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Computational Investigation of Square Embedded Delamination of a Composite Laminate using Surface based Cohesive Contact Behavior

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Abstract: The fiber reinforced polymer laminates have found extensive applications because of its advantages over other materials in terms of thrust to weight ratio, strength to weight ratio, manufacturing benefits such as tailoring, resistance to erosion and corrosion and so on. In the transverse direction, strength, stiffness and stability are comparatively less so that a failure mechanism called interface delamination comes into picture due to poor manufacturing or when tools are dropped that would create an impact load. In this paper, Surface based Cohesive contact behavior is implemented at the interface between base and sub laminate to investigate for 60mm square embedded buckling driven delamination growth. The computational prediction of delamination growth initiation is obtained by solving a HTA/6376C composite laminate specimen for geometric non linearity using SC8R continuum shell elements of Abaqus CAE and by plotting the inplane loads versus out of plane displacements.
Keywords: Square Embedded Delamination, Surface based cohesive contact behaviour, uniaxial compression, B-K criterion, energy release rate.

I. INTRODUCTION

The failure mechanisms of a Fiber Reinforced Polymer materials are matrix debonding, matrix cracking, interface delamination, micro buckling, fiber bridging, kink bands and fiber pullout. And the attention of this paper is on interface delamination under uniaxial compressive loads. Delaminations are known to weaken the overall strength and stiffness of the specimen which diminishes the load bearing capacity under compressive loads. The reasons for causes of delamination are cut outs, Load generating transverse stresses, Impact, In-service loads, notch, Material and structural discontinuities, bonded joints and plydrop. Practically the interface is weaker in the transverse direction which will lead to great transverse and normal stresses which would induce interlaminar stresses that would lead to separation of layers. Therefore the interface is weaker compared to that of other directions of plies. Hence it is essential to predict the delamination initiation growth by means of damage tolerance technique [1].

II. LITERATURE SURVEY

When no information was available, the basic foundation works were achieved by Chai et al for 1D and 2D problems [2][3]. Whitcomb and Shivakumar examined the delamination growth due to the local buckling of a composite plate with square and rectangular embedded delaminations [1].

The buckling and post buckling behavior of debonded composite laminates were considered by Wang and Zhang [4]. Nilsson et al explored the delamination buckling and growth of cross ply composite panel using numerical and experimental methods and showed that for all delamination depths, the delaminated panels failed by delamination growth below the global buckling load of the undamaged panel. Also, they found that the energy release rate of laminate is increased when global buckling mode takes place [5]. Albiol studied the buckling and post buckling behavior of composite laminates containing embedded delamination in the composite laminate with artificial delamination. They studied the effect of various parameters on predicted response in the post buckling [6].

III. METHODOLOGY

The methodology is carried out by surface based cohesive behaviour that works on the basis of traction separation relationship [7] that defines linear elastic behaviour of normal and shear stresses at the interface defined by,

$$\mathbf{t} = \begin{Bmatrix} t_n \\ t_s \\ t_t \end{Bmatrix} = \begin{bmatrix} K_{nn} & K_{ns} & K_{nt} \\ K_{ns} & K_{ss} & K_{st} \\ K_{nt} & K_{st} & K_{tt} \end{bmatrix} \begin{Bmatrix} \delta_n \\ \delta_s \\ \delta_t \end{Bmatrix} = \mathbf{K}\boldsymbol{\delta}.$$

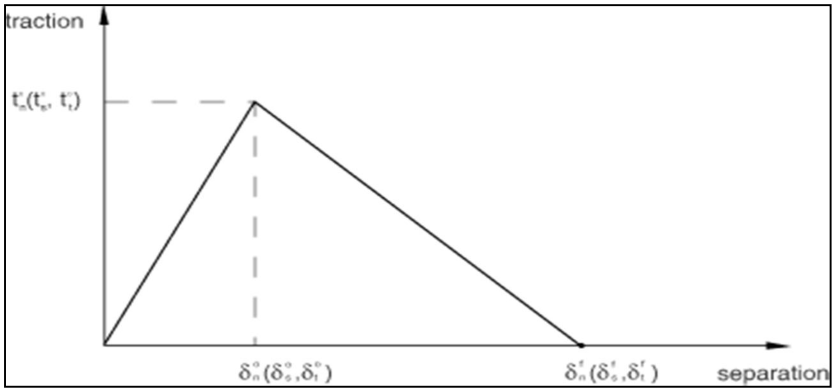

Fig 1: Cohesive surface showing Traction v separation

Where t is nominal traction stress vector and includes t_n, t_s and t_t. t_n is normal traction and t_s, t_t are the shear tractions. In addition, the corresponding separations are denoted by δ_n, δ_s and δ_t. The cohesive contact behavior comprises 2 phases; they are damage initiation and damage evolution. Basically damage initiation occurs when the cohesive behavior (as shown in the figure 1) at a point in the contact domain starts degrading which is captured by quadratic stress criterion given by

