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Optimization of Punch Force in Deep Drawing of High Strength Steel Specimens

Venkat Jogeshwara Karthik Kalaga
School of Mechanical and Building Sciences, Vellore Institute of Technology, Chennai

Abstract: Deep drawing is an industrial process that is widely used in the manufacturing sector, specifically in sheet metal works to make automotive and aerospace components. Various experiments were conducted in ANSYS Explicit Dynamics for six parameters, namely, die and punch corner radius, blank holder force, blank diameter, friction between die and the blank and punch velocity. Using the approach of analysis of variance, the six parameters are analysed and tested for the case of minimum possible punch force and the parameter levels for lowest punch force are predicted. It was found that friction between the die-blank and blank holding force are the main contributors in punch force and the specific levels of each parameter were predicted, verified and simulated to verify the conditions needed for lowest possible punch force during deep drawing.
Keywords: Deep drawing, Punch force, Taguchi orthogonal matrix, Friction, Explicit analysis.

I. INTRODUCTION

Deep drawing is a sheet metal forming process that deforms a sheet metal of various shapes, called the blank, by the mechanical action of the punch [2]. A typical deep drawing setup has the following parts: die, blank holder, punch and a blank. These parts are custom made for every deep drawing process based on the shape of the final product as well as the size of the blank. In our analysis we are making use of a circular blank. The die and the blank holder in this case is also circular. The punch in this case is made to be cylindrical to as the inner surface of the cup is also to be cylindrical [1-3]. The other important parameters necessary for deep drawing punch nose radius [13,14], die shoulder radius, blank holder force, punch speed, lubrication at various contact areas, blank thickness, punch force etc. In our analysis we are looking at the effect of punch nose radius, die shoulder radius, punch speed, blank diameter, blank holder force and lubrication at three interfaces; i.e. blank-blank holder, blank-die and blank-punch; on punch force and the stress distribution within the cup. The material for the deep drawing process, High Strength Steel has unusually high Ultimate Tensile Strength and Yield Strength value [4-7], hence increasing the chances of defects in the form of tearing and formation of wrinkles because of which final product quality is hindered.

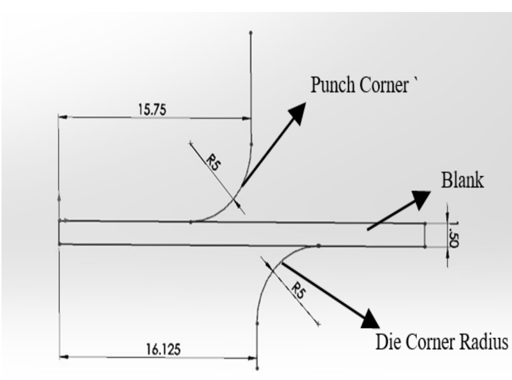

Fig.1. Punch Corner, Die corner radius and blank thickness

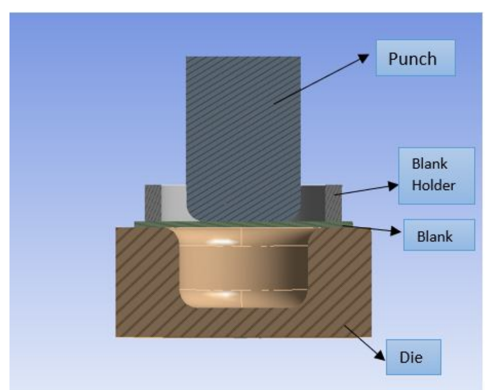

Fig.2. Simulation setup for deep drawing a cup

II. LIST OF SYMBOLS

A. Blank Diameter
B. Die Corner Radius
C. Punch Corner Radius
D. Blank Holding Force
E. Friction Value
F. Punch Speed

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Table 1. Taguchi Orthogonal Matrix Iterations

