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Coupled Thermal Structural Analysis of 3D Cantilever Beam

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Abstract: In any steel structural analysis, the performance of steel structures is very important. The performance is considered on the basis of external conditions like water, fire, air etc., considering fire applied on steel structure, strength and performance of steel structure depends on many different conditions like material degradation at elevated temperature and restraint stiffness of member. In order to face minimal damage fire resisting studies and implementation is to be performed on the structure for which structural behaviour studies are very important. For this study, Indian Standard beam is considered, which is exposed to differential temperature conditions with varying time on both solid beam and a notched beam. Different characteristics and behaviour of the considered beam is studied to know the responses of a beam under different temperature conditions. This study gives an overview of material behaviour and tells us to design considering various conditions. The experiment on actual steel structure under controlled fire, is not always feasible as it requires time, money, and space as well. Hence, the thermal analysis is carried out using finite element software (ANSYS).

Keywords: thermal analysis, fire loading, heat transfer, stress, coupled analysis

I. INTRODUCTION

The steel has a major application in construction as structural components. Higher load carrying capacity, reduction in cross section area and ease of erection of building with structural and architectural advantages made it a top priority in the construction field. But steel structures predominantly have shown high rate of failure under thermal load. This is one of the major concerns that overtook since last few decades. The reduction in strength and stiffness of steel member under thermal load, has led to an extensive study on steel structures, and improvised the behaviour as a fire protection system.

Mechanical properties of steel structures are important in any steel structure analysis. The study of mechanical properties of steel structural members at regular temperature is conventionally different from behaviour of steel structure at elevated temperature.

Mechanical properties of a steel structure are important in any steel structure analysis study. The mechanical properties at regular temperature is conventionally different from varying elevated temperature a steel structure behaves identically different at every elevated scenario the following are the mechanical properties to be considered.

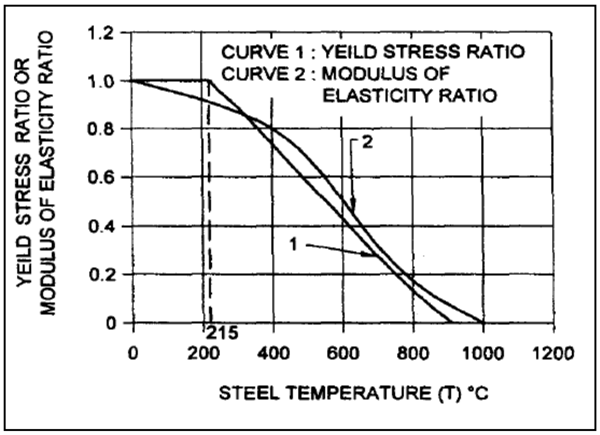

Fig. 1 Variation of Mechanical properties of steel at elevated temperature

Madan *et al* (2016) studied behaviour of steel plane frame under different fire exposure conditions using ANSYS. The performance of different protective materials in FE model under different fire exposure conditions are studied. Hemangi et al (2013) described the structural behaviour of a steel structure when exposed to fire including the earthquake loads with the help of advanced structural FE software. In general effects of rising of temperature in the fire hour induce an expansion in beam components.

