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Static Structural Analysis of Automotive Crankshaft Using Digital Prototyping

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Abstract: **This paper presents the static structural analysis conducted on a Crankshaft using ANSYS software. Three different materials En8D, Cast Steel and Stainless Steel are used with the same loading conditions to perform this analysis. The review of existing literature and analysis is presented. Three dimensional model of crankshaft is creates in Inventor and then imported to the ANSYS Workbench software. The load is then applied to the FE model and boundary conditions were applied according to the engine conditions. Static structural analysis is executed on the crankshaft to obtain information about the stresses that are affecting the crankshaft. Finite element analysis method is used to determine stress, strain and deflection at most stressed point which results into failure.**

***Index Terms*—Ansys, Crankshaft, Static Analysis**

I. INTRODUCTION

Crankshaft is a heart of an automobile engine and is most important part of it. A crankshaft has a very wide range of applications from small one cylinder to multi cylinders. Crankshaft must be strong enough to take the downward force of the power stroke without excessive bending. So that the reliability and life of the Internal Combustion engine is totally depends on the strength of the crankshaft. Finite element method is used to carry out stress analysis of engine crankshaft by applying a specific load.

II. FUNCTION OF A CRANKSHAFT

Rajkumar Patil [1] presented that the crankshaft, connecting rod and piston constitute a four bar slide-crank mechanism, which convert a sliding motion of the piston (slider in the mechanism) to a rotary motion. Since the rotation output is more practical and applicable for input to other devices, the concept design of an engine is that the output would be rotation. In addition, the linear displacement of an engine is not smooth, as the displacement is caused by the combustion of gas in the combustion chamber. Therefore the displacement has sudden shock and using this input to other device may cause damage to it. The concept of using crankshaft is to change this sudden displacements to a smooth rotary output, which is the input to many devices such as generator, pump and compressor.

Amit Solanki [2] introduced that the performance of any automobile largely depend on its size and working in dynamic conditions. Since the crankshaft experiences a large number of loads cycles during its service life, stress performance and durability of this component has to be considered in the design process.

III. DESIGN AND MANUFACTURING

A. Design

Chang, Javier Silva[3],[4] presented that the feacher based and parametric modelling techniqe have been widely adopted in the mainstream CAD tools such as Pro/Engineer, Solidworks, Solidedge, Unigraphics, CATIA, I-DEAS, and even Mechanical Desktop of AutoCAD. With such techniques, designers are able to create part through geometric featutes, and assemble part or subassemblies for the product digital mock-up in the CAD environment. In addition, the designer will be able to define design variables by relating dimensions of the part features and imposing assembly constraints between parts to parameteriza the product model through thw parametric modelling technique. The designer can make a design change simply by changing design variable values and asking the CAD software to automatically regenrate the part that are affected by change, hence regenerating the entire assembly.

The 3-D digital image of crankshaft is created s shown in fig:1 using Inventor Software. Inventor software creates a single digital model that gives engineer the ability to design, visualize, and simulate their products.

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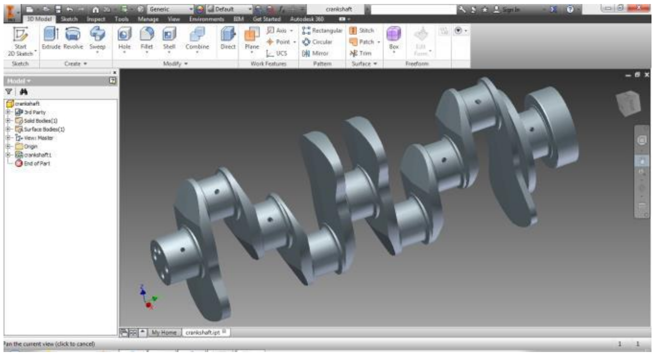

Figure 1: 3-D model of crankshaft

Inventor software enables to create a digital prototype, helps to reduce reliance an costly physical prototype and get more innovative designs to market faster. Created model is exported as IGS file for next process.

