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Performance Evaluation of Automobile Crankshaft

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Abstract— ***The crankshaft is the main component of IC engine. So the design & analysis is carried out for important aspects to get high power transmission & efficiency. Selection of suitable material plays a important role while designing any mechanical component. In order to absorb the shocks and fatigue, the material should have high strength & capacity, and have less wear tendency. The crankshaft should have high torque transmitting capacity. The subject was picked on account of expanding enthusiasm for higher payloads, lower weight, higher efficiency and shorter load cycles in crankshaft. The static structural and fatigue analysis of four cylinder engine crank shaft is carried out in this project work. The objective includes modelling and analysis of crankshaft, inorder to identify the effect of stresses on crankshaft and fatigue life of the materials to compare different materials and to deliver possible solution. Results acquire from the analysis are used in optimization of the crankshaft. Results obtained shows that mild steel is better material to be considered with respect to stress and fatigue life as per analysis.***
Keywords— ***Crankshaft, Modal analysis, Static analysis, Fatigue analysis***

I. INTRODUCTION

It is the biggest and essential component in internal combustion engines. It has complicated geometry converts reciprocating movement of the piston to a rotating movement with four link mechanism. In working condition it is subjected to critical loads which inturn experience the cyclic loads as torsional and bending loads. Crankshaft should be very strong inorder to withstand downward force of a power stroke without extreme bending.The life and reliability of the internal combustion engine relies on the strength of the crankshaft to great extent. During the process the driving force hits the crankshaft in one spot and another, torsional vibrations shows up as a power driving force hits a crankpin towards the front of the engine and power stroke closes,in case if not controlled it breaks the crankshaft. They are usually manufactured by forging and casting process, compared to casting process manufactured by forging have some advantages of getting a homogenous part that shows minimum number of micro structural voids and defects, in addition to that it helps to gain strength and greater toughness in the grain flow direction. Crankshaft has complex geometry consisting of cylinder as a bearing and plates as the crank webs. As the geometry section changes in the crankshaft results in stress concentration at fillet areas where bearing are connected to the crank web. In addition to this component subjected to both torsional and bending load during its service life, Therefore critical stress are accumulated near the fillet areas during its service life. These areas are responsible for fatigue failure of the component.
Crankshaft comprises of shaft parts, two journal bearing and one crank pin bearing. The shaft parts rotating in the main bearing, the biger end of connecting rod is associated with crankpin. The crank webs which fix the shaft parts and crank pin, as the displacement is created by the ignition chamber, the linear displacement of an engine is not smooth, therefore the displacement has sudden shocks. The idea of utilizing crankshaft is to convert these sudden displacement to smooth rotary output which is input to many devices like pumps, generators ,compressors. The use of flywheel also helps in smoothing the shocks.

II. OBJECTIVE

A. First the modal analysis is performed for three different materials such as steel, cast iron, aluminium alloy to determine the first natural frequency and mode shapes, and also compared with the theoretical results.
B. Static analysis is also performed for three different materials such as steel, cast iron, aluminium alloy to evaluate the displacement, stresses, and strains at critical location of the crankshaft.
C. Fatigue analysis is performed in nCode Design Life software to study the total life estimation of a crankshaft component.

III.METHODOLOGY OF THE PROJECT

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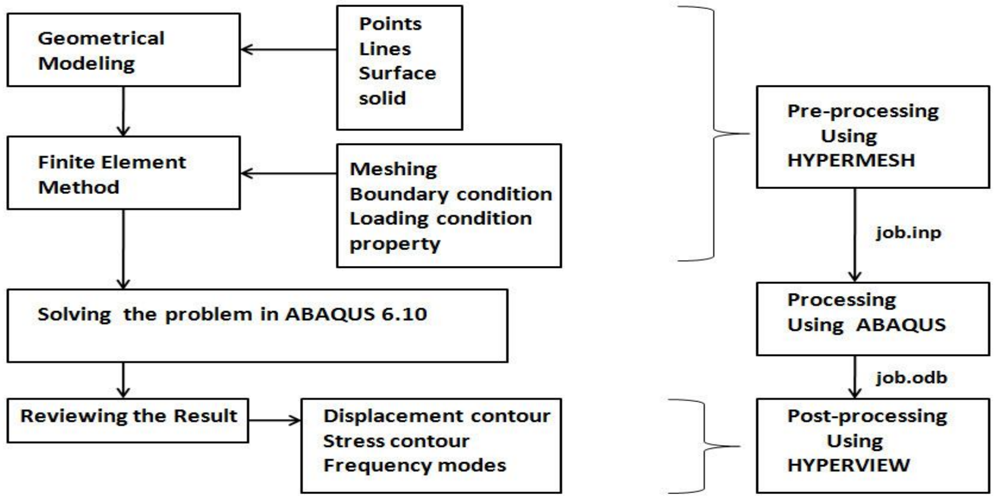