Exp. No.	A (mm)	B (mm)	C (mm)	D (kN)	E	F (mms^{-1})	Maximum punch force (kN)
L1	54	5	5	10	0.1	0.17	106.09
L2	54	5	6	15	0.25	0.2	100.96
L3	54	5	7	20	0.35	0.245	95.59
L4	54	6	5	10	0.1	0.17	123.17
L5	54	6	6	15	0.25	0.2	151.73
L6	54	6	7	20	0.35	0.245	93.97
L7	54	7	5	10	0.1	0.17	105.09
L8	54	7	6	15	0.25	0.2	108.22
L9	54	7	7	20	0.35	0.245	136.06
L10	57	5	5	10	0.1	0.17	138.17
L11	57	5	6	15	0.25	0.2	104.72
L12	57	5	7	20	0.35	0.245	70.12
L13	57	6	5	10	0.1	0.17	125.14
L14	57	6	6	15	0.25	0.2	85.21
L15	57	6	7	20	0.35	0.245	125.29
L16	57	7	5	10	0.1	0.17	214.63
L17	57	7	6	15	0.25	0.2	102.66
L18	57	7	7	20	0.35	0.245	119.24
L19	60	5	5	10	0.1	0.17	113.51
L20	60	5	6	15	0.25	0.2	179.73
L21	60	5	7	20	0.35	0.245	88.75
L22	60	6	5	10	0.1	0.17	130.79
L23	60	6	6	15	0.25	0.2	158.38
L24	60	6	7	20	0.35	0.245	77.62
L25	60	7	5	10	0.1	0.17	118.78
L26	60	7	6	15	0.25	0.2	100.15
L27	60	7	7	20	0.35	0.245	128.41

Table 2. Process parameters and values at different levels

Parameter/Level	1	2	3
Blank Diameter(mm)	54	57	60
Die Corner Radius (mm)	5	6	7
Punch Corner Radius (mm)	5	6	7
Blank Holding Force (kN)	10	15	20
Friction Value	0.1	0.25	0.35
Punch Speed (mms^{-1})	0.17	0.2	0.245

Table 3. Mechanical properties of High Strength steel

Steel grade	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (% min)
Strenx 700 CR EN10131	700	1060	7

Table 4. Chemical Composition of High Strength steel used

C	Si	Mn	P	S	Al	Ni + TI	Fe
0.16	0.4	1.8	0.02	0.01	0.015	0.1	Balance

III. METHODOLOGY AND SIMULATION

Simulation of deep drawing process is done using ANSYS Explicit Dynamics is shown in Fig.1. The dimensions used for simulation correspond to the dimensions of the practical set-up. The assembly consists of a die, punch, blank and a blank holder. The die, blank holder and the punch were rigid while the blank is a flexible (deformable) part. The parts in the assembly have frictional contacts with the rigid parts set as target objects each and is varied with each iteration. The contact between the blank and the punch is given a constant friction value of 0.3 for all the iterations while the contact between the blank and die has a friction value that varies with the iteration as we have different friction values for the die in cases of dry, lubricated and coated die setup. The die corner radius and punch corner radius are varied to a certain degree to check its relationship with maximum punch force. The blank holder force during simulation was the most difficult to carry out as the time step for the force must be changed after the punch displaces a certain distance as the final cup should not have a flange. The experiment was conducted on blanks of different diameter to check its relationship with the maximum punch force values simulated.

Taguchi analysis for six-parameters for three-levels was conducted. The parameters were varied across Taguchi iterations (single three-level L27 design) as explained in Table 1. Analysis was conducted and key values such as punch force were obtained. Taguchi analysis for punch force is done to find the least punch force value combination of the six parameters, hence using “smaller the better” solution method. The material of the blank was chosen to be non-linear high-tensile steel with a maximum tensile strength of 1060 MPa. The material characteristics specific to the practical experiment were manually added and altered, as per the need. The material for the rest of the parts was chosen to be AISI D2 steel. The die is fixed in all direction while the punch is displaced along only one axis. A cup depth of 22mm is to be simulated which is monitored by observing directional deformation along the axis of punch. ANSYS Explicit Dynamic requires the user to input an initial velocity which is one of the six varying parameters. A downward force is applying on the blank holder for a certain period after which the force is retracted. Tearing and wrinkling in the blank was observed in some cases. All the simulations were conducted for equal number of iterations for homogeneity of results.