B. Manufacturing

Amit Solanki, Ketan Tamboli [2] studied the design considerations and concluded that to apply the selection of material and manufacturing process need comparitive study to have cost effectiveness and defect free shape respectievely. In crankshaft the crack grows faster on the free surface while the central part of the crack front become straighter. The very prevailing mechanism of failure of crankshaft is fatigue. So the accurate stresses are critical input for fatigue. Residual imbalances along with the length of the crankshaft are crucial to performance. Also the stress and strain analysis must be conducted due to nature of load applied on the crankshaft.

Prajakta Pawar, Santosh Dalvi [5] examines the crankshaft manufacturing methods along with their advantages and disadvantages. Traditionally, there are three methods Forging, Casting and Machining. In this, Forging is nothing but shaping of metal by plastic deformation with three typical stages reducer rolling, blocker forging, and finisher forging. Casting is basically pouring the molten metal into the mold for producing desired product. Machininig is material removal process from a billet with a required diameter.

IV. FAILURE OF CRANKSHAFT

Ms. Shweta Ambadas Naik [6] presented stresses and failure of crankshaft. Various forces acting on the shaft but failure takes place in two positions, bending and twisting. Failure may occur at the position of maximum bending; at the center of crank or at either end.in this condition failure occur due to bending and the pressure in the cylinder is maximal. Also the crank may fail due to twisting. So the connecting rod need to be checked for the shear at the position of maximal twisting. Vibration is one of the cause for crankshaft failure. If engine is running with heavy vibration especially torsional vibration, it may lead crack in the crankpin and journal. Insufficient lubricant is one of the reason to fail crankshaft. If the lubrication in bearing in the crankshaft is starved, it may lead to wipe out of the bearing and failure of the crankshaft takes place.

Kanwa J.S.Gill [7] introduced that the crankpin is like a built in beam with a bending and twisting. Journal would be principally subjected to twisting. Bending cause tensile and compressive stresses. Twisting causes shear stresses. Due to shrinkage of web onto the journals, compressive stresses are set up in journal and tensile hoop stresses in the webs.

Farzin H.[8] compares the magnitude of maximum torsional and bending loads at different engine speeds. The maximum of total load magnitude, which is equal to maximum of bending load decreases as the engine speed increases. The load caused by inertia increases in magnitude as the engine speed increases.

Mr.S.M.Nagare[18] presented that crankshaft is one of the critacal components of an I C Engine, failure of which may result in disaster and makes engine useless unless costly repair performed. It posesses intricate geometry and and while operation experiences complex loading pattern. The dynamic load and rotating system exerts repeated bending and shear stress due to torsion, which are common stresses acting on crankshaft and mostly responsible for crankshaft failure. Hence stress analysis plays an important role in crankshaft development cosidering its safety and reliable operation.

Ali Fatemi,[9] concluded that the crankshaft is subjected to complex loading due to the motion of the connecting rod, namely combustion and inertia. Optimization of crankshaft requires a determination of an accurate assessment of the loading.

V. THEORY OF CRANKSHAFT ANALYSIS

Static analysis is done by Bhalerao Ganesh Nandkumar[10]. In the work fron design to finite element analysis of crankshaft of a 4-cylinder petrol engine.six materials based on their compositions are used for the analysis. The parameter like von-misses stress, deformation, maximum and minimum principle stress and strain were obtained. Jian Meng[11] analysed stress analysis on a 3D model of diesel engine crankshaft. The maximum deformation, maximum stress point and dangerous ares are found by stress analysis of crankthrow. The model was created in PRO/Engineer and imported in ANSYS software. Aftre analysis, concluded that the maximum deformation appears at the centre of crankpin neck surface. The maximum stress appears at the fillets between the crabkshaft journal and crank cheeks, and near the central point journal. The edge of main journal is high stress area.

