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Flexural Behavior of Cold-Formed Steel I-section Beam under Temperature

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Abstract: The cold-formed steel is becoming popular in construction industry because of its various advantages and flexibility in use. The cold-formed steel is manufactured and molded in desired shape at room temperature hence there is a need to study the behavior of cold-formed steel at high temperature. Most of the research has been already done on various properties of cold-formed steel at high temperature like ductility, stress strain curve, etc. but the study on flexural strength and maximum deflection is yet to be done. Therefore in this project the properties like ultimate load, flexural strength, maximum deflection and weight change are studied at temperature up to 550^{0}C. I-section beams were subjected to the various temperatures at 100^{0}C, 250^{0}C, 400^{0}C and 550^{0}C. After cooling the flexure tests were performed on beams in Universal Testing Machine. From the experiments it was observed that, the ultimate load and flexural strength reduces as temperature goes on increasing due deterioration in properties of cold-formed steel at high temperature, while the maximum deflection increases and there is no any weight change of cold-formed steel due to increase in temperature.
Keywords: Cold-formed steel, high temperature, flexural strength, ultimate load, maximum deflection, weight change.

I. INTRODUCTION

Nowadays construction steel is playing very important role in construction industry. The light weight structures, temporary structures are built using construction steel. There are mainly two types of construction steel, one is “hot rolled steel” and another is “cold-formed steel”. The only basic difference in these two types of steel is manufacturing process of both. The hot rolled steel is manufactured by application of heat to the steel. At high temperature hot rolled steel softens hence can be molded in any shape very easily. The manufacturing process of cold-formed steel is just reverse of hot rolled steel i.e. the cold-formed steel members are manufactured by rolling and bending at room temperature only.

The cold-formed steel sections are manufactured by two processes:

1) *Cold Rolling:* This method is useful for large production. The heavy sections are manufactured using this method like wall panel, floor, roof, etc.
2) *Press Braking:* This method is suitable for production of small quantity of cold-formed steel sections.

A. I-section Beams

I-beam is also called as W-beam, H-beam, wide beam, universal beam. It is mostly preferred section for beams, columns by the engineers because it handles variety of loads. I-section beams can be manufactured with different length, size and specifications. I-section beams have so many uses in the steel construction industry. These beams are used as main framework or critical support trusses in buildings. I-section steel beams provide strength and support, ensuring the structural integrity of building. I-section beams reduce the number of support structures, which saves time and money improving the structures stability. I-beams are a valuable resource for every builder because of their adaptability and dependability. Because of its great functionality, I-beams are the preferred shape for structural steel construction. . The shape of I-beams makes them excellent for unidirectional bending parallel to the web. The horizontal flanges resist the bending movement, while the web resists the shear stress. I-section beams are resistant to buckling under shear stress and variety of loads. I-section is economic shape as it does not use excess steel.

The cold-formed steel is manufactured at room temperature hence there are chances of loss of properties when exposed to high temperature. So there is need to check performance of the steel at higher temperature when subjected to fire. This research focuses on determination of properties of like weight change, ultimate load carrying capacity, flexural strength and maximum deflection of cold-formed steel beam at high temperature.

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The results of performance of cold-formed steel at temperature 100^0C, 250^0C, 400^0C and 550^0C are assessed and results indicated that the ultimate load carrying capacity and flexural strength of cold-formed steel beam decreases by increase in temperature. There is no any weight change in steel by application of heat. The maximum deflection of beam increases by increase in temperature of steel.

II. EXPERIMENTAL DETAILS

There are varieties of steel sections available in market. But for this project I-section is selected as it is most commonly used section in beams, columns, purlins, etc. The selected section dimensions are as follows:

Table 1
I-Section Beam Dimensions

Sr. No.	Section Parameters	Dimension (mm)
1.	Flange	120
2.	Flange thickness	1
3.	Web	120
4.	Web thickness	2
5.	Lip	10

The cold-formed sheet available in market is of 0.91m X 2.45m. From one sheet 9 channel sections of length 910mm and size 120mm X 60mm X 1mm was prepared. Hence for 9 back to back built-up channel section (I-section) beams of desired dimensions, two sheets were used. The beams were fabricated as per selected dimensions and section.

