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Designing of Multi-cavity Extrusion Die to Increase Productivity: A survey and perspective

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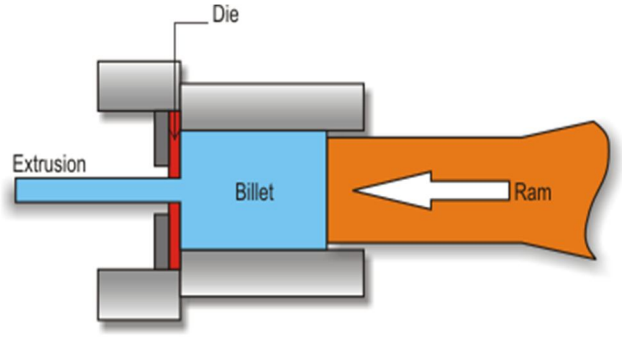
Abstract: ***Extruded rubber is used extensively in many applications and products, either alone or in combination with other materials. It is often desirable to find the best possible way to maximize the production output with least possible capital input and changes in existing plant layout. The changes that are permitted are in the department of pre-processing that is designing stage and machine selection. The proper design of an extrusion die is extremely important to achieve the desired shape and accurate dimensions of the extruded product also to ensure that production level will produce maximum profit and lead minimum cost. The increase in productivity can be defined as the effectiveness of productive effort, especially in industry, as measured in terms of the rate of output per unit of input. Here the productivity is considering the re-designing of single cavity die to multi-cavity die, the die is a metal block that is used for forming materials like sheet metal, plastic, rubber, etc.***
The scope of current study takes into consideration of re-designing the most commonly used design of rubber extrusion die with a single cavity and would evaluate the effect of introducing the design of double cavity design on the overall increase in productivity of the industry. After redesigning the die for rubber extrusion moulding we would compare the statistical data of existing output data for productivity and hence the other changes required to keep up the increased productivity rate.
Keywords: ***die design, multi-cavity, productivity, rubber extrusion,***

I. INTRODUCTION

The purpose of this paper is to give the brief idea of how the introduction of Die Designing for Double-Cavity will lead to increase in the productivity and maximize profit. The material extruded is rubber and hence the properties of rubber also to be studied and examined while implementing the changes in the die design. There are certain unique features of rubber which makes it an important product which finds use in diverse fields as transportation, material handling, health care, and sport and leisure activities. Due to the diversity of rubber products manufactured, the rubber industry services a range of downstream industries including manufacturing, construction, and agriculture.

The exact process for turning rubber into finished products varies depending on how the rubber will be used. The big weakness of rubber products in the 18th and early 19th century was temperature. Cold turned rubber brittle; heat reduced rubber goods to gluey sludge. In 1839, the drawbacks leading to failure in the application of rubber changed drastically with vulcanization, a treatment that made rubber temperature-resistant. Vulcanization is still widely used in rubber manufacturing. The rubber is heated, and then mixed with an additive such as sulfur, peroxide or bisphenol. This improves elasticity as well as weatherproofing the rubber. Manufacturers can use different additives to give the rubber slightly different properties.

Now the main aim is to design a die for the change in cavity for the increase in productivity. Extrusion dies can be made to limitless design of shapes and sizes. The die itself is a steel disk normally of properties having to sustain high temperature and different materials to be extruded so that it does not interfere with the properties of the extruded rubber product. Depending upon the size and shape of the intended cross-section of the final extruded product, cut through it.



Dies are broadly grouped as solid (or flat) dies, which produce solid shapes and hollow dies, which produce hollow or semi hollow shapes.

Solid die may have number of slots or apertures through which the pre-treated rubber in solid form and room temperature is forced (extruded). For the required multiple slots or apertures in a single die produce multiple extrusions with each rotation of the screw of the horizontal extrusion.

Hollow dies take a variety of forms include a fixed stub mandrel as an integral part of the die. Each type of hollow extrusion die serves certain functions and carries its own advantages and disadvantages.

