iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** XII **Month of publication:** December 2017

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor :6.887
Volume 5 Issue XII December 2017- Available at www.ijraset.com

Experimental & Finite Element Analysis of Strength of a Fillet Weld for two 1020 MS Plates

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Abstract**: *T-joint fillet welding is the most common welding in engineering applications. Transport vehicles, marine ships, mobile plant equipment are few examples where fillet welding are used extensively. Analysis of welded structures is still remains a challenge for the designer to produce desired output results. In welding process rapid heating and cooling introduced residual stress and geometrical deformations. Heat effected zone play pivotal role in determining the strength of a welded joint which changes the properties of parent material and reduce the strength after welding operation. There are many case which structures are continuously under cyclic loading when the fatigue life of the welded joints are a major design consideration The aim of this project is to analyses the normal stress and fatigue life of fillet welded joints using computer modeling and experiments. Finite element based tool ANSYS Workbench 18.0 was been used to analyses the normal stress and the fatigue life under cyclic loading. Computer model of the joint developed using three different types of material which was parent metal, heat affected zone metal and weld metal***

Keywords: material, welding, specimen, fillet

I. INTRODUCTION

Welding is a manufacturing process of creating a permanent joint obtained by the fusion of the surface of the parts to be joined together, with or without the application of pressure and a filler material. The materials to be joined may be similar or dissimilar to each other. The heat required for the fusion of the material may be obtained by burning of gas or by an electric arc. The latter method is more extensively used because of greater welding speed. Welding is extensively used in fabrication as an alternative method for casting or forging and as a replacement for bolted and riveted joints. It is also used as a repair medium e.g. to reunite a metal at a crack or to build up a small part that has broken off such as a gear tooth or to repair a worn surface such as a bearing surface Miss R.B. Sonawane is PG Scholar at Jaihind College of Engineering Kuran with Mechanical Design as specialization (E-mail:annasonawane93@gmail.com). Mr. R.L Mankar is Assistant Professor at Jaihind College of Engineering Kuran. (E-ma*il: rajmankar@gmail.com*) Welding is the most commonly used process for permanent joining of machine parts and structures. Welding is a fabrication process which joins materials (metals) or thermoplastics, by causing union (A. Thirugnanam 2014). In the joining process of welding application uses heat and/or pressure, with or without the addition of filler material. Various auxiliary materials, e.g. shielding gases, flux or pastes, may be used to make the process possible or to make it easier. The energy required for welding is supplied from outside sources Welding, a metal joining process can be traced back in history to the ancient times. In the Bronze Age, nearly 2000 years ago, circular boxes made of gold were welded in lap joint arrangement by applying pressure. Later on in the Iron Age, Egyptians started welding pieces of iron together. But welding as we know nowadays came into existence only in the 19th century. Sir Humphrey Davy produced an electric arc using two carbon electrodes powered by a battery. This principle was subsequently applied to weld metals. Resistance welding finally developed in the year 1885by Elihu Thomson. Acetylene gas was discovered in 1836 by Edmund Davy, but it could not be used in welding application due to lack of a proper welding torch. When the require welding torch was invented in 1900, oxy-acetylene welding became one of the most popular type of welding mainly due to its relatively lower cost. However in the 20th century it lost its place to arc welding in most of the industrial applications. Advance welding techniques like Plasma Arc Welding, Laser Beam Welding, Electron Beam Welding, Electro-Magnetic Pulse Welding, Ultrasonic Welding, etc. are now being extensively used in electronic and high precision industrial applications

II. LITERATURE SURVEY

Peter A. Gustafson studied analytical and experimental methods for adhesively bonded joints subjected to high temperatures studied recent advances in material systems have expanded the temperature range over which adhesively bonded composite joints can be used. In this work, several tools are developed for use in modelling joints over a broad range of temperatures. First, a set of dimensionless parameters is established which can be used for analysis of joint performance for an orthotropic symmetric double lap joint. A critical dimensionless ratio of mechanical and thermal loads is identified. The ratio predicts characteristics of the resulting stress distribution.[1]

