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Structural and Thermal Analysis of Magnesium Based Brake Friction Material

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Abstract: Conventional brake pad friction materials are made of organic, metallic and ceramic materials but they suffer from various shortcomings like dampening effects, formation of undesirable phases, sensitivity to high temperature and brittleness. However, in the recent years due to better tribological properties of magnesium and its composites they have gained considerable importance to be used as brake pad friction material. In present article the structural and thermal analysis of six magnesium composites (viz., AZ91 + 0.5 wt.% GNP, AZ91 + 30 wt.% TiC, Mg + 1 Al + 0.6 wt.% CNT, AZ91D + 1.5 wt.% B_4C, Mg + 10 % TiC + 5 wt.% MoS_2, Mg+ 5 wt.% Graphite) in ANSYS software has been carried out. During the structural and thermal simulation it was observed that AZ91+0.5wt%GNP and Mg+1Al+0.60CNT gave the best results for total deformation, equivalent stress and strain and were found to be the most suitable composites for making brake pad friction material. This behaviour of the GNP and CNT composites can be attributed to their respective honey-comb and cylindrical structure lattice and high thermal properties.
Keywords: Brake pad friction material, Structural analysis, Thermal analysis, Composites, GNP, CNT

I. INTRODUCTION

Magnesium in the recent years is gaining importance in automobile industry due to its efficient mechanical properties, less weight and high machinability. [1]It is also noticed that magnesium is 35% lighter than aluminium and four times lighter than steel. [2]Alloying of magnesium with manganese, zinc and rare earth materials increases the strength to weight ratio, which makes it suitable for applications where reduction of weight inertial forces is imperative. Incorporation of structural filler material viz., Carbon nano tube (CNT) and Graphene nano plates (GNP) leads to increase in thermal properties of magnesium composites.

Brake pads are a crucial component in the braking system of an automobile. They have to be designed in such a way that a constant coefficient of friction is maintained over a wide range of structural and thermal conditions. Although the wear of the brake pad is inevitable, however, it should be minimized as far as possible.

[3] Highlighted that asbestos brake pads released carcinogenic materials during wear and thus have a negative effect on the human health. [4] reported that organic brake pads were not homogenous in nature as they depend highly on the type and conditions of the raw material. [5] highlighted that metallic matrix composites display low hardness and low strength to weight ratio, which effects the strength of brake pads.

[6]observed that magnesium has a high strength to weight ratio. According to [7] incorporations of CNT in the magnesium metal matrix composite rapidly increases its strength. The wear characteristics of the matrix is also improved by the addition of GNP, TiC and B_4C composites. In context of the above discussion, the present study aims to do a comparative analysis of the structural and thermal behaviour, of six different magnesium composites brake pad friction materials (viz., AZ91 + 0.5 wt% GNP, AZ91 + 30 wt% TiC, Mg + 1 Al + 0.6 CNT, AZ91D + 1.5 wt% B_4C, Mg + 10 % TiC + 5 wt% MoS_2, Mg+ 5 wt% Graphite) under similar boundary conditions.

II. MATERIALS AND SIMULATION TECHNIQUES

In present study the simulation of the brake pad and disc model is carried out on ANSYS 2020 R2 software. The performance of the six-brake pad friction material composites (viz., AZ91 + 0.5 wt% GNP, AZ91 + 30 wt% TiC, Mg + 1 Al + 0.6 CNT, AZ91D + 1.5 wt% B_4C, Mg + 10 % TiC + 5 wt% MoS_2, Mg+ 5 wt% Graphite) were evaluated under the boundary conditions mentioned in Table 1. The mechanical properties of the six magnesium composite materials are discussed in Table 2[8,9,10,11,12,13,14,15,16]. The boundary conditions and the faces upon which the boundary conditions have been implemented on the model are shown in Figure 1.

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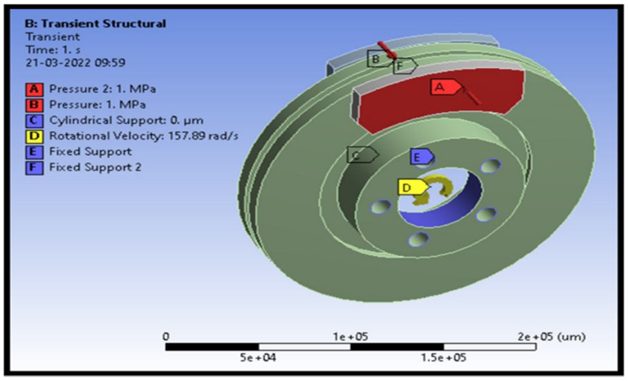


Fig.1 Model design and boundary conditions used for simulation on ANSYS

The structural analysis was done for a braking period of 4 seconds whereas the thermal analysis was carried out for a braking period of 1 second. The brake pressure (i.e., 1MPa) was applied uniformly over the brake pad surface and tetrahedron mesh was used in the analysis. Fine meshing of the model was done in order to get accurate results across the disc and pad.

Table 1. Boundary conditions applied on the model

Type of condition	Value/ Faces applied
Pressure 1	1 MPa
Pressure 2	1 MPa
Cylindrical support	Axial and tangential direction is fixed, radial is given free support
Rotational velocity	157.99 rad/s
Fixed support	At grooves and brake pads

Table 2. Mechanical properties of the six different magnesium composites

Properties of brake friction material	AZ91 + 0.5 wt% GNP	AZ91 + 30 wt% TiC	Mg + 1 Al + 0.6 CNT	AZ91D + 1.5 wt% B4C	Mg + 10 % TiC + 5 wt% MoS_2	Mg+ 5 wt% Graphite
Density (Kg/m^3)	1782	1850	1735	1819.7	2110	1760
Young's Modulus (MPa)	65500	47450	63475	47500	46120	45900
Poisson ratio	0.31	0.29	0.3	0.25	0.24	0.28
Tensile Yield Strength (MPa)	210	172	215	165	-	-
Compressive Yield Strength (MPa)	248	195	241	190	188	145
Ultimate tensile strength (MPa)	278	254	291	245	230	225
Ultimate compressive strength (MPa)	425	255	430	250	174	185

A. Material Analysis

During simulation, structural parameters viz., total deformation, shear stress, equivalent stress and thermal parameter (i.e., temperature gradient) were studied. These simulations are carried out to know the applicability of Magnesium composite-based friction materials under wide range of temperatures and stress values.

