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Modelling and Analysis of Engine Assembly Using Some Unconventional Alloying Materials

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ABSTRACT

As the time goes on, different grades of various unconventional alloy materials have come into market and industry. Among such unconventional alloy three different materials such as ASTM A47, FC 0208-50 and 42CrMo+QT have been chosen to investigate the suitability of the material for a 4-stroke 4-cylinder diesel engine crankshaft, connecting rod and piston assembly. Analysis of these materials is performed using ANSYS software considering static structural analysis of whole assembly, modal analysis of crank shaft, buckling analysis of connecting rod and thermal analysis of piston. From the study, it is noted that '42CrMo+QT' turns out to be the best fit for the entire engine assembly except piston part. As, three considered materials are not suitable for piston part, therefore, AMC 225 XE is chosen to study the piston after checking the material property. In case of piston, AMC 225 XE shows better result for both the static structural analysis and thermal analysis.

Keywords: Diesel Engine Design, Crankshaft, Piston, Buckling Analysis, Modal Analysis.

INTRODUCTION

Crankshaft is the main component which holds the Diesel Engine together. It is a shaft driven by a crank mechanism which consists of a series of crank and crankpins with which the connecting rods of the engine are attached. It is a mechanical part which is able to perform a conversion between reciprocating motion and rotational motion. Connecting rod connects the piston to the crankshaft. Connecting rod must be sufficiently strong to withstand the thrust from the piston during the combustion process. Connecting rod consists of small end, shank and big end. Small end of the connecting rod is connected to piston by gudgeon pin or wrist pin and the big end connects to the crankpin on the crank shaft. It helps in transmitting the compressive and tensile forces into motion. Piston is the moving component that lies in the cylinder and is made gas tight by piston rings. In the present research, four different alloy materials have been considered to investigate the suitability of these materials in a 4-stroke 4-cylinder diesel engine assembly. Analysis of these materials is performed using ANSYS software considering static structural analysis of whole assembly, modal analysis of crank shaft, buckling analysis of connecting rod and thermal analysis of piston.

LITERATURE REVIEW

A brief review of literature is given here. Solanki et al. [1] have studied briefly on materials and manufacturing process of crankshaft considering durability assessment and cost reduction. By some Computer Aided analysis, they have concluded that crankshaft construction when mixed with 0.1% Sulphur and micro-graded alloy offers a cost reduction up to 11 to 19 %. It also attracts attention on optimising residual imbalance of forces acting along the length of the crankshaft. Thriveni and Chandraiah [2] have considered a basic model of crankshaft in CATIA-V5 and then they have transferred the model to ANSYS software. They have analysed the entire project in ANSYS Workbench. They have intended to evaluate Von Mises stress and Shear stress of the Crankshaft model. Prasad and Somasundar [3] have conducted static analysis to get variation of stress magnitude at critical locations of a cast iron crankshaft for a single cylinder 4-stroke diesel engine. A model have been designed in CATIA and imported into ANSYS to carry out static Structural analysis. In their study, weight optimization is achieved by varying crankpin diameter. They have concluded that if the weight of the crankshaft is reduced, frictional force also decreases, engine performance increases and cost is reduced. Fonte et al. [4] have studied fatigue life of marine diesel engine crankshafts to obtain operational safety and reliability. They have presented a semi-built crankshaft failure and the probable root case of damage. They have noted that an excessive torsional vibration of rotary components like crankshafts is an important matter in defining the operational reliability of rotary equipment. The design and maintenance are of paramount importance for the safety and lifetime improvement of crankshafts. Sowjanya and Reddy [5] have designed a 4 stroke, single cylinder Diesel engine. They have used Pro-E software. 4 different materials, titanium alloy, aluminum alloy, child cast iron and mild steel are considered and comparative analysis has been done. Total deformation and equivalent stress analysis is carried out and compared for the different materials. Shahane and Pawar [6] have performed both static structural and dynamic analysis on a single cylinder four stroke diesel engine. They have noted that the optimization study on shape and geometry of the crankshaft has helped to reduce the weight of the crankshaft by 4.37%. They have studied modal analysis part and crankshaft frequency under different mode shapes using dynamic boundary condition. Gopal et al. [7] have studied an assembly of a piston, connecting rod and crankshaft. Analysis has been done twice, once considering as a rigid body and then as a flexible body. All possible analysis has been done during their study. These are static structural, thermal, dynamic (transient), fluid flow, harmonic analysis, coupled field, modal. Tejashree and Kumar [8] have studied that the mechanical property of the crankshaft. 3D model of the engine parts have been built in the software 'CATIA V5' and then it is transferred to 'ANSYS'. The analysis of crank throw distortion and stress provided a conceptual support to enhance the design by weigh reduction. Dindore and Badiger [9] have used AISI 4140 material in their experimental work. They have used engine as Honda City 2015 edition. In their study, crank pin and crank web is designed. Then theoretical values of shear stress and Von mises stresses have been calculated. They have observed that Von mises stress is less than yield stress of the material. So, the design is considered to be safe. Cihan [10] has experimentally studied the comparative analysis of two crankshafts for single cylinder and four cylinders engines. Cast iron has been taken as the material. Solid works has been used to design both the crankshafts. Then finite element analysis is done on both of them separately. They have noted that the stress of single cylinder engine crankshaft is greater than the four-cylinder engine crankshaft. The deformation is also higher in the single cylinder engine's crankshaft. This higher stress in single cylinder engine's crankshaft reduced the life of the engine. As both the stress and deformation are higher, the thermal conductivity coefficient should also be higher in this crankshaft. So, better material should be used in case of single cylinder engine. So, the cost would be higher as compared to the 4-cylinder engine.

