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Effect of Material Properties on the Structural Integrity of Honda Supra Crankshaft - An FEA Approach

Valentin Mereuta
Faculty of Engineering, University, "Dunarea de Jos", Galati, Romania

Abstract: This study presents a detailed finite element analysis of the crankshaft for a Honda Supra motorcycle, focusing on the static and fatigue behavior under realistic loading conditions. The crankshaft model was developed in Autodesk Inventor, including the inner bearing rings for a more accurate simulation, and imported into ANSYS for analysis. Three materials: 42CrMo4 Alloy Steel, AISI 1045 Steel, and AISI 4340 Steel, were compared based on their stress distribution, deformation, and safety factors. The results indicate that AISI 1045 Steel offers the best fatigue resistance, AISI 4340 Steel provides superior stiffness, and 42CrMo4 Alloy Steel represents a balanced, cost-effective choice. These findings support informed material selection depending on the desired balance between durability, rigidity, and efficiency, contributing to the optimization of crankshaft design in motorcycle engines.
***Keywords:** FEM analysis, Solid modeling, Autodesk Inventor, Ansys Workbench.*

I. INTRODUCTION

The crankshaft represents an essential component of internal combustion engines, having the role of converting the linear motion of the pistons into rotational motion. It is supported by bearings, and its rotation is achieved through the torque transmitted by the connecting rod, which links the piston to the crankshaft [1]. Due to the severe operating conditions and the complex stresses to which it is subjected, the study of crankshaft behavior is of major interest in the field of mechanical engineering [2]. Manufacturers frequently face challenges related to multi-axial loading, such as torsion and bending, stress concentration, stress gradient, and the effects of variable amplitude loads. With the advancement of technology, the stresses within the crankshaft can now be accurately determined using Finite Element Analysis (FEA). Since the crankshaft is subjected to a fully reversible loading cycle, it is prone to fatigue failure. However, the prediction of fatigue life remains difficult to achieve accurately, even under controlled laboratory conditions. In this context, numerical simulation offers a significant advantage, being less costly and allowing a deeper understanding of the failure mechanism. In most cases, failure occurs due to crack initiation, and a conservative approach considers the component as failed once a crack has initiated [3]. This simplifying assumption allows designers to use linear elastic stresses, obtained from multibody dynamic finite element simulations, to estimate the fatigue life.

C.M. Balamurugan, R. Krishnaraj, and M. Sakthivel [4] evaluated and compared the fatigue performance of crankshafts manufactured using two different technologies: forged steel and ductile iron. The study included a dynamic simulation performed on two crankshafts taken from similar four-stroke single-cylinder engines, using ANSYS software to determine the stress variations in critical regions. The results formed the basis for the optimization of the forged steel crankshaft, considering manufacturing constraints and cost factors. The optimization process involved geometric modifications compatible with the existing engine, as well as fillet rolling, which led to increased fatigue strength and reduced production costs, without requiring any modification of the connecting rod or engine block. Farzin H. Montazersadgh [5] conducted a finite element analysis to determine the stress distribution in the critical areas of the crankshaft. The dynamic analysis provided the load spectrum applied to the crank pin bearing, which was subsequently used in the optimization of a forged steel crankshaft. The primary goal of the optimization was to reduce the mass of the crankshaft while maintaining the same stress levels as the original design. The process resulted in an 18% reduction in weight, an increase in fatigue strength, and a decrease in manufacturing costs.

Chatterley et al. [6] compared the fatigue performance of crankshafts made of ductile iron, austempered ductile iron, and forged steel, concluding that austempered ductile iron exhibits significantly lower fatigue strength than forged steel when standard fillet rolling forces are applied. In a complementary study, Park et al. [7] demonstrated that the fatigue life of a crankshaft can be considerably improved through surface treatments such as fillet rolling and nitriding, without any dimensional modifications.

Jaimin Brahmbhatt and Abhishek Choubey [8] performed a dynamic simulation of a crankshaft, the three-dimensional model being created in SolidWorks, while the finite element analysis was carried out in Ansys. The study investigated the distribution of Von Mises stresses, as well as the vibrational behavior through modal and harmonic analysis. In a similar study, Rinkle Garg and Sunil Baghla [9] conducted a static analysis of a cast iron crankshaft for a single-cylinder four-stroke engine, using Pro-E for modeling and Ansys for FEM analysis. The results were subsequently used for shape optimization of the crankshaft without altering the connecting rod or engine block.

