Comparative Study and FEM Based Analysis of Multi-Cylinder Diesel Engine Crankshaft

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Abstract— Existing crankshaft gets crack and fails within reliable time period. So, the reliability and life of the crankshaft is based on the properties and the composition of materials used. In this project, conventional materials are replaced by Metal Matrix Composite of aluminium with boron carbide. Three dimensional model of multi cylinder diesel engine crankshaft and crank-throw were created using SOLIDWORKS software. The stress and modal analysis of a four cylinder diesel engine crankshaft were discussed using Finite Element Method. The ANSYS WORKBENCH is used to analyze the modal and stress status of the crankshaft. The maximum deformation in the crank-throw and stresses were found, and compared with conventional material and metal matrix composite.

Key words: Crankshaft, Aluminum Boron Carbide, Mechanical Properties, Finite Element Analysis-Stress Analysis, Modal Analysis

I. INTRODUCTION

Crankshaft is one of the most important moving parts in internal combustion engine. It must be strong enough to take the downward force of the power stroked without excessive bending. So the reliability and life of internal combustion engine depend on the strength of the crankshaft largely [1]. Pandey has done investigation of crankshaft made up of forged carbon steel and resulting into premature failure in the web regions. Different types of tests are conducted for the evaluation of material properties. The analysis shows that to avoid such failure along the discontinuity in web regions machining and grinding need to be done carefully and it has been also suggested that fillet radius must be increased [2-3]. Existing connecting rod is manufactured by using Carbon steel. This paper describes modeling and analysis of connecting rod. The connecting rod is replaced by Aluminum reinforced with Boron Silicide, data for carbon steel is took and used for current analysis [4].

Aluminium metal matrix composites (AMMCs) have considerable applications in aerospace, automotive and military industries due to their high strength to wear ratio, stiffness, light weight, good wear resistance and improved thermal and electrical properties. Ceramic particles such as Al_2O_3, SiC are the most widely used materials for reinforcement of aluminium. Boron carbide (B_4C) could be an alternative to SiC and Al_2O_3 due to its high hardness (the third hardest material after diamond and boron nitride). Boron carbide has attractive properties like high strength, low density (2.52 g/cm^3), extremely high hardness, good wear resistance and good chemical stability. There has been an increasing interest in composites containing low density [5-6]. Lee et al. investigated the effect of reinforcement type on the tensile properties of the Al-B_4C and Al-SiC composites and observed that the strength of Al-B_4C composite is greater than that of the Al-SiC composites [7].

So, we go for Al-B4C. The effect of A1-B-Cphase formation on the properties of B_4C/Al composites. This should make it possible to optimize B_4C/Al composites for specific applications and analysis data is collected from this composite[8]. Since the crankshaft has a complex geometry for analysis, finite element models have been considered to give an accurate and reasonable solution whenever laboratory testing is not available. Naveen Kumar et al. did stress analysis and modal analysis of a 6-cylinder crankshaft is discussed using finite element method [9].

II. MODELING

A. Crankthrow Model

It is necessary to simplify the model in the stress analysis of crankshaft using ANSYS software. Because the diesel engine crankshaft structure is symmetrical and all the crank-throw is identical, one crank-throw model, one-half crank-throw model and one-quarter crank-throw model can be used to compute the static strength instead of whole crankshaft model. The three models are the equivalent in computing the static strength of diesel engine crankshaft, and the one-quarter crank-throw model uses the least computer resources [1]. In this paper, one crank-throw model was used to calculate the static strength of crankshaft. The model was created by using SOLIDWORKS software (see fig. 1), using main dimensions of crank-throw (measured) which is shown in Table 1.