Ashwini kumar singh [12] presented work static analysis which was conducted on the single cylinder four stroke engine crankshaft with two dwo different material properties. Finite element analysis was performed to obtained the variation of stress magnitude at critical locations. The value of the Von –Misses stresses that comes out from the analysis is for less than material yield stress so design is safe. Yogesh khaladkar [13] concluded that finite element analysis (FEA) is best method for analysis of permissible stress. The optimization results into reduction in weight and cost. Finite element analysis of six cylinder crankshaft has been done using FEA too ansys by V. Mallikarjun Reddy [14]. The effect of stresses on crankshaft is analysied with three different material Cast Iron, High Carbon Steel, and Forged Steel with their properties. The optimization process results in comparitive study of different stresses which are generated by three different materials and their properties. Pachpande JE [15] details the optimization process, their combination under a set of defined constraints and a comparison between the original forged steel crankshaft and the final optimised forged steel component. The main objective of this analysis was to optimised the weight and manufacturing cost of the forged steel crankshaft, which not only reduces the final production cost of the component, but also results in a lighter weight crankshaft which increase the fuel efficiency of the engine. The optimization process was categorised in different stages and paper concludes with the sufficient reduction in weight and ultimatey cost. The optimization resulted in 18% weight reduction of the forged steel crankshaft.

Bhumesh J,Bagde[16] in this paper deals with the problem occoured in a single cylinder engine crankshaft. It consist of a static structural analysis. It identifies and solves the problem by using the modelling and simulation technique. The analysis of the crank is done using five different materials. Analysis was performed in ANSYS software and stresses were compared. Analysis has been performed on existing material of crankshaft and foue alternate materials also considered for crankshaft. Analysis shows the critical portion where stress acting are maximum and chances of crack formation are maximum. Rinkle Garg [17] in this study a static analysis was conducted on a Cast iron crankshaft from a single cylinder four stroke engine Finite element analysis was performed to obtained the variation of the stress magnitude at critical locations. Results shows the improvement in the strength of the crankshaft as the maximum limits of the stresses, total deformation, and strain is reduced. Mr. B. Varun [19] performed a finite element analysis to obtained a variation of stress magnitude at critical location of crankshaft. Simulation inputes are taken from the engine specification chart. The analysis is done for finding critical location in crankshaft. Stress variation over the engine cyle and the effect of torsion and bending load in the analysis are investigated. Von-Misses stresses are calculated.

Shubham Singhmar [20] in this paper simulation was conducted on a single cylinder 4-stroke diesel engine crankshaft. Von-Misses shtesses. Maximum Principle stress and Minimum Principle stresses are analysed with the help of ANSYS software. Based on the results, forecasting the possibility of mutual interference betwwen the crankshaft and other parts. Bhumesh J. Bagde [21] presented the analysis of crankshaft using five different materials. These materials are EN9, SAE 1046, SAE 1137, SAE 3140 and Nickel Cast Iron. The comparison of analysis results of all five materials will show the effect of stresses on different materials and this will help to select suitable material. Jaimin Brahmbhatt [22] conducted simulation on single cylinder 4-stroke diesel engine crankshaft. The material used is Forged Steel and concluded that at the neck surface area of crankpin deformation appears maximum.