Additionally, Bhumesh J. Bagde and Laukik P. Raut [10] performed both static structural and fatigue analyses of a single-cylinder engine crankshaft, comparing multiple materials (SAE 1045, SAE 1137, and SAE 3140) in terms of strength and fatigue performance. Reddy [11] conducted a similar static structural analysis for crankshaft design optimization, providing relevant data on the stress and deformation fields for different materials and design alternatives.

Mourelatos [12] highlighted the importance of varying load cycles on the dynamic behavior of the crankshaft, emphasizing the need for dynamic structural analysis due to torsional, flexural, axial, and combined vibrations that occur during operation. Most analyses have shown that the central region of the crankshaft experiences the highest stresses and deformations, particularly at the crank pin and fillet radius areas [13].

II. CRANKSHAFT DESIGN

The crankshaft of the Honda Supra motorcycle was modeled using Autodesk Inventor Professional 2026 to ensure accurate geometric representation. To achieve a more realistic finite element analysis (FEA), the model, shown in Fig. 1, also included the inner rings of the bearings, which play a critical role in load distribution and contact behavior. After completing the detailed assembly, the entire model was exported in .step format to facilitate seamless import into Ansys for subsequent structural and fatigue analysis.

Incorporating the bearing inner rings into the crankshaft model enhances the fidelity of the simulation by accounting for the interaction between the crankshaft and the bearing assembly. This approach helps to better capture stress concentrations and potential failure points under operational loads.

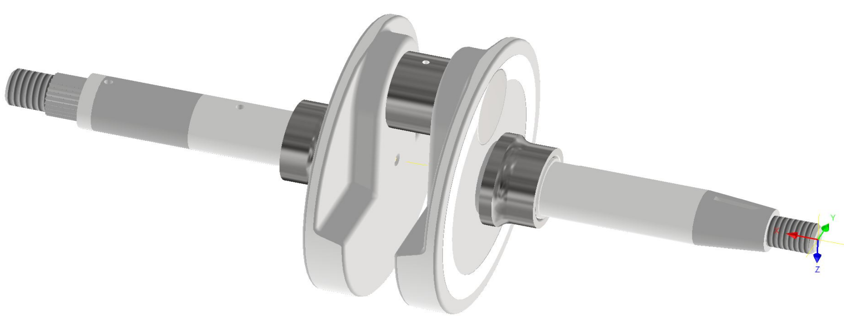

Fig. 1 3D model of the crankshaft

III.STATIC ANALYSIS

The .step file format was chosen for its compatibility and ability to preserve geometric integrity during the transfer from Autodesk Inventor to Ansys Workbench, ensuring that the finite element mesh generation is based on an accurate and complete model.

A. Choosing Material

For the material selection of the crankshaft, a comparative analysis was conducted between three commonly used steels: 42CrMo4 Alloy Steel, AISI 1045 Steel, and AISI 4340 Steel. These materials were chosen due to their widespread application in automotive and motorcycle engine components, particularly for parts subjected to high mechanical stresses.

42CrMo4 Alloy Steel is a chromium-molybdenum alloy steel known for its excellent strength, toughness, and fatigue resistance, making it a popular choice for high-performance crankshafts. AISI 1045 Steel, a medium carbon steel, offers good machinability and moderate mechanical properties but generally exhibits lower fatigue strength compared to alloy steels. AISI 4340 Steel, a nickel-chromium-molybdenum alloy steel, stands out for its superior strength and toughness, especially after heat treatment, making it suitable for demanding applications.

The comparative study involved evaluating the mechanical properties such as tensile strength, yield strength, hardness, and fatigue life, to determine the optimal material for durability and performance of the Honda Supra crankshaft. The results highlight the trade-offs between cost, manufacturability, and mechanical performance, guiding the selection of the most appropriate material for the application. Materials and their properties are shown in Table 1.