Structural parameters	Values
Crankpin diameter (mm)	45
Crankpin axial length (mm)	24
Crankthrow main journal diameter (mm)	50
Crank cheek thickness (mm)	14
Crank cheek height (mm)	135

Table 1: Crankthrow Main Dimensions

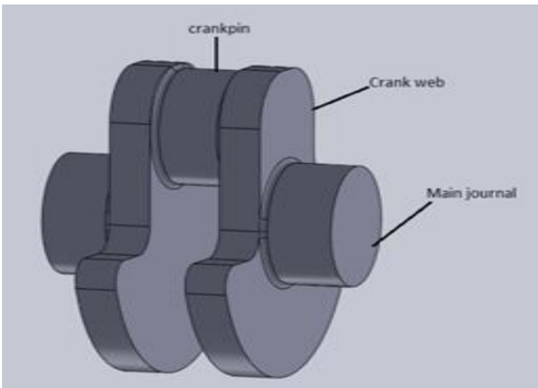

Fig. 1: crank-throw model

B. Crankshaft Model

The crankshaft has four crank-throws, three rod journals and two main journals, and the main dimension parameters (measured) are shown in Table 2. The crankshaft model was created by using SOLIDWORKS software. The structure of the crankshaft has more small fillets and fine oil hole. Considering these factors in establishment process, finite element mesh of crankshaft becomes very densely, the number of node equation increase greatly. These factors would extend the solution time, make the unit shape unsatisfactory and amplify the accumulative error. This would lower the simulation accuracy. Hence, in this paper, the real crankshaft was represented by a simplified model. In this simplified model, the chamfers which radius less than 5mm and the oil holes which diameter less than 10mm were ignored. The model of four-cylinder crankshaft is shown in Fig. 2.

Structure parameters	Values
Crankshaft length (mm)	440
Crankshaft height (mm)	135
Crankpin diameter (mm)	45
Main journal diameter (mm)	50
Crankpin axial length (mm)	24
Main journal axial length (mm)	26
Counterweight radius (mm)	50.5
Crank cheek thickness (mm)	14

Table 2: Crankshaft Main Dimensions

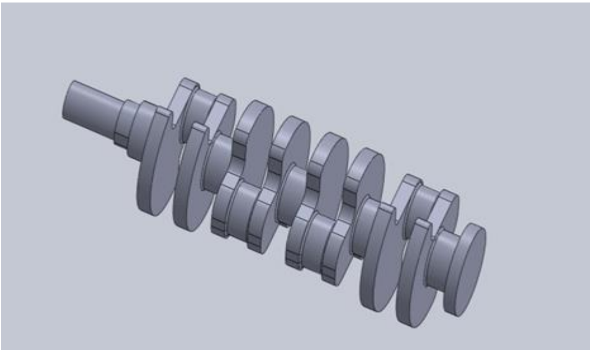

Fig. 2: 3-D entity model of crankshaft

The material properties for both carbon steel[4] and B_4C/Al composite[8] are taken for further analysis. The selection of new material is based on low density, high modulus and high fracture toughness.After updating the material properties to solidworks, the mass of the crankshaft is found for carbon steel crankshaft is 11.478kg and for B_4C/Al composite crankshaft is 3.8894kg.

III. RESULTS AND DISCUSSIONS

The model is created and imported to ANSYS WORKBENCH for conducting stress and modal analysis for comparing the most preferable crankshaft under deformation and weight reduction and also natural frequency. The analysis are as follows:

A. *Stress Analysis*

Eventhough there is a change of material for crank-throw, crankpin area is similar for both cases. So obtained stress value is similar due to force/area. The stress result for both carbon steel and B_4C/Al is shown in fig. 3.1

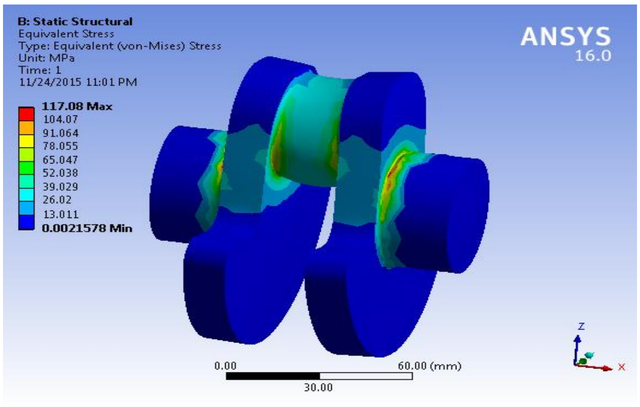

Fig. 3 Stress analysis

From the fig. 3, the maximum stress value observed is 117.08 (MPa)