Sinjo Jose, M. James Selvakumar studied an Overview of Fillet Weld Joints Subjected to Tensile and Compressive Loads in which Mechanical assemblies and parts that are in service may be subject to high stresses and different types of loads such as fatigue loads, tension loads, compression loads. In this study, finite element analysis software, ANSYS, is used for a parametric study to research the effect of weld toe radius in fillet welded joint on compression strength and tensile strength. In metal constructions, machine assemblies, shipbuilding and other heavy industries, fillet joint is a widely used structural member. There are different types of loads acting on the fillet weld joints. There are various application of fillet weld joints .We can use fillet weld joints in steel bridge girder, building structures, machine assemblies etc. [2]

Lucas F.M. Silva, J.P.M. Gonc studied multiple-site damage in riveted lap-joints: experimental simulation and finite element prediction The multiple-site damage (MSD) phenomenon is discussed, and exemplified by the behaviour of riveted lap-joint specimens of aluminum alloy 2024-T3 alclad. The tests performed, on which the paper is based, are part of the contribution of IDMEC to a project on the fatigue behaviour of ageing aeronautical structures—the BRITE-EURAM project ‘SMAAC’, partially funded by the European Union. The study involves fatigue testing under constant amplitude loading of 1.6-mm-thick riveted lap-joints, and includes examination of the specimens during and subsequent to testing (post-mortem analysis of the fracture surface in a scanning electron Microscope) in order to determine the time of occurrence, location and extent of fatigue damage. Crack growth rates are determined from periodic crack length measurements with a travelling microscope. [3]

A.Dr. D.V. Bhope and S.N.Pilare, [2012] has explained that as the gap between parent plates increases from 0.1 mm to 1.0 mm, the maximum Von-misses stresses decreases from 133.34 MPa to 110.22 MPa with few exceptions. From this analysis, it is evident that the effect of stress concentration reduces as the gap between parents plates increases. Thus, the slight gap between parent plates may be desirable for tensile load [4]

M.N.Buradkar, Dr. D.V. Bhope,[2013**]** have worked on “Experimental and photo elastic of arc welded Lap Joint” In this they explained The static stress analysis on arc lap weldment performed to take into account the positional error which may occur during manufacturing. For this purpose the gap between the parent plates is varied from 0.1mm to 1mm in the step of 0.1 mm and it is observed that the maximum shear stress in the weldment varies gap between the parent plates. It is seen that the maximum shear stress reduces as the gap between the plate increases. This may be due to shifting of shearing zone of the weldment which resulted into increase in the throat length. Further investigations are required to verify this fact under fatigue loading and also under other loading condition like bending load etc. [5]

C. Rasche & U. Kuhlmann [2009**]** have worked the evaluations of the test results shows that the determined ultimate stresses II, due to the failure in the weld, exhibit a good correlation with the tensile strength of the filler metal. Thus, the load bearing capacity of the connection is essentially determined by the strength of the filler metal. Further investigations are planned to determine the behaviour of fillet welded lap joints with steel grade S690 in detail.[6]

Ch. Alk. Apostolopoulos, P. Th. Savvopoulos, L. Dimitrov , explained Lap welded splices of steel rebar are susceptible to eccentricity problems and probable failures of the surrounding concrete due to the kinematic behaviour of the end connections. Questions are raised for their acceptance after workability problems generate significant displacement of the ends and their potential association of the guaranteed nominal mechanical strength of steel (B500c) with yield point of Rp = 500MPa After the segments long before the external imposition of good Rp load at the ends of the bars, the area of welded connection has already exceeded the yield stress Rp [7]