TABLE I
MATERIAL PROPERTIES

Parameters	*42CrMo4 Alloy Steel*	*AISI 1045 Steel*	*AISI 4340 Steel*
Young's Modulus [MPa]	210000	207000	207000
Poisson's Ratio	0.3	0.33	0.33
Shear Modulus [MPa]	80000	77820	77820
Mass Density [Kg/m^3]	7850	7850	7850
Tensile Strength [MPa]	1100	2067	1240
Yield Strength [MPa]	950	1825	1178

B. The Restrictions and Load Condition

The loading conditions and constraints for the crankshaft analysis were carefully defined to simulate realistic operating scenarios. The primary force applied was the combustion force transmitted from the connecting rod to the crankpin, representing the peak pressure exerted inside the cylinder during the power stroke.

The torque applied to the crankshaft was derived from the engine's power output and rotational speed. Given a power of 7.08 kW at 7700 rpm, the resulting torque was calculated as 8.7804 Nm. Additionally, the maximum cylinder pressure was determined to be 68.95 bar, which, combined with the piston diameter of 49.5 mm, yielded a combustion force on the crankpin of approximately 13.27 kN.

All these conditions and loads, as show in Fig. 2, were incorporated into the finite element model to ensure that the simulation reflects the actual mechanical stresses and deformation behavior of the crankshaft during operation.

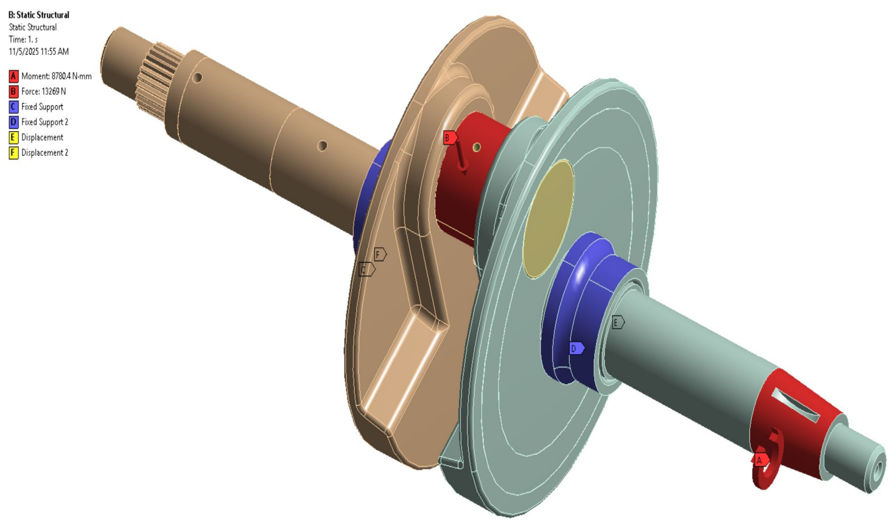

Fig. 2 Restrictions and load condition

C. Generate Meshing

For the mesh generation, a Hex Dominant method was used, combining the advantages of hexahedral elements with increased flexibility in complex areas. The model was discretized into a total of 77905 nodes and 44791 elements, ensuring a detailed and accurate representation of the crankshaft geometry. This mesh configuration allows for effective capturing of stress and deformation variations in the critical regions of the component, Fig. 3.

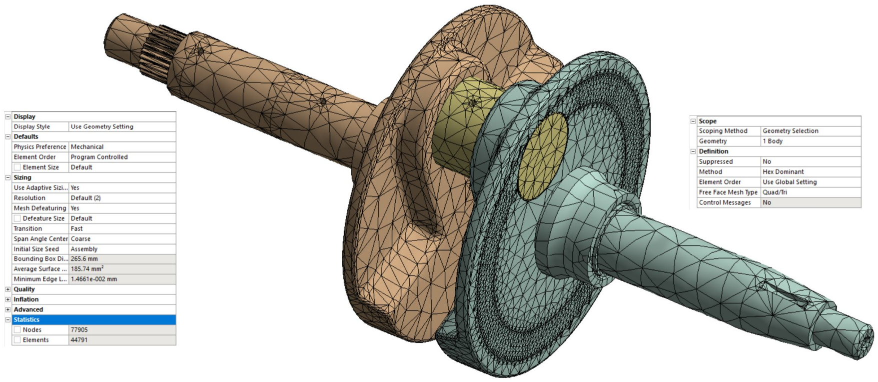

Fig. 3 Crane hook meshing

D. Static Analysis Results

The static analysis of the crankshaft made from 42CrMo4 Alloy Steel revealed a maximum Von Mises stress of 269.83 MPa, Fig. 4. The maximum deformation recorded was 3.611 mm, Fig. 5, indicating the component's elastic response under the applied loads. The calculated Factor of Safety (FOS) for static loading is 3.521, Fig. 6, demonstrating a sufficient margin against yielding under the given operating conditions.