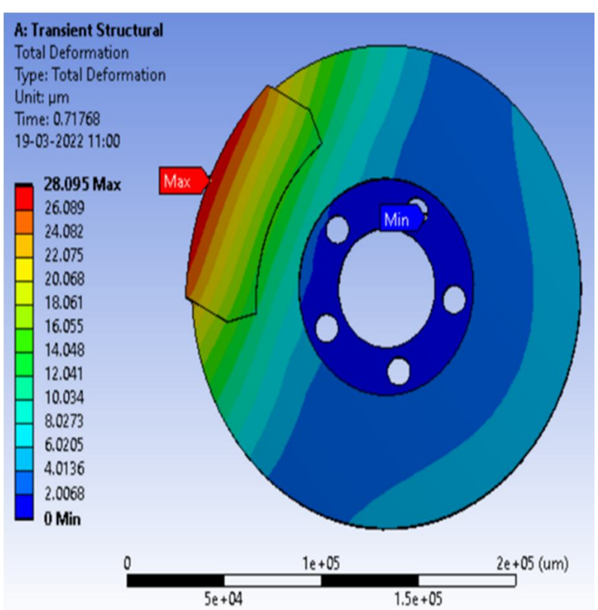
B. Total Deformation

The following figures shows the simulation results of total deformation on different magnesium composites. A comparitive desscription of the range of deformation obtained in the six simulations results are shown in table 3.

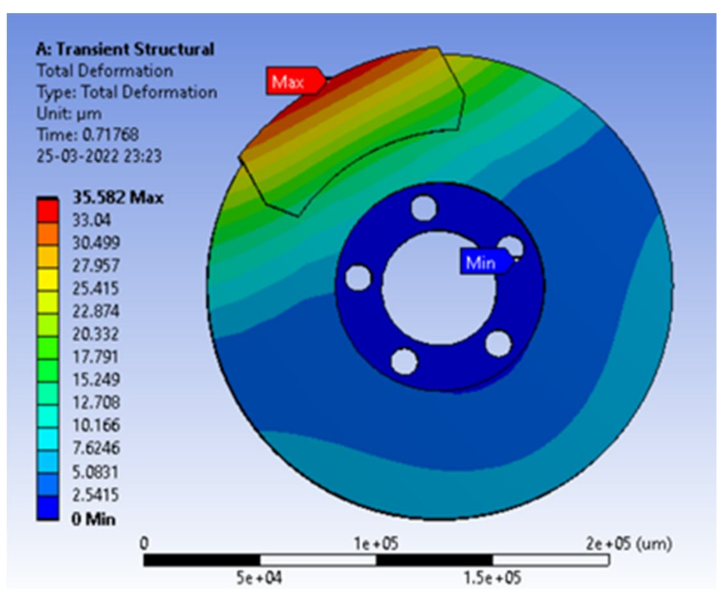
Table 3. Total deformation ranges of the six Magnesium composites

Name of composite	Range of deformation (in µm)
AZ91+ 0.5 wt.% GNP	0-28.095
AZ91+ 30 wt.% TiC	0-35.582
Mg + 1Al + 0.6 CNT	0-29.769
AZ91D + 1.5 % B_4C	0-36.034
Mg + 10% TiC + 5% MoS_2	0-46.581
Mg + 5% Graphite	0-43.575

Results from figure 2 and table 3 showed that AZ91+0.5 wt.% GNP had the minimum range of deformation. It was observed that Mg + 1Al + 0.6 CNT showed the next lowest deformation range (refer figure 2c and table 3). Mg + 10% TiC + 5% MoS_2 was seen to have the maximum range of deformation (refer figure 2e and table 3). The maximum deformation was seen at the periphery of the brake pad (represented by red colour) and the minimum at the centre of the disc (represented by blue colour). Analysis of the simulation results showed that the deformation in each case increased outwards in the radial direction.



a) AZ91+ 0.5 wt.% GNP



b) AZ91+ 30 wt.% TiC

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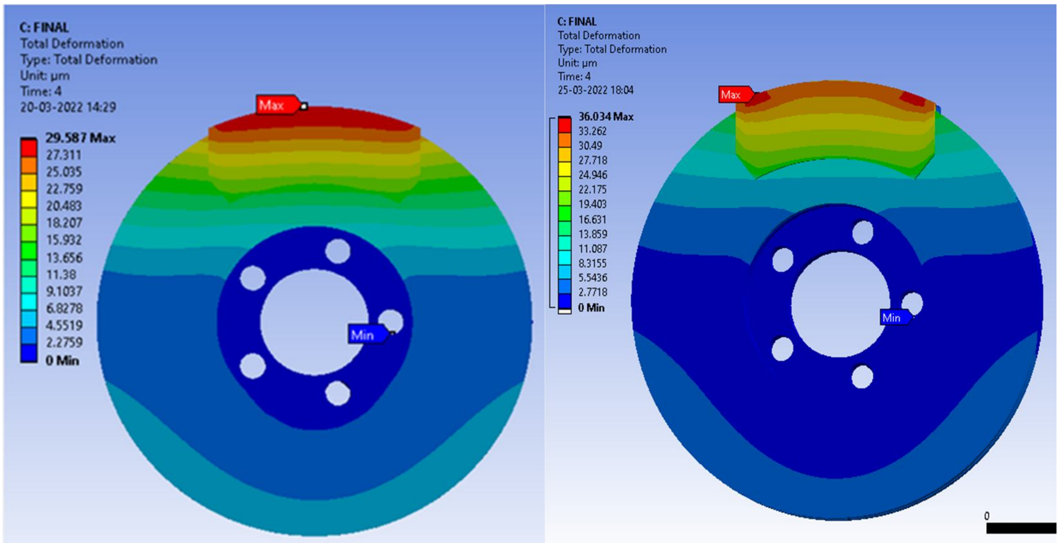