Dr. Reynold welding codes which are conservative recommendations (not standards) based on “good practice” in the opinion of K. Watkins, P. E.Robert J. Card, P.E., and Nash Williams , had investigated and explained the ASME qualified experts in high pressure and temperature, high risk, pressure vessels. For analysis of single welded lap joints in water pipe, ASME welding codes are conservative. Compare, for example, the ASME statement on fillet welds; Bednar (1991); “In the absence of definite rules the designer has to estimate the efficiency, E. A good engineering practice would be to select (in terms of decimal fractions): For fillet welds: E = 0.60 – 0.80 (based on throat area) E = 0.45 – 0.55 (based on leg area) The ASME code, for good engineering practice, is interpreted generally as E = 0.45 – 0.55 based on throat area. For single welded lap joints, E = 45%. For double welded lap joints, E = 55%.” . The ASME Codes for joint efficiencies apply to internal pressure in pressure vessels. They do not address the conditions for performance of welded lap joints in buried (or above ground) steel water pipe. Weld strength for pipe, should be based on full, 3-D pipe tests, not on 2-D coupons. Weld strengths for single welded lap joints should be analyzed by a safety factor defined as the ratio of weld strength to maximum longitudinal stress in the pipe wall.[8]

Marcelo Leite Ribeiro, Ricard Afonso Angelico, VolneiTita [2009] explained Concerning plane stress state, SAJ is capable to determine the stresses in each laminate ply and predict the failure mode for laminate adherents both for single and double bonded lap joints. Since the differences between SAJ and ABAQUSTM finite element mode are small, mostly for double lap joints, SAJ is a strategic computational tool to determine the joint stress state. Meanwhile, when studying single lap bonded joints, the prediction of failure must be conducted carefully using plane stress state. It is desirable to investigate the out-of-plane stresses before proceed with failure analysis, checking the intensity of out-of-plane stresses in order to reduce the errors on predicting the bonded joints behavior H. Bisadi1, M. Tour1, A. Tavakoli, [2011] explained at lower rotational speeds, lower welding speed leads to better properties of the weld joint. But at higher rotational speeds, changing of the welding speed has an inverse effect on the joint properties. At lower rotational speeds because of lower material flow, lower welding speed is needed to decrease the welded joint defects by increasing the heat generation and decreasing the heat gradient at the joint areas during the process. Also at higher rotational speeds because of large amount of material flow that can cause several defects on the joint, higher welding speeds should be applied to increase the thermal gradient at the weld zone. In fact at the tool rotational speed of 600rpm the main reasons for the joint defects are caused by low heat transfer during the process and insufficient stirred joint area. Also at the higher rotational speeds like 1550rpm, excessive heat transferred to the weld area causes many defects like hooking at the thermo mechanical zone of the advancing side. 2-The nugget of the weld has the finest grain size and highest hardness among the other welding areas and the base material at the tool rotational speed of 825rpm and welding speed of 32mm/min, in contrast with the heat affected zone that has the highest grain size and lower strength. In fact almost all of the fractures took place at the heat affected zone of the advancing side of the weld.[9] Hans Nordberg [2005], explained and shown numerous times that fatigue properties for joints in carbon steel sheets with different parent material strengths are similar. In the fatigue results for different stainless steels with yield strengths in the range 290 - 725 MPa are compared. Furthermore, results by Maples show that the fatigue strength for a stainless steel spot welded joint is similar to that for a galvanized carbon steel. For round clinched joints there are indications that increased strength leads to increased fatigue strength but within a limited range since use of the clinching process set limitations on the clinch ability of thicker material [10] Lakshman Vinnakota, [2008] explained the Increasing the uniform axial load increases the stress concentration. A 15% increase in stress concentration was observed when uniform axial load was varied from 50 MPa to 200 MPa. [11]
Björk T., Toivonen J., Nykänen T, [2012] Experimental test were carried out for fillet welded joints weld made of ultra high strength S960 steel and the capacities were compared with results from nonlinear FEA. The following conclusions can be drawn out: - load carrying capacity of the studied joints seems to be evaluated using the current design rules [1, 2] - deformation capacity was remarkable lower compared the capacities of conventional structural steel up to $fy \leq 460$ MPa - failure mode was ductile rupture for all in room temperature tested joint - using of under matched filler material can be improved the deformation capacity of filled welds - FEA predicted the ultimate capacity and failure path quite well but not the ultimate deformation capacity - heat input is essential due to softening effect in HAZ and it should be considered (like in aluminum structures) if the critical heat input limits cannot be followed.[12]