The reduction in stiffness and strength when a structure is exposed to high temperature is observed. Harshad D Mahale and S.B Kandekar (2016) studied material degradation at elevated temperature and restraint stiffness are the different variables on any steel structure when a fire load is applied with the help of advanced structural software. Beam components of the critical section are optimised and processed to thermal analysis. Bramhanand V. Patil and Milind S. Ramgir (2016) studied the effect of temperature on mode shape and modal frequency of a steel structure using ANSYS. Bhavana B and Abhishek N Naik (2017) studied the behaviour on non-coated and protective coated steel beam structures under direct thermal loading with relation with the total deformation and stress- strain are investigated with help of FEM based software. In general effects of rising of temperature in the fire hour induce an expansion in beam components. If the expansion is restrained, stress induces over the region of restraining, resulting in the change or rise in deformation. Load bearing capacity of steel structural components drastically reduces in the fire condition. The performance of steel structural components under accidental fire loads is investigated. Crosti (2009) studied the structural response of a simple steel structure building using different scenarios to understand the responses of structural element under different fire loads and also differential behaviour of a steel structure for multiple fire loads. Effect of temperature on mode shape and modal frequency of a steel structure using ANSYS is performed. Egle Rackauskaite et al (2017) presented an overview on travelling fire and a traditional design fires in a multi storey steel frame in any large open plan compartments travelling temperature. When 2–38% of smallest travelling fire is applied, irregular oscillations are observed, which are regularly not observed in any of the uniform fire. Lenka Lausova et al (2016) presented the behaviour of non-linear temperature distributed across a section of steel structure. Increase in temperature result in additive internal forces due to restrained conditions and compared the study of temperature in two different areas, one with non-protected steel hollow cross section of different size and other with protected steel hollow cross section using a Finite Element Analysis. In any steel structural analysis, the performance of steel structures under increased temperature is very important. The performance is considered on the basis of external environmental conditions like water, fire, air etc., considering fire applied on steel structure. The strength and performance of steel structure depends on many different conditions like material degradation at elevated temperature and restraint stiffness of member. In order to face minimal damage fire resisting studies and implementation is to be performed on the structure for which structural behaviour studies are very important. For this study, the Indian Standards I-beams are considered, and are exposed to differential temperature conditions with varying time on both solid beam and notched beam. Since the experimental study on actual steel structure is not always feasible as it requires time, money, space and controlled fire, finite element software's like ANSYS is the best alternative. The behaviour of these steel beams are studied under different temperature conditions, for both healthy/original/undamaged and damaged/notched beams. This study gives an overview of material behaviour and tells us how to design and construct steel structures. This paper focused on the characteristics and behaviour of the solid steel beams and notched steel beams when exposed to exponentially increasing fire. Three dimensional I-section steel cantilever beams, ISMB 300@44.2 kg/m steel section, of length 1200mm are considered for the present study. Practically, it is very hard to conduct the fire load on steel structure, it is consuming time and money. Also, there is a very high risk when handling exponential fire. In such cases, the analysis using a finite element software (like ANSYS) as a tool is very useful. The beam is analysed using ANSYS/Thermal with various fire loads at various interval of time. The beams are modelled as solid beams and notched beams at 5mm, 50mm, 200mm and 400mm from the fixed support. The results obtained from the coupled structural thermal analysis of solid beam and notched beam are compared.

II. MODELLING

For the present study, I- section steel cantilever beam of length 1200 mm is considered. The load is applied at the free end. Initially, thermal analysis on the structures are performed. The solid steel beams are analysed for various thermal loads say 250˚C, 500˚C and 1000˚C adopted and for time intervals say 300 seconds, 600 seconds and 900 seconds. Also, the study of transfer of temperature, three different nodes are selected at different positions. Similarly, notched beams, with notches provided at 5mm, 50mm, 200mm and 400mm from the fixed end are considered with similar thermal loads at different time intervals.

TABLE I BEAM SPECIFICATIONS

Beam	ISMB 300 @ 44.2 kg/m
Length of the Beam	1200 m
Poisons ratio (μ)	0.3
Density of steel (ϱ)	7850 kg/m^3
Young's modulus of steel (E)	2 x 1011 kN/m^2
Specific heat (C)	500 J / K kg
Coefficient of Thermal conductivity (K)	40 W/m K
Coefficient of Thermal expansion (α)	13 x 10-6 /˚C