Fig. 1 Cold-formed steel sheet

Fig. 2 I-section beams

After fabrication, weight of each beam was recorded to study the effect of temperature on weight of beam. For weighing the beams, electronic weighing machine of capacity 15 kg was used. The beams then put in electric furnace for application of heat at temperature of 100^0C, 250^0C, 400^0C and 550^0C. The temperature capacity of electric furnace is 1000^0C.

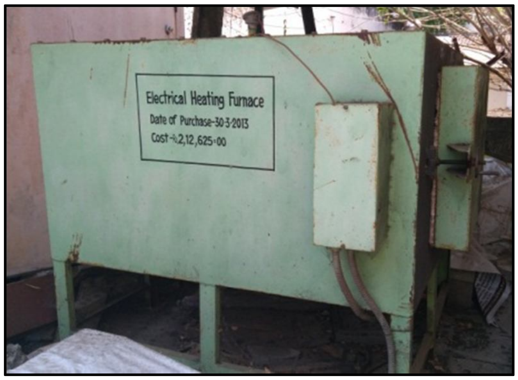

Fig. 3 Electric furnace

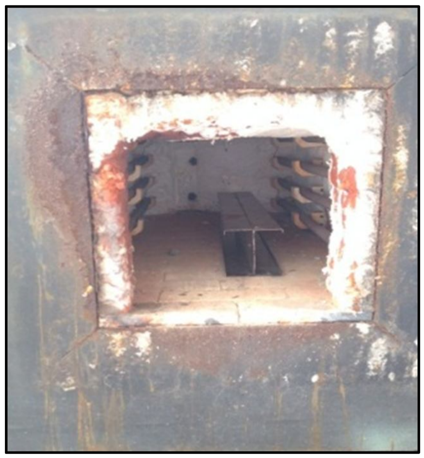

Fig. 4 Beams in electric furnace

On each day two beams were put in furnace at the particular temperature. In electric furnace the settings were required to be done to set the temperature. First of all the previous cycle should be closed while setting new temperature. For that in page 0 select strt (start) “No”. Then in page 14 the temperature settings are done. In that do “Enbl Profile”, then select r.band 20 and s.band 20. Then choose the rate of temperature to be applied i.e. rrt.1 – 3.04^{0}C/min. After that select the temperature as tsp.1 – 250^{0}C (select the required temperature). Again go to the page 0 and select strt (start) “Yes”, cycle will start for the given temperature. The following flowchart shows the steps to be followed to set the temperature:

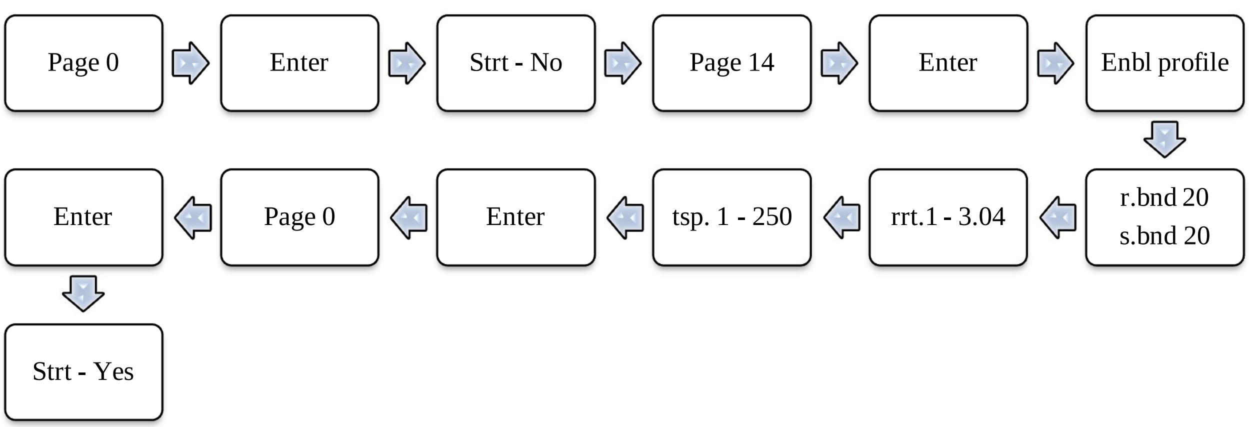

Fig. 5 Electric furnace flowchart (For 250^{0}C)

On next day beams were taken out from the electric furnace and allowed them to cool down up to room temperature. After cooling the weight of each beam was again recorded to see the difference in weight of beams before and after subjecting to temperature. The flexural test was performed on each beam to determine ultimate load capacity of beam, flexural strength and maximum deflection. These tests were conducted in Universal Testing Machine (UTM).

The two point loading was applied to determine the ultimate load of beam. The loading girder was prepared with 270mm center to center spacing between loading bars. The support was given at 5cm from each end of beam.

In UTM the beam was placed exactly at middle and loading girder was placed above it. Then the movable cross head was moved downward to touch to the girder. Then the dial gauge was placed below beam to measure deflection of beam. After all the settings the load was gradually applied on beam until it fails.

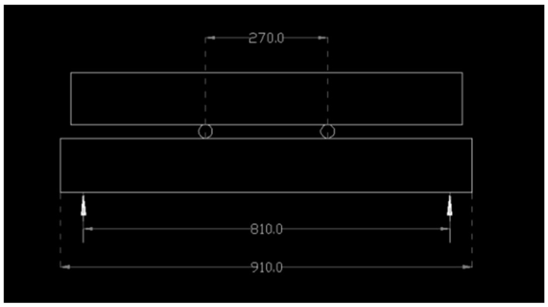

Fig. 6 Loading diagram

Fig. 7 Experimental setup

The deflection of beam was recorded using dial gauge. From the ultimate load, flexural strength was calculated using formula,

Flexural strength = (Ultimate load / Cross sectional area)

Now cross section area of one channel section of size 120mm X 60mm X 1mm is 251mm^2. The cross section area of I-section beam will be twice the cross section area of channel section.

$\therefore$Cross sectional area of I-section beam = 2 X cross sectional area of channel section = 2 X 251 = 502 mm^2

Fig. 8 Beam testing in UTM

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III. RESULT AND DISCUSSION

A. Weight Change

The weight change parameter for cold-formed is important to check whether any chemical changes occurred or is there any disturbances occurred in steel structure which leads to weight change. From this research project the following table shows the recorded weight of beam before and after subjecting to temperature:

TABLE 2
WEIGHT CHANGE

Sr. No.	Beam temperature (Degree Celsius)	Weight at room temperature (kg)	Weight at high temperature (kg)
1.	Room temperature	4.42	4.42
2.	100	4.4	4.4
3.	250	4.45	4.45
4.	400	4.47	4.47
5.	550	4.45	4.45

The above table shows, there is no any weight change of cold-formed beams before and after subjecting to temperature up to 550^0C. It indicates that cold-formed steel does not scale at high temperature up to 550^0C.

B. Ultimate Load

Ultimate load carrying capacity of beam is the maximum load carrying capacity of beam without failure. This is the maximum value of load for which beam can withstand. The further increase in load causes failure of beam. This is very important property for any structural element.