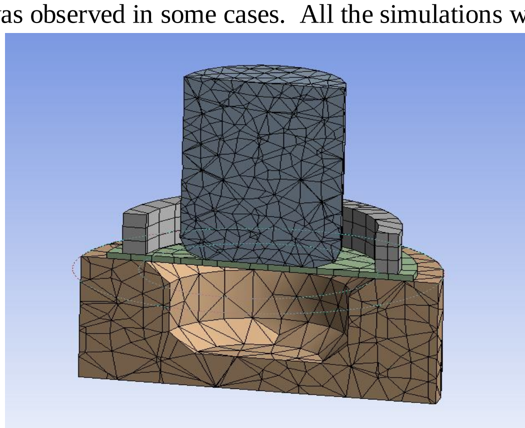

Fig.3. Mesh set-up in ANSYS 19

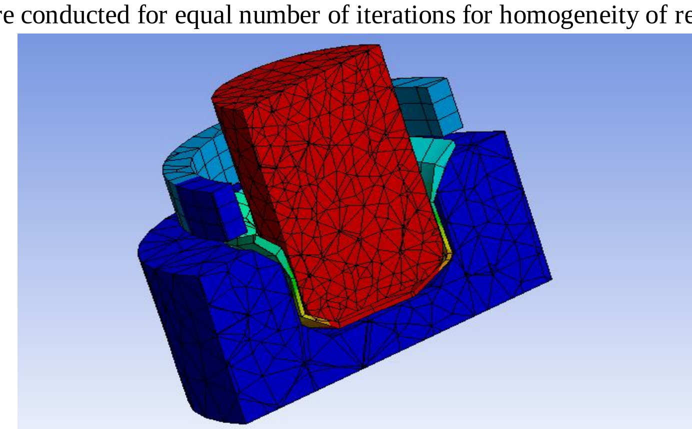

Fig.4. Formation of cup after punch travel.

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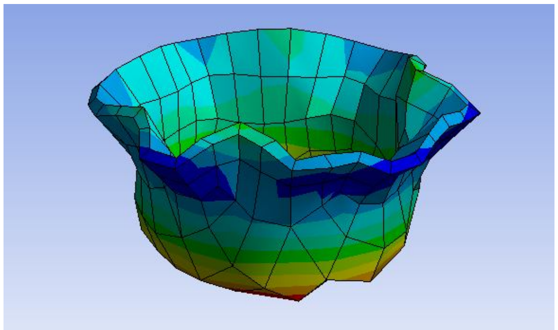

Fig.5. Cup formed after deep drawing

IV. RESULT AND DISCUSSION

The Analysis of Variance (ANOVA) is used to achieve optimal levels for each of the six parameters to obtain minimum punch force and also defining the percentage contributing of each parameter on Minitab 17. Taguchi Orthogonal Array Design is used instead of Full Factorial Design to cut down on time and money. After analysing the Taguchi matrix, we obtained the main effect plots Means and SN ratio with respect to Maximum punch force and each parameter, for smaller is better case. In Fig.8, the individual parameter contributions are found out. The table shows that friction between the blank and the die has the highest contribution. Analysis of mean as show in Figure 6 shows that an increase in friction value results in the decrease of maximum punch force value. Blank diameter has a direct relation with maximum punch force value. Increasing the die corner radius increases the maximum punch force value while it does not vary linearly with punch corner radius value. Blank force has a non-linear relation with maximum punch force, as does punch speed.