From the brief literature review it may be mentioned that very few investigations have been worked out on some non-traditional alloying elements apart from the ongoing alloying materials. Therefore, in this paper authors have tried to find out the suitability of various unconventional alloy materials in different parts of the engine and have checked different safety criteria to use these materials.

DESIGN PROCEDURE

The design has been modelled by using SOLIDWORKS software and used IGES (Initial Graphic Exchange Specification) format. After that, the model has been studied in various aspects using ANSYS software. To get stress, strain, deformation and shear stress value at different locations of engine assembly, Finite Element Analysis (FEA) is carried out with the use of ANSYS. In this project work, at first various critical dimensions of different parts of the crankshaft are computed by conventional hand calculation. Thus, a standard model of engine assembly including crankshaft has been picked up which goes in line with the safety criteria as indicated by hand calculations. At different parts under different conditions, Von-Mises stress have been found out and checked whether these are under yield limit of the respective material or not. After that Factor of Safety values for all the materials are determined to show the extent of safe limits.

A. Specifications of Engine

To design the engine assembly, the engine specifications are needed. The specifications of our engine are tabulated in Table 1.

Table 1: Engine Specifications

Engine Displacement	1997.43 CC
Number of strokes	4
Number of cylinders	4
Fuel type	Diesel
Max Power	150 KW @ 3750 rpm
Torque on engine at Max Power	381 N-m

B. Design consideration of Engine Assembly

- Connecting Rod Length: 201.20 mm
- Piston Diameter: 85 mm
- Crank Mean Radius: 80 mm
- Crankshaft Length: 590 mm
- Main Journal Diameter: 72 mm
- Crankpin Diameter: 54 mm

C. 3D Modelling of Engine Assembly

Fig. 1 shows 3D modelling of the engine assembly which is prepared using SOLIDWORKS.

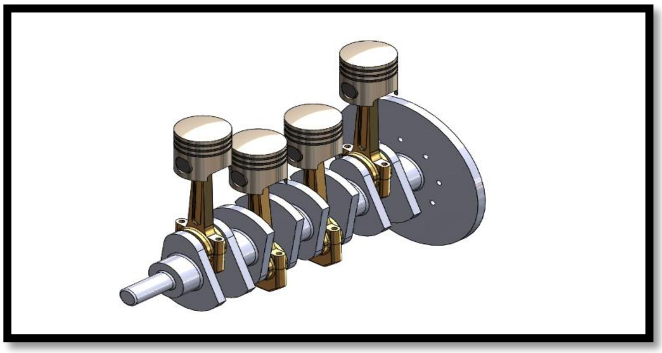


Figure 1. Engine assembly

D. Material Composition

Table 2: Material Composition

Material	ASTM A47 (Malleable Steel)	FC 0208-50 (Copper Steel)	42CrMo+QT (Quenched Steel)	AMC 225 XE (Alluminium Alloy)
Physical Properties				
Density	6700 kg/m^3	6850 kg/m^3	7800 kg/m^3	2800 kg/m^3
Thermal Conductivity	150 W/mK	40 W/mK	40 W/mK	150 W/mK
Specific Heat	502 J/kgK	480 J/kgK	480 J/kgK	880 J/kgK
Mechanical Properties				
Ultimate Tensile Strength	345 MPa	410 MPa	940 MPa	570 MPa
Tensile Yield Strength	224 MPa	380 MPa	800 MPa	480 MPa
Bulk Modulus	120 GPa	172 GPa	210 GPa	70 GPa
Poisson's Ratio	0.25	0.29	0.30	0.28

E. Boundary Conditions

Primarily four factors are considered:

a) Rotational velocity of 5000 RPM on Z direction along the axis of the crankshaft.