B. *Total Deformation*

1) *For Carbon Steel*

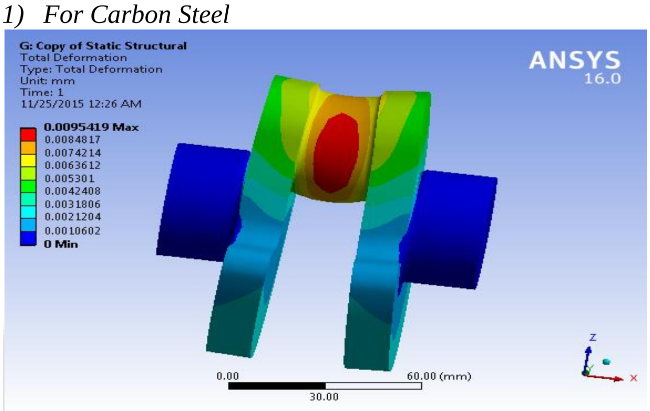

Fig. 4: Total deformation for carbon steel

2) *For B_4C/Al Composite*

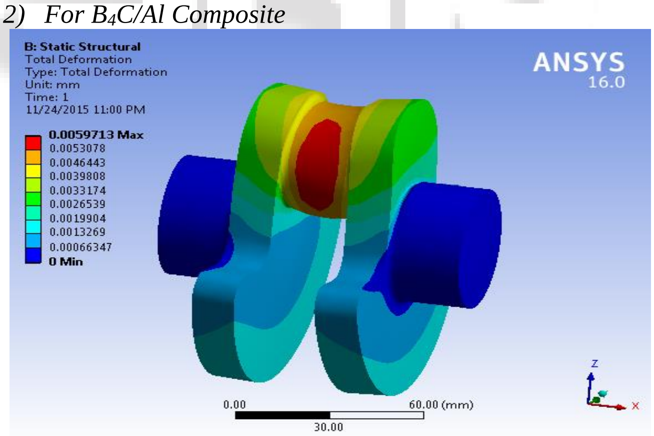

Fig. 5: Total deformation for B_4C/Al composite

From the Fig. 4, Total deformation for carbon steel is 0.0095419mm and from fig. 5, Total deformation for B_4C/Al composite is 0.0059713mm.

From the above, difference in deformation is about 0.0035706mm.

C. *Modal Analysis*

The vibration characteristics of crankshaft were obtained with modal analysis. The former six modal parameters for frequency and type of mode was obtained through analysis. The modal analysis for carbon steel and aluminium boron carbide composite is discussed below.

a) Modal analysis for carbon steel

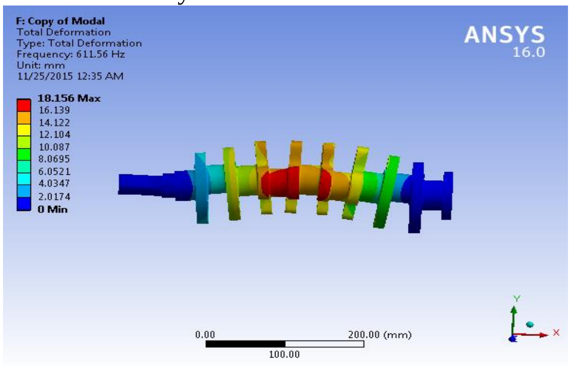

Fig 6: First mode

From Fig. 6, The maximum deformation obtained for natural frequency of 611.56 Hz is 18.156mm.