c) Mg + 1Al + 0.6 CNT

d) AZ91D + 1.5 % B_4C

e) Mg + 10% TiC + 5% MoS_2

f) Mg + 5% Graphite

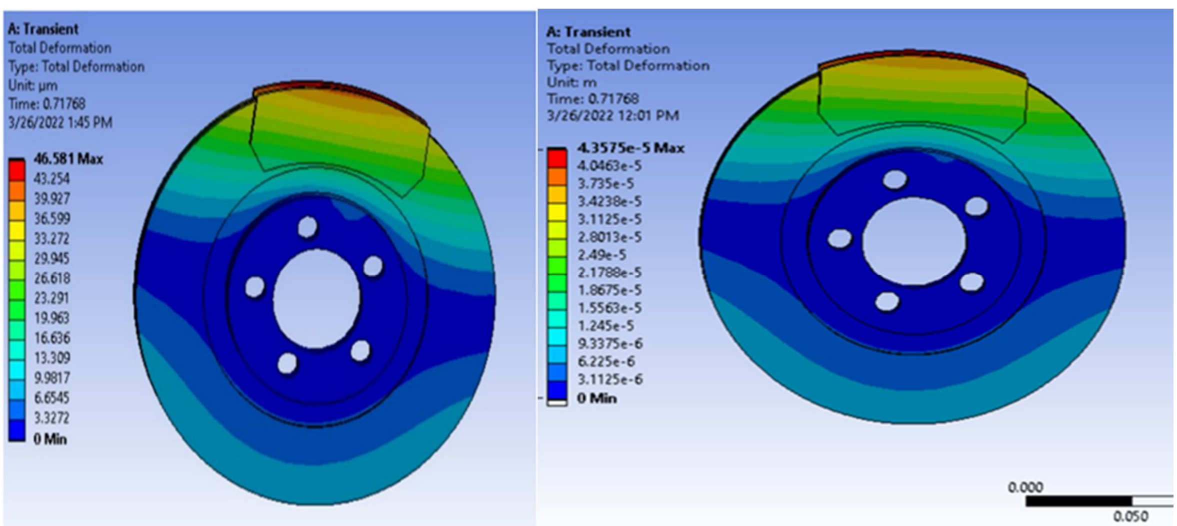

Fig 2. (a,b,c,d,e,f) Total deformation of the six magnesium composites

C. *Equivalent (VON MISES) Stress*

The results of Equivalent stress simulation are shown in figure 3. The range of equivalent stress of the six magnesium composites are shown in table 4.

Table 4. Equivalent stress ranges of the six Magnesium composites

Name of composite	Range of Equivalent stress (N/mm^2)
AZ91+ 0.5 wt.% GNP	0.030587 – 27.674
AZ91+ 30 wt.% TiC	0.043936 – 31.752
Mg + 1Al + 0.6 CNT	0.01136 – 29.825
AZ91D + 1.5 % B_4C	0.017221 – 33.454
Mg + 10% TiC + 5% MoS_2	0.044209 – 37.60
Mg + 5% Graphite	0.041136 – 36.80

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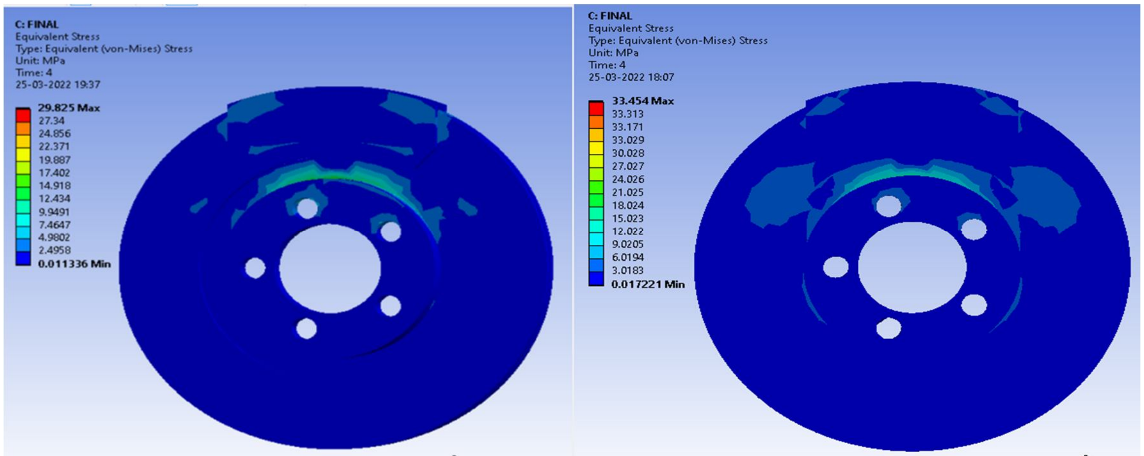
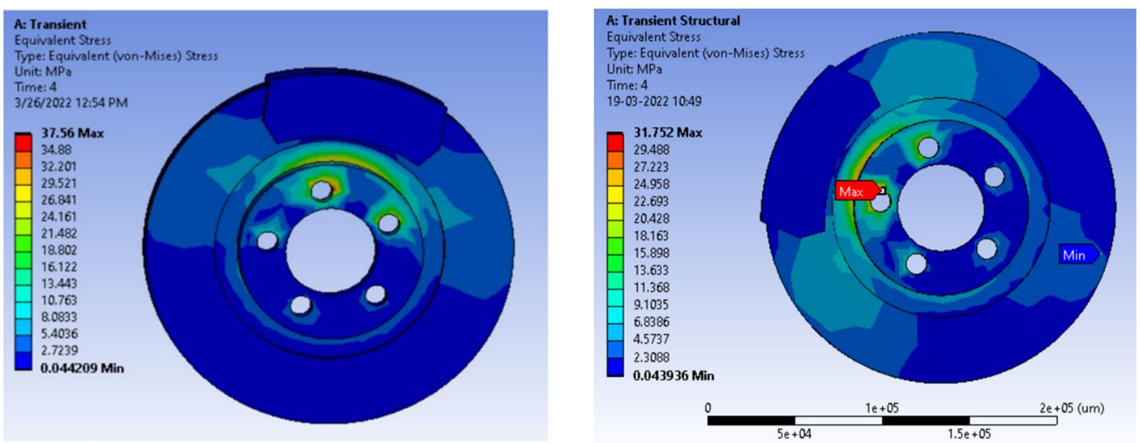
Results from figure 3 and table 4 showed that AZ91+0.5 wt.% GNP had the minimum range of equivalent stress (i.e., 0.030587 – 27.674). It was observed that Mg + 1Al + 0.6 CNT showed the next lowest range of equivalent stress (i.e., 0.01136 – 29.825, as shown in figure 3c). The maximum range of equivalent stress was seen in Mg + 10% TiC + 5% MoS_2 (i.e., 0.044209 – 37.60, as shown in figure 3e). Results from table 4 also highlighted that the upper limit of the equivalent stresses in AZ91+ 30 wt.% TiC (i.e., 31.752) and AZ91D + 1.5 % B_4C (i.e., 33.454) were almost equal. Maximum equivalent stresses were observed in mid-section of the disc. There was a uniform distribution of equivalent stress on the disc