A typical extrusion operation will make use of a die assembly, including the die itself, which, together with a backer, is enclosed within a die ring, placed in front of a bolster, with a sub-bolster behind, all held together as a unit by a tool carrier. The backer, bolster, and sub-bolster provide the necessary support for the die during the extrusion process.

Acquiring the die profile to achieve the desired extrudate dimensions is a very difficult task and there has to be extensive data of material properties and flow and heat rate, and vast experience with extrusion processing. Extrusion die design is still more of an art than a science, more relevant data for die design is available due to technology optimization hence with powerful computation and modeling of complex flow and heat transfer processes, before, though, and after the die.

Aim of this re-designing is to find an appropriate design for the conversion of single cavity die into double cavity die for the increase in the productivity quickly by least changes in the set up and plant layout for minimization of cost which directly reflects to profit of the company.

II. OBJECTIVE OF THE STUDY

Objective of this case study is to determine which appropriate design of double cavity die is more suitable and quick for the company so that we can apply that process for betterment of the company productivity. The analysis is divided into two main parts. The first section of this case study introduces the re-designing of the die for rubber extrudate of circular shape for hollow as well as solid type of product required. In second section of the case study we will design the die for rubber extrudate of rectangular shape for hollow as well as solid type of product required. After getting final extrudate product from both the study we will compare and search for any deformities or deviations from the actual requirement. As a part of the study for project report new concept of multiple cavity die designing is considered we double the production.

III. DATA COLLECTION

In a mold with a single branch in the runner, the velocity, shear rate, temperature, and viscosity distribution across the branching runner will become non-symmetrical from side to side in the secondary runner. The hotter outer laminates on one side of the primary runner will flow along the left wall of the secondary runner. The cooler center laminates will go to the opposite right side of the secondary runner. Similarly, the hotter outer laminates at the bottom portion of the primary runner will follow along the wall of the left side of tertiary runner. One half of the secondary runner will be hotter than the other half. Therefore, using this technique molders can control the variation in flow rate and shear distribution inside the branched runner.

The results have shown, especially for pressure in elements, that molders can predict and control the shape and size requirements of molds in order to achieve the required parameter at the entrance of the gate. Initial pressure at the inlet was not that important; in that any values depending on number of cavity can be used. This was true given that larger number of cavity requires larger injection pressure. Flow rate at each element entering the gate, must be equal so that, it can achieve the required pressure drop. From all these constraints, size of runner length and diameter can be adjusted to achieve the desired results.

A. Re-designing of Die for Circular Cross Section

For a single cavity die design the cross section the feeder is provided at the exact center of the bolster. So in case of double cavity die we need to have the calculations done in order to have uniformity in the both extruder. Thus both cavities are placed at the equal distance from the centre of the bolster and the feed plate will now have two cavities both on the horizontal diameter of the die and minimum gap between the two strips to be maintained is about 6-8mm from diameter of cavity 1 to diameter cavity 2 on the feed plate which is about 50mm in diameter.

B. Re-designing of Die for Rectangular Cross Section

For a single cavity die design the cross section the feeder is provided at the exact center of the bolster having the centre of feed plate coinciding with the point of intersection of the diagonals of the rectangular cross section. So again in case of double cavity

die we need to have the calculations done in order to have uniformity in the both extruder. Thus both cavities are placed at the equal distance from the centre of the bolster and the feed plate will now have two the two strips to be maintained is about 8-10mm from wall of cavity 1 to wall cavity 2 on the feed plate which is about 50mm in diameter.

IV. RESEARCH APPROACH

Kunkun Fu et al, 2018 [1] during the research shear-thickening fluids (STFs) exhibit solid-like behavior at high strain rates. This study focused on STFs with styrene/acrylate particles at 58% volume fraction. The theoretical density of the STFs was 29% lighter than that of the STFs with 54% volume fraction silica particles. The microstructure and dispersion of the particles were measured, together with the rheological behavior of the STFs.