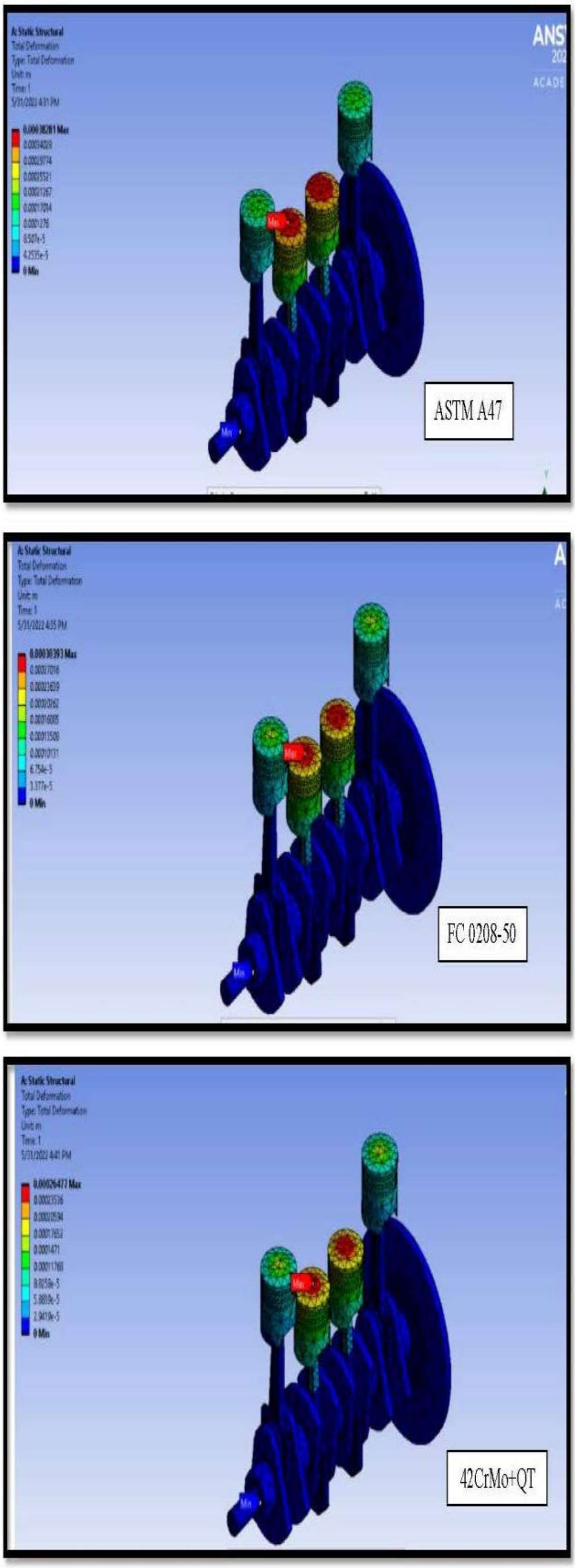
b) Force 42500N on Negative Y axis.

c) Fixed support at Journal end of the Crankshaft

d) Fixed Cylindrical support on main journal

1. RESULTS

Three different unconventional alloy materials have been chosen to investigate the suitability of the material for a 4-stroke 4-cylinder diesel engine crankshaft and piston assembly. These materials are ASTM A47, FC 0208-50 and 42CrMo+QT. To select the proper material different analysis is performed using ANSYS software. During study static structural analysis of engine assembly, modal analysis of crank shaft, buckling analysis of connecting rod and thermal analysis of piston have been considered.