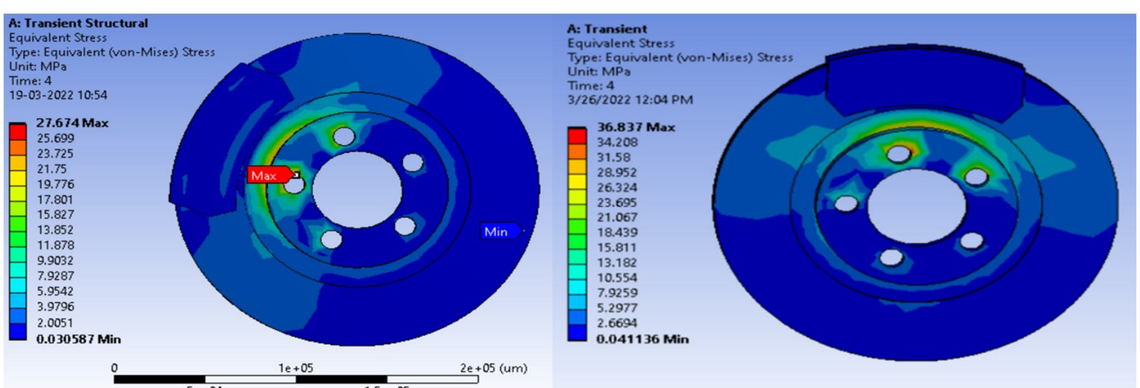
a) AZ91 + 0.5 wt.% GNP

b) AZ91+ 30 wt.% TiC



c) Mg + 1Al + 0.6 CNT

d) AZ91D + 1.5 % B_4C



e) g + 10% TiC + 5% MoS_2

f) Mg + 5% Graphite

Fig.3 (a, b, c, d, e, f) Equivalent stress of six magnesium composites

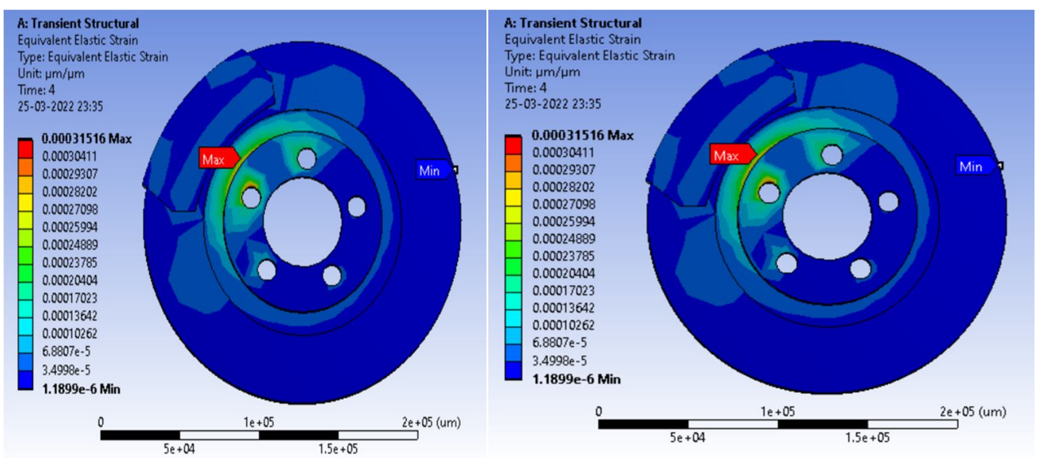
D. Equivalent Strain

The results of Equivalent strain simulation are shown in figure 4. The maximum values of the equivalent strain of the six magnesium composites are shown in table 5.

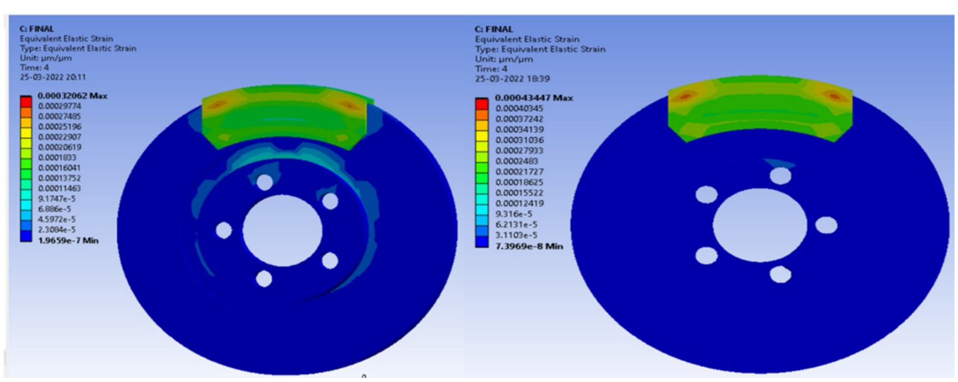
Table 5. Maximum Equivalent strain range of the six Magnesium composites

Name of composite	Maximum value of Equivalent strain
AZ91+ 0.5 wt.% GNP	0.00031516
AZ91+ 30 wt.% TiC	0.00041219
Mg + 1Al + 0.6 CNT	0.00032062
AZ91D + 1.5 % B_4C	0.00043447
Mg + 10% TiC + 5% MoS_2	0.0004467
Mg + 5% Graphite	0.0004515

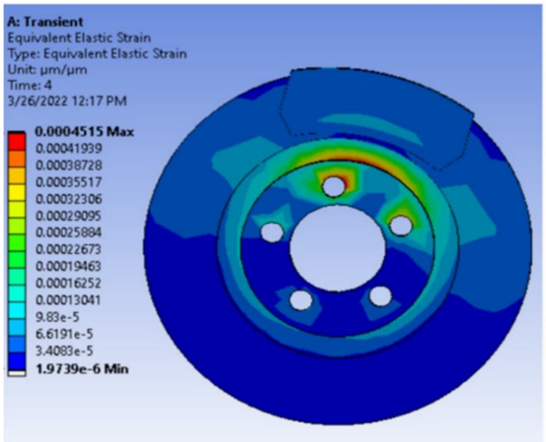
It was observed that the minimum value of the equivalent strain was very low as a result we have taken only the upper limit of the simulation results for analysis. From table 5 and figure 4 it was seen that AZ91+ 0.5 wt.% GNP had minimum value (i.e., 0.00031516) of the equivalent strain. Mg + 1Al + 0.6 CNT composite as seen in table 5 had the next lowest value of equivalent strain. It was observed that AZ91+ 30 wt.% TiC and AZ91D + 1.5 % B4C had approximately equal values of equivalent strain. Out of all the six composites Mg + 10% TiC + 5% MoS2 composite had the highest value of maximum strain. The maximum equivalent strain was seen on the brake pad in Mg + 5wt% Graphite and Mg + 10% TiC + 5% MoS2 composite as shown in figure 4e and 4f. However, in case of all the other composites (refer to figure 4a, 4b, 4c, 4d) the equivalent strain was distributed across the entire disc and not concentrated on the brake pad only