Sushil Kainth, 2018 [2] this guide helps to understand the principles of die design for the extrusion of pipe and tubes,
wire coating, cables covering, etc., The principle of design can be followed for designing dies of other sizes, but the dilemma of the die designer is whether the die will work or not. There are three methods of proving that the die works and of ensuring that its design is suitable for its purpose, as follows: Experimental Approach, Mathematical Calculations of the Flow Characteristics and Computer Simulation. Die designers since the old days have been designing dies either from the experience they have gained over the years working practically on the extrusion lines; or, in some cases, reproducing the work of other designers.

Apichart Khiansanoiet al, 2018 [3] Designing of PLA and two components silicone rubber blends was studies. Frozen food packaging application is the main ultimate aim. The statistical method using 23 DOE was conducted. The standard testing methods, in particular impact testing at sub-zero temperature, were performed. The preliminary biodegradability investigation found that the PLA/silicone blend initially triggered at the second week. Its degradation rate was likely to be faster than neat PLA.

Jian-Wei Tseng et al, 2018 [4] the study shows that excellent flow stability (< 3% variation) and high printing speed (up to 370 mm/s) for PEEK printing were achieved. Highly reproducible mechanical tests of the printing products were demonstrated with 96% of the bulk material strength for the first time. Furthermore, an exchangeable printing head was built to cover both line- and plane-printing needs to widen its applications and improve printing surface quality (up to 0.945 nm in Ra).

Ekta Chaturvedi et al, 2017 [5] In this work, High Density Polyethylene (HDPE) was used in the extrusion molding machine to study the effect of screw rotation on extrudate mass flow rate experimentally. The screw of L/D ratio 20 was taken for experimentation. The proposed model was also shows the good fitness with the experimental data.

Dariusz Kwiatkowski et al, 2017 [6] it shows the results of heat flow simulation in a flash pocket of an extrusion blow mould, made using ANSYS Polyflow software, are presented in this article. The efficiency of plastic cooling speed depending on the flash pocket. Higher temperature values of the mould and lower values of the polymer on the mould wall are recorded for the semicircular shape. This means that this shape is the most efficient in the heat transfer and the flash cooling using this design should be the fastest profile shape was evaluated on the basis of polymer and mould temperature values.

Vikram Bhargava, 2017 [7] his study found as a vast majority of the apparent material, tooling, processing, and even abuse issues can ultimately be traced back to poor design. The discussion assumes that the designer is familiar with the normal stress and strain calculations. Ultimately, calculations for stress, strain, wear, etc. on a component are the same regardless of the material being used. As an example, the stress on a certain member is P/A (where P is the applied load and A is the cross-sectional area), regardless of the material.

Evelien Uitterhaegen et al 2017 [8] Vegetable oils present a valuable class of bioresources with applications in both food and non-food industries and a production that has been steadily increasing over the past twenty years. Their extraction from oilseeds is a key process, as it exerts a strong impact on the resulting oil characteristics and quality. In view of the recent pressure towards sustainability, oilseed processing industries are taking renewed interest in thermo mechanical pressing as a means to obtain high quality oils.

Massimiliano Annoni et al, 2016 [9] A new extrusion-based manufacturing technique is described in this paper together with the main components of the machine capable of carrying out the process. The extrusion head and nozzle have been designed in order to be able to extrude high viscosity mixtures with low polymeric content. Preliminary tests prove that a good final density can be obtained after de-binding and sintering and that it is possible to achieve a good bonding of extruded and deposited wires in case of AISI 630 stainless steel.

Christian Hopmann et al, 2016 [10] reported that the diversity of products made from this various class of polymers, have many of the dies common in the processing of thermoplastics are found again in the extrusion of materials based on elastomers(rubbers). The most important applications of the mechanical design are the design of screw joints and sealing surfaces with respect to the internal pressure, the design of wall thickness for a permissible deformation by the internal pressure and the design of system for

the die in the exit region (automatic dies and blow-moulding die with an adjustable outer ring for the programming of the wall thickness of extrudate).