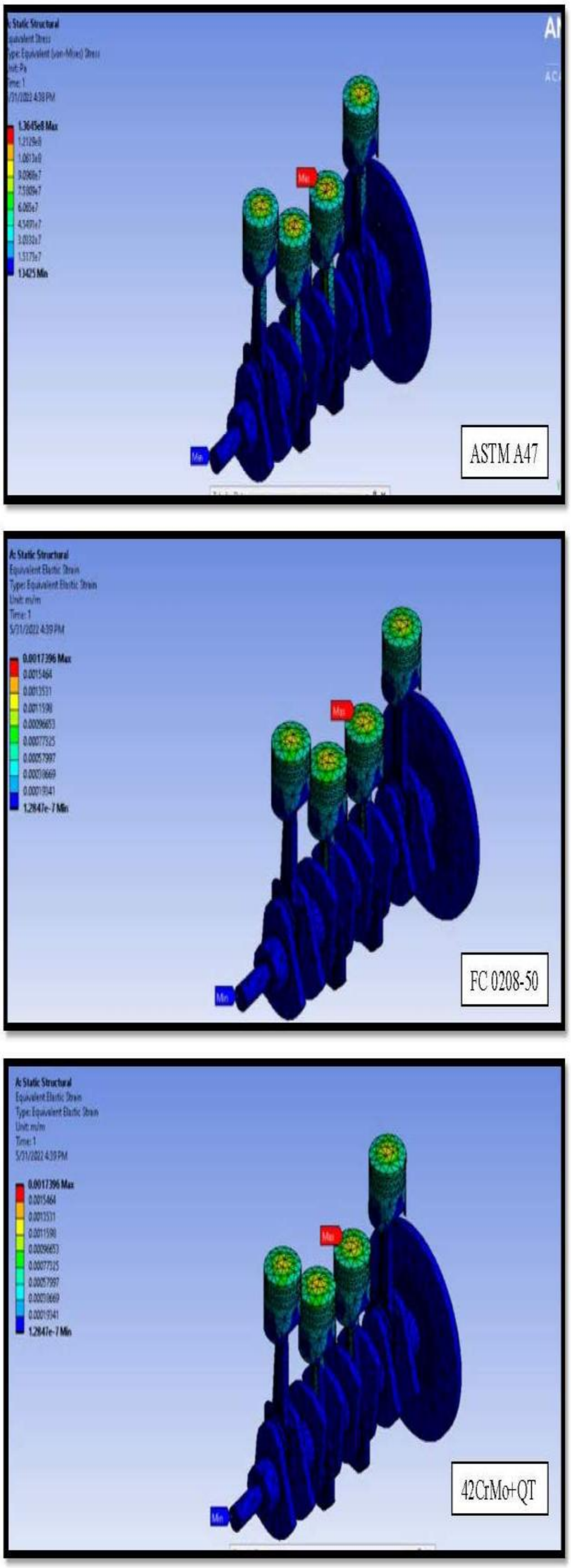


Figure 2. **Total deformation**

Figure 3. **Equivalent elastic strain**

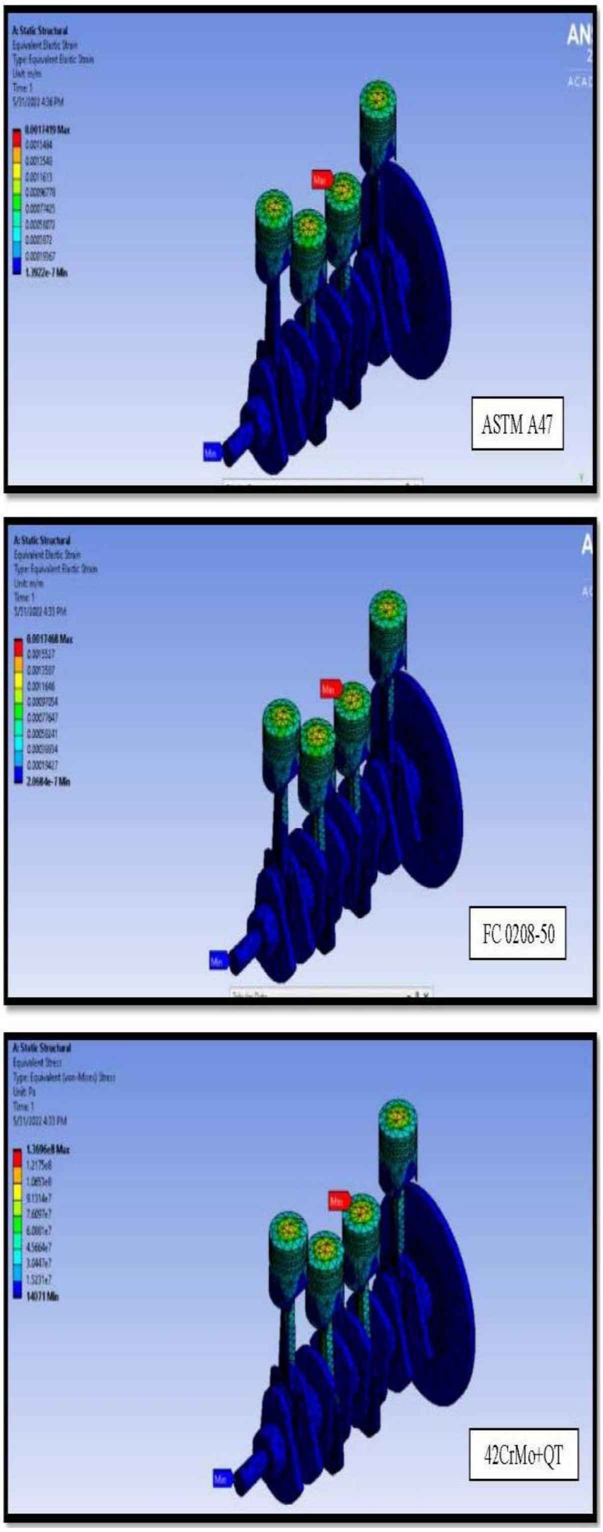


Figure 4. **Equivalent stress**

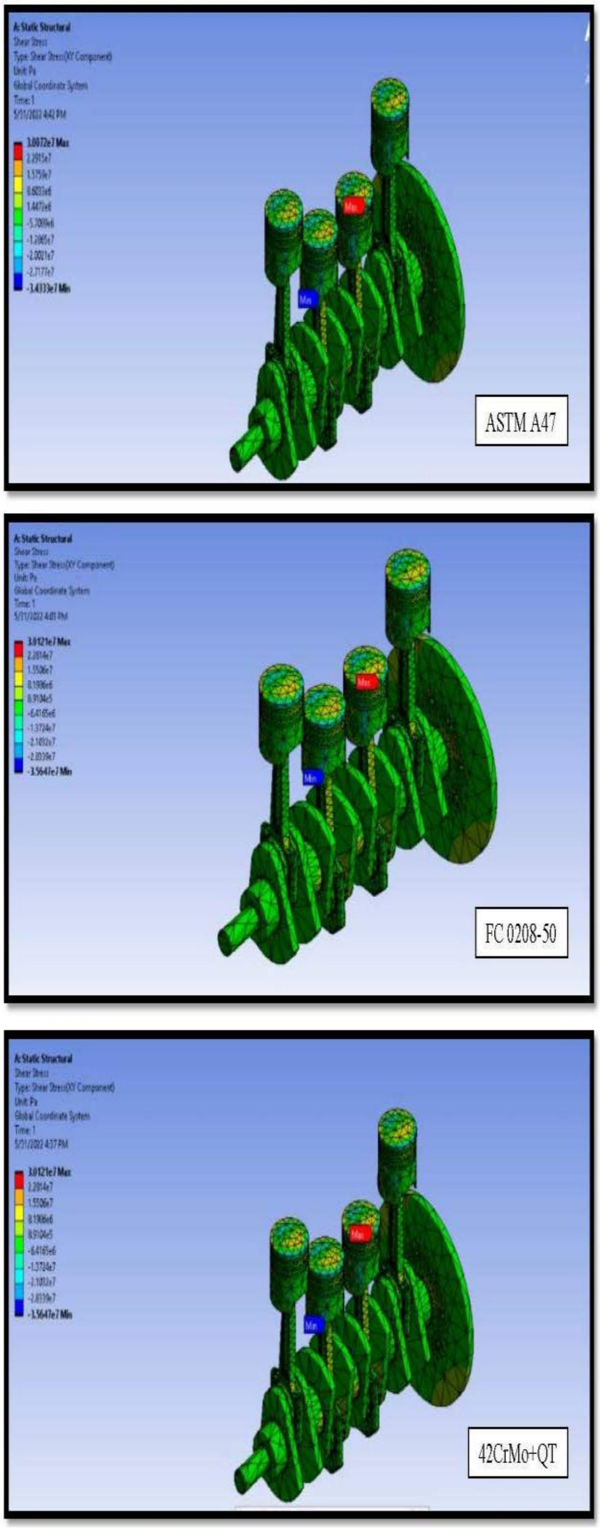


Figure 5. **Shear stress**

Figure 2, 3, 4 and 5 are showing the effect of engine assembly on material properties considering total deformation, equivalent elastic stain, equivalent stress and shear stress respectively. For all the cases ASTM A47, FC 0208-50 and 42CrMo+QT are considered. From all these figures, it may be mentioned that except