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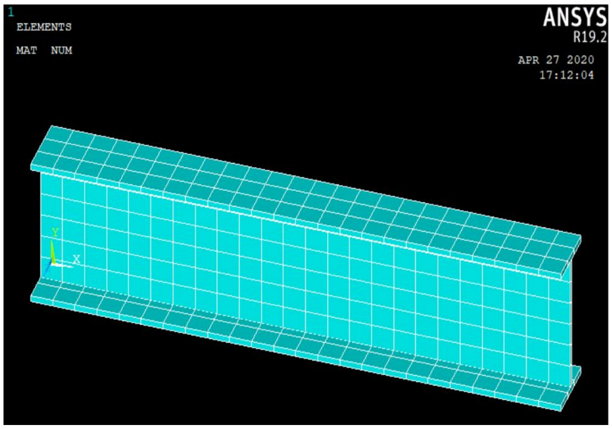

Fig.2 Model of solid beam

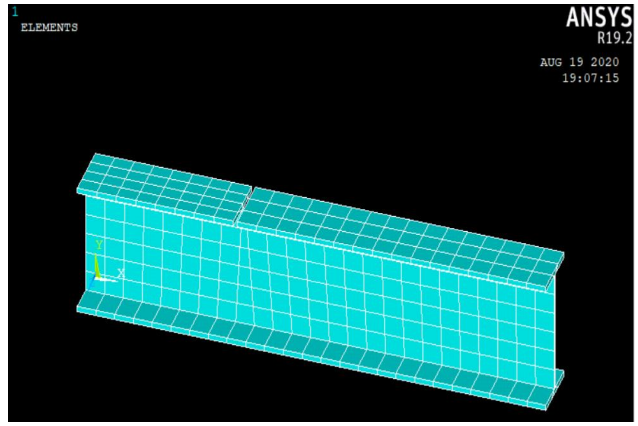

Fig.3 Model of notched beam

III.RESULTS AND DISCUSSIONS

Example problem: ISMB300@44.2kg/m beam member under various thermal loads at different time intervals is analysed. For the variation of temperature along beam length, total deformation and equivalent stress are compared for different conditions.

The analysis results like displacement and stresses of Solid beam are compared with Notched beam.