Matthew Moles et al, 2016 [11] in this study, a design of an ultrasound–assisted injection mold machine is explored. Simulation results are presented here for the design evaluation of the US-assisted injection molding interstitial die. The effect of service conditions on the resonance mode were considered, then the thermal risk to the piezoceramics was assessed. Finally, fluid dynamics approaches using Abaqus for the prediction of the polymer melt interaction with an ultrasonic device are considered.

Jing Deng et al, 2014 [12] Polymer extrusion, in which a polymer is melted and conveyed to a mould or die, forms the basis of most polymer processing techniques. Extruders frequently run at non-optimized conditions and can account for 15–20% of overall process energy losses. In times of increasing energy efficiency such losses are a major concern for the industry. Product quality, which depends on the homogeneity and stability of the melt flow which in turn depends on melt temperature and screw speed, is also an issue of concern of processors.

Har Bhajan Singh et al, 2014, [13] Natural dyes are always preferred because of their brightness, soothing and non-toxic nature.But after the advent of synthetic dyes by William Henry Perkin in 1856, the use of natural dyes has gradually gone out of existence from most part of the world.

However, natural dyes are traditionally used in certain parts of India despite synthetic dyes insurgency. Lately, people have come to realize the toxic effects of synthetic dyes, especially the azo dyes and Benzedrine derivatives. They release harmful amines, allergens, carcinogens, and other poisonous compounds that caused cancer, allergy and are detrimental to human health and environment.

Javier Vera-Sorroche at el, 2014 [14] in this work, a highly instrumented single screw extruder has been used to study the effect of polymer rheology on the thermal efficiency of the extrusion process. Three different molecular weight grades of high density polyethylene (HDPE) were extruded at a range of conditions. Three geometries of extruder screws were used at several set temperatures and screw rotation speeds. The extruder was equipped with real-time quantification of energy consumption; thermal dynamics of the process were examined using thermocouple grid sensors at the entrance to the die.

R.H. Schuster, 2012 [15] the study reviles that the diversified and sophisticated property set of modern elastomer can be achieved by blending polymers having specific physical and chemical properties with particulate reinforcing fillers that are necessary to cross link the entire system to form homogeneous networks. The aim of mechanically mixing the polymer with solid fillers, processing oils, oxidants, cuing agents, plasticizer and other is to cost-efficiently produce a homogeneous mix with filler particles that are reduced as much as possible in size and randomly distributed with the compound ingredients.

Alan N. Gent, 2012 [16] the study shows that that rubber consists of long flexible molecules that are in continous Brownian motion at normal temoeratures due to thermal agitaion. As a result, the molecules take up a variety of random configurations like a basket full of snakes when the moelcules are straightened out by an applied force and released, they spring back to random shapes as fast as their thermal motion allows.

Mark Berry et al, 2011 [17] this study provides a general background to how process monitoring and control technologies and strategies are applied to two major plastics processes: injection molding and extrusion. While the term “process control” could apply to anything that provides some aspect of machine control, discussion is limited to devices and methods that are applicable to some of the unique aspects of plastics processing. It is not the intention to discuss the technical details of data acquisition (DAQ). While new techniques continue to be studied and tested, there is a general acceptance that to survive and flourish in the plastics industry, manufacturers need to understand the process to develop and execute an effective monitoring and control strategy.

Hongyan Guan at el, 2011 [18] according to the characteristics of use and evaluation of rubber materials for sealing, the construction flow of evaluation index system was established, and the purposes and contents of evaluation were defined. The results indicated that the evaluation index system can reflect the use connotation of rubber materials for sealing and provide lessons for development and evaluation of other various materials.

S. H. Choi et al, 2009 [19] Rubber compounds have high viscoelastic property. One of the viscoelastic behaviors shown in profile extrusion is an extrudate swell and circulation flow at the corner of inside of die. Application of viscoelastic model to a capillary extrusion has been investigated in this study. Experiments and simulations have been performed using Fluidity Testerand commercial computational fluid dynamics (CFD) code, Polyflow respectively. Die swell of rubber compounds in a capillary die were predicted using a non-linear differential viscoelastic model, Phan-Thien and Tanner (PTT) model for various relaxation times and relaxation modes. As relaxation time and number of relaxation mode increase, die swell increases. The results of simulations were compared with the experiment. Pressure and velocity distributions, and circulation flows at the corner of reservoir have been analyzed through computer simulation.