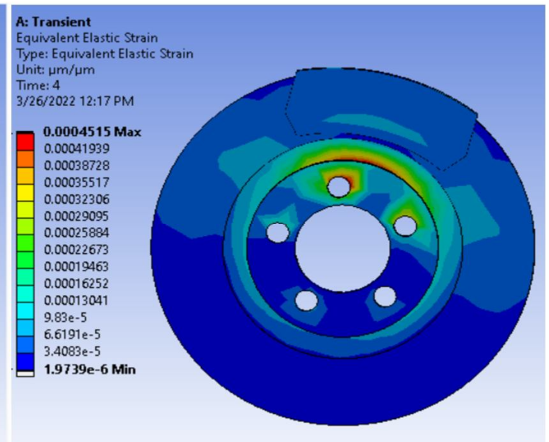
a) AZ91 + 0.5 wt.% GNP b) AZ91+ 30 wt.% TiC



. c) Mg + 1Al + 0.6 CNT d) AZ91D + 1.5 % B_4C



e) Mg + 10% TiC + 5% MoS_2



f) Mg + 5% Graphite

Fig.4 (a, b, c, d, e, f) Equivalent strain of six magnesium composites

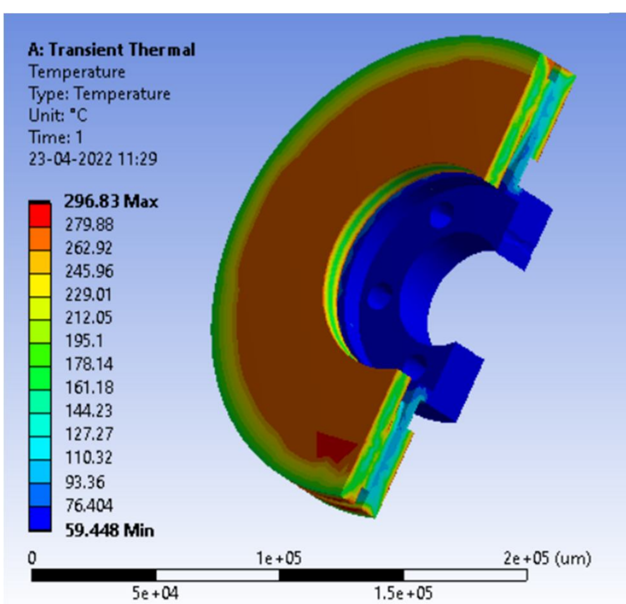
E. Thermal Analysis

The thermal simulation of the disc and pad was carried out under the boundary conditions stated in Table 1. This simulation was carried out in order to observe the temperature gradient of the disc when the brake pads were subjected to a pressure of 1 MPa. Table 6 gives details about the values of thermal conductivity of the different composites used in the study.

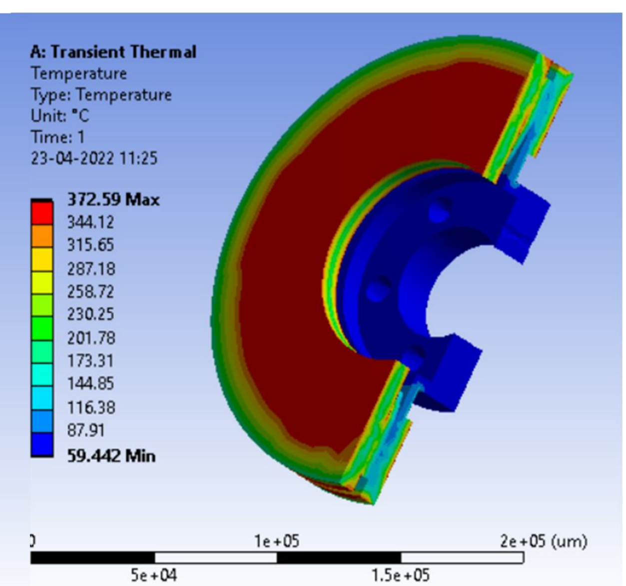
Table 6. Thermal properties of the six Magnesium composites

Property	AZ91 + 0.5 wt% GNP	AZ91 + 30 wt% TiC	Mg + 1 Al + 0.6 CNT	AZ91D + 1.5 wt% B_4C	Mg + 10 % TiC + 5 wt% MoS_2	Mg+ 5 wt% Graphite
Thermal conductivity (W/mK)	200	80	197	82	165	298.2

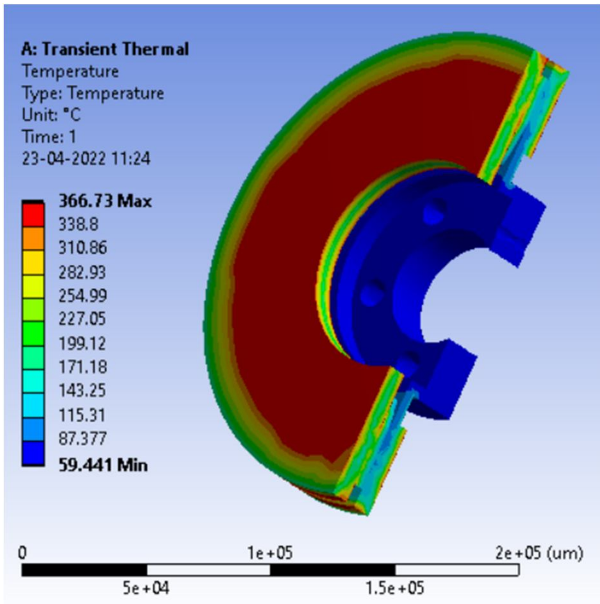
The thermal simulation results of the composites are shown in the following figures.