piston part considered engine assembly is giving better result. Figure 6 and figure 7 show the comparison of three materials for total deformation and factor of safety. Figure 6 shows that least deformation is obtained in case of 42CrMo+QT. Figure 9 clearly shows that highest Factor of Safety is obtained in case of 42CrMo+QT. Therefore, 42CrMo+QT alloy is best suitable material out of three considered unconventional alloy materials for whole the engine assembly except piston part.

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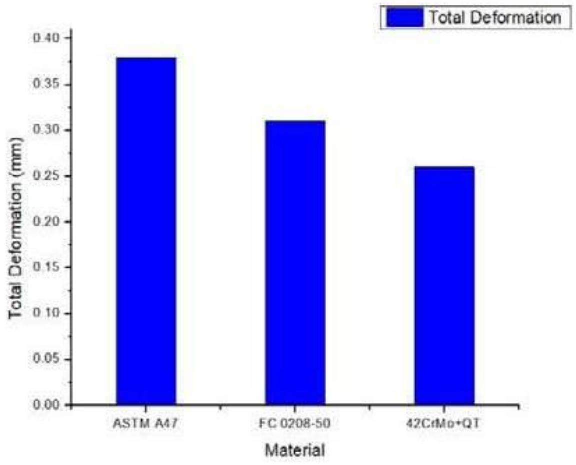