For fatigue analysis, the Factor of Safety (FOS) was determined to be 1.835, Fig. 7, which suggests that the material can endure the cyclic loading with a reasonable safety margin before fatigue failure is expected. These results confirm that 42CrMo4 Alloy Steel is a reliable choice for the crankshaft material, balancing strength, durability, and deformation under typical engine loads.

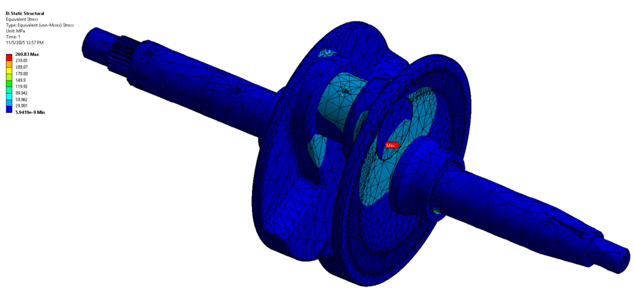

Fig. 4 Von Mises Stress – *34CrMo4 Alloy Steel*

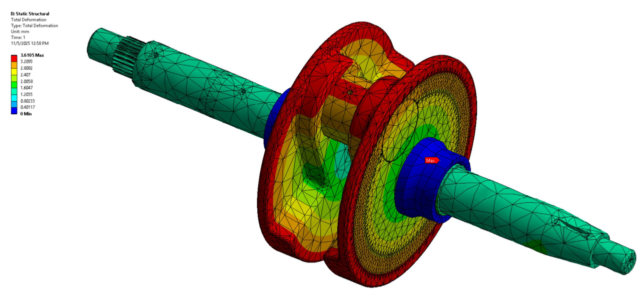

Fig. 5 Deformation – *34CrMo4 Alloy Steel*

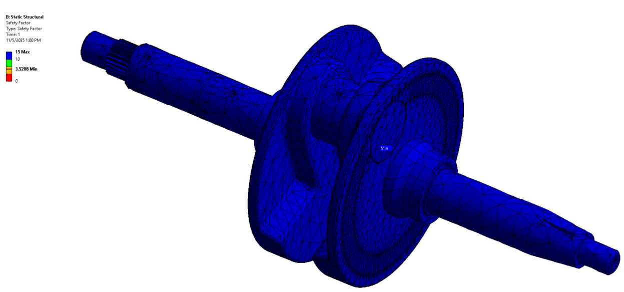

Fig. 6 Factor of Safety – *34CrMo4 Alloy Steel*

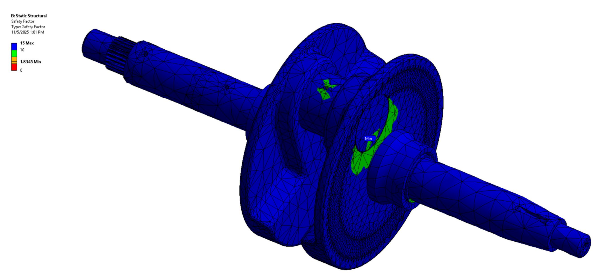

Fig. 7 Fatigue Safety Factor – *34CrMo4 Alloy Steel*

The static analysis of the crankshaft modeled with AISI 1045 Steel material revealed a maximum Von Mises stress value of 264.48 MPa, which remains well below the material's yield strength, indicating a safe operational stress level, Fig. 8. The maximum deformation recorded was 3.648 mm, Fig. 9, demonstrating the component's ability to maintain structural integrity under the applied load conditions without excessive displacement.

The Factor of Safety (FOS) against static failure was calculated to be 6.9, Fig. 10, reflecting a significant safety margin that ensures the crankshaft can endure unexpected overloads or transient load peaks without permanent deformation or failure.

Regarding fatigue performance, the crankshaft exhibited a fatigue Factor of Safety of 3.517, Fig. 11. This result indicates that the material can tolerate cyclic loading conditions typical in engine operation with a comfortable margin before fatigue failure may occur. The high fatigue safety factor suggests enhanced durability and reliability over the expected service life, making AISI 1045 Steel a strong candidate material for crankshaft manufacturing, especially in applications where resistance to repeated stress cycles is critical.