Hnin Hnin New [23] analysed a static analysis on crankshaft. It shows that the high stress region mainly concentrates in the knuckles of the crank arm, main journal and crank arm, and connecting rod journa, which is the ares most easily broken. Mr. Basavaraj S. Talikoti [24] presented static structural analysis on single cylinder crankshaft using ANSYS.Analysis is done mainly for stress and deformation. And concluded that by static structural analysis the knowledge about the total deformation and stress can be obtained which can prevent damage in crankshaft and can also be helpful in designing good quality of crankshaft with optimum structural strength and reliability. Anand S. [25] analysed a multycylinder crankshaft for I C Engine. The multycylinder petrol engine crankshaft was made up of EN-19 Steel and Nitriding coated EN-19 Steel. The various analysis was conducted on crankshaft such as Von-Misses stresses, Yield, Tensile, Hardness and Thermal Expansion. Author concluded that Nitride Coated EN-19 steel is best suitable for manufacturing crankshaft for multicylinder IC Engine. Ilya Piraner [26] introduced a new method of combined stress analysis. Two separate throws are taken for analysis purpose and concluded that the maximum stress occours in the last web where the maximum bending moment is achieved. With the Von-Mises stress approach, however a more uniform stress distribution along the crankshaft is observed because the Von-Mises stress is more sensitive to the shear component of the stress tensor. Momin Muhammad Zia Muhammad Idris [27] concluded that stress analysis is a powerful tool to check adequacy of crankshaft dimensions and find scope for design modification. From the analysis it is found that weakest areas in crankshaft are crankpin fillet and journal fillet.

VI. FINITE ELEMENT ANALYSIS OF CRANKSHAFT

A. Procedure for Static Analysis

First model is created in Inventor software and saved as IGS file format. This IGS file can be easily imported in ANSYS. Specifying the correct details of the geometry and the material of the structure is very important step, as it decides on which part of the structure will the stress actually act. The analysis begins with meshing which is an important step as it forms the basics of making the structure means segmented into finite number of segments. After which boundary conditions have to be specified, which include specifying the part of the structure which will be fixed and the part which will be affected by the force or stress. The parts which can be affected by force will be subjected to the appropriate amount of force by applying directed force on those parts. Finally the crankshaft structure can be analyzed by using the appropriate analysis tools in ANSYS.

B. Material Properties

The following chart gives the details about the material of crankshaft and its properties.

Table 1: Material properties used for analysis

Material	EN-8D	Cast steel	Stainless steel
Density (Kg/m3)	7850	7870	7850
Young's modulus (MPa)	210000	200000	200000
Poisson's Ratio	0.28	0.29	0.30
Tensile yield strength (Mpa)	862	415	250
Compressive yield strength (Mpa)	862	415	250
Tensile Ultimate Strength (Mpa)	1050	540	460

C. Meshing of Crankshaft

Before analyzing any structure or complex structure, it is necessary to divide the complex geometry of the structure into small parts. Because the stress or the effect of the force and load will not be the same on all the parts of a huge and complex structure. Finite element analysis basically consist dividing a given structure into a finite numbers of elements, which is done by meshing, also called as a 'Discretization'. Figure 2 shows the meshed geometry of the both throws.

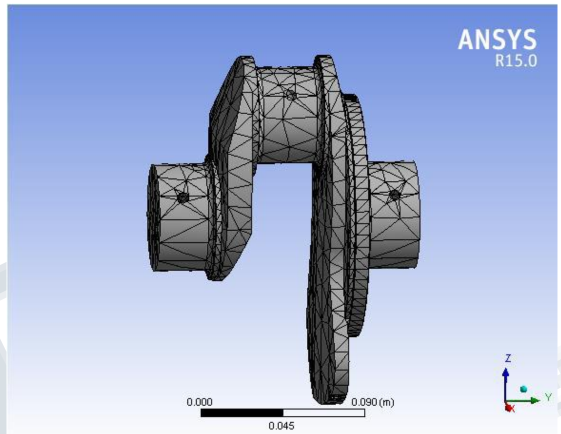

Figure 2: Meshed geometry of Crankshaft

D. Applying Boundary Conditions

Boundary condition is very important factor in analysis. It decides the degree of freedom of different parts of the crankshaft. The material also should be specified as rigid or flexible depending upon the type of parts. Here two crankshaft throws are taking into consideration for analysis. For 4th throw flywheel end is fixed and the other end is axially constraint as shown in figure 3