III. PROBLEM STATEMENT

The aim of this research project has been to study dissimilar metal joint using a filler metal. Dissimilar welding is used to fabricate the pressure vessels and piping in power plant but failures occur frequently due to
Thermal Stress which is generated due to difference in co-efficient of thermal expansion.
Difference in mechanical properties, the local heating and subsequent cooling results in large residual stress.
This thermal stress superimposed on weld residual stress and operating tensile stress promotes brittle fracture, increase susceptibility to fatigue and stress corrosion cracking during its service life. The domain of this research covers cause, effect and elimination of problems caused due to stresses, carbon migration and stress corrosion cracking. The metal plates to be welded are of 1020 plain carbon steel and the filler metal used is 302 Stainless steel . The welding process has been simulated using finite element analysis. The software used for this analysis is ANSYS 18.0 using its Workbench module. It is because Workbench is a very powerful tool to simulate a welding joint and infer the results. Also it has a reputation of coming up with results very close to the practical values. The input parameters are easily fed and boundary conditions, simulation programs and geometrical modelling is very convenient due to its user-friendly graphic interface

IV. OBJECTIVES

A. Static stress analysis of weldment will be carried out by FEM using ANSYS WORKBENCH.
B. Experimentation will also be carried using UTM to determine the breaking strength of weldment to validate the FE model & results.

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C. Comparison between FEM and Experimental Results.

D. The stresses in the weldment are evaluated by varying the gap between the parent plates which may occur during manufacturing

V. METHODOLOGY

This research work deals with the stresses in the weldment of welded lap-joint under. For the analysis, Finite Element method along with experimental techniques is used. A single arc welded lap joint subjected to transverse static load is considered for the analysis. The stresses in the weldment will be evaluated by varying the gap between the parent plates which may occur during manufacturing. The breaking strength of the weldment is also determined analytically and experimentally to verify F.E. results.

VI.MECHANICAL PROPERTIES OF MATERIAL

Table.1..Mechanical Properties of 302 Stainless Steel

Variation of properties with temperature	Density (kg/m^3) * 10^3	Poisson's Ratio	Modulus of Elasticity (Pa) * 10^{11}	Yield Strength (Pa) * 10^8
0 ^{0}C	7.9	0.295	2.0	2.7
200 ^{0}C	7.78	0.3	1.9	1.9
400 ^{0}C	7.67	0.31	1.8	1.6
600 ^{0}C	7.55	0.315	1.7	1.2
800 ^{0}C	7.43	0.32	1.5	0.8
1000 ^{0}C	7.32	0.327	1.0	0.6
1200 ^{0}C	7.2	0.335	0.4	0.55
1400 ^{0}C	7.12	0.341	0.5	0.5
1600 ^{0}C	7.04	0.346	0.5	0.5

Table.2.Mechanical Properties of 1020 Mild Steel

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Variation of properties with temperature	Density (kg/m^3) * 10^3	Poisson's Ratio	Modulus of Elasticity (Pa) * 10^{11}	Yield Strength (Pa) * 10^8
0 ^{0}C	7.8	2.9	2.0	3.1
200 ^{0}C	7.8	2.9	1.8	2.5
400 ^{0}C	7.8	2.9	1.6	1.8
600 ^{0}C	7.8	2.9	1.4	1.1
800 ^{0}C	7.8	2.9	0.7	0.4

Table.3.Thermal Properties of 302 SS

Variation of properties with temperature	Thermal Conductivity (W/m^{0}C)	Specific Heat (J/Kg^{0}C)	Thermal Expansion Coefficient (^{0}C^{-1}) * 10^{-5}
0 ^{0}C	15	501	1.8
200 ^{0}C	18	530	1.9
400 ^{0}C	21	580	2.0
600 ^{0}C	26	620	2.05
800 ^{0}C	34	650	2.1
1000 ^{0}C	36	680	2.15
1200 ^{0}C	36	690	2.2
1400 ^{0}C	36.1	700	2.25
1600 ^{0}C	36.1	705	2.29