The following table shows the ultimate load carrying capacity of cold-formed steel beam at different temperature:

Table 3
Ultimate Load

Sr. No.	Beam temperature (Degree Celsius)	Ultimate load (kN)	Percentage change w.r.t. room temperature results
1.	Room temperature	16.15	-
2.	100	14.4	10.84%
3.	250	13.1	18.89%
4.	400	12.5	22.60%
5.	550	12.3	23.84%

The graph of the same was plotted with temperature on X-axis and ultimate load on Y-axis:

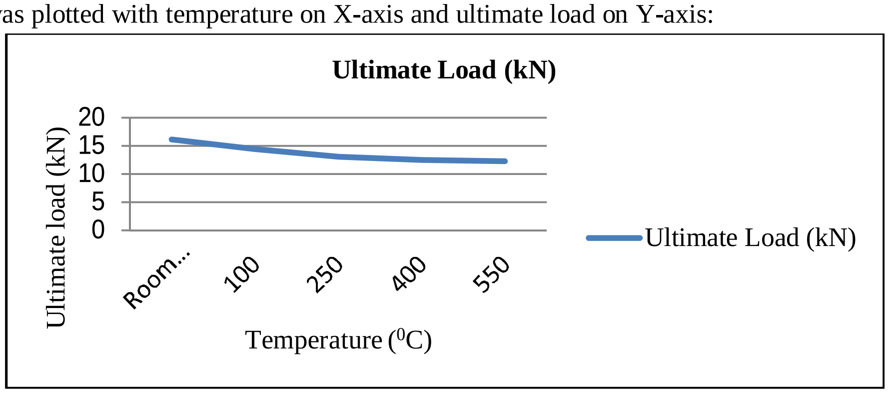

Fig. 9 Ultimate load Vs. Temperature

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The ultimate load of cold-formed steel beam was determined by two point loading test in UTM. The failure mode of each beam was recorded. From the above table and graph it is observed that the ultimate load decreases by increase in temperature of beam. The percentage change of ultimate load at elevated temperature with respect to room temperature was also determined which is 10.84%, 18.89%, 22.60% and 23.84%. Hence the percentage change in ultimate load is reducing from lower to higher temperature.

C. Flexural strength

Flexural strength of element is defined as the ability to resist the deformation under load. Flexural strength is the representation of highest stress experienced by the element at the yield point. This is also the important parameter to be considered while selecting the material and section as this depends upon the load carrying capacity of material and cross section area of selected section.

The flexural strength of beam was calculated from ultimate load and cross sectional area of beam. The cross section area of I-section beam is $502mm^2$.

$$\text{Flexural strength} = (\text{Ultimate load} / 502)$$

The flexural strength of beam at different temperatures is noted in table and the plot of flexural strength versus temperature is also shown in the figure below:

Table 4
Flexural strength

Sr. No.	Beam temperature (Degree Celsius)	Flexural strength (N/mm^2)	Percentage change w.r.t. room temperature results
1.	Room temperature	32.1713147	-
2.	100	28.685259	10.84%
3.	250	26.0956175	18.89%
4.	400	24.9003984	22.60%
5.	550	24.501992	23.84%