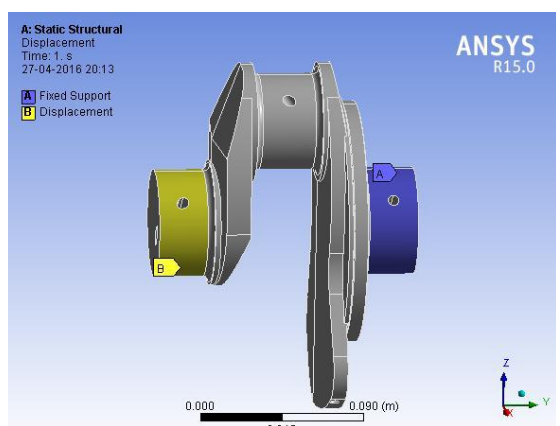

Figure 3: Boundary condition on 4th throw

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For the 2nd throw of crankshaft both the ends ate axially constraint i.e. Displacement at x, y,and z axis is zero as shown in figure 4

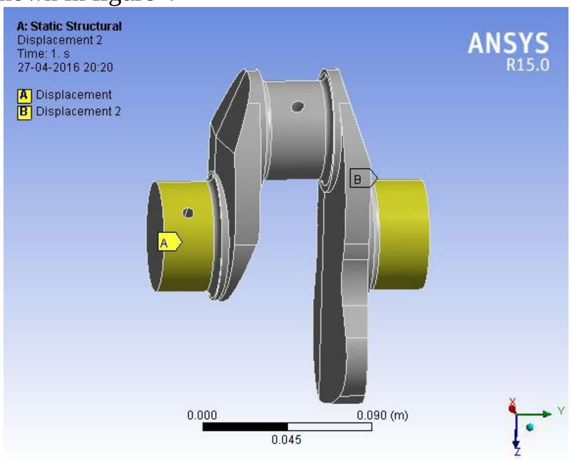

Figure 4: Boundary condition on 2nd throw

The force is applied at the center of the crankshaft. Here gas load is not in fully vertical condition. The applied force is rotate by 70 . Because peak load is not at Top Dead Centre (TDC). It produces 50 – 100 after TDC. Total pressure applied is 75 bar as shown in figure 5.

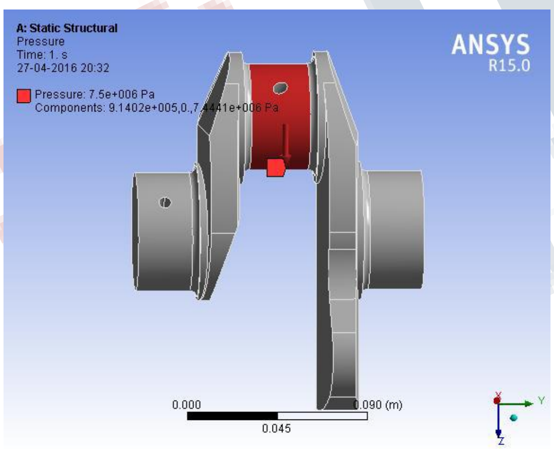

Figure 5: Application of pressure

E. Result and Discussion

Equivalent stress is obtained which is basically a Von-Misses stress. Von-Misses stress is fundamentally a standard that decides whether a structure is in state of failure or not. It primarily defines a formula using which the stresses in different direction of the three axis X, Y and Z are combined to give Von-Misses stress. The criterion which decides whether the structure is in a condition of failure is that, if the Von-Misses stress is greater than the yield stress of material, then the structure is in a condition of a breakdown. Following figures shows the Von-Misses stress for 2nd throw with three different materials.

Figure 6, figure 7 and figure 8 showing the equivalent stress (Von-Misses Stress) on the 2nd throw of the crankshaft with the EN-8D, Cast Steel and Stainless Steel material respectively.

