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Mixed Mode Crack Propagation Analysis using XFEM

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Abstract: In all across the globe, we encounter to different situations where we face serious challenges in designing of pressure vessels, aerofoil shapes for aerospace industry, civilian structures, pipe lines, automobiles sector. These all structures are dominated by loading conditions of complex type. Under such situation, notches & cracks play very important role in deciding the destiny of safety and leading to catastrophic failures. Crack growth takes place under combined effect of tensile and shear force [MIXED MODE TYOE]. A well known specimen for fracture tests is PMMA [polymethyl methacrylate]. It has tendency to fail as brittle manner under room temperature and moderate loading rates. Also it has factors such as machinabilty, low cost, convenience in test specimen preparation and optical transparency direct observation of the crack tip region and the crack growth path. So, experiments were performed on DLSP specimen [diagonally loaded square plate]. Also to take account of crack trajectory, a special technique called XFEM [extended finite element analysis] was used in ABAQUS software. Crack initiation angles were also deducted with numerical methods of MTS criteria and matched with results of XFEM as well as experimental data. After DLSP, SENT [side edge notched tension] and SCB [semi circular bend] were also analyzed.
Keyword: 1. Mixed Mode and Pure Mode, 2. Crack propagation, 3. Fracture mechanics, 4. XFEM, 5. PMMA

I. INTRODUCTION

Engineering structures can fail due to various reasons, including uncertainties in the loading or environment, inappropriate design, defects in the materials, and deficiencies in construction or maintenance. Generally disasters occur because engineering structures contain cracks-arising either during production or during service, and the results can be fatal. Human mankind have witnessed many Catastrophes in wide ranges of applications involving aeronautics, automobiles, bridges and highways, and great loss has been induced in human life along with economics. Defects in materials are inevitable, and complex factors are often involved in the scope of the entire picture. The principles of mechanics for continuous media break down when engineering structures contain cracks. Over the past 50 years, contributions have been made for the understanding of crack-related structural failures and various approaches were introduced to deal with the problems. Material science looks into the microscopic composition and crystallographic defects of materials and provides us with understandings about the fundamentals of crack nucleation and crack propagation. Fracture mechanics aims at studying the driving force on a macroscopic crack and the material's resistance to fracture. Research is mainly divided into two categories: brittle fracture and ductile fracture, depending on the macroscopic deformation characteristics of the material without considering time-dependent behaviour.

II. EXPERIMENTAL WORK

1) *Material Selection:* Poly methyl methacrylate (PMMA) is a well-known polymer that usually fails in a brittle manner at room temperature and under moderate loading rates. Due to its good mechanical and physical properties, PMMA has been widely used in many laboratory fracture studies. This is because of its certain advantages like: brittle type of fracture at room temperature, machinability and optical transparency that allows a direct observation of the crack tip region and the crack growth path using optical methods such as caustics. In addition to its role as a suitable test material, PMMA has also found many practical applications in engineering components and structures. For example, in orthopaedic surgery the PMMA bone cements are commonly used for fixing or replacement of artificial joints as cemented prostheses to the hosting bone. Therefore, the crack growth analysis of such materials under complex tensile and shear loading conditions (i.e. mixed mode I/II) is an important task for designing biomedical components. PMMA (cast Acrylic) sheet of 4mm used to prepare specimens. Geometry of test specimens is taken as specified in ASTM D638-02a for material property.
2) *Model Geometry:* 3D Deformable geometry of the DLSP specimen made of PMMA material considered in this analysis. Dimension of the specimen are taken as shown in Fig.3.4 with 4 mm thickness. All parts were modelled with elastic material models. The material properties used in these simulations are shown in Table 3.1 for PMMA. The XFEM analysis requires additional material information in the enriched area of the crack. The maximum principal stress criteria (Maxps Damage in Abaqus) was selected for the damage initiation criteria. The calculated true ultimate strength was used as the limiting maximum principal stress [11]. Fracture energy was used for the damage evolution criteria

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Material Property	Value
Young's Modulus	2940 MPa
Poisson's Ratio	0.38
Ultimate Stress	46.2 MPa

Material properties PMMA

A. Specifying XFEM in ABAQUS

Model containing a precrack so the following steps to be done:

Part Module →Create a 3D deformable solid for a UN cracked part and 3D deformable shell for model crack. Fig. 3.12 shows the UN cracked and crack model separately.