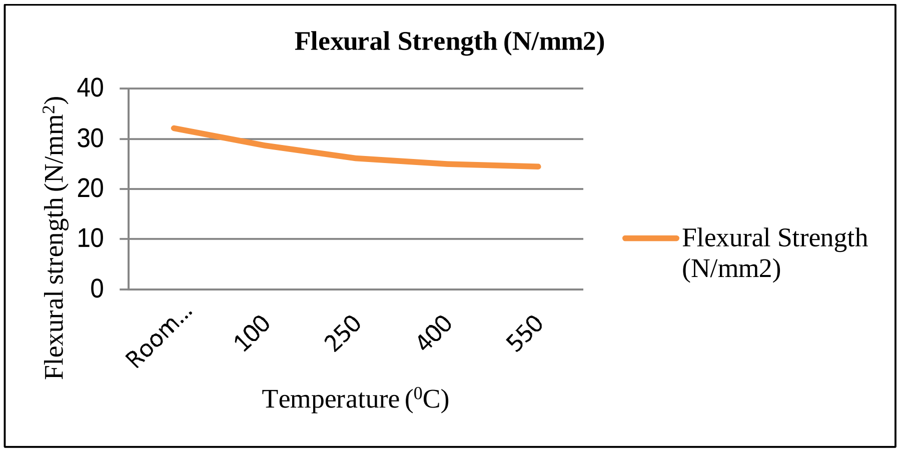

Fig. 10 Flexural strength Vs. Temperature

From the above table and graph it is observed that, the flexural strength of beam reduces by increase in temperature of beam. The percentage reduction in flexural strength with increase in temperature is 10.84%, 18.89%, 22.60% and 23.84%.

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D. Maximum Deflection

The maximum deflection of beam was recorded using the dial gauge. The maximum deflection of beam at different temperature levels is listed below in table and the graph of same is shown in following figure:

Table 5
Maximum deflection

Sr. No.	Beam temperature (Degree Celsius)	Maximum deflection (mm)	Percentage change w.r.t. room temperature results
1.	Room temperature	6.9	-
2.	100	6.95	0.72%
3.	250	7.4	7.25%
4.	400	8.05	16.66%
5.	550	8.8	27.54%

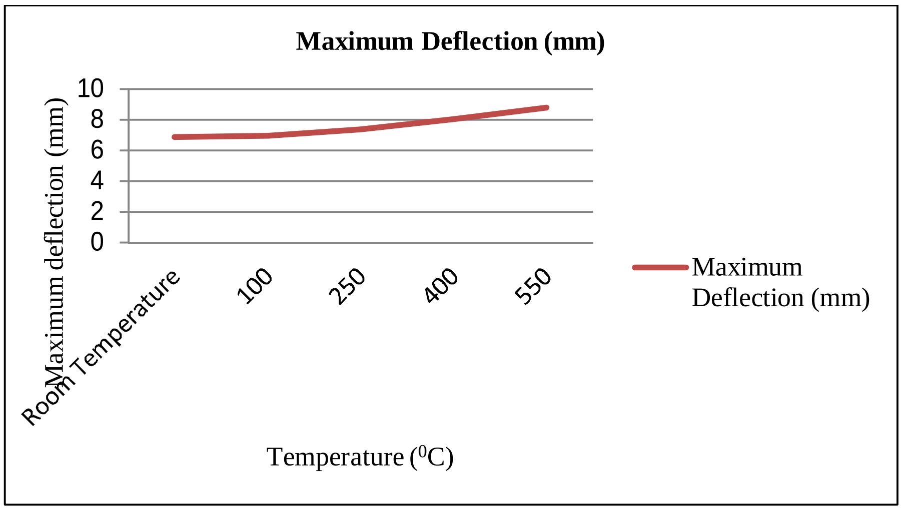

Fig. 11 Maximum deflection Vs. Temperature

From recorded maximum deflection it is observed that it is increasing with increase in temperature from room temperature to 550^{0}C. The percentage increase in maximum deflection of beam is 0.72%, 7.25%, 16.66%, 27.54%.

In each beam the torsional buckling was observed by application of load. After failure of beam, its shape changes and deflection was observed in beam. But after removal of load the beam regain its original shape. This means the elastic deformation of beam vanishes after removal of load.

IV. CONCLUSION

From above results and discussions, following conclusions are drawn:

A. Flexural strength of cold-formed steel reduces at higher temperature.
B. There is no any weight change of cold-formed steel even after subjecting to the high temperature (up to 550^{0}C) because no film layer is added or no any scaling takes place after heating or no any chemical reaction takes place which may lead to increase or decrease in weight of steel.
C. The maximum deflection of beam increases as temperature goes on increasing because the load carrying capacity of beam decreases.
D. Elastic deformation of beam vanishes after removal of load.