$(\langle t_n \rangle / t_{no})^2 + (t_s/t_{so})^2 + (t_t/t_{to})^2 = 1$

Where t_{no}, t_{so}, t_{to} represents the values of the highest contact stress (traction). The damage evolution law shows the cohesive stiffness degradation. Fig.1 shows the cohesive law for single loading. A scalar damage variable, *D*, represents the damage at the contact point given in [7] as

$$D = \frac{\delta_m^f (\delta_m^{max} - \delta_m^0)}{\delta_m^{max} (\delta_m^f - \delta_m^0)}$$

which δ_m^{max} refers to the maximum value of the effective separation, δ_{mf} is the effective separation at complete failure and δ_{mo} is relative to the effective separation at the initiation of damage. The constitutive response of Fig. 1 can be written as

$t = K_p\delta \quad \delta < \delta_o$

$t = (1-D)K_p\delta \quad \delta_o \le \delta \le \delta_f$

$t = 0 \quad \delta \ge \delta_f$

For delamination growth initiation, B-K criterion is applied [9].

For practical problems, delamination growth occurs due to energy release rates in all 3 directions namely normal and 2 shear directions. Therefore total energy release rate is given by $G_T = G_I + G_{II} + G_{III}$ and the nodes open up and the damage grows when the condition $G_T/G_C \ge 1$ is satisfied, where critical energy release rate is found by B-K criterion that has contribution from all 3 modes given by $G_C = G_{IC} + (G_{IIC} - G_{IC})(G_S/G_T)^\eta$, where $G_S = G_{II} + G_{III}$.

Now a HTA/6376C composite laminate specimen having stacking sequence of [90/(0/90)3//(0/90)14] is considered as in [6]. The symbol // shows pre-delamination location in the material. The geometry of specimen with single delamination is shown in the Fig. 1. The material properties of HTA/6376C composite plate are E11=131 GPa, E22=E33= 11.7 GPa, G12=G13=5.2 GPa, G23 =3.9 GPa, ν12 = ν13 =0.3, ν23=0.5, N=30 MPa, S=T=30MPa, G_I^C= 260 (J/m2) and $G_{II}^C = G_{III}^C$=1025(J/m^2).

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The total thickness of the laminate is h=4.5mm as shown in the Fig 2.