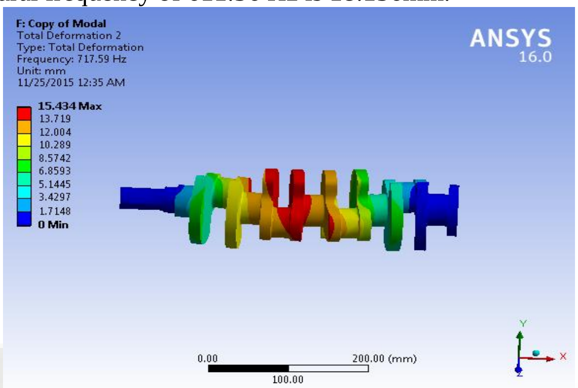

Fig. 7: Second mode

From fig. 7, The maximum deformation obtained for natural frequency of 717.59 Hz is 15.434mm.

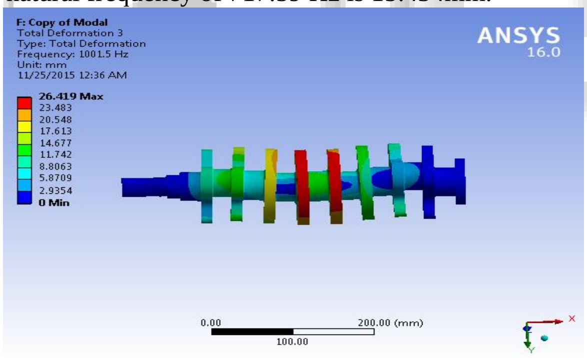

Fig. 8: Third mode

From fig. 8, The maximum deformation obtained for natural frequency of 1001.5 Hz is 26.419mm.

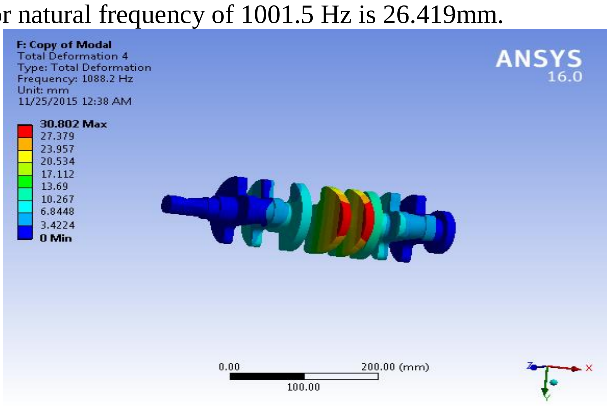

Fig. 9: Fourth mode

From fig. 9, The maximum deformation obtained for natural frequency of 1088.2 Hz is 30.802mm.

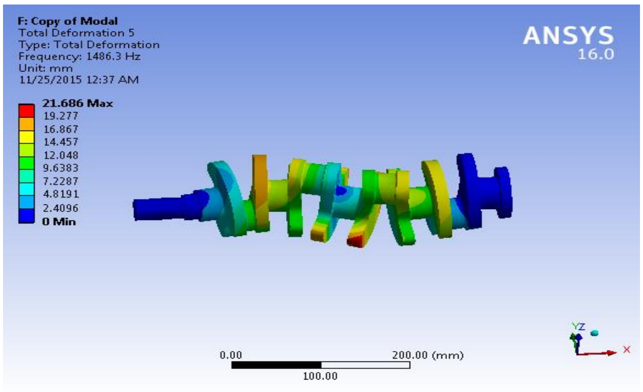

Fig. 10: Fifth mode

From fig. 10, The maximum deformation obtained for natural frequency of 1486.3 Hz is 21.686mm.

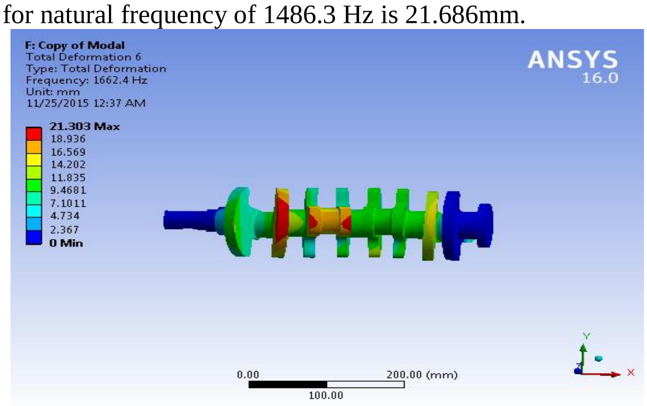

Fig. 11: Sixth mode

From fig. 11, The maximum deformation obtained for natural frequency of 1662.4 Hz is 21.303mm.