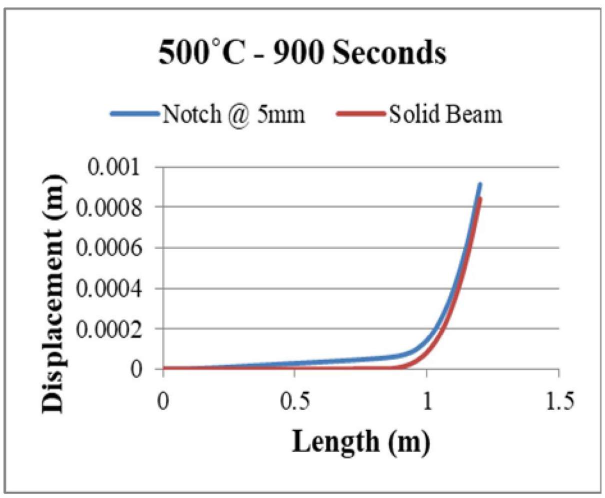

Fig 4 Displacement v/s Length curve for 500˚C for 900 seconds for Notch at 5mm

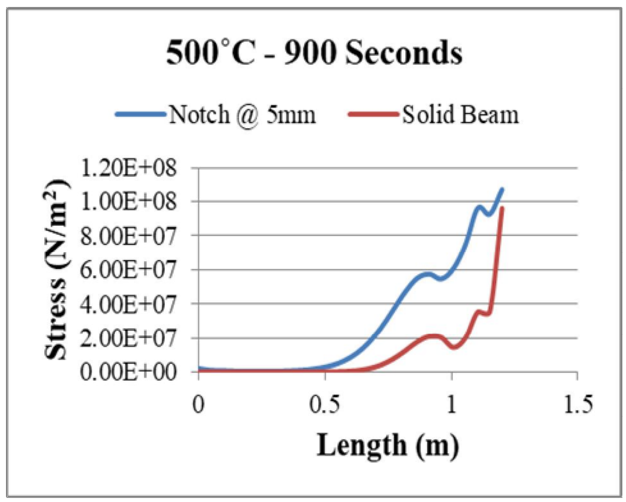

Fig 5 Stress v/s Length curve for 500˚C for 900 seconds for Notch at 5mm

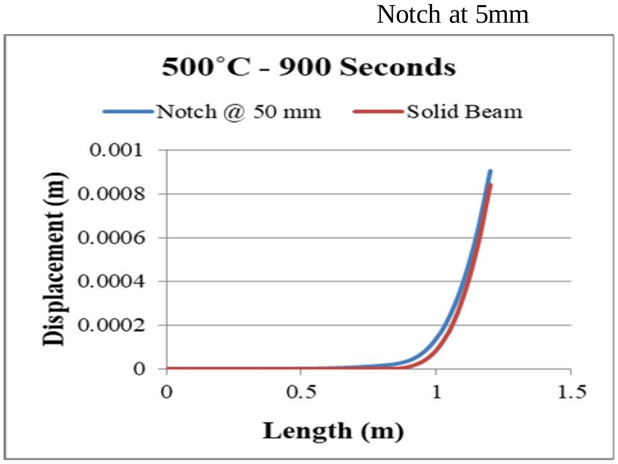

Fig 6 Displacement v/s Length curve for 500˚C for 900 seconds for Notch at 50mm

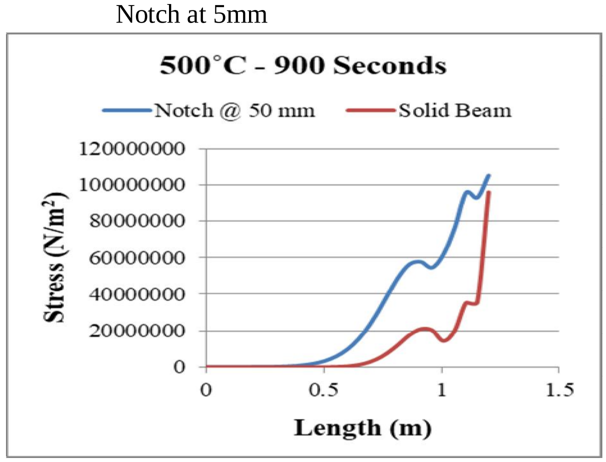

Fig 7 Stress v/s Length curve for 500˚C for 900 seconds for Notch at 50mm

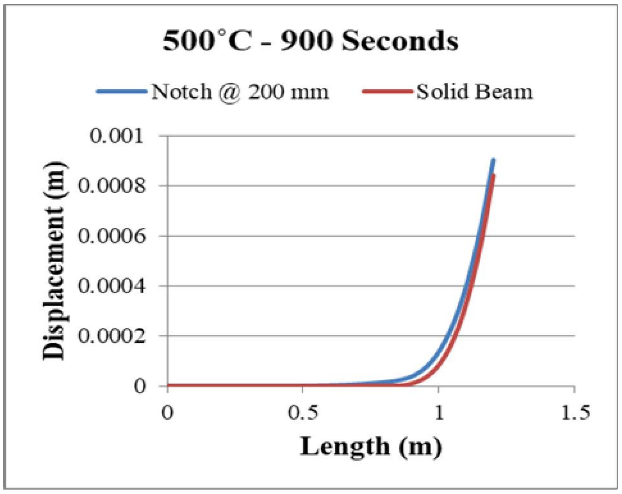

Fig 8 Displacement v/s Length curve for 500˚C for 900 seconds for Notch at 200mm

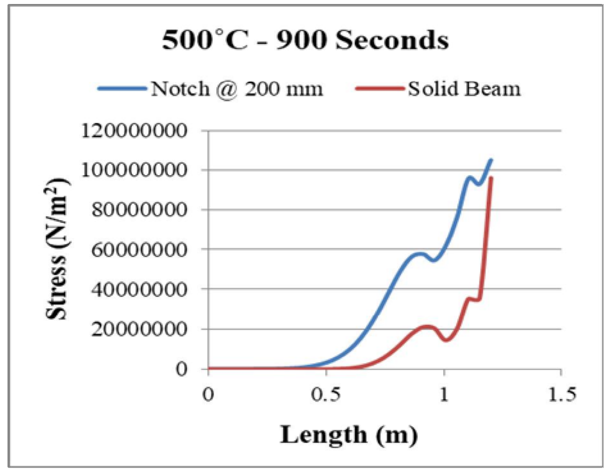

Fig 9 Stress v/s Length curve for 500˚C for 900 seconds for Notch at 200mm

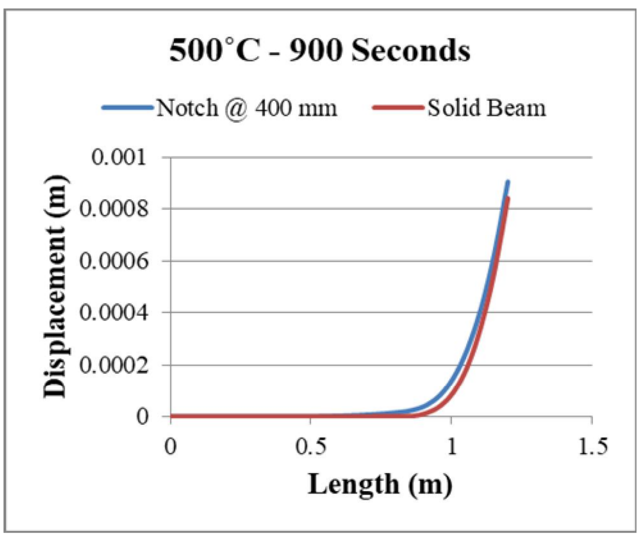

Fig 10 Displacement v/s Length curve for 500˚C for 900 seconds for Notch at 400mm

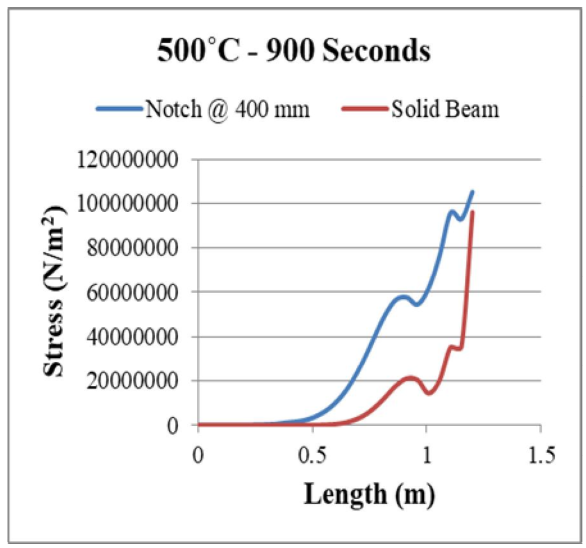

Fig 11 Stress v/s Length curve for 500˚C for 900 seconds for Notch at 400mm

IV. CONCLUSIONS

Based on the results and discussions, the following conclusions are drawn,

A. Higher the intensity of thermal load applied, higher is the rate of heat transfer along the beam length.
B. The duration of thermal load on the surface is directly proportional to the rate of heat transfer along the length of beam.
C. Displacement and Stress intensity in a cantilever beam is higher for thermal load applied for a longer duration than for thermal load for shorter duration, and is also higher for high intensity thermal load than lesser thermal load.
D. The thermal load transfer and rate of flow of heat had less effect due to the introduction of notch. The introduction of notch in the beam, reduces the stiffness in the beam and hence increased the displacement compared to solid beam.
E. The stress distribution patter varied predominately for notched beam compared to solid beam.
F. The change in location of notch along the beam had less effect on the heat transfer.