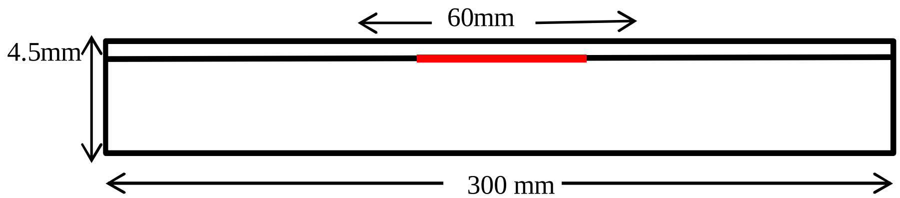

Fig 2: Illustration of the specimen

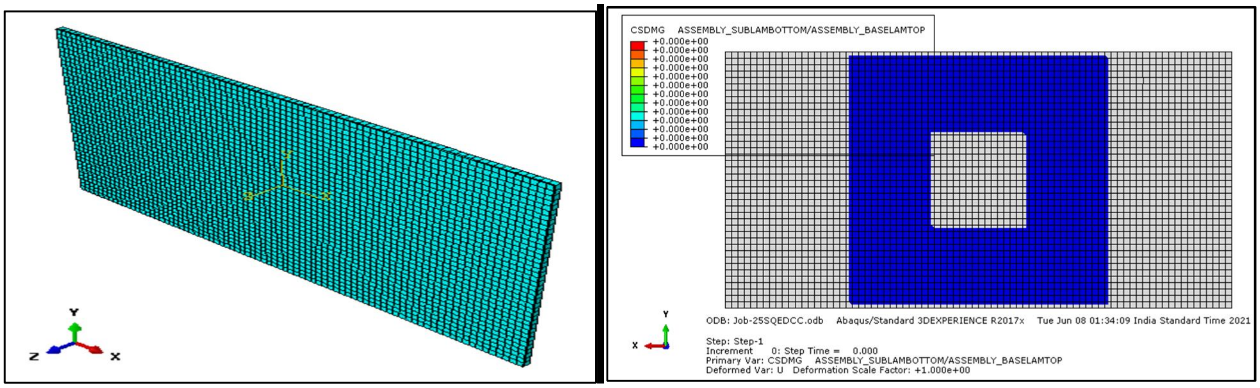

Fig 3: Meshed plate and initial delamination geometry

The above Fig 3 shows the meshed plate and initial delamination geometry of the specimen whose boundary conditions are u1=u2=u3=0 on the left extreme side, and u2=u3= 0 on the right side with a compressive load of u1=2mm compressive load is applied for the first step in terms of displacement. And for the second step, 5mm is applied.

IV. RESULTS AND DISCUSSION

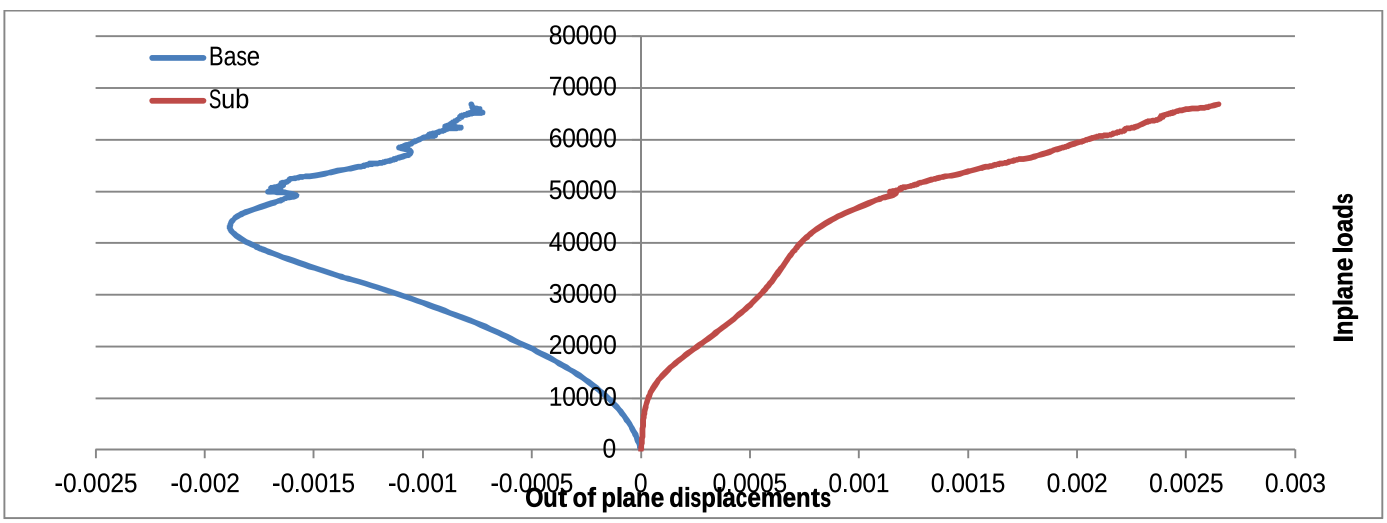

Fig 4: Inplane loads vs Out of plane displacements

Inplane loads at the left support versus out of plane displacements at the centre of the base and sublaminate is plotted as shown in Fig 4. From the plot it can be clearly observed that delamination initiation growth and Local buckling can be observed at 11.92KN. The initial post-buckling response is ruled by the buckling of the thinner sub-laminate alone which is known as thin-film buckling. Postbuckling behaviour can be either stable or unstable. In this analysis, stable post-buckling happens initially followed by local buckling occurs at 11.92KN and after the delamination growth initiation, the shape of the laminate slowly changes to sinusoidal shape in the longitdunal direction and becomes unstable followed by collapse much later.