From the above analysis, the six modal parameters for carbon steel shows natural frequency and its type of mode is observed. The crankshaft deformation was mainly bending deformation under the lower frequency. The type of mode (either bending or torsion) is seen by animating in ANSYS. The result is discussed below in table 3.

Mode No.	Type Of Mode	Frequency (Hz)
1.	Bending	611.56
2.	Bending	717.59
3.	Bending+Torsion	1001.5
4.	Bending	1088.2
5.	Bending+Torsion	1486.3
6.	Bending	1662.4

Table 3: Frequencies and Type of Modes

b) Modal analysis for b_4c/al composite

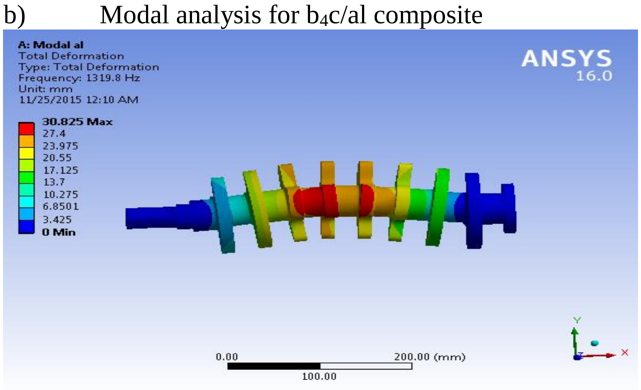

Fig. 12: First mode

From Fig. 12, The maximum deformation obtained for natural frequency of 1319.8 Hz is 30.025mm.

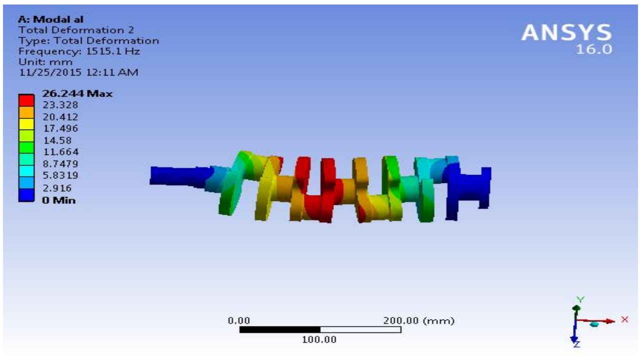

Fig. 13: Second mode

From fig. 13, The maximum deformation obtained for natural frequency of 1515.1 Hz is 26.244mm.

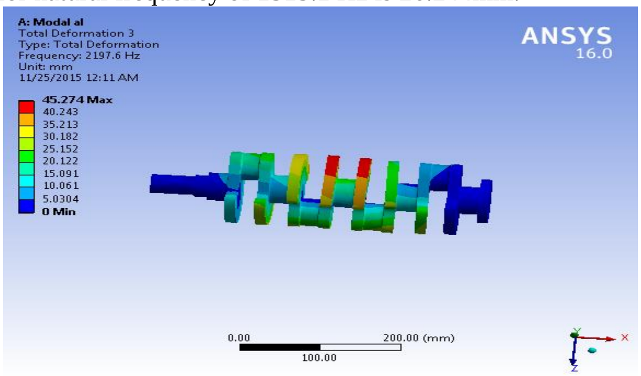

Fig. 14: Third mode

From fig. 14, The maximum deformation obtained for natural frequency of 2197.6 Hz is 45.274mm.