1) Assembly Module →Translate the crack instance in the place where precrackis situated that can be seen in Fig. 3.13
2) Interaction Module→ Special→ Crack →ManagerCreate→ XFEM→Continue →Select sections or part for crack location →Allow crack growth (checkbox) →Crack location (check box) →Select Planar Shell part that represents the crack! Specify contact property →okay
3) Mesh Module →An aspect ratio near 1 for the element dimensions in the enriched area are used. In order to visualize the crack in the output database the following changes need to be made to the Step Module:
4) Step Module → Output → Field Output Requests → Manager→F-Output1→Edit→Fracture/Failure→PHILS→STATE/FIELD/USER/TIME →STATSXFEM →OKAY

B. DLSP: Diagonally Loaded Square Specimen

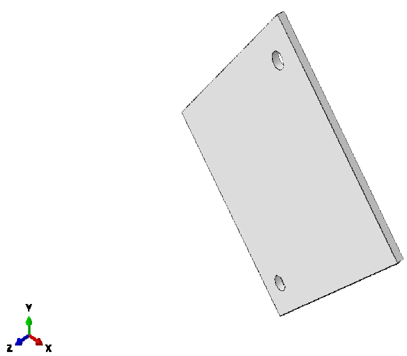

Fig1.Part 1

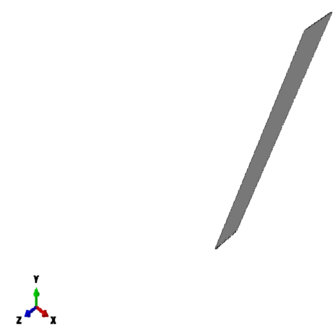

Fig2. Part 2

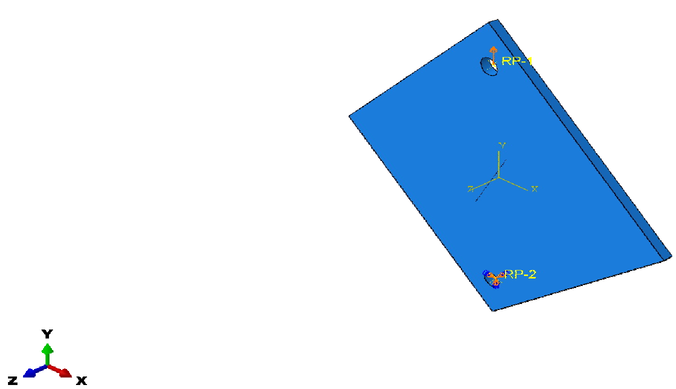

Fig3.Boundary conditions, assembly & interaction

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Fig4. Meshing

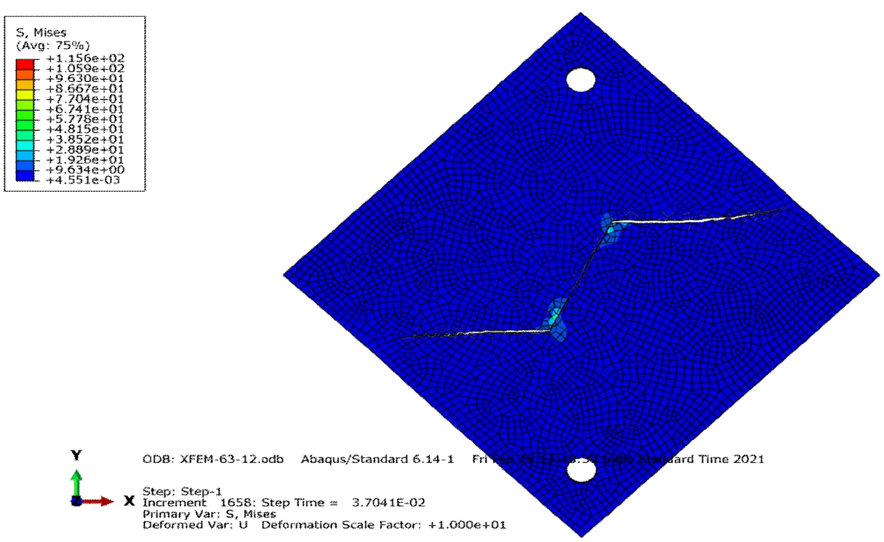

Fig5. Crack growth trajectory in ABAQUS using XFEM

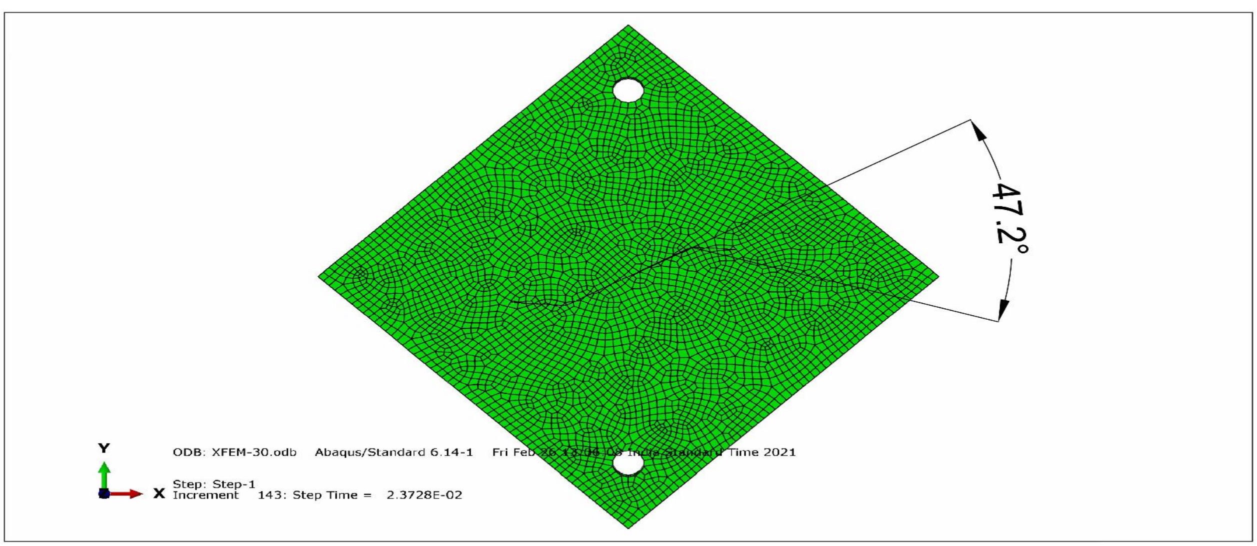

Fig6. Crack initiation angle

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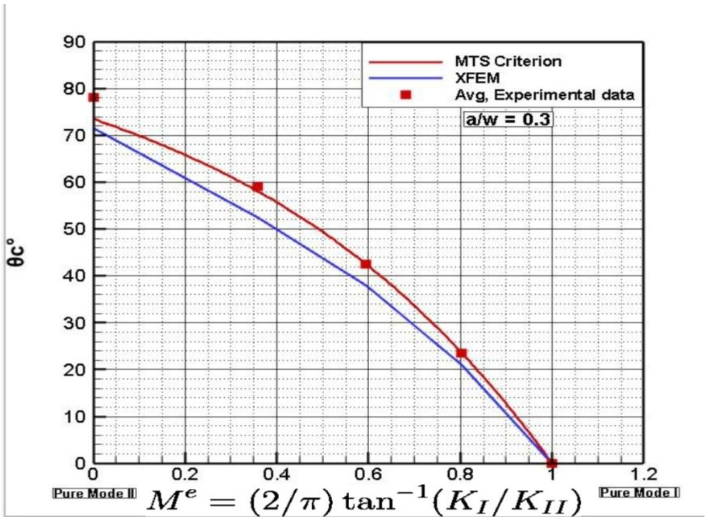


Fig7. Crack Initiation Angle through MTS & XFEM:-

C. SENT [Side Edge Notch Tension]

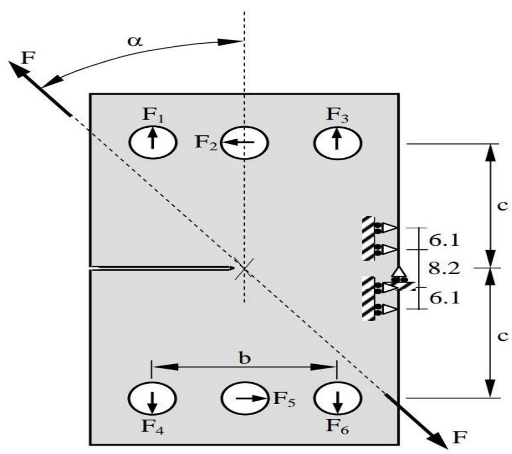
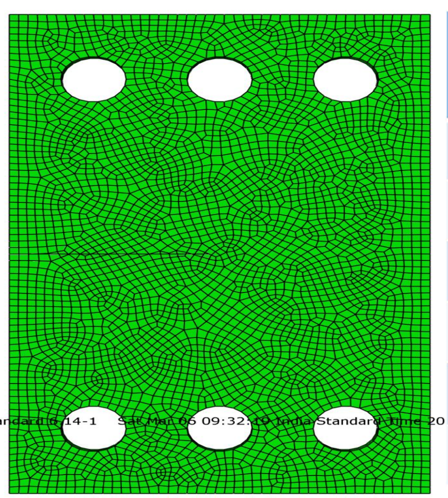


Fig8. Force Value and Direction in Software (ABAQUS)



Loading Direction From Vertical Axis.
0^0
18^0
36^0
54^0
72^0
90^0

Fig9. Loading angles.

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D. Force Value

	α	RP1	RP2	RP3	RP4	RP5	RP6	F
		CF2	CF1	CF2	CF2	CF1	CF2	
		F1	F2	F3	F4	F5	F6	
Pure MODE I	0	681	0	681	-681	0	-681	1362
mix mode	18	1038.73791	-409.138501	220.460913	-220.460913	409.138501	-1038.73791	1324
	36	1359.44244	-805.265796	-251.089154	251.089154	805.265796	-1359.44244	1370
	54	1615.76259	-1185.2099	-754.657199	754.657199	1185.2099	-1615.76259	1465
	72	1855.13809	-1595.87283	-1336.60758	1336.60758	1595.87283	-1855.13809	1678
Pure MODE II	90	2118	-2118	-2118	2118	2118	-2118	2118

