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Design and Analysis of an Impeller of a Turbocharger

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ABSTRACT

In the present work the impeller of a turbocharger was designed with three different materials (Nickel, Structural Steel, and Titanium). The investigation can be done using CREO and ANSYS software. The CREO software is used for modeling the impeller and analysis is done in ANSYS. A modest attempt has been made to investigate the effect of temperature, pressure and induced stresses on the impeller. A structural analysis has been carried out to investigate the various stresses, strains and displacements of the impeller. A thermal analysis has been carried out to investigate the total heat flux and direction heat flux. Based on the results the Nickel alloy exposed better properties and is recommended for its further usage in impeller of a turbocharger.

Keywords: Impeller, Turbocharger, Three different materials, Static structural analysis, Thermal analysis.

INTRODUCTION

Turbocharger is highly utilized in the diesel type engines for increasing the overall efficiency. By using the turbocharger effectively the specific fuel consumption of the engine is reduced significantly. The two types of impellers called compressor impeller and turbine impeller were fixed on either side of the turbocharger. Both the impellers has to work sequentially for compressing and expanding the air simultaneously. The selection of material for the impeller design plays a significant role in deciding the overall efficiency. The impeller material should withstand the high pressure of incoming compressed air at the time of working. Many materials were experimented by the researchers for improving the performance of the impeller used in the diesel engines. The impeller angle plays a significant influence over the performance of the turbocharger. The Inconel alloy were selected and simulated by using its material properties which exhibited a 15% improvement over the existing type of conventional turbocharger. The nickel alloy and titanium material also experimented by many researchers towards its implementation in impeller of the turbochargers. The various composite materials also developed and experimented by the researchers for matching the specific properties required by the impeller. The challenge faced in conversion of a composite material for its effective application in impeller production lies in the near net shape machining which is a cost consuming process. So the usage of the existing alloys by enhancing its properties is carried out by many researchers. In the present study three materials say Nickel, Structural Steel and Titanium were considered for the analysis. The material properties of these three materials were considered. The 3D model of the impeller were designed by using CREO software.

The created models were exported to ANSYS software where the static structural analysis, thermal analysis were performed by approximating the corresponding material properties. The principal stress and strain conditions were thoroughly analyzed along with heat flux properties.

OBJECTIVES OF THE STUDY

- To design the impeller of a turbocharger using CREO software using three materials (Nickel, Structural Steel, Titanium).
- To perform structural and thermal analysis of the impeller for the above specified materials.
- To discuss and compare the results and the best material is chosen for the application of the impeller.

EXPERIMENTATION

The dimensions of the impeller used for this investigation is taken from the real diesel engine turbocharger. The dimensions were measured and it is used for the development of 3D model by using CREO software. The picture of the impeller considered for this study is shown in figure 1 as follows.

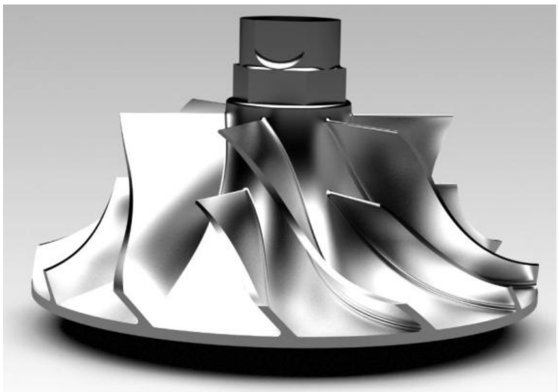

Figure 1. Impeller considered in this study.

The properties of the structural steel, titanium alloy and nickel alloy material selected for the analysis is shown in table 1, 2 and 3 respectively. Based on the material properties assumed the required dimensions were designed by using the CREO software. The error in the geometrical file is checked carefully by analysing the overlapping of facets, geometrical data redundancy and vertex to vertex rule between the facets. After confirming the geometrical error now the created solid model is checked for the mass property calculations like mass, volume, density. After analysing the mass property calculations carefully the created 3D models are exported to a neutral file format called standard for exchange of product data to facilitate the easy file transfer between various vendor software.

Table.1 Properties of the structural steel

Sl. no	Parameters	Values
1	Density (ρ)	7850 kg/m^3
2	Young's modulus (E)	2 * 10^{11} Pa
3	Poisson's ratio (i)	0.3
4	Thermal conductivity(K)	60.5 Wm-^{1}c-^{1}

Table.2 Properties of the Titanium alloy

Sl. no	Parameters	Values
1	Density(ρ)	4430 kg/m^3
2	Young's modulus (E)	1.138 * 10^{11} Pa
3	Poisson's ratio(i)	0.342
4	Thermal conductivity(K)	25000 Wm-^{1}c-^{1}

Table.3 Properties of the Nickel alloy

Sl. no	Parameters	Values
1	Density (ρ)	8190 kg/m^3
2	Young's modulus (E)	2.05* 10^{11} Pa
3	Poisson's ratio(i)	0.284
4	Thermal conductivity(K)	11.4 Wm-^{1}c-^{1}

The finite element analysis was carried out over all the three assumed materials separately. The static structural analysis and thermal analysis was carried out. Both the analysis was carried out by using ANSYS version 14.5 software. The finite element analysis of the every material is discussed in detail in the following figures. The model of the impeller loaded into the ANSYS version 14.5 is shown in figure 2.The loaded impeller is then finely divided into the meshes by using hexahedral elements for ensuring the very accurate results. The image of the meshed impeller design is shown in figure 3.