Figure 6. **Comparison of Total Deformation**

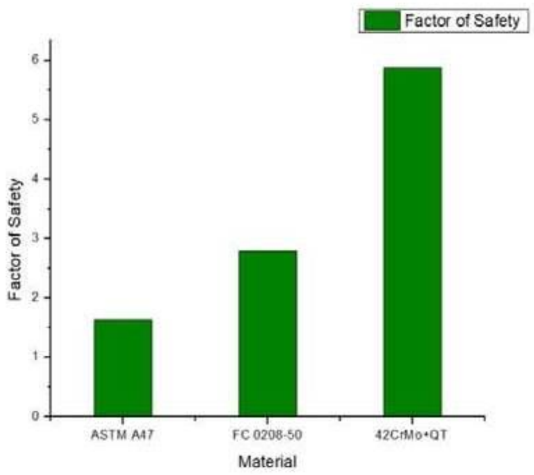

Figure 7. **Comparison of Factor of Safety**

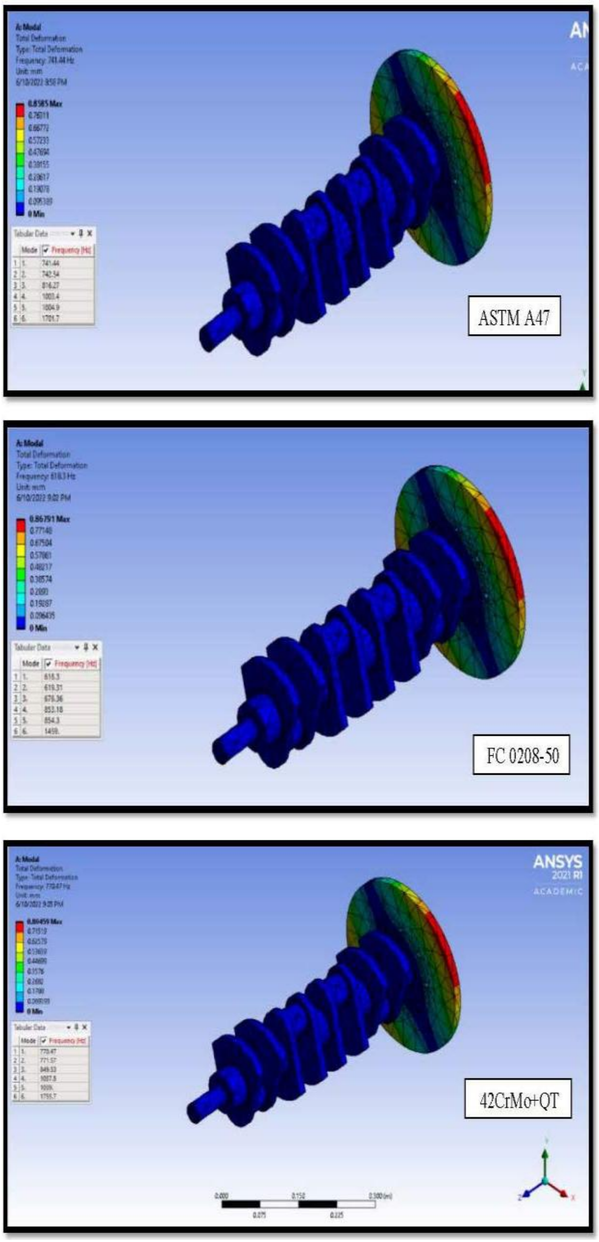

Figure 8. **Modal analysis of Crankshaft**

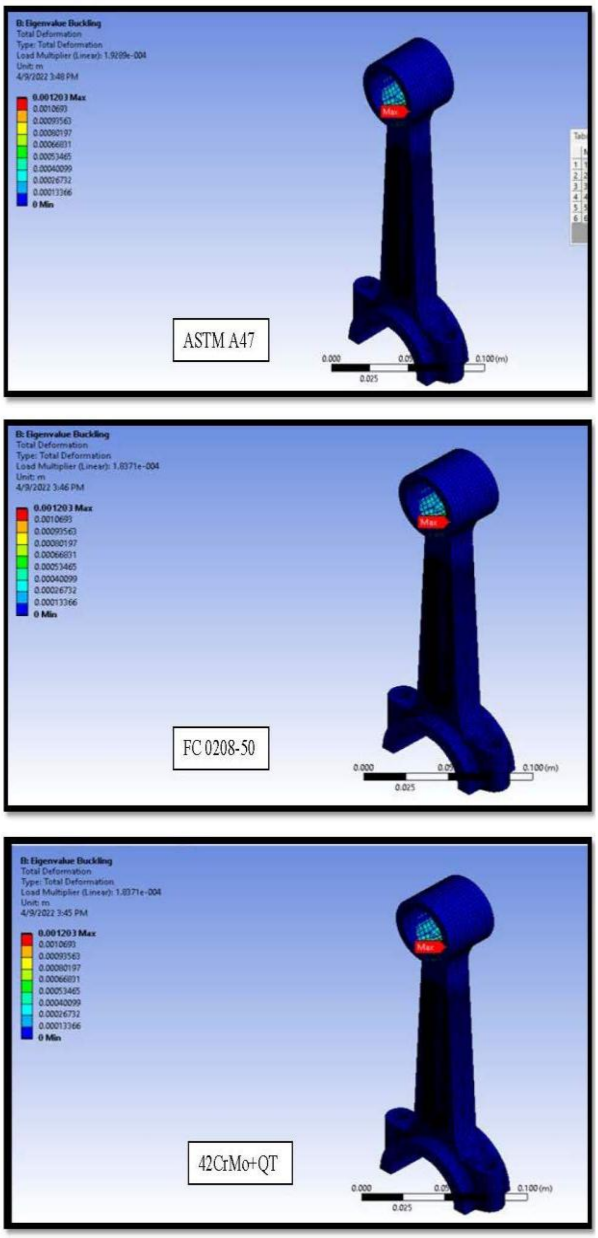

Figure 9. **Buckling analysis of Connecting rod**

Modal Analysis is necessary to determine characteristics of a mechanical structure or component under mechanical vibration like natural frequencies, mode shapes etc. It helps us to determine the movement of different parts under dynamic loading condition such as due to rotation of crankshaft and to and fro motion of connecting rod etc. Figure 8 shows the mode frequencies variation of three different materials. During study it is observed that mode frequencies for ASTM A47, FC 0208-50 and 42CrMo+QT alloy are 0.85 mm, 0.86 mm and 0.8 mm respectively. In modal analysis of crankshaft, therefore, it is noted that 42CrMo+QT material is giving better result compared to other considered materials.

When a column-like structure is under vertical loading, it may buckle. As the connecting rod is under vertical pressure generated by combustion of fuels, buckling safety conditions of the connecting rod needs to be checked. First the gas pressure is anticipated and is multiplied with piston head area in order to get Buckling load. The bottom of the connecting rod is fixed. Buckling analysis of Connecting rod for three considered material are showing in figure 9. After simulation, the total deformation for all the 3 steel alloys has come out to be in the range of 1.203 mm to 1.283 mm which is negligible deformation and is under tolerable limit.