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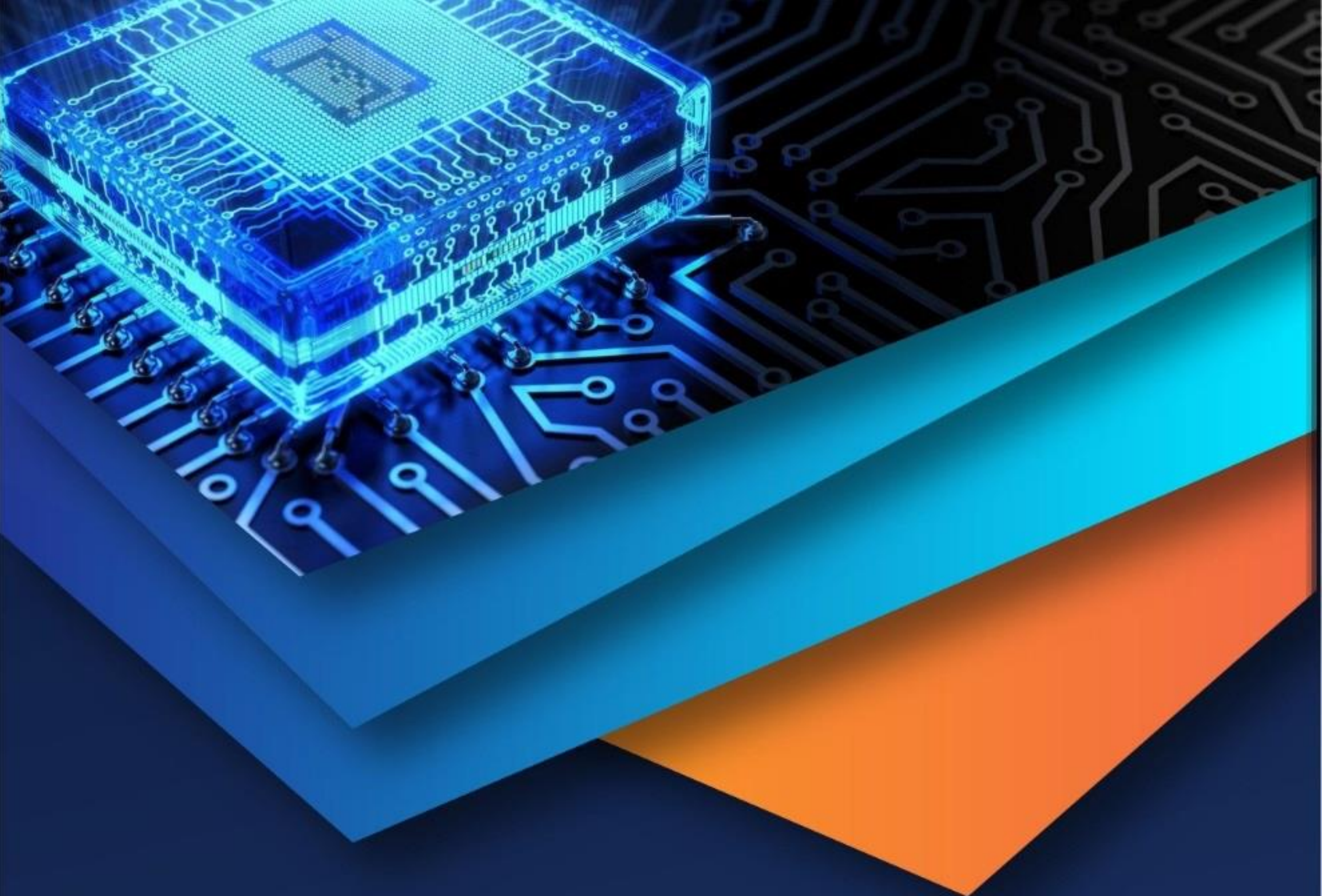

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