A. A 3D model of crankshaft is exported to pre-processing Hypermesh software, which involves the meshing, material selection, applying suitable loading and boundary conditions to the model.

B. The model is imported to the ABAQUS software to run the analysis, time required for this process depends on complexity of component, after the analysis has completed successfully without any errors, results are obtained.

C. Results obtained are shown in the form of plots and graphs in Hyperview which is popularly known post-processor of Hyper Works software.

IV. MATERIAL PROPERTIES

Table I. Mechanical Properties for various materials

Material	Young's Modulus N/mm^2	Poisson's Ratio	Density Kg/mm^3	Yield Stress N/mm^2	Ultimate Stress N/mm^2
Steel	2.1×10^5	0.3	7.89×10^{-6}	250	420
Cast Iron	1.2×10^5	0.28	7.2×10^{-6}	85	220
Aluminium Alloy	0.75×10^5	0.33	2.79×10^{-6}	165	260

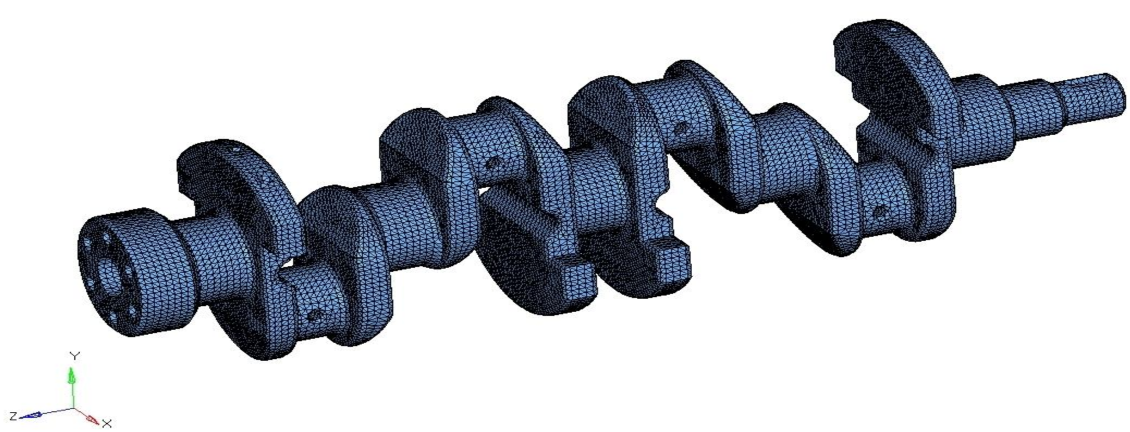

Fig.1. 3D meshed model of a Crankshaft

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Table II. Meshing details of the crankshaft model

Type of Elements	Tetrahedrons
Number of Nodes	48085
Number of Elements	217824

V. THEORETICAL CALCULATIONS OF MODAL ANALYSIS

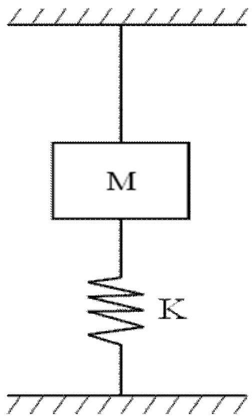

Fig.2. Spring mass system of crankshaft

Crankshaft is converted into spring mass system to evaluate the natural frequency.
M = mass of crankshaft, kg
K = stiffness of the crankshaft, N/mm
L = length of crankshaft, mm
A = area of crankshaft , mm^2
F_n = natural frequency, Hz