Using Response Optimization in Minitab 17, a combination of parameter levels was found to give the lowest maximum punch force value, lower than iterations in L27 Taguchi Orthogonal Matrix. In Figure 8. the optimized condition parameters can be used to simulate the maximum punch force in ANSYS to compare the value of punch force.

In Fig. 8, contribution order of the parameters to maximum punch force value is shown. The suggested parameters were used to simulate deep drawing again on Ansys Explicit Dynamics and the maximum punch force value was the lowest when compared to the L27 simulation iterations done for Taguchi analysis. The value of maximum punch force is even lower than the value predicted by Minitab 17. Hence, the parameters, friction, blank diameter, die corner radius can be varied to obtain smaller values of maximum punch force. Desirably, friction has the highest contribution according to ANOVA, hence that can be used to an advantage by coating the die with some coating or lubricate the set-up, thus reducing the friction to a certain value were the maximum punch force is lowest/optimum.

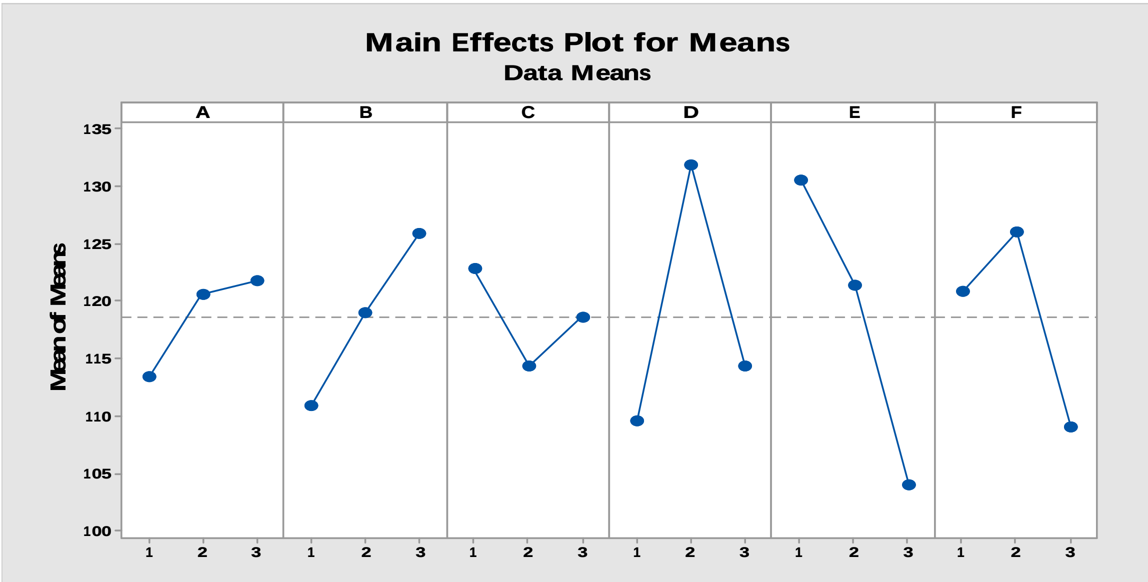

Fig.6. Taguchi Analysis results for Maximum punch force and Mean.

