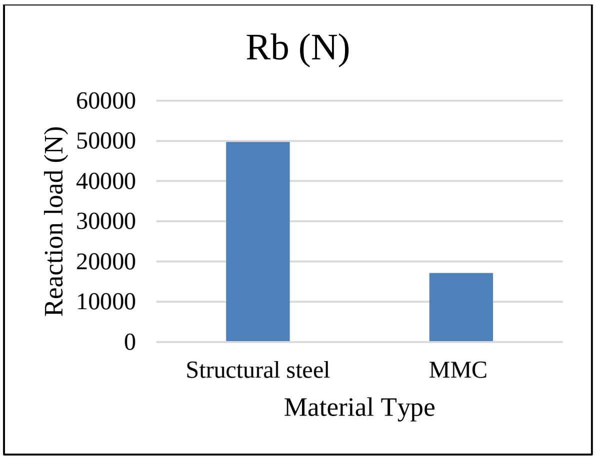

Fig. 6 Reaction load comparison at point B

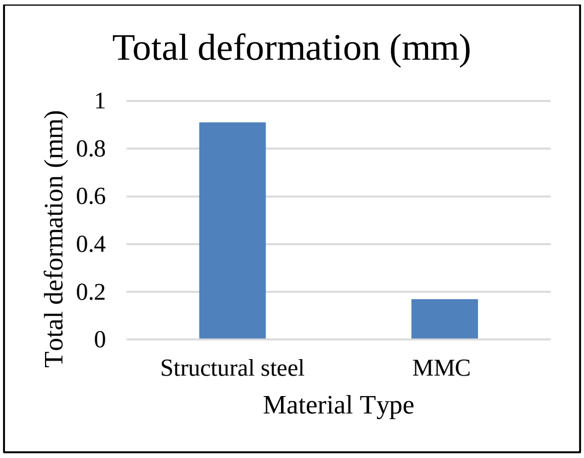

Fig. 7. Total deformation comparison

The reaction loads comparison charts are determined for trusses at left end support. The reaction load of MMC truss is lower than reaction load of structural steel truss.
The reaction loads comparison charts are determined for trusses at right end support. The reaction load of MMC truss is lower than reaction load of structural steel truss.

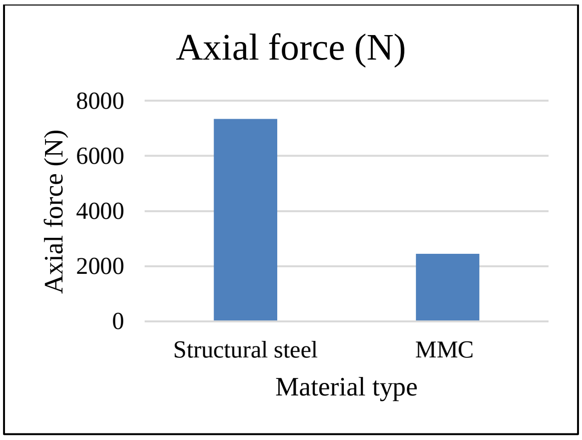

Fig. 8 Axial force comparison

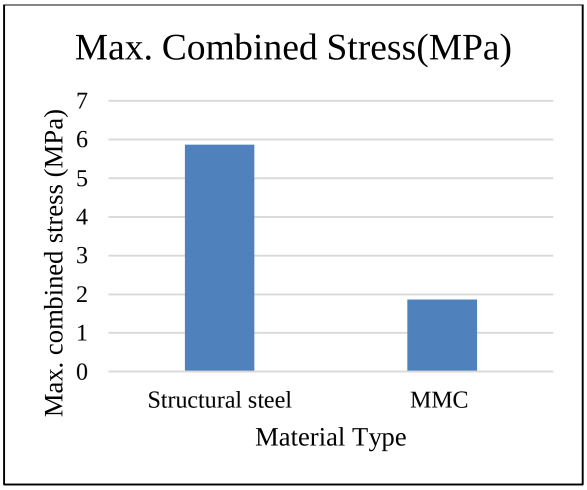

Fig. 9 Max. combined stress comparison

The axial force comparison plot is generated for trusses made of structural steel and MMC material as shown in fig. 5.16 above. The axial force obtained for MMC truss is lower than axial force obtained for structural steel truss.
The maximum combined stress comparison chart is obtained for structural steel truss and MMC truss as shown in fig. 5.17 above. The trusses made of MMC material has lower combined stress as compared to structural steel truss.