Bauman et al, 2008 [20] reveled that when finite element codes , which could handle the large deformations and near incompressibility of elastomers, were not available so simple design formulas were the only mathematical guide design engineers had to aid elastomers components design. FEA methods can more accurately describe rubber stress-strain behavior than any of the equations presented. The equation shows that first set consist of traditional one that depend on how small the rubber deformations, e.g., 10% less, approximately linear rubber stress-strain behavior and incompressible material.

N. S. Hanspal, et al, 2005 [22] Studied about the finite element technique is used to model the free surface flow regime representing injection mould filling of elastomeric material such as rubber compounds. The results represented in this paper have also been compared against the Phan-Thien/Tanner model and are shown to be in closer agreement with the theoretical expectations than those obtained by the P-T/T equation. The results prove the applicability of the developed model to industrially relevant situations.

A.L.F.de Moura Giraldi et al, 2005 [23] studied the interfacial adhesion and mechanical properties of injection-molded recycled poly(ethylene terephthalate) with glass fibre has been studied as a function of two variables involved in the extrusion process: screw speed and screw torque. The composites properties studied included DMTA, flexural strength, Young's modulus and impact strength. The Young's modulus and impact resistance of the composites increased with the addition of glass fibre in recycled PET matrix. A factorial experimental design

(FED), based on the screw speed and torque of the double screw extruder used, was done to get the best thermo-mechanical properties versus processing conditions. Screw speed at the high level (200 rpm) was significant to increase Young's modulus.

T. Miki et al, 2003 [24] he suggested that wood-based materials are environment-friendly resources as they eventually decompose into carbon dioxide and water after disposal. However, there are a number of productivity and workability related problems: it takes many years for a tree to grow to a useable size, and wood materials are more difficult to process than metal and plastic materials

Peter A. Ciullo et al, 1999 [25] found that today there is a wide variety of rubber polymers, each with its own set of characteristic attributes, and each offered with modifications designed to enhance one or more of those attributes. In most cases, nevertheless, the elastomer by itself lacks one or more property necessary to produce a saleable product. These lead to the final processing step of vulcanization or curing in which the compound changes from a thermoplastic to a thermoset or cross linked state.

S. Karam et al, 1998 [26] The aim of this study is to show the relevant physical parameters related to rubber injection moulding, and especially compressibility, vulcanization and wall slippage. Three materials are studied: an SBR compound, without and with a lubricant, and an EPDM compound. The viscosity is determined by capillary rheometry. The modified SBR exhibits wall slippage. Rheological vulcanization kinetics is determined with a Moving Die Rheometer. Precise moulding experiments are carried out with an injection moulding machine and a mould equipped with pressure and temperature transducers. At low flow rate, the influence of the curing reaction on the pressure appears clearly especially for the fast curing EPDM.

A.N. Gent, 1994 [27] this author elaborates various aspects related to the process of vulcanization. Useful rubber articles, such as tires and mechanical goods, cannot be made without vulcanization. Un-vulcanized rubber is generally not very strong, does not maintain its shape after a large deformation. Vulcanization can be defined as a process which increases the retractile force and reduces the amount of permanent deformation remaining after removal of the deforming force. Thus, vulcanization increases elasticity, while it decreases plasticity. It is generally accomplished by the formation of a cross-linked molecular network.

V. CONCLUSION

The detailed study of previous work done in the synopsis about the factors that have increase in the productivity, we have found that the re-designing of die from single to double cavity, have significantly reduced the lead time and over all manufacture cycle time of the production of various products. Improvement in properties like appearance, abrasion resistance, uniform compressibility etc. is observed in previous studies in various designs of different cross sectional areas. Also, it presents that the productivity of the plant producing different product is enhanced due to re-designing of the die of the rubber extruder. Also it is worth noting that same parameters cannot be applied to the cavities are more than two on a single die because the designing aspects would be distinctly different for different cross section and also the further process layout will be required to be reconsidered.