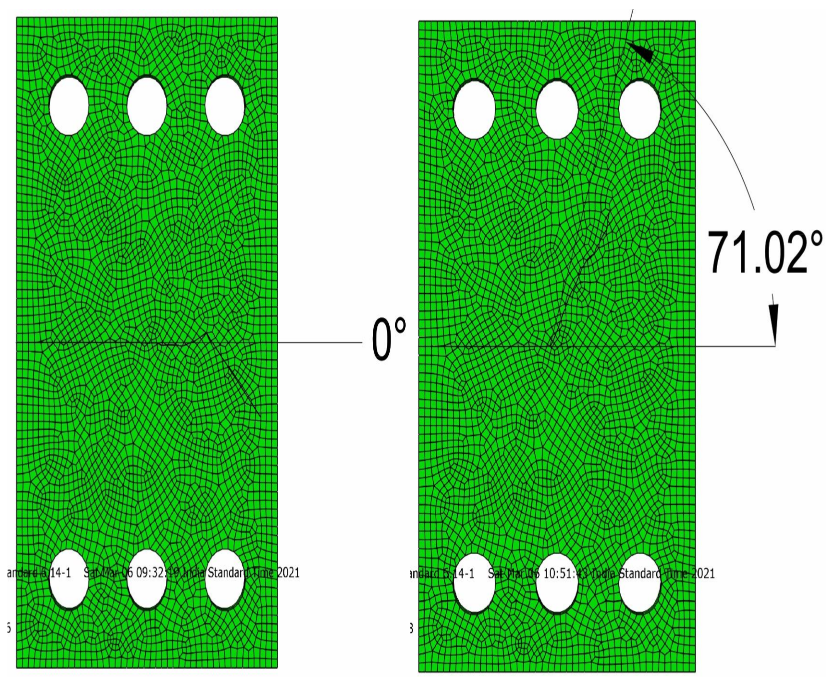

Fig10. Pure mode I & Pure mode II

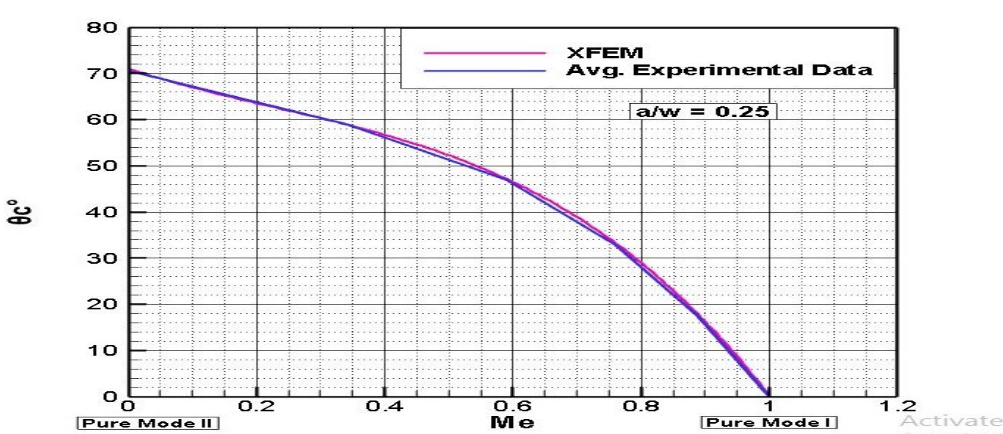

Fig11.graph for SENT

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E. SCB [Semi Circular Bend]