Overall, the results highlight that AISI 1045 Steel offers a balanced combination of strength, ductility, and fatigue resistance, ensuring safe and reliable crankshaft performance under both static and dynamic loading scenarios.

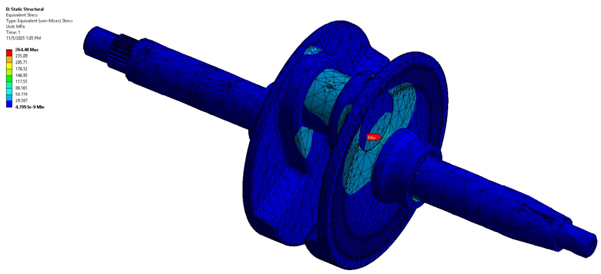

Fig. 8 Von Mises Stress – *AISI 1045 Steel*

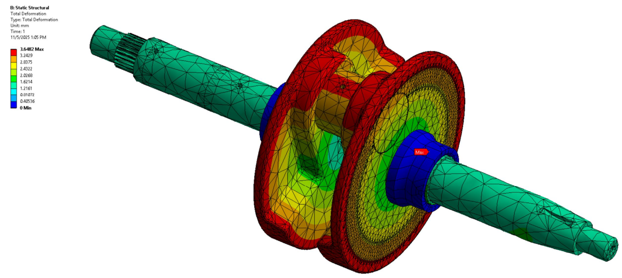

Fig. 9 Deformation – *AISI 1045 Steel*

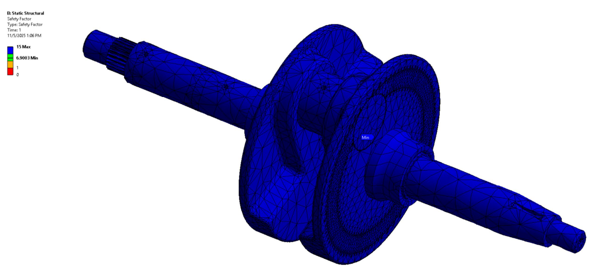

Fig. 10 Factor of Safety – *AISI 1045 Steel*

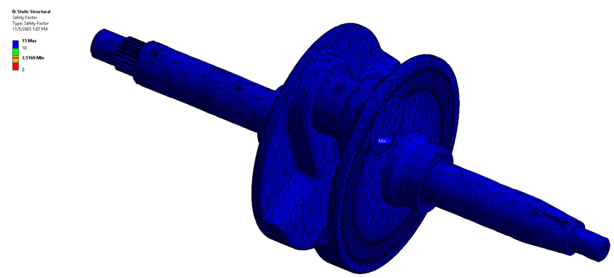

Fig. 11 Fatigue Safety Factor – *AISI 1045 Steel*

The static analysis of the crankshaft made from AISI 4340 Steel indicated a maximum Von Mises stress of 267.06 MPa, Fig. 12, which is well within the material's allowable limits, ensuring structural safety under the applied loading conditions. The maximum deformation recorded was 1.999 mm, Fig. 13, significantly lower compared to other materials, highlighting AISI 4340's superior stiffness and resistance to elastic deformation.

The Factor of Safety (FOS) against static failure was calculated at 4.411, Fig. 14, indicating a robust safety margin that provides confidence in the crankshaft's ability to withstand unexpected or peak static loads without yielding or permanent damage.

In terms of fatigue performance, the fatigue Factor of Safety was determined to be 2.089, Fig. 15. This value suggests that while the material can endure cyclic stresses typical in engine operation, it has a moderate margin before fatigue failure may occur. Nonetheless, this level of fatigue resistance ensures reliable performance over the crankshaft's service life under normal operating conditions.

Overall, AISI 4340 Steel exhibits an excellent balance between strength and stiffness with satisfactory fatigue resistance, making it a suitable choice for applications requiring enhanced mechanical performance and durability.