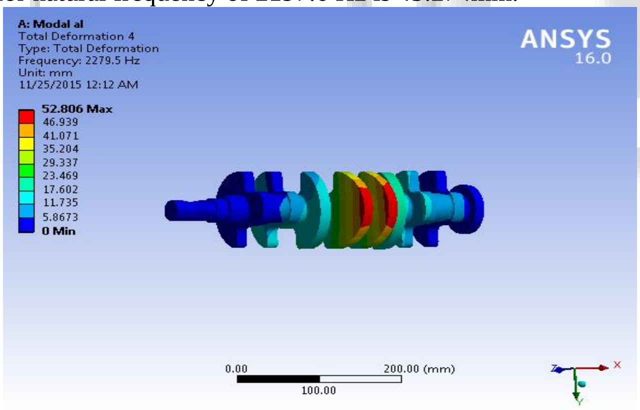

Fig. 15: Fourth mode

From fig. 15, The maximum deformation obtained for natural frequency of 2279.5 Hz is 52.806mm.

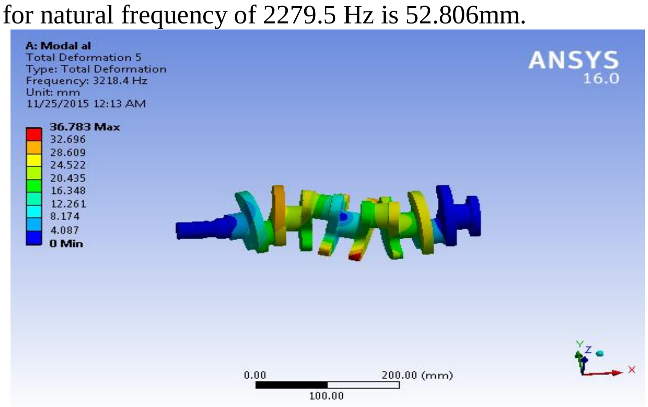

Fig. 16: Fifth mode

From fig. 16, The maximum deformation obtained for natural frequency of 3218.4 Hz is 36.783mm.

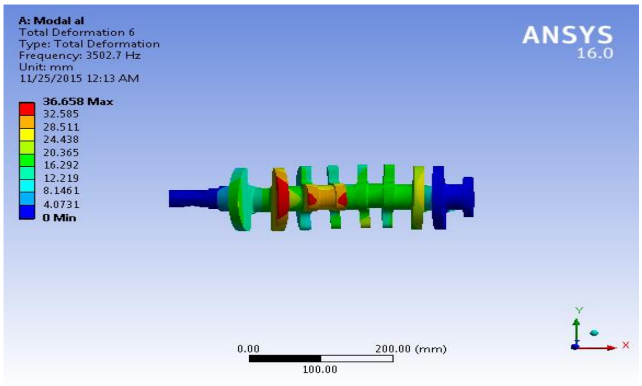

Fig. 17: Sixth mode

From fig. 17, The maximum deformation obtained for natural frequency of 3502.7 Hz is 36.658mm.

From the above analysis, the six modal parameters for aluminium boron carbide shows natural frequency and its type of mode is observed. The type of mode (either bending or torsion) is seen by animating in ANSYS. The result is discussed below in table IV. The resonance vibration of system can be avoided effectively by appropriate structure design.

Mode No.	Type of Mode	Frequency (Hz)
1.	Bending	1319.8
2.	Bending	1515.1
3.	Bending+Torsion	2197.6
4.	Bending	2279.5
5.	Bending+Torsion	3218.4
6.	Bending	3502.7

Table 4: Frequencies and Type of Modes

IV. SUMMARY AND CONCLUSION

ANSYS equivalent stresses for both the materials are almost same. Weight can be reduced by changing the material of existing carbon steel crankshaft into Aluminium boron carbide metal matrix composite crankshaft. Weight reduction is upto 66%.Total deformation for carbon steel is 0.00954mm and for aluminium boron carbide is 0.00597mm. The crankshaft deformation was mainly bending deformation under the lower frequency and the maximum deformation was located at the link between main bearing journal, crankpin and crank cheeks. So this area prone to appear the bending fatigue crack. Modal analysis was carried out for a four cylinder diesel engine crankshaft. The natural frequency and deformation based on type of mode was studied.

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