A. Steel

$E = 2.1 \times 10^5$ N/mm^2
$M = 1.103 \times 10^{-2}$ Ton = 11.03 kg
L = 470 mm
A = 189006.291 mm^2

$$K = \frac{AE}{L} = \frac{189006.291 \times 2.1 \times 10^5}{470} = 84449619.38 \text{ N/mm}$$

$$F_n = \frac{1}{2\pi}\sqrt{\frac{K}{M}} = \frac{1}{2\pi}\sqrt{\frac{84449619.38}{11.03}} = 440.38 \text{ Hz}$$

B. Cast iron

$E = 1.2 \times 10^5$ N/mm^2
$M = 1.014 \times 10^{-2}$ = 10.14 kg
L = 470 mm
A = 189006.291 mm^2

$$K = \frac{AE}{L} = \frac{189006.291 \times 1.2 \times 10^5}{470} = 48256925.36 \text{ N/mm}$$

$$F_n = \frac{1}{2\pi}\sqrt{\frac{K}{M}} = \frac{1}{2\pi}\sqrt{\frac{48256925.36}{10.14}} = 347.2 \text{ Hz}$$

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C. Aluminium Alloy

$E = 0.75 \times 10^5\ N/mm^2$

$M = 3.818 \times 10^{-3}\ Ton = 3.818\ kg$

$L = 470\ mm$

$A = 189006.291\ mm^2$

$$K = \frac{AE}{L} = \frac{189006.291 \times 0.75 \times 10^5}{470} = 30160578.3\ N/mm$$

$$F_n = \frac{1}{2\pi}\sqrt{\frac{K}{M}} = \frac{1}{2\pi}\sqrt{\frac{30160578\ .3}{3.818}} = 447.32Hz$$

VI. MODAL ANALYSIS

This analysis is done by neglecting damping and applied loads and considering only boundary conditions of the crankshaft to find the natural frequency and mode shapes during free vibration. It gives idea of dynamic behaviour of the structure, how it response to a dynamic loading. Modal analysis is carried out on three different materials such as steel, cast iron, aluminium alloy for first eight modes, the natural frequency obtained from this analysis is cross checked and should be within the allowable frequency, then the design is safe.

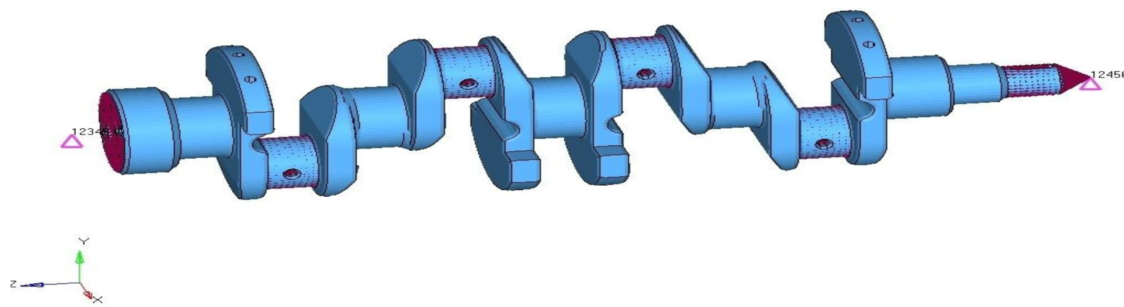

Fig .3. Boundary condition applied to the Crankshaft

The left end of crankshaft is constrained in all degrees of freedom in all directions (12345) except z-rotation (6), The right end is constrained in all degrees of freedom in all directions (12456) except z-translation (3).