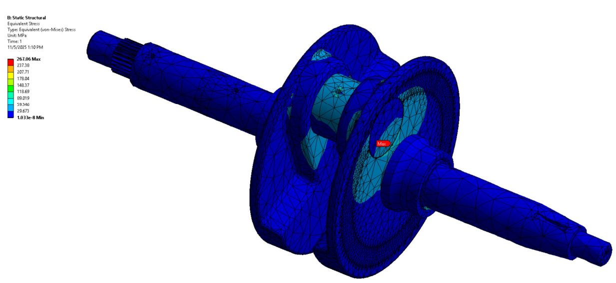

Fig. 12 Von Mises Stress – *AISI 4340 Steel*

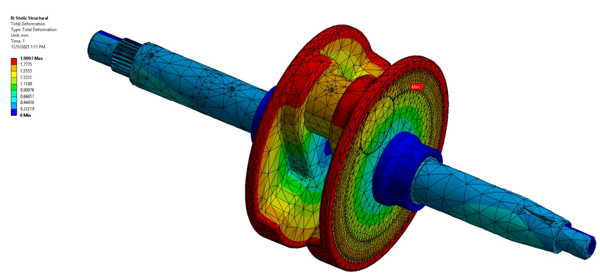

Fig. 13 Deformation – *AISI 4340 Steel*

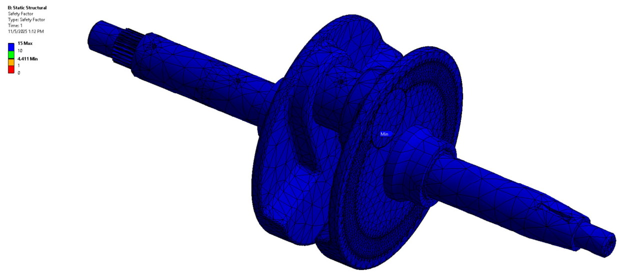

Fig. 14 Factor of Safety – *AISI 4340 Steel*

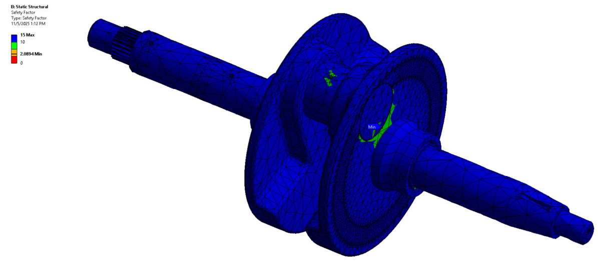

Fig. 15 Fatigue Safety Factor – *AISI 4340 Steel*

The comparative analysis of the three selected materials: 42CrMo4 Alloy Steel, AISI 1045 Steel, and AISI 4340 Steel revealed important differences in their mechanical behavior and suitability for use in the crankshaft of the Honda Supra motorcycle.

42CrMo4 Alloy Steel exhibited a relatively high Von Mises stress value (269.83 MPa) and the highest maximum deformation (3.611 mm) among the three materials. While its static Factor of Safety (3.521) was adequate, the fatigue Factor of Safety (1.835) was the lowest, indicating a comparatively reduced resistance to cyclic loading and potential fatigue failure over time.

AISI 1045 Steel demonstrated the best performance in terms of safety margins, with a static FOS of 6.9 and an excellent fatigue FOS of 3.517. Although the Von Mises stress (264.48 MPa) and maximum deformation (3.648 mm) were similar to those of 42CrMo4 Alloy Steel, the significantly higher safety factors make AISI 1045 Steel a more reliable option under both static and fatigue conditions.

AISI 4340 Steel offered a balanced compromise with a moderate Von Mises stress (267.06 MPa) and the lowest maximum deformation (1.999 mm), reflecting its superior stiffness. Its static FOS of 4.411 and fatigue FOS of 2.089 position it between the other two materials in terms of strength and durability, providing a good combination of mechanical performance and fatigue resistance.

IV. CONCLUSION

The comparison of the three materials showed distinct advantages for each. AISI 1045 Steel offers the highest safety factors for both static and fatigue loads, making it the most durable choice. AISI 4340 Steel provides the best rigidity with the lowest deformation, balancing strength and fatigue resistance. Meanwhile, 42CrMo4 Alloy Steel is a cost-effective option but has lower fatigue safety margins. The final material selection should consider the project priorities: durability, rigidity, or cost efficiency.