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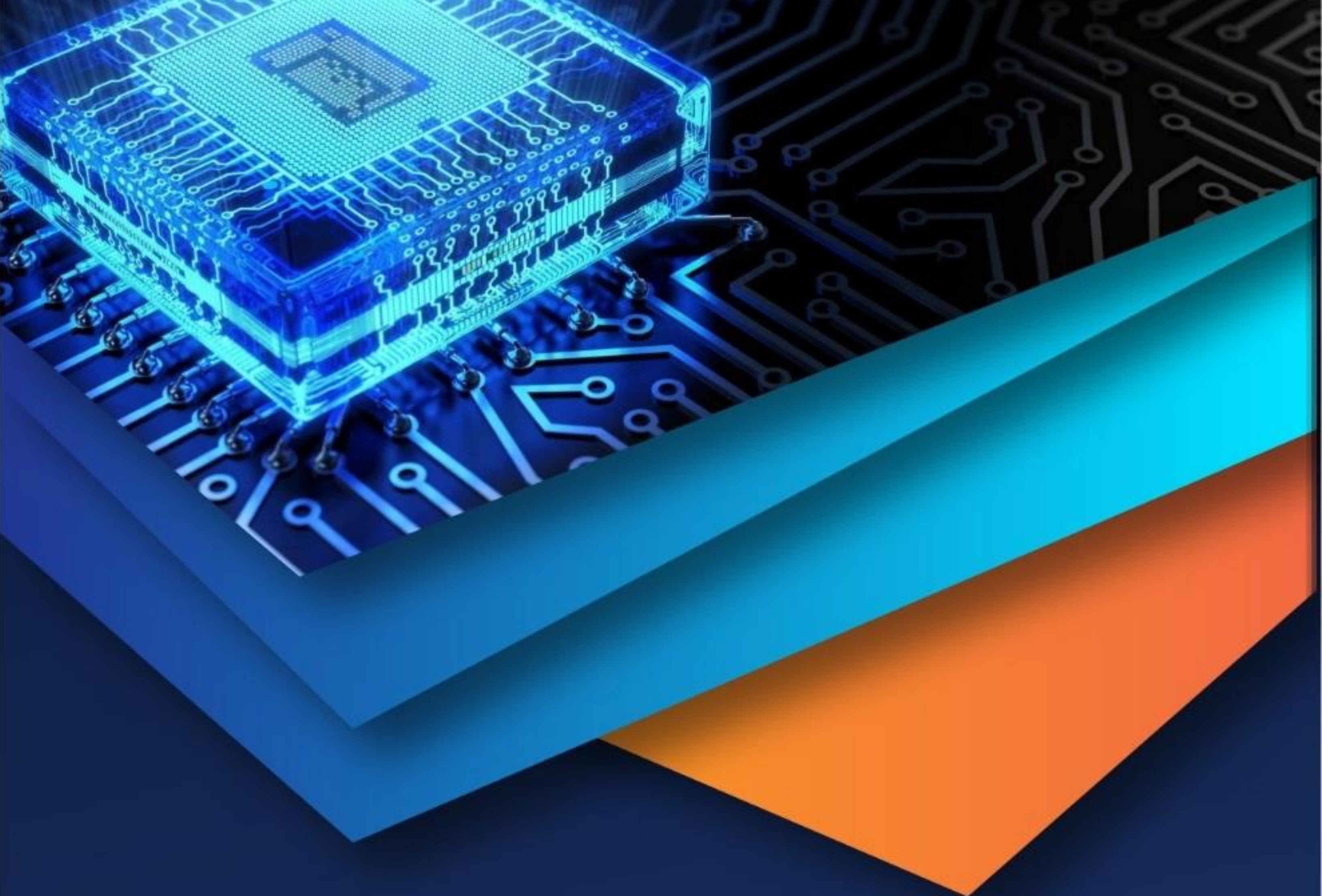

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