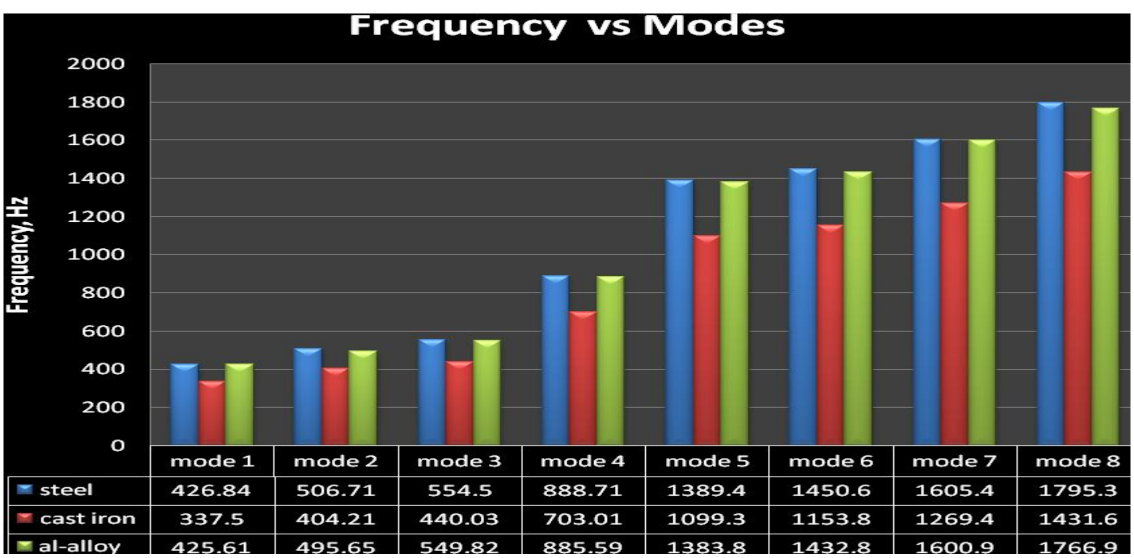

Fig .4. Comparison of frequency vs modes for various materials

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VII. STATIC ANALYSIS

It is carried out to find displacement, stress, strain etc. Under static loading condition neglecting inertia and damping effect. Static analysis consists of linear and nonlinear analysis. Nonlinearities involves plasticity , large deflection, large strain, creep ,contact surface.

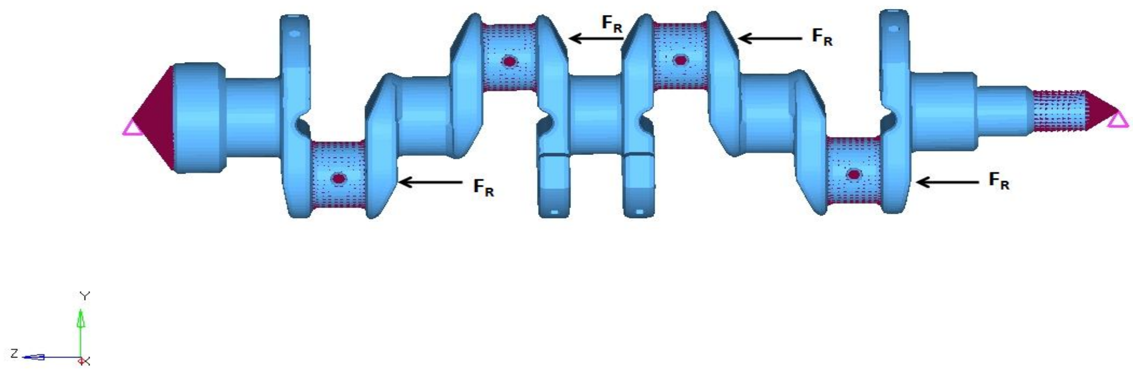

Fig .5. Radial Force applied on the crankshaft.

The above figure shows that a radial load of 5.83 KN is applied by using rigid RBE2 elements in z-direction.

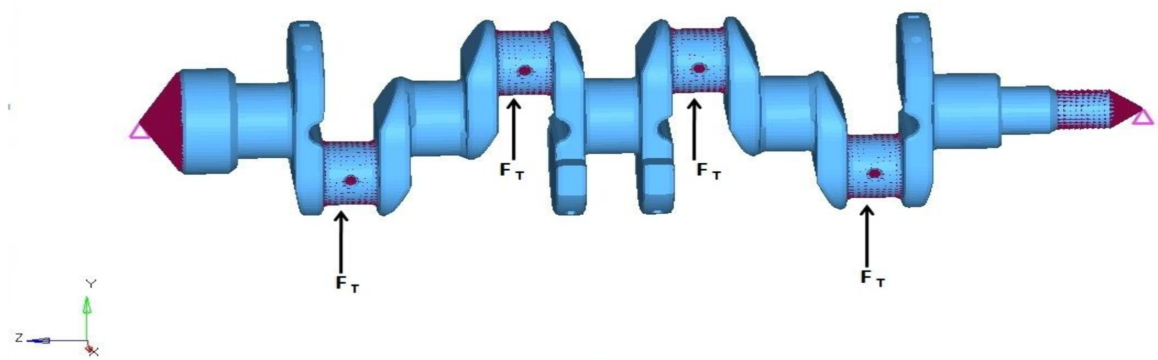

Fig .6. Tangential Force applied on the crankshaft.