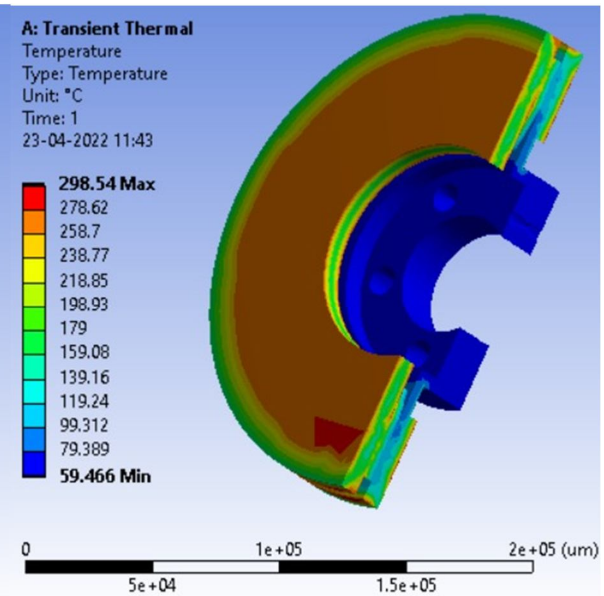
a) AZ91+30wt%TiC



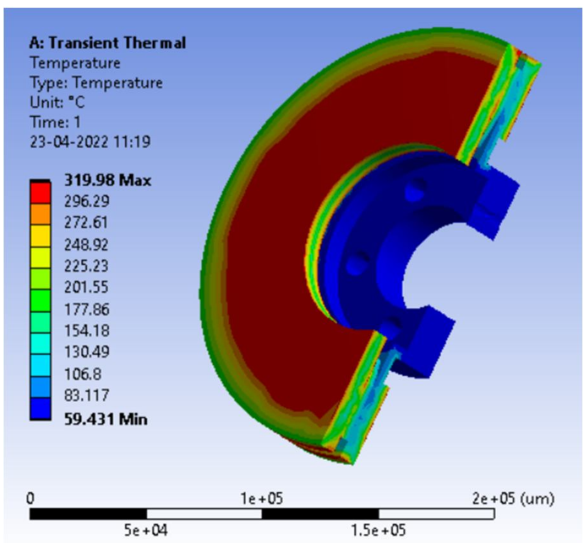
b) AZ91+0.5wt%GNP



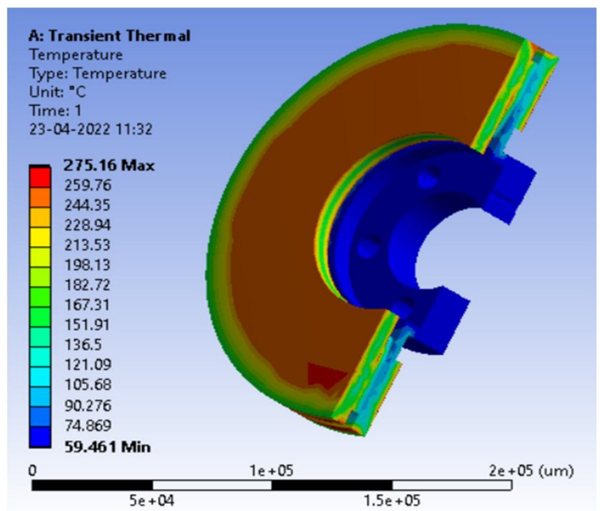
c) AZ91+1.5 wt.% B_4C



d) Mg+1Al+0.60CNT



e) Mg + 10 % TiC + 5 wt% MoS_2



f) Mg+ 5 wt% Graphite

Fig.5 (a,b,c,d,e,f) Thermal analysis of the six magneisum composites

The range of temperature observed for each composite after simulation is given in table 7

Table 7. Temperature ranges of the six Magnesium composites

Name of composite	Temperature range (in ^oC)
AZ91+ 0.5 wt.% GNP	59.448 – 296.83
AZ91+ 30 wt.% TiC	59.442 - 372.59
Mg + 1Al + 0.6 CNT	59.429 – 298.54
AZ91D + 1.5 % B_4C	59.367 – 366.73
Mg + 10% TiC + 5% MoS_2	59.430-319.98
Mg + 5% Graphite	59.461 – 275.16

From the simulation results as shown in figure 5 it was seen that Mg+ 5 wt% Graphite, AZ91+ 0.5 wt.% GNP and Mg + 1Al + 0.6 CNT had a low range of temperature.

The maximum temperature of Mg+ 5 wt% Graphite, AZ91+ 0.5 wt.% GNP and Mg + 1Al + 0.6 CNT was 275.16, 246.17 ^{o}C and 253.98^{o}C respectively (as shown in table 7.). Analysis of the simulation results showed that the temperature was distribute uniformly across the disc. It was seen that in all composites the temperature increased radially outwards. Lower temperatures were seen at the centre of the disc.

AZ91+ 30 wt.% TiC and AZ91D + 1.5 % B_4C showed maximum temperature of 372.59^{o}C and 366.73^{o}C respectively. The highest temperature achieved for was approximately same. However, there was difference in the minimum temperature values of both the composites (as shown in figure 5c and 5d).

III. RESULT AND DISCUSSION

The structural and thermal behaviour of six different magnesium composites were analysed by doing simulation in the ANSYS software. The magnesium composites were subjected to the same boundary conditions of temperature and pressure in order to do comparative analysis.

Once the simulations were executed, the results of the simulation were plotted in order to analyse the behaviour of each type of composite under the boundary conditions.

The thermal behaviour of the composites during the simulation are shown in figure 5, figure 6 depicts total deformation, figure 7 depicts the equivalent stress and figure 8 depicts equivalent strain.

It can be observed from figure 5 that AZ91+0.5wt%GNP and Mg+1Al+0.60CNT displayed very less range of equivalent strain (i.e., $3*10^{-4}$ and $3.1*10^{-4}$ respectively). While the Mg + 10% TiC + 5% MoS_2 had maximum equivalent strain (i.e., $4.5 * 10^{-4}$). Results from figure 6 showed similar results that AZ91+0.5wt%GNP and Mg+1Al+0.60CNT had very low equivalent stress (i.e. 25 MPa and 30 MPa respectively). Total deformation results are discussed in figure 7. It was observed that AZ91+0.5wt%GNP and Mg+1Al+0.60CNT had the lowest deformation (i.e., 28.57 µm and 30 µm respectively) whereas Mg + 10% TiC + 5% MoS_2 had maximum deformation (i.e., 46.581).

The results of structural simulations highlighted that AZ91 + 30wt% TiC and AZ91 + 1.5 wt.% B_4C had considerably more deformation, stress and strain as compared to the above discussed two materials but showed better strength and elastic properties as compared to Mg + 10% TiC + 5% MoS_2 and Mg + 5% Graphite. The results of thermal simulation also showed that AZ91+0.5wt%GNP and Mg+1Al+0.60CNT composites had a lower range of temperature as compared to all the other composites except Mg+5 % Graphite.