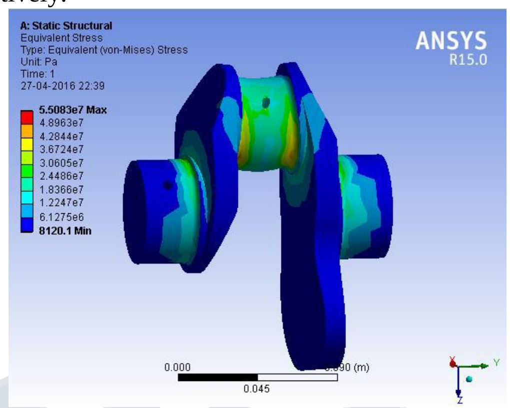

Figure 6: 2nd Throw equivalent stress with EN8D

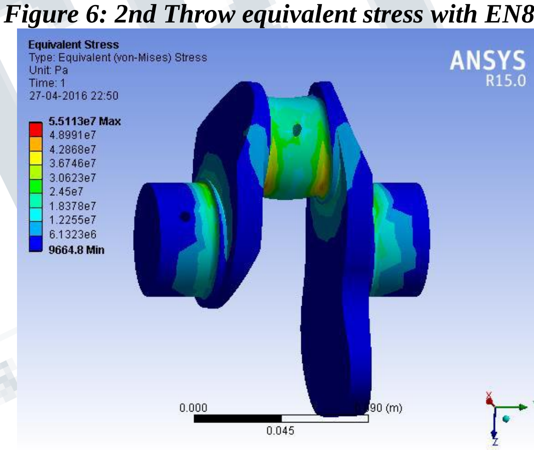

Figure 7: 2nd Throw equivalent stress with Cast Steel

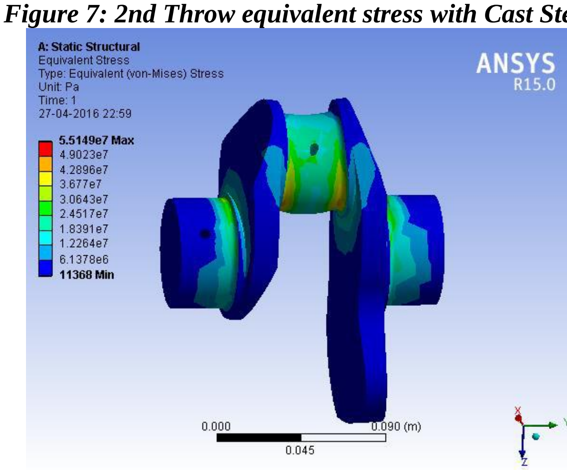

Figure 8: 2nd Throw equivalent stress with Stainless Steel

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Equivalent stresses on the 4Th throw are as shown in figure 9, Figure 10 and Figure 11 with the material EN-8D, Cast Steel and Stainless Steel respectively