Among the three materials, AISI 1045 Steel stands out for durability, showing the highest safety factors under both static and fatigue conditions. AISI 4340 Steel excels in rigidity, with the lowest maximum deformation, making it ideal where stiffness is crucial. For efficiency (balancing cost and performance), 42CrMo4 Alloy Steel is a viable option, though with lower fatigue safety. Therefore, AISI 1045 Steel is preferred for long-lasting applications, AISI 4340 Steel for applications requiring higher stiffness, and 42CrMo4 Alloy Steel for cost-sensitive projects.

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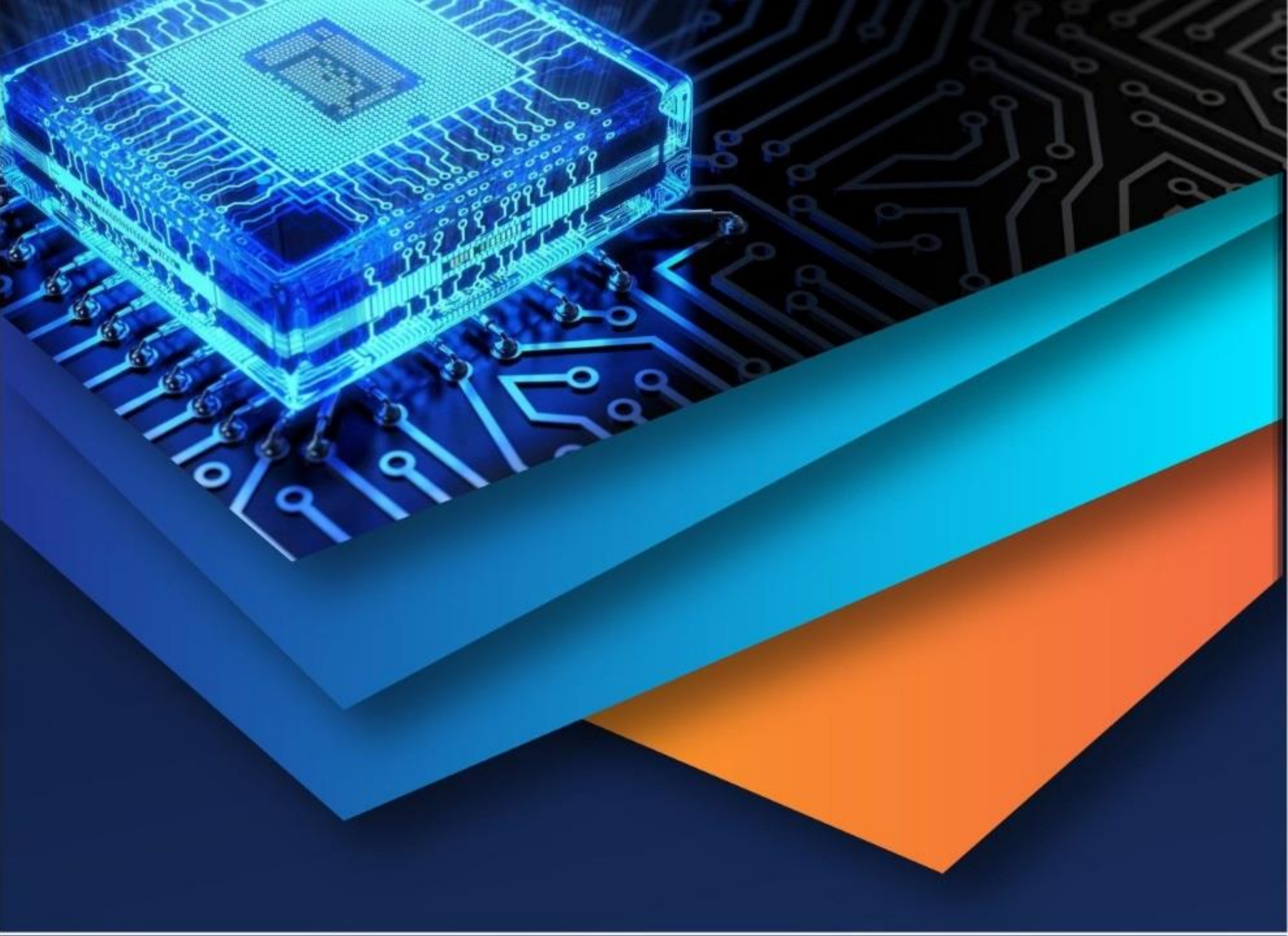

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