This low temperature gradient of Mg+5 wt.% Graphite was observed because of its high conductivity, due to the presence of Graphite layer in it. However, unlike CNT and GNP composites the presence of this graphite layer was not able to give very high structural strength to the composite. The thermal gradient across the disc highlighted that during braking mechanism, the heat was distributed uniformly across the entire disc.

One of the major reasons for the good structural behavior of CNT and GNP based magnesium composites was the presence of respective honey comb lattice. This kind of lattice displays very high strength and specific area per unit volume which helps in the uniform distribution of load. Under the tensile loading the stress gets transferred from strained matrix to the reinforced lattice. [12]has also reported that GNP as a reinforcing material improved the tensile properties and increased the strain to fail rate. It was found that the addition of 0.3 wt.% GNP to the pure Mg matrix increased its elastic modulus, yield strength, UTS by 10.6%, 5% and 8%, respectively.

In case of Mg+1Al+0.60CNT high aspect ratio is observed as a result dislocation cannot easily overcome the obstacle, which increases the creep resistance of the material.

Hall Petch Strengthening mechanism occurs in CNT, based on the refinement of the grains, and is responsible for explaining the enhancement in compressive yield strength of CNTs reinforced MMCs. [17]reported that magnesium CNT composite prepared through friction stir welding reported a 90 % increase in hardness.

In the case of Mg + 10% TiC + 5% MoS_2 low values of hardness and other structural properties was observed, due to interfacial reaction of the composite along with the formation of brittle reaction associated with the surface and delamination in the reinforcing materials towards the matrix. It was observed that AZ91 + 30wt% TiC and AZ91 + 1.5 wt.% B_4C, showed good structural and thermal properties for small amounts of additives (i.e., TiC and B_4C). However, increasing the proportion of these additives deteriorated the thermal and mechanical properties of the two above mentioned