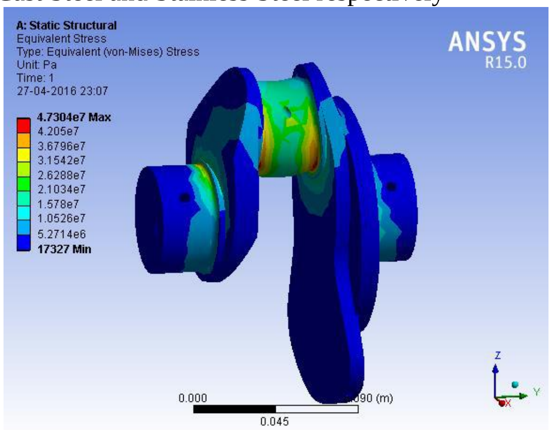

Figure 9: 4th Throw equivalent stress with En8d

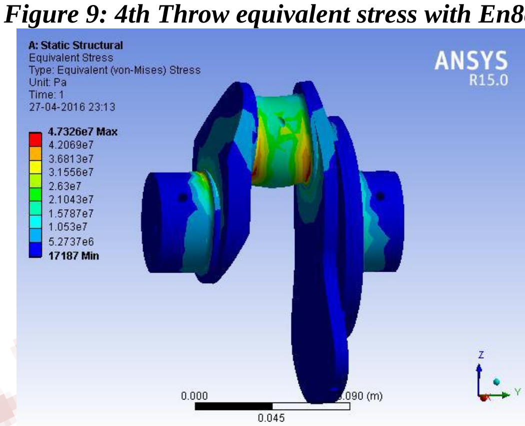

Figure 10: 4th Throw equivalent stress with Cast Steel

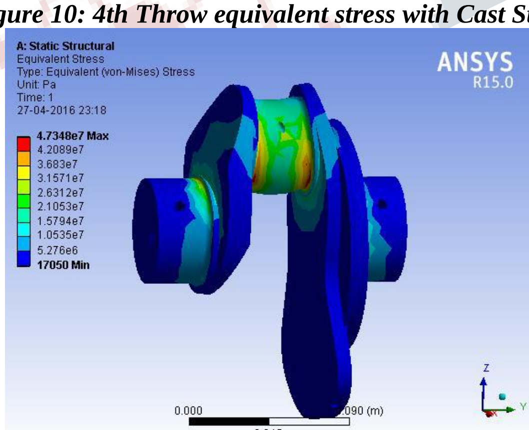

Figure 11: 4th Throw equivalent stress with Stainless Steel

Following figures shows the total deformation on the crankshaft model with the application of three different materials properties. Figure 12, Figure13 and Figure 14 shows total deformation on the 2nd throw ad Figure 15, Figure 16 and Figure 17 shows the total deformation on the 4th throw of the crankshaft.