The above figure shows that a Tangential load of 5.48 KN is applied by using rigid RBE2 elements in y-direction.
Static analysis is performed with application of load on crankpin .The radial force is applied in z-direction and tangential force is applied in y-direction. Boundary conditions applied are left end of crankshaft is constrained in all degrees of freedom in all directions (12345) except z-rotation (6), The right end is constrained in all degrees of freedom in all directions (12456) except z-translation(3) .The stress, displacement and strain are separately developed and compared with different materials.

VIII. FATIGUE ANALYSIS

A. N-code design life is a CAE durability software tool which identifies fatigue life prediction using finite element analysis in order to know the life of the component even before a prototype is made. Loading and boundary condition is same as that of static analysis but to minimise time, load of 1N is applied in z and y direction.

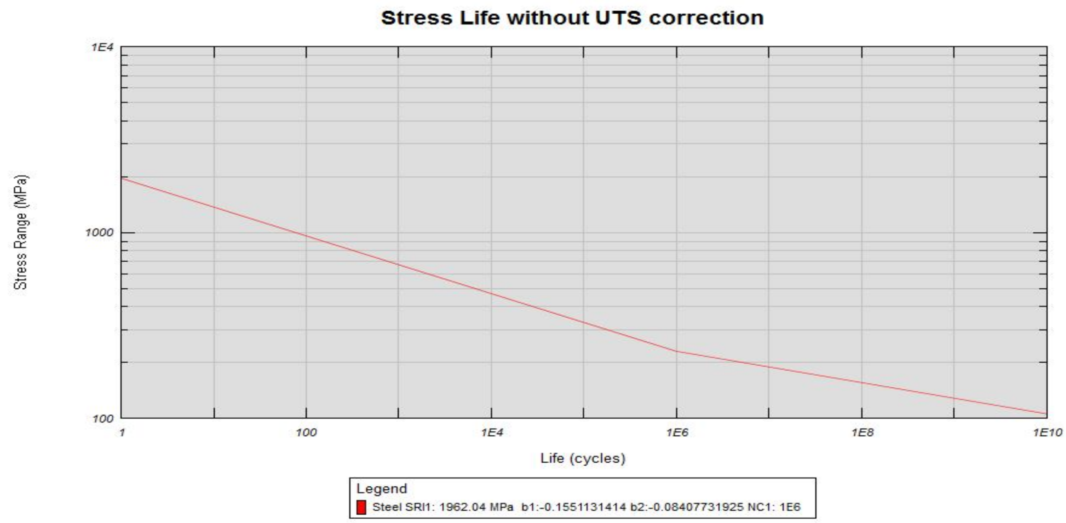

Fig.7. graph shows S-N curve for steel

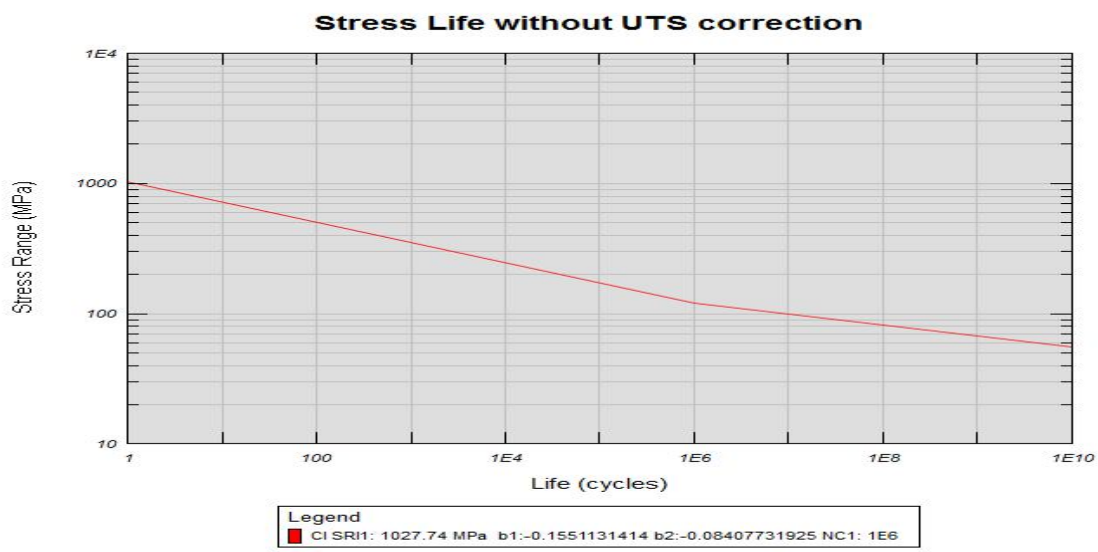