Table.4.Thermal Properties of 1020 Mild Steel

Variation of properties with temperature	Thermal Conductivity (W/m^{0}C)	Specific Heat (J/Kg^{0}C)	Thermal Expansion Coefficient (^{0}C^{-1}) * 10^{-5}
0 ^{0}C	48	480	1.2
200 ^{0}C	32	510	1.3
400 ^{0}C	30	550	1.3
600 ^{0}C	29	600	1.3
800 ^{0}C	29	640	1.2
1000 ^{0}C	29	680	1.2
1200 ^{0}C	30	690	1.2

VI. FINITE ELEMENT APPROACH

To verify the experimental result for breaking stress, FE model is prepared with same geometric dimensions of model used during experimentation. The material properties specified are as follows. Modulus of elasticity of parent plate material (E) = 2.3 x 105MPa
Poisson's ratio of parent plate material (μ) = 0.3
Modulus of elasticity of weld material (E) = 1 x 105 MPa
Poisson's ratio of weld material (μ) = 0.4
For this analysis, "SHELL63" element is used which is a 2-D structural higher order element, which allows a coarser mesh with good solution accuracy. The mesh is generated using triangular meshing. Loads and constraints required are added to perform a static finite element analysis. The stress contours for maximum shear stress in weldment.

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VII.EXPERIMENTAL STRESS ANALYSIS

For the FE & Theoretical analysis on the weldment of Arc Welded Lap-joint, three plates will be used. Two plates of uniform dimensions of 100mm X 50mm X 8mm thick will be welded with one plate with weld size of 5 mm providing the gap between them to take into account the positional error which may occur during welding or manufacturing. The analysis will be carried out using analytical, experimental & Finite Element method considering transverse loading on weldment. The gap between parent plates will be varied from 0.1 mm to 1.0 mm in the step of 0.1 mm to take into account the positional error.

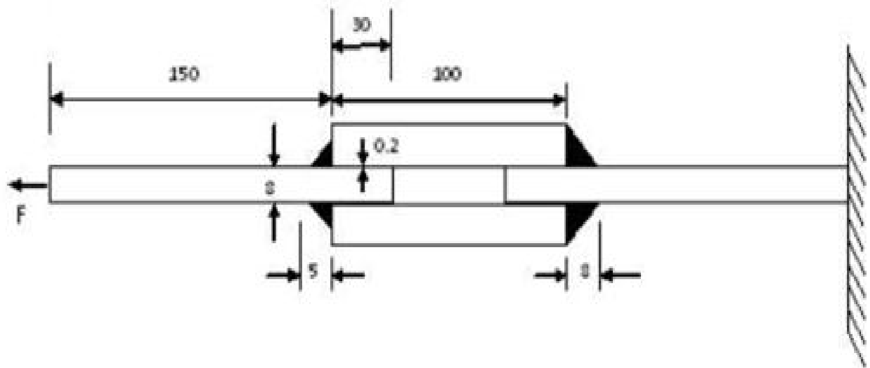

Fig .1: dimension for test specimen

Fig. 2: mounting and loading of test specimen on UTM

IX. CONCLUSION

The ultimate purpose of the project has been achieved with developing techniques of the finite element analysis of fillet welded joint. In this project, the effect of weld toe radius on tensile strength and compressive strength of fillet weld joint has been analyzed. In experimental study, tensile test and compressive test were carried out by using Universal Testing Machine. The experiments have been validated by using ANSYS software. It has been found that when toe radius increases, tensile strength and compressive strength of fillet weld joint decreases

X. ACKNOWLEDGMENT

It is of immense pleasure to me in expressing sincere and deep appreciation towards my guide Prof. R.L. Mankar., for priceless execution of steering this contribution all the way through this work with soft suggestions, embedded supervision and invariable advocacy. Special thanks to the principal and teaching staff of JCOE Kuran, for needful support and encouragement throughout the course.