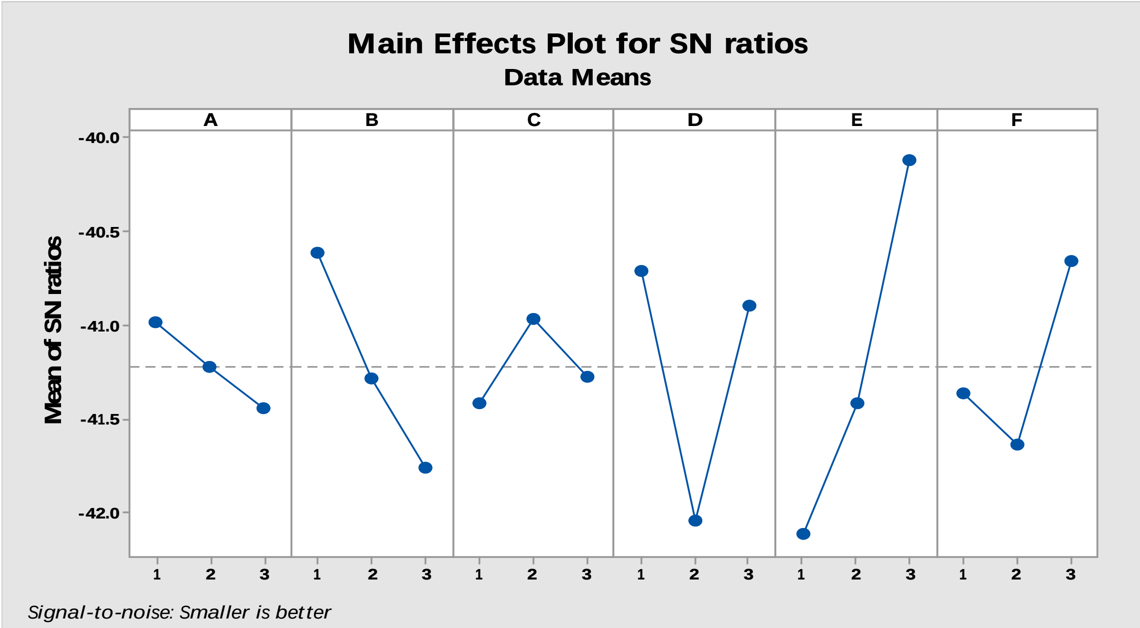

Fig.7. Taguchi Analysis results for Maximum punch force and Signal-to-noise ratio.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
A	2	367.2	1.44%	367.2	183.6	0.16	0.857
B	2	1024.1	4.03%	1024.1	512.0	0.43	0.657
C	2	327.2	1.29%	327.2	163.6	0.14	0.872
D	2	2505.2	9.85%	2505.2	1252.6	1.06	0.373
E	2	3307.5	13.01%	3307.5	1653.7	1.40	0.279
F	2	1355.1	5.33%	1355.1	677.5	0.57	0.576
Error	14	16536.6	65.05%	16536.6	1181.2		
Total	26	25422.9	100.00%				

Fig. 8. Analysis of Variance

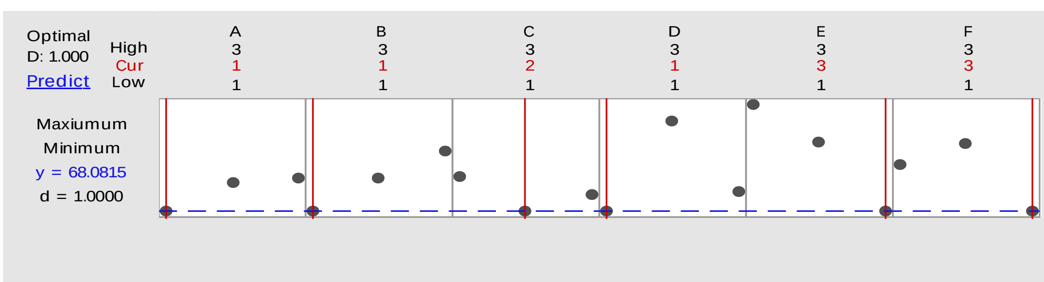

Fig. 9. Response Optimization Plot for Maximum Punch Force

V. CONCLUSIONS

The Using Ansys Explicit dynamics and Taguchi Orthogonal Matrix, six parameters were analysed for their contribution in maximum punch force value for High Strength Steel samples. The effects of the six parameters is substantiated and relations are observed. Friction is the highest contributing factor in controlling the maximum punch force value for a deep drawing process. The result owes 65% contribution to error which shows that the L27 matrix is not the right choice for optimization in all conditions. For the conditions selected in this paper, the optimization is successful and can be reported valid and novel.