Fig .8. graph shows S-N curve for cast iron

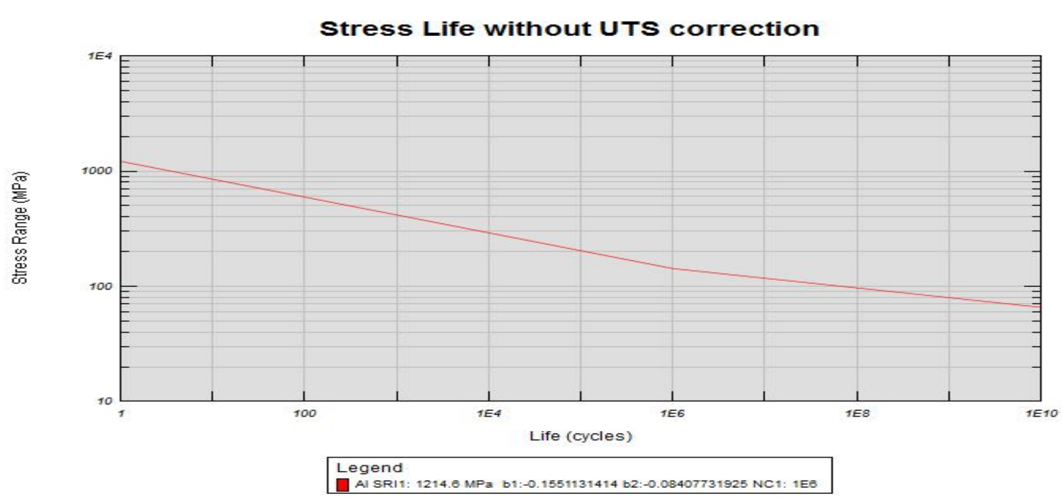

Fig .9. Graph shows S-N curve for aluminium alloy

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IX. RESULTS AND CONCLUSIONS

A. *Theoretical Validations*

Table III. Comparison of Modal analysis results for first mode.

Material	Theoretical modes Natural Frequency, Hz	FEA modes Natural Frequency, Hz	Percentage of Error
Steel	440.38	426.84	13.54
Cast iron	347.2	337.5	9.7
Aluminium alloy	447.32	425.61	27.71

B. *Comparison of Static analysis results*

Table IV.Comparison of static analysis results for various materials

Material	Displacement mm	Vonmises stress N/mm^2	Maxprincipal stress N/mm^2	Plastic strain
Steel	0.335	195.484	242.303	0.001
Cast iron	0.607	160.424	221.234	0.003
Aluminium alloy	0.987	198.053	246.299	0.001

From the above table it can be concluded that Vonmises stress of steel is below the material yield strength and displacement is less when compared to other materials .Hence steel is preferred material. After the results have been got from FE analysis, many discussions have been made.