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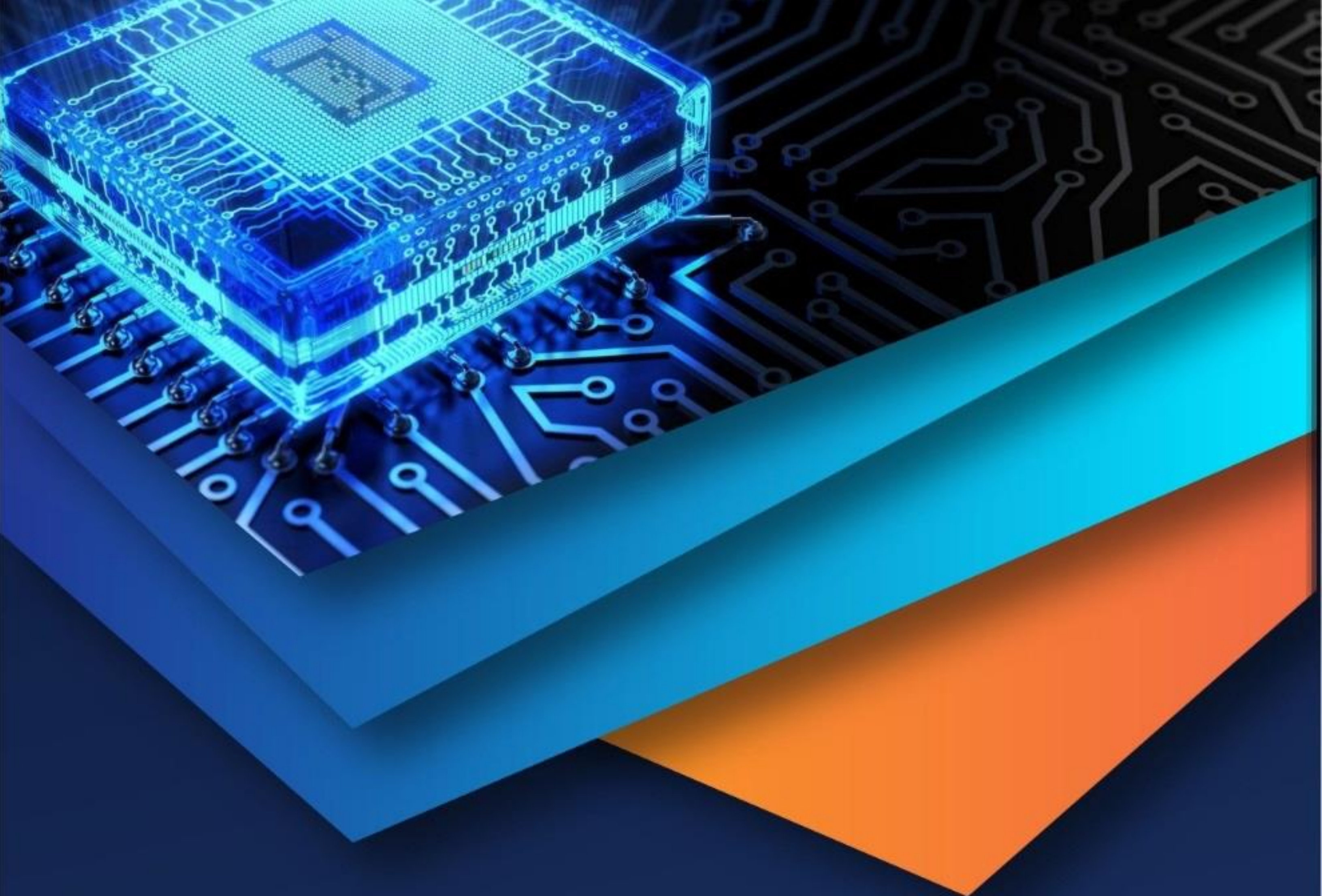

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