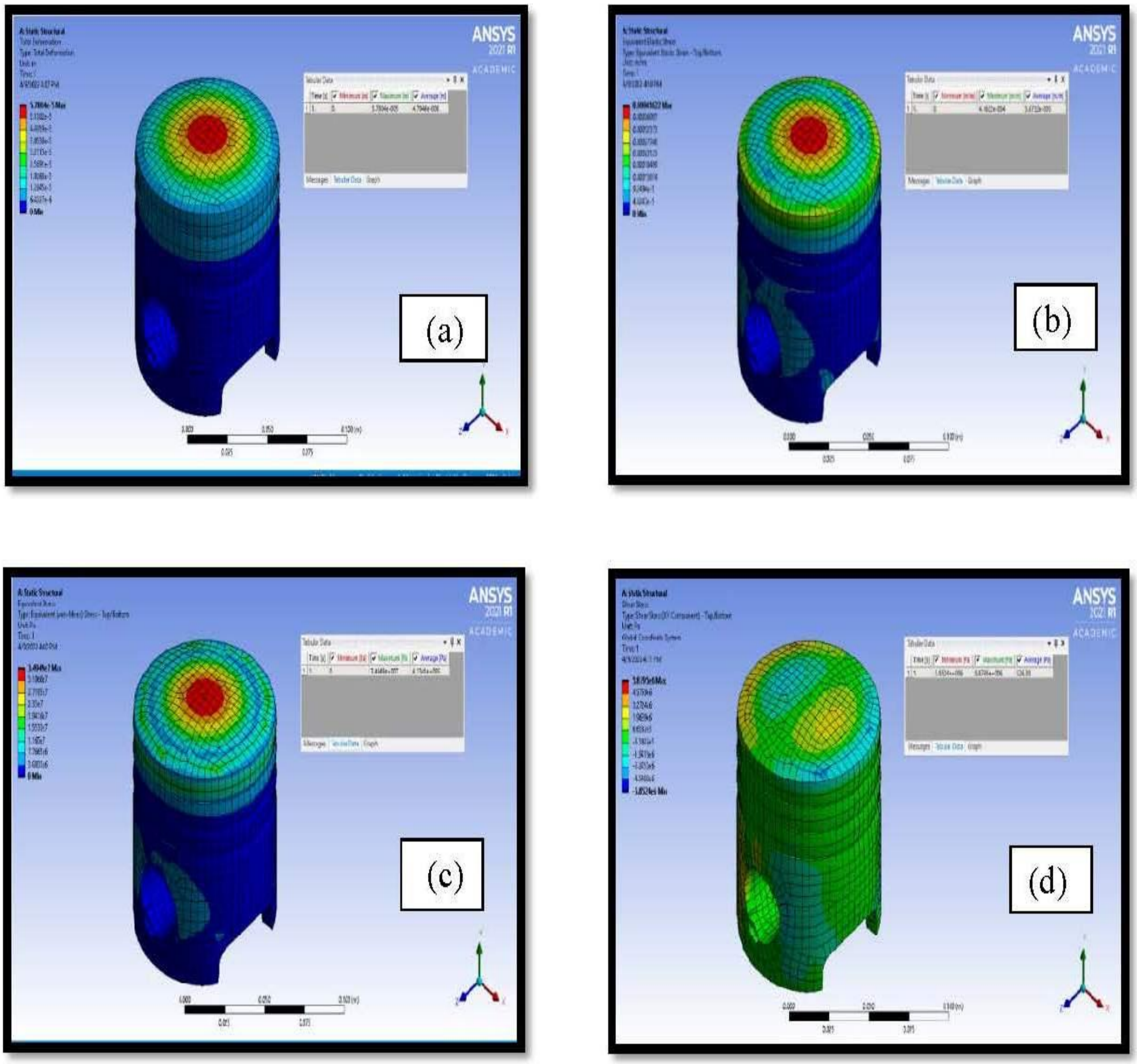

Figure 10. Static structural analysis of piston (a) Total Deformation (b) Equivalent elastic strain (c) Equivalent stress and (d) Shear stress

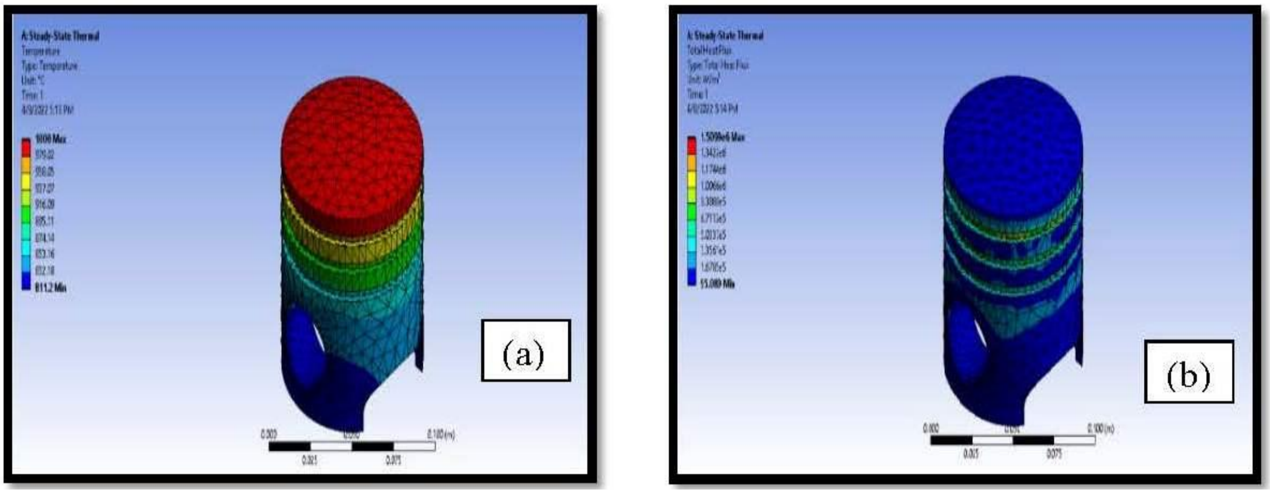

Figure 11. **Thermal analysis of piston (a) Temperature Distribution (b) Distribution of Total Heat Flux**

Thermal analyses of piston for different conditions are studied in figure 10 and figure 11. During analysis, AMC 225 XE alloy material is selected after proper checking. It is noted that this material is suitable to use in piston part for static structural analysis as well as thermal analysis.

CONCLUSION

From the study, the followings can be concluded:

- Among the all alloy steels used here namely ASTM A47, FC 0208-50 and 42CrMo+QT, the combination of 42CrMo+QT is best suitable to manufacture crankshaft, connecting rod and flywheel.
- For piston, ‘AMC 225 XE’ has given excellent results both under static structural analysis and for thermal analysis also
- Both the materials of 42CrMo+QT and AMC 225 XE provide higher factor of safety.

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