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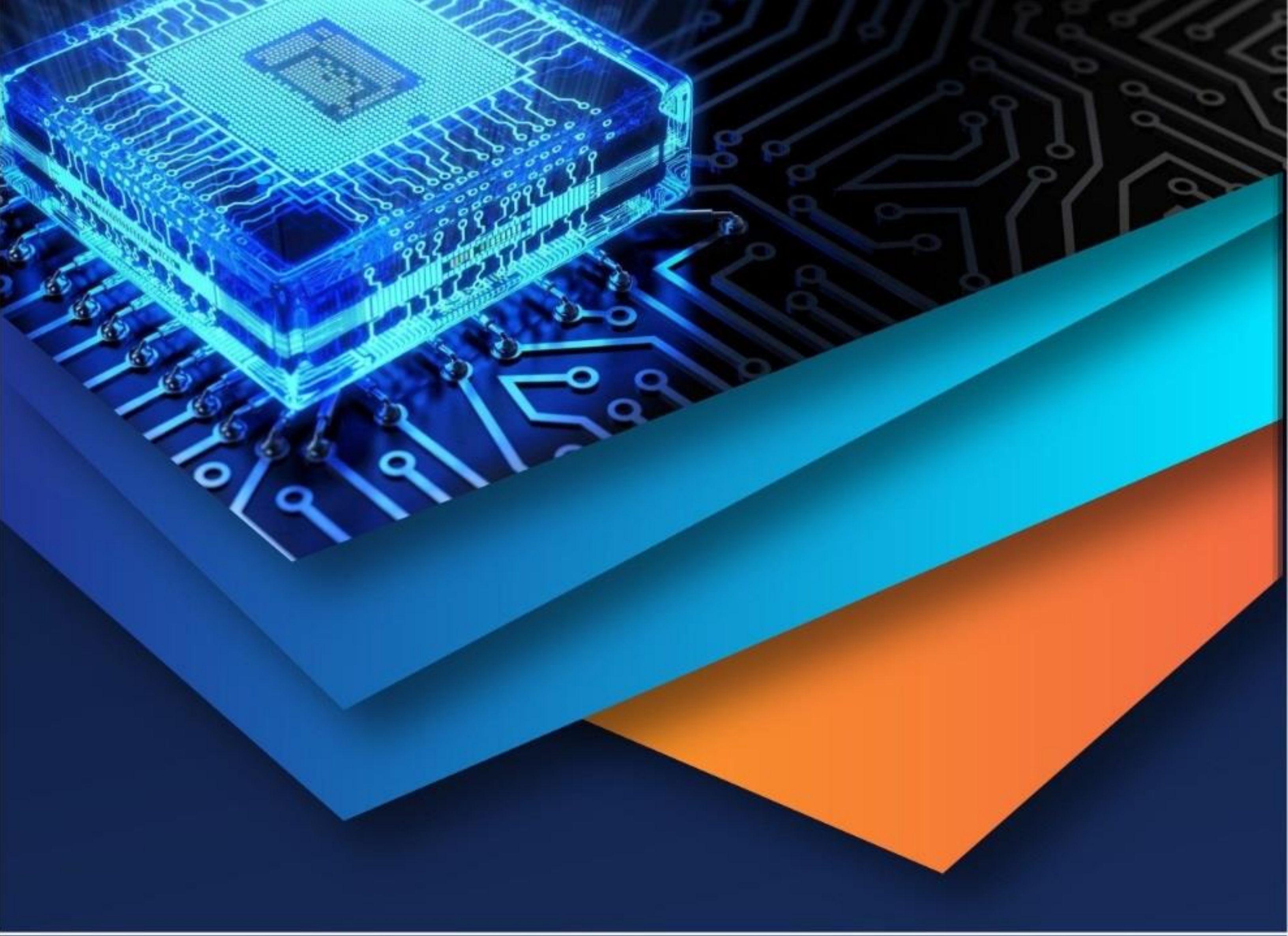

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