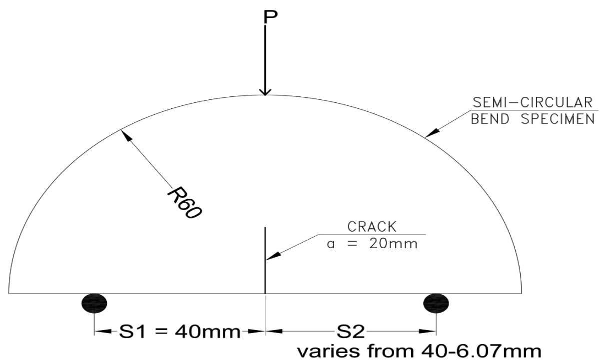

Fig..12 Dimensions of SCB

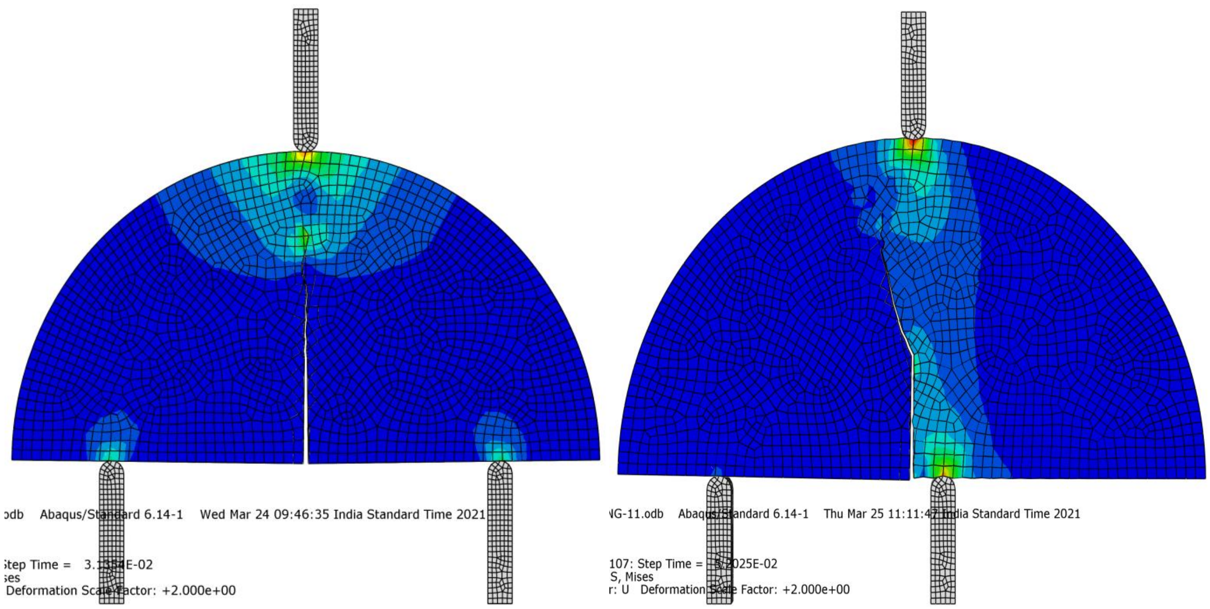

Fig.13 Pure mode I & Pure mode II

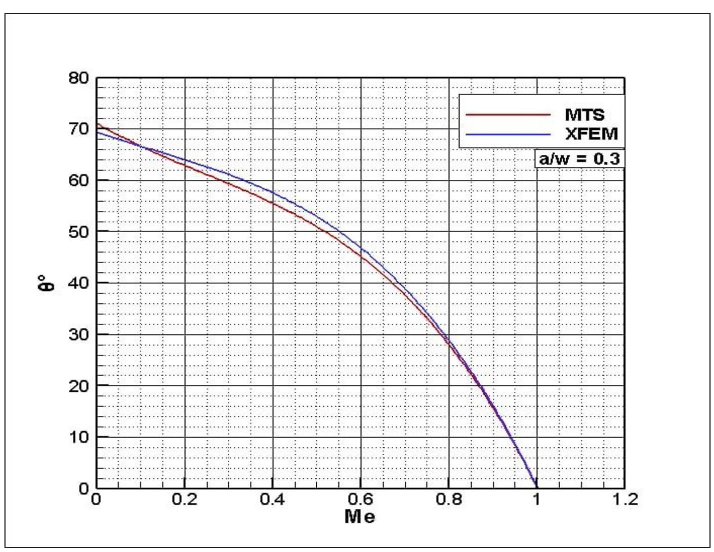

Fig14. Graph for SCB

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III.CONCLUSION

Bye performing XFEM analysis in ABAQUS software on different types of specimens, we can conclude that crack Initiation Angle from MTS theory and Experimental data were similar to XFEM .