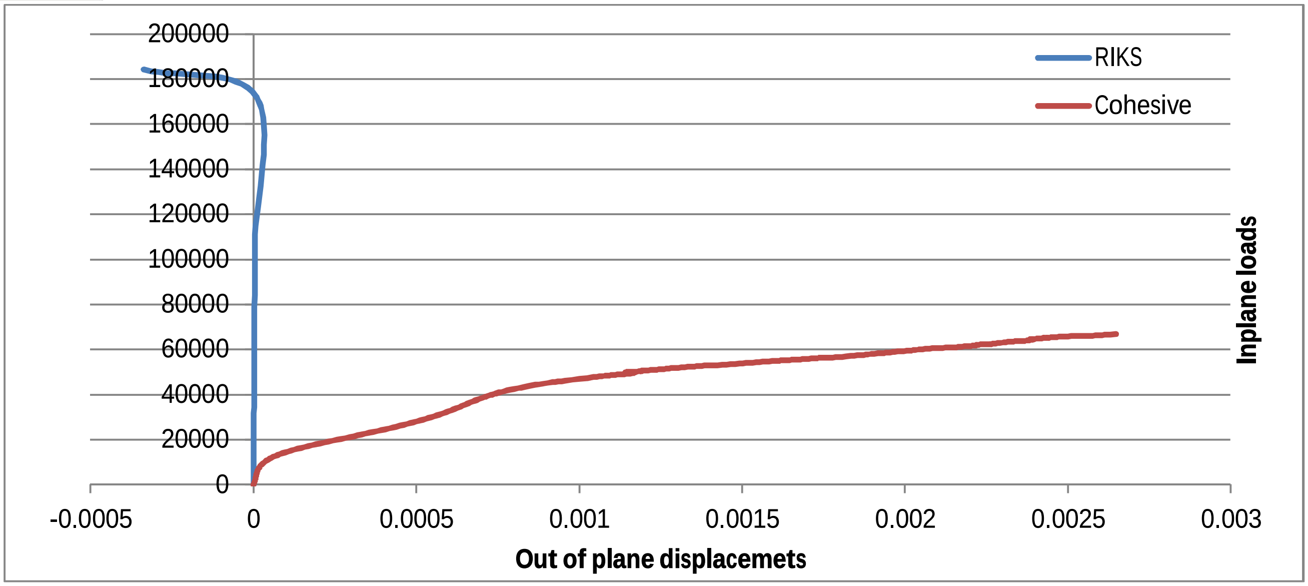

Fig 5: Inplane loads vs Out of plane displacement

Fig 5 shows plot of inplane loads versus out of plane displacement of the specimen considered in this paper by RIKS method and Delamination using surface based cohesive contact method. It is clear that the overall load carrying capability has reduced considerably which is about 66.85KN because the analysis is not carried until collapse and is stopped much earlier right after the laminate becomes unstable and tends to become sinusoidal in the longitudinal direction.