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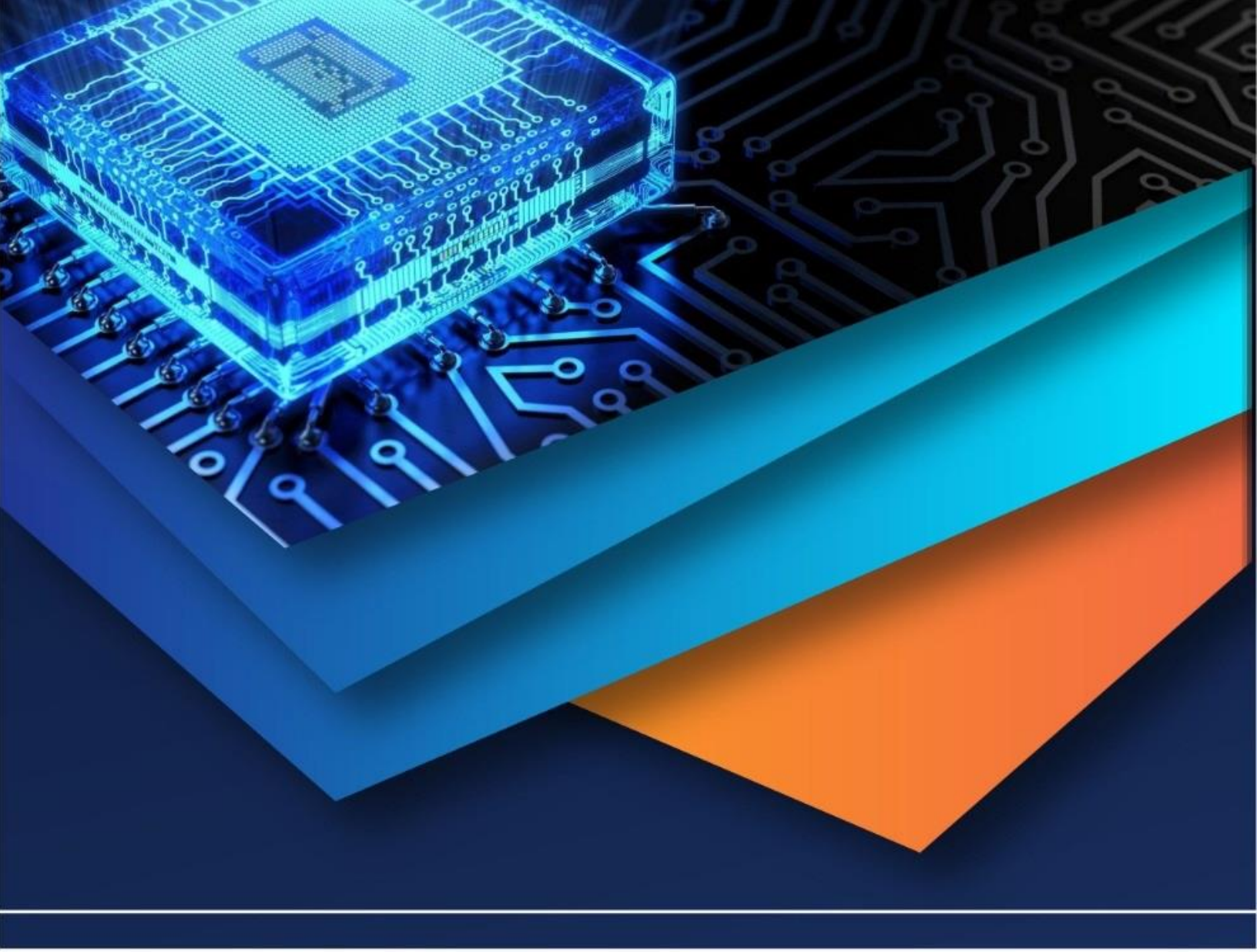

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