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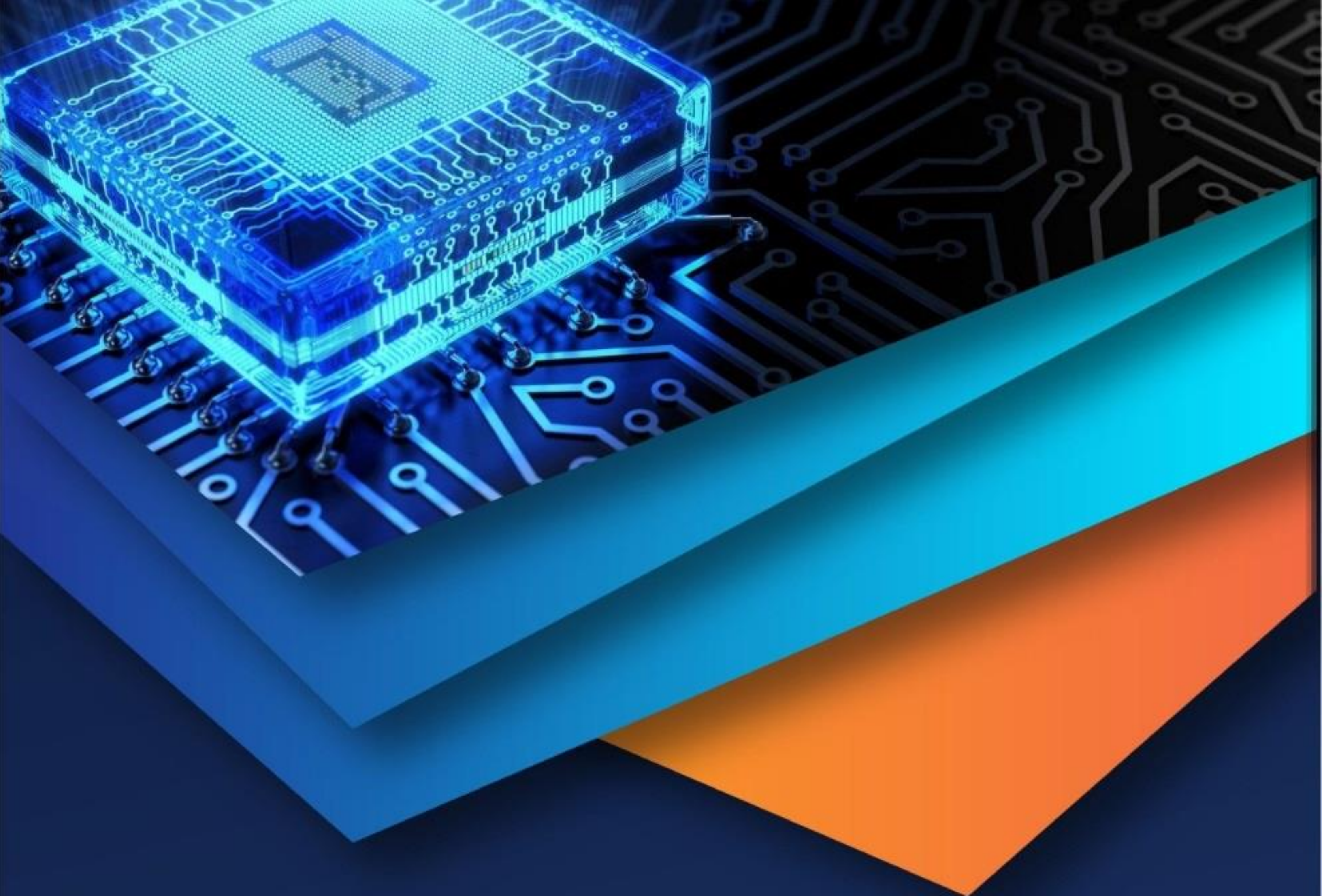

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