V. CONCLUSIONS

Here are the inferred conclusions for above analysis.

- For total deformation, the highest sensitivity percentage is observed for the baselength2 variable, while the lowest sensitivity percentage is associated with truss height. This indicates that baselength2 has a greater impact on total deformation compared to truss height. The sensitivity percentage of baselength1 is 39.97%, which is intermediate between truss height and baselength2.
- For combined stress, the highest sensitivity percentage is associated with truss height, and the lowest is with baselength2. This suggests that truss height has a more significant influence on maximum combined stress compared to baselength2. The sensitivity percentage of baselength1 is 32.326%, placing it between truss height and baselength2.
- For direct stress, the highest sensitivity percentage is observed for truss height, while the lowest is for baselength2. This shows that truss height has a greater effect on maximum direct stress than baselength2. The sensitivity

percentage of baselength1 is 22.666%, making it intermediate between truss height and baselength2.

- For axial force 2, truss height shows the highest sensitivity percentage, and baselength2 has the lowest. This indicates that truss height has a more pronounced effect on axial force 2 compared to baselength2. The sensitivity percentage of baselength1 lies between the two variables.
- For axial force 3, the highest sensitivity percentage is linked to truss height, while the lowest is associated with baselength1. This highlights that truss height has a stronger effect on axial force 3 compared to baselength1. The sensitivity percentage of baselength2 is 29.084%, placing it between the other two variables.
- For maximum bending stress, truss height exhibits the highest sensitivity percentage, whereas baselength2 has the lowest. This indicates that truss height has a more significant impact on bending stress compared to baselength2.

The analysis reveals that truss height has the most significant influence on combined stress, direct stress, axial forces, and bending stress, while baselength2 has a stronger effect on total deformation. Baselength1 consistently exhibits intermediate sensitivity across all parameters.

Table 2: A DOE chart emerged from the optimization process that employed central composite design method

Design Point	Truss height (m)	Base length 1 (m)	Base length 2 (m)	Total Deformation Maximum (mm)	Maximum Combined Stress (MPa)	Direct Stress Maximum (MPa)	Axial Force 2 Maximum (N)	Axial Force 3 Maximum (N)	Maximum Bending Stress (MPa)
1	2.70	1.20	1.20	0.91	5.86	2.36	-7113.00	5795.67	5.86
2	2.43	1.20	1.20	0.91	5.96	2.54	-7299.35	6146.12	5.96
3	2.97	1.20	1.20	0.91	5.78	2.21	-6994.49	5508.36	5.78
4	2.70	1.08	1.20	0.89	5.82	2.30	-6976.18	5688.51	5.82
5	2.70	1.32	1.20	0.93	5.91	2.42	-7247.83	5901.26	5.91
6	2.70	1.20	1.08	0.89	5.86	2.31	-6990.03	5617.05	5.86
7	2.70	1.20	1.32	0.94	5.87	2.40	-7230.84	5966.98	5.87
8	2.48	1.10	1.10	0.87	5.90	2.41	-7036.46	5833.32	5.90
9	2.92	1.10	1.10	0.87	5.75	2.16	-6815.26	5339.77	5.75
10	2.48	1.30	1.10	0.90	5.97	2.51	-7255.20	6007.63	5.97
11	2.92	1.30	1.10	0.91	5.83	2.25	-7029.98	5501.18	5.83
12	2.48	1.10	1.30	0.91	5.91	2.49	-7251.24	6129.73	5.91
13	2.92	1.10	1.30	0.92	5.76	2.22	-6986.20	5604.37	5.76
14	2.48	1.30	1.30	0.94	5.98	2.59	-7480.05	6315.85	5.98
15	2.92	1.30	1.30	0.95	5.84	2.32	-7209.36	5776.22	5.84

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