1) Results demonstrate the improvement in the strength of the crankshaft as the maximum limits of stresses. The von-misses stresses thus obtained from the analysis is below the material yield stress so considered design is safe.
2) Results obtained declares that FEA results matches with the theoretical calculation, therefore we are able to say that FEA may be a good tool to minimise the time consuming theoretical work.
3) The modal analysis is carried out to know the fundamental natural frequency for different materials and behaviour of the material i.e.mode shapes for free vibration.
4) The fatigue life of materials steel, cast iron and aluminium alloy are almost comparably with each other. By using this software it takes less time and efforts to perform analysis and accuracy is also good.

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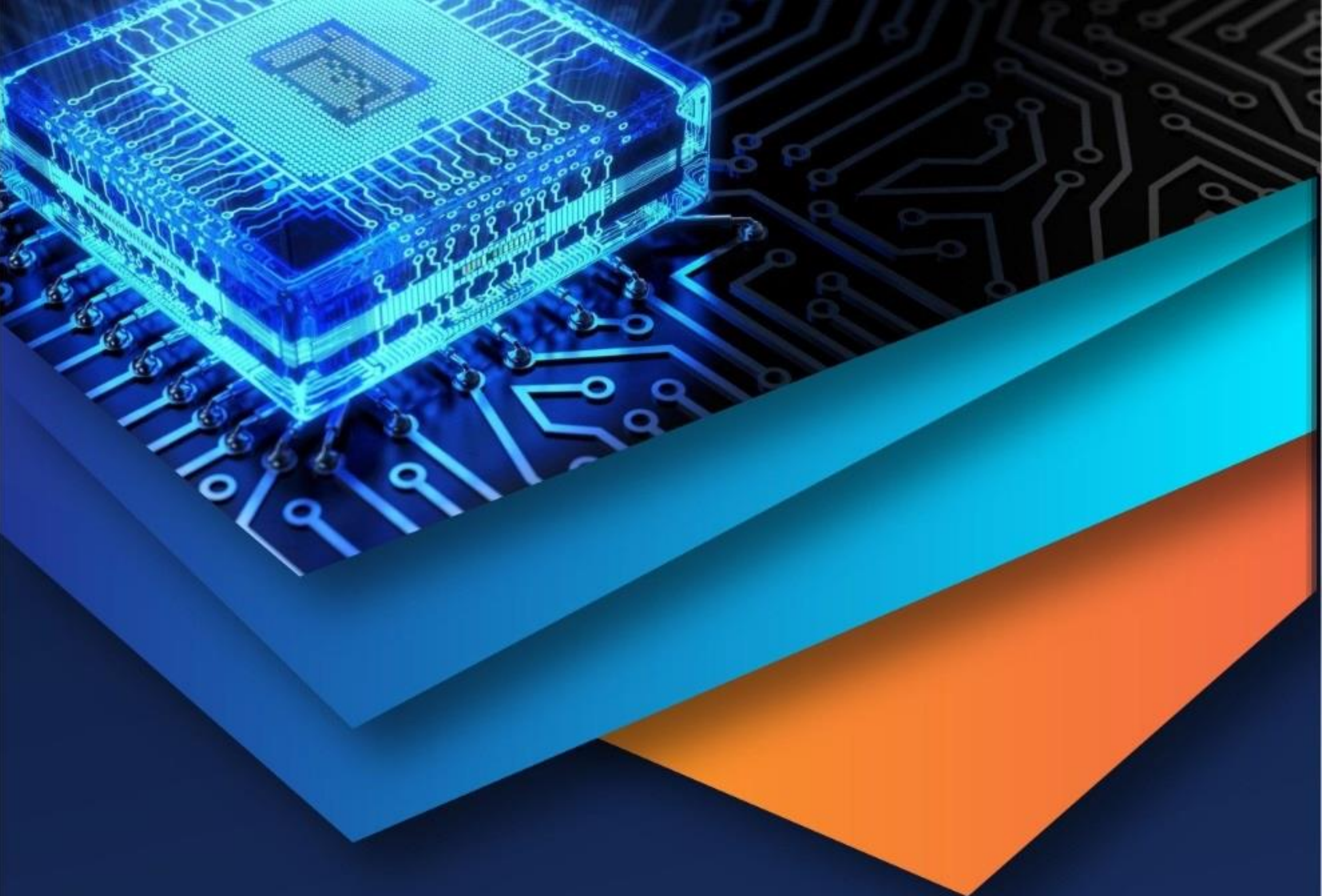

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