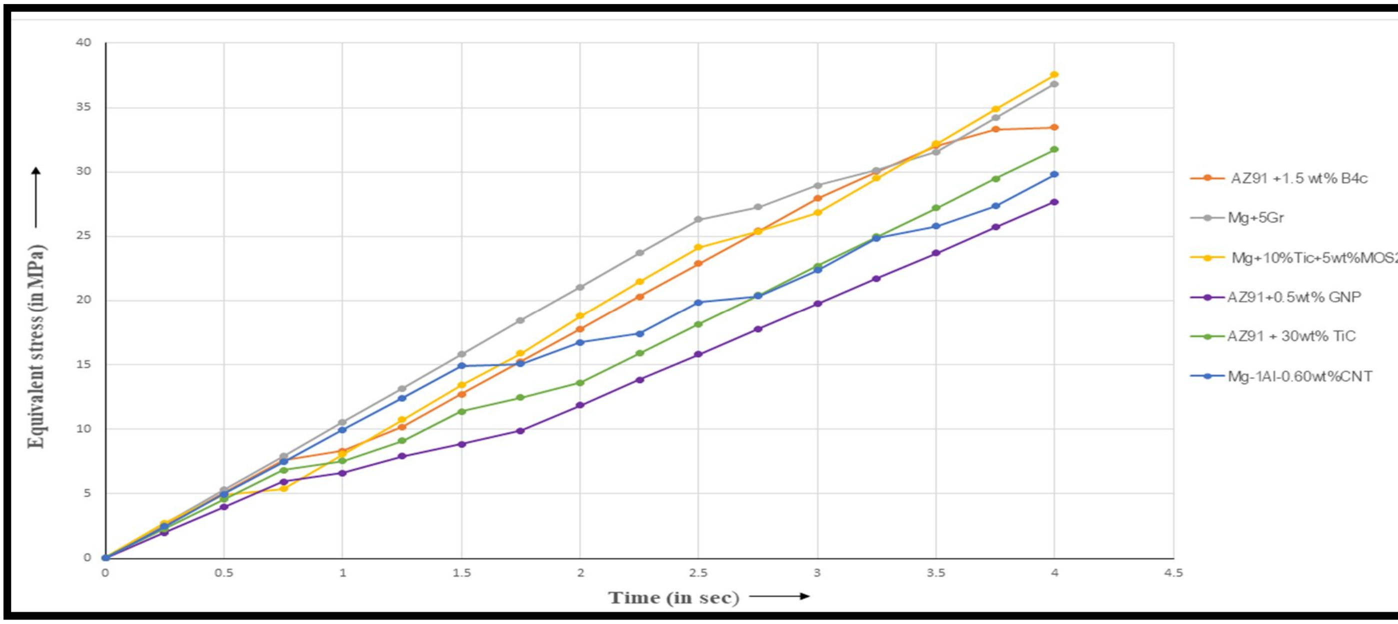


Fig 5 Equivalent Strain

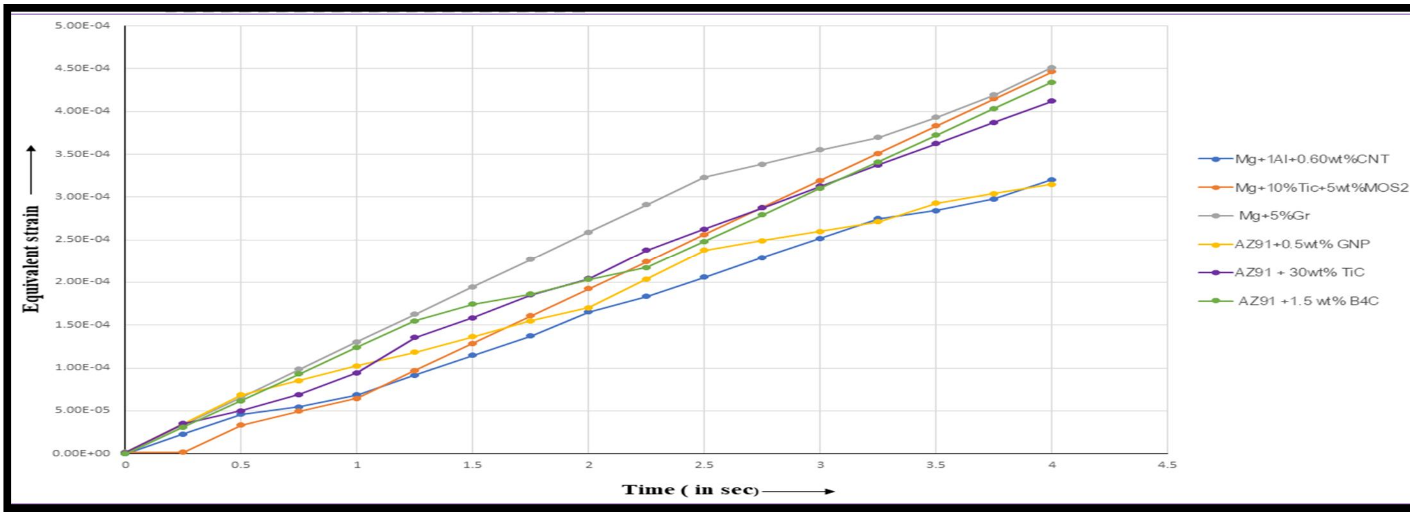


Fig.6 Equivalent stress

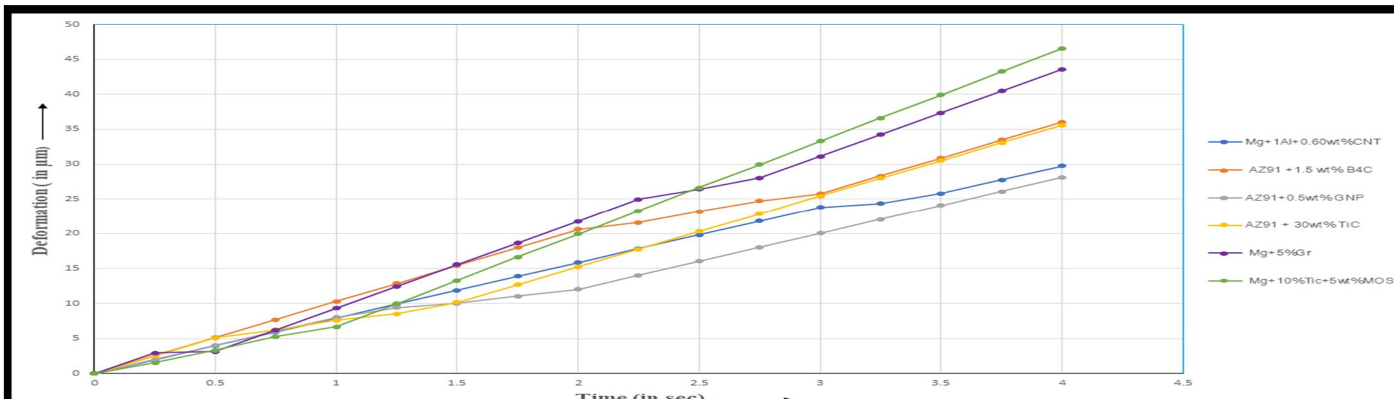


Fig.7 Total Deformation

IV. CONCLUSION

1) From the structural and thermal simulation results it was concluded that AZ91+0.5wt%GNP and Mg+1Al+0.60CNT were the ideal composites for making brake pad friction material.
2) There is a need to validate the simulation results through lab experiments.

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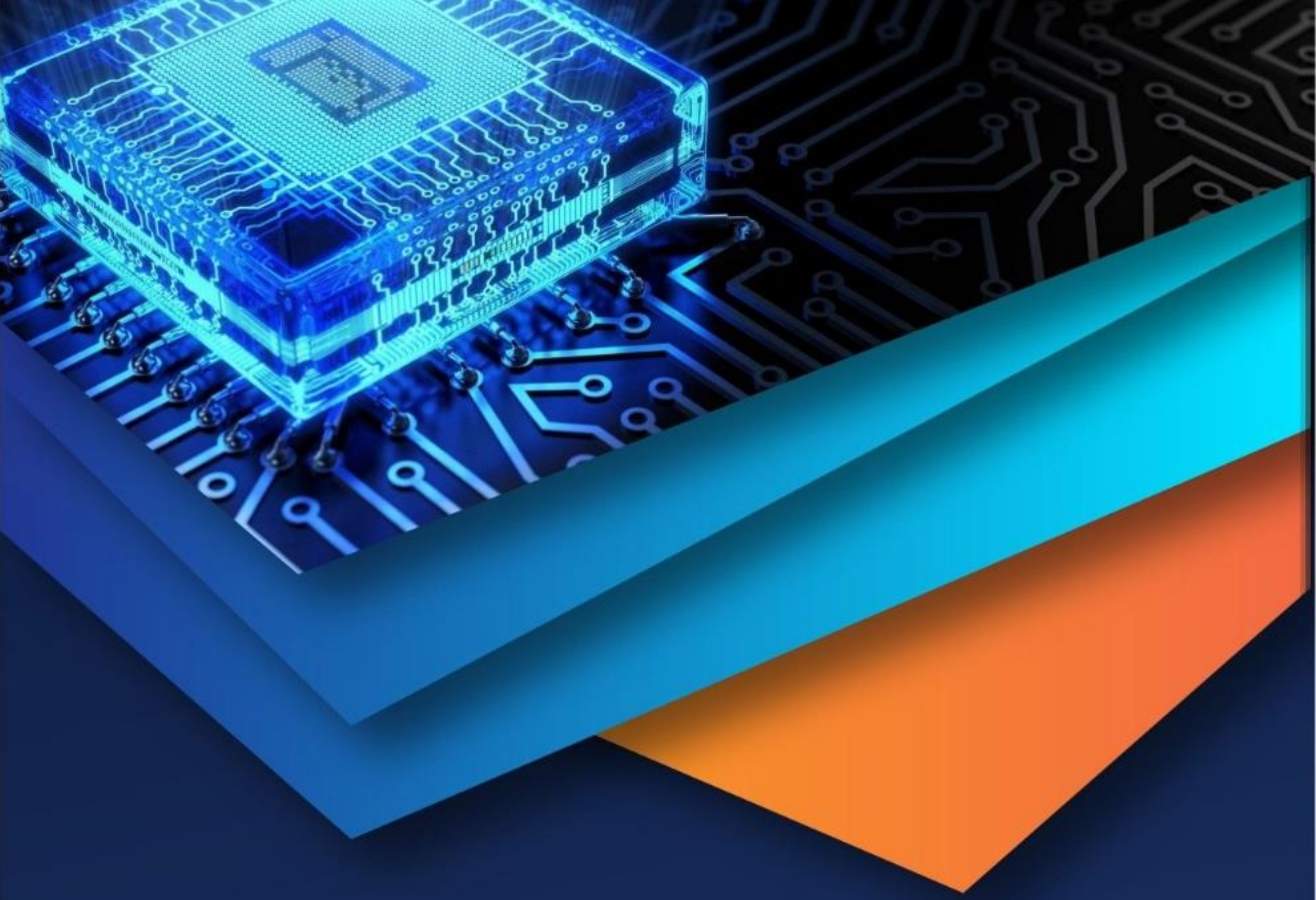

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