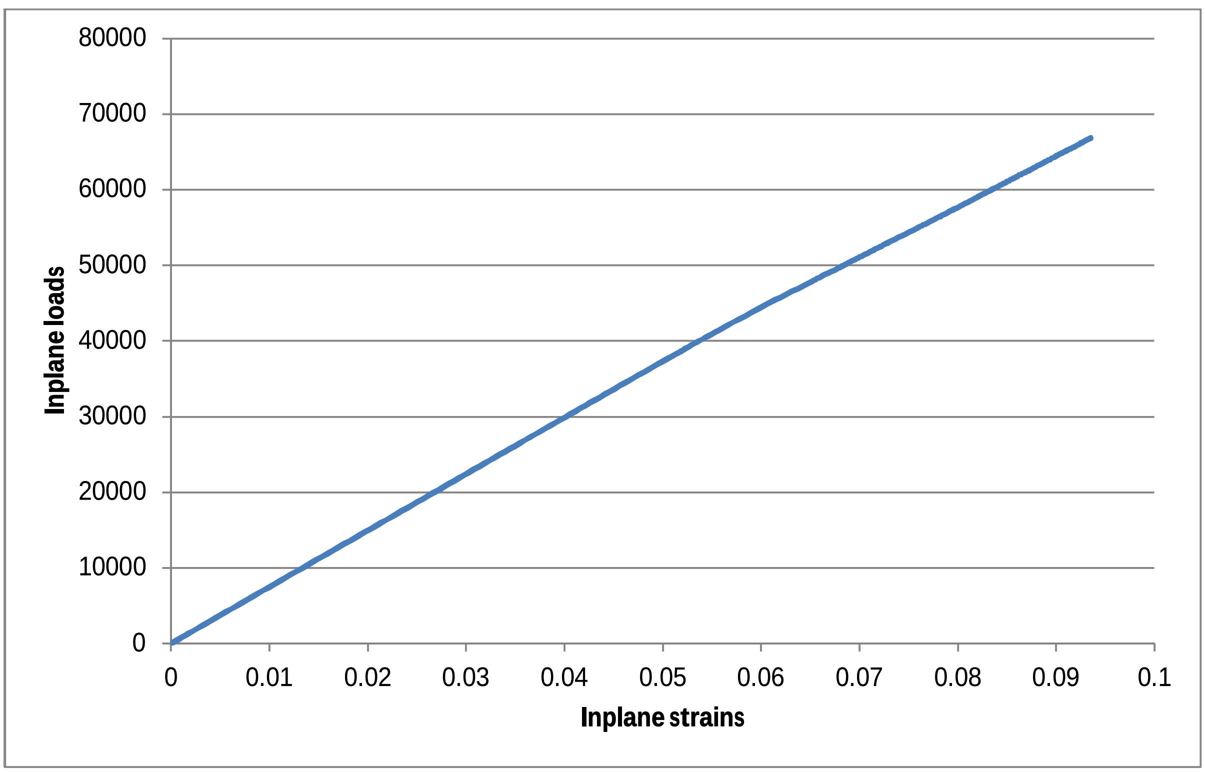

Fig 6: Inplane loads vs Inplane strains

The above Fig 6 shows the behavior of the specimen in which inplane loads versus inplane strains is plotted in which local buckling is not clear even when the laminate becomes unstable. It only behaves linearly throughout the process.

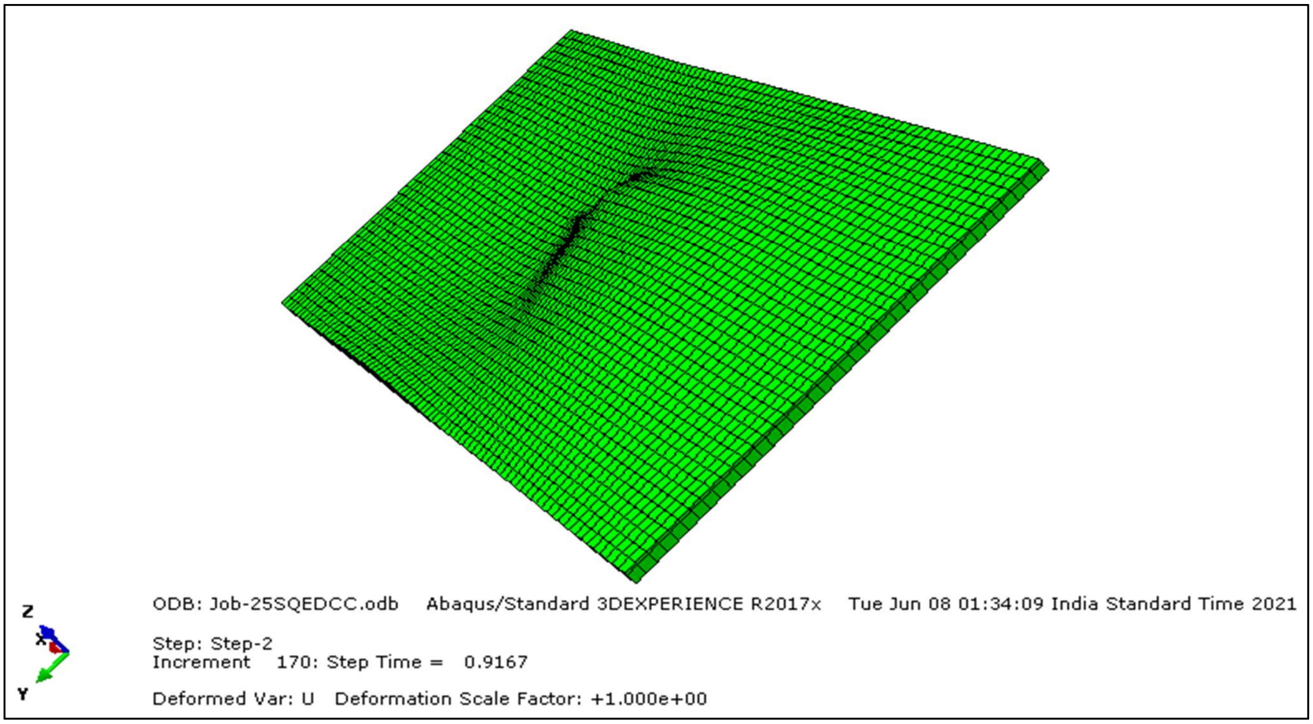

Fig 7: Deformed plot of the laminate

Fig 7 shows the deformed plot of the laminate after the analysis is completed.