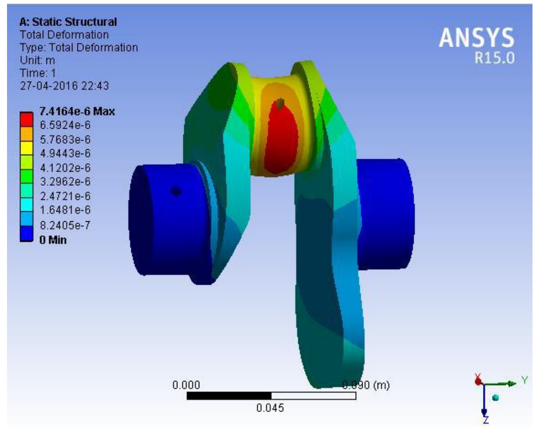

Figure 12: 2nd throw Total Deformation with En8D

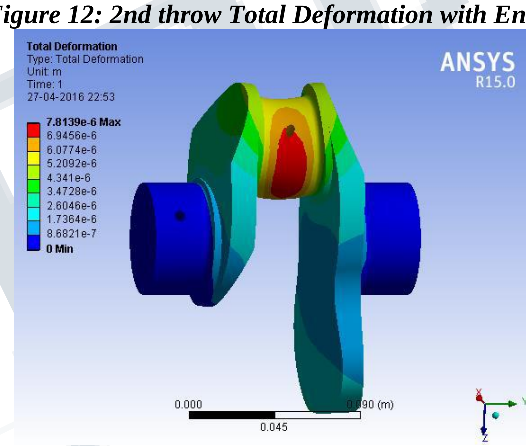

Figure 13: 2nd throw Total Deformation with Cast Steel

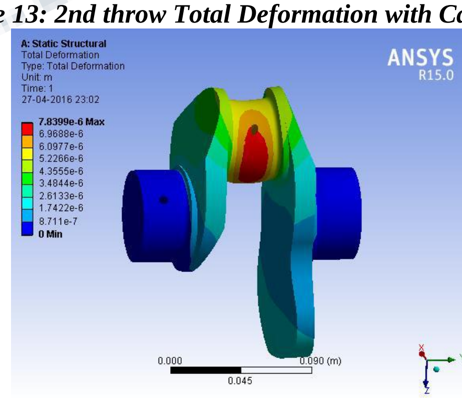

Figure 14: 2nd throw Total Deformation with Stainless Steel

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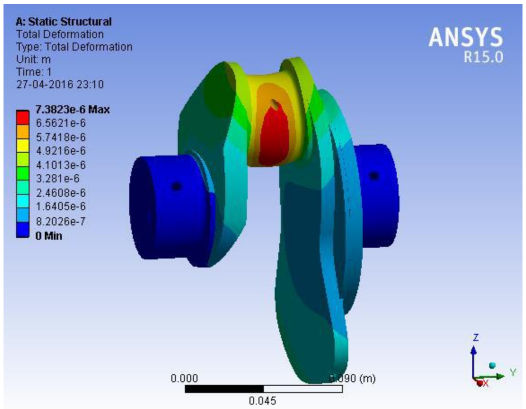

Figure 15: 4nd throw Total Deformation with En8D

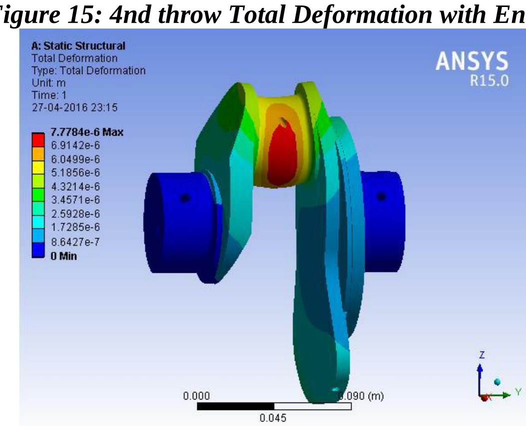

Figure 16: 4nd throw Total Deformation with Cast Steel

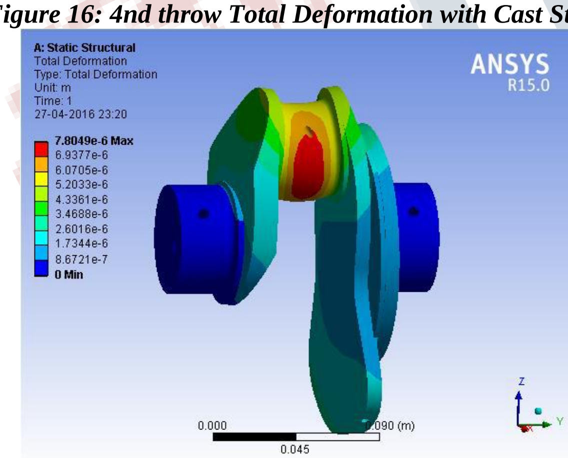

Figure 17: 2nd throw Total Deformation with Stainless Steel

The result analyzed in the tabular format with the all three material.

Table 2: Comparative Results of 2nd Throw

		En8D	Cast steel	Stainless Steel
Total Deformation(m	Max	7.4164e-6	7.8139e-6	7.8399e-6
	Min	0	0	0
Equivalent Stress (Pa)	Max	5.5083e7	5.5113e7	5.5149e7
	Min	8120.1	9664.8	11368

Table 3: Comparative Results of 4th Throw

		En8D	Cast steel	Stainless Steel
Total Deformation(m	Max	7.3823e-6	7.7784e-6	7.8049e-6
	Min	0	0	0
Equivalent Stress (Pa)	Max	4.7304e7	4.7326e7	4.7348e7
	Min	17327	17187	17050

CONCLUSION

This paper provides the crankshaft analysis theory and the Finite Element Analysis on the two crankshaft throws. Analysis is done with the three different materials. By analyzing all results material can be chosen for the further work. Results clearly shows the maximum stressed area and the total deformed areas mainly the crankpin neck surface and the fillets.

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