V. CONCLUSION

In this paper a specimen considered from [8] is analyzed computationally using surface based cohesive contact behaviour in ABAQUS CAE. From the analysis, buckling, post buckling using both RIKS and surface based cohesive behaviour has been observed and compared for reduction in load carrying capacity followed by damage evolution and the transitions made by base and sub laminates so that local buckling, unstable delamination were observed.

VI. ACKNOWLEDGEMENT

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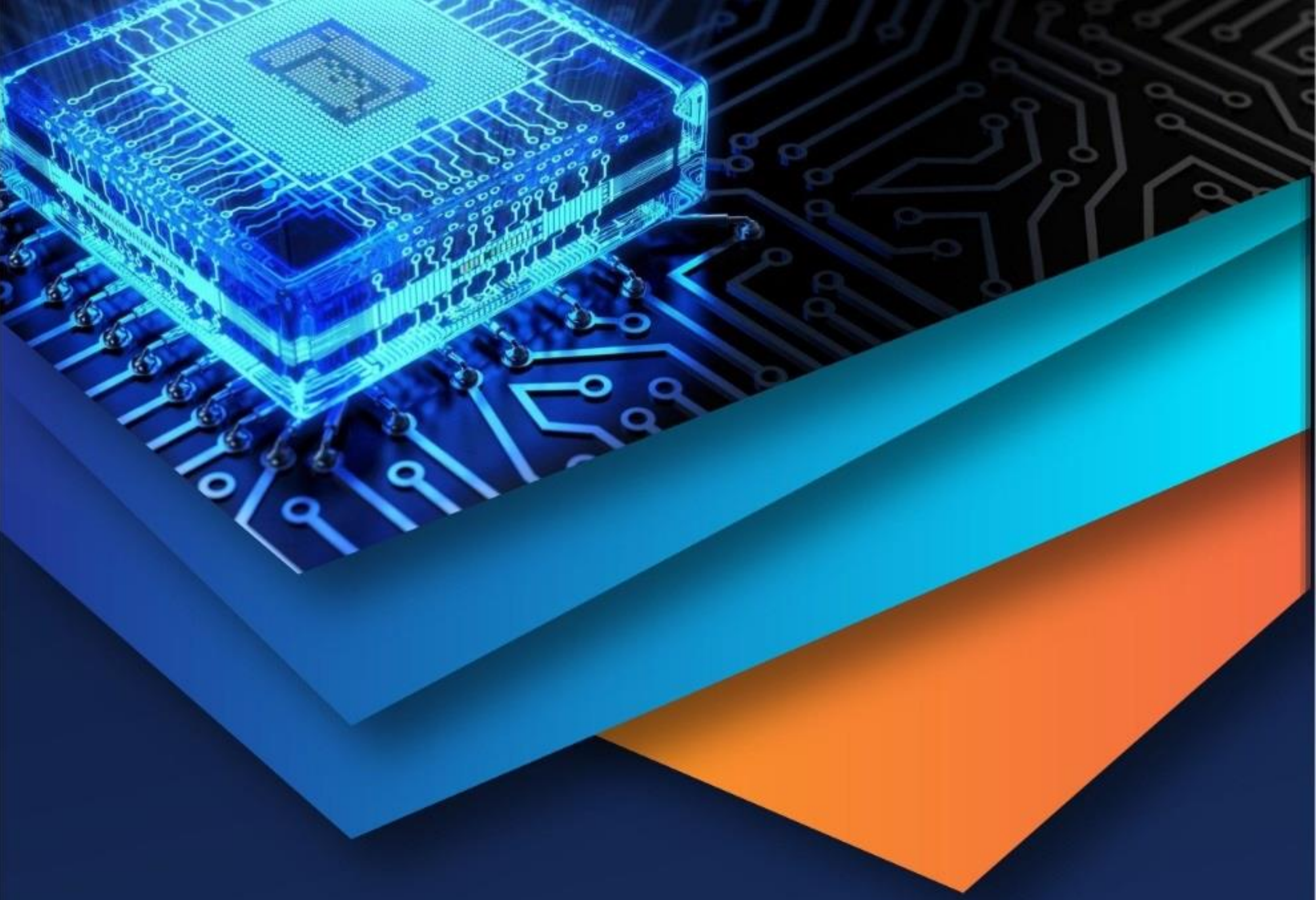

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