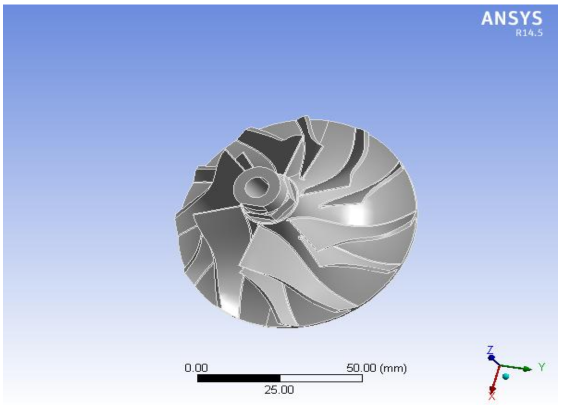

Figure 2. Model of the Impeller

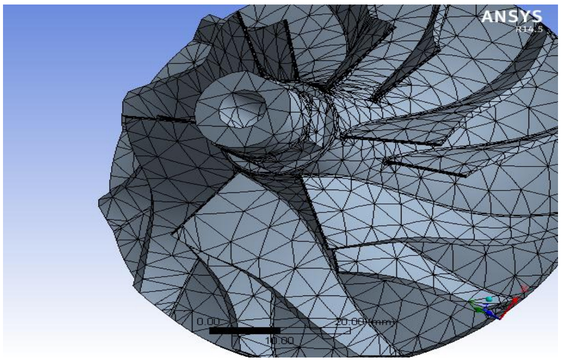

Figure 3. Meshed model of the Impeller

The constraints used for the fixing the impeller, rotational velocity specified and maximum pressure conditions used are shown in the figures 4, 5, 6 respectively.

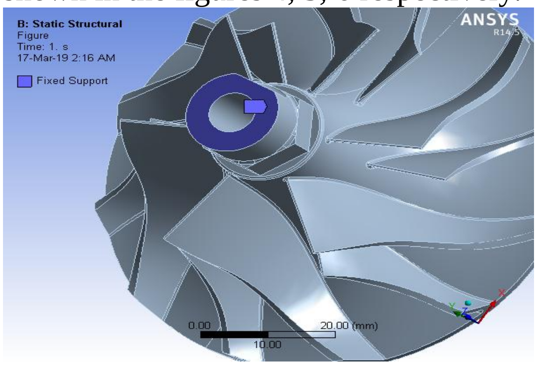

Figure 4. Specification of the constraint

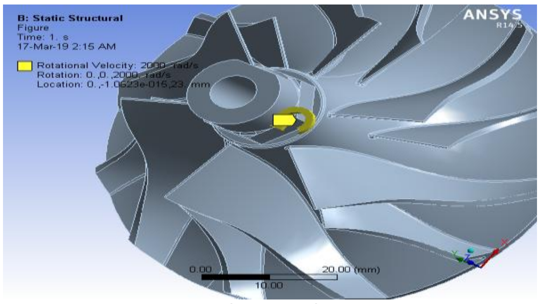

Figure 5. Specification of rotational velocity

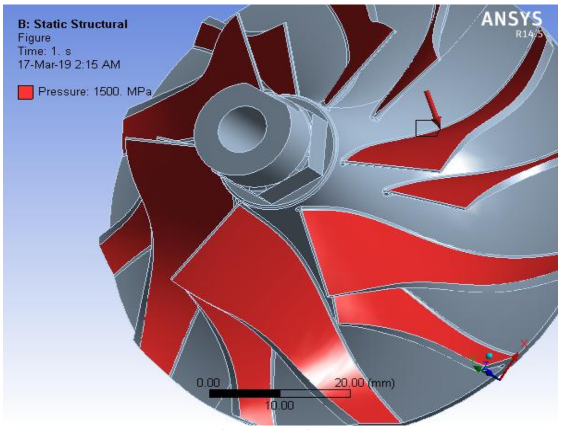

Figure 6. Specification of maximum pressure.

RESULTS AND DISCUSSION

FEA RESULTS OF STRUCTURAL STEEL

The finite element analysis of the structural steel was carried out for analysing the two important properties namely static structural and thermal analysis. The total deformation, equivalent stress analysis, equivalent strain analysis of the structural steel is shown in figure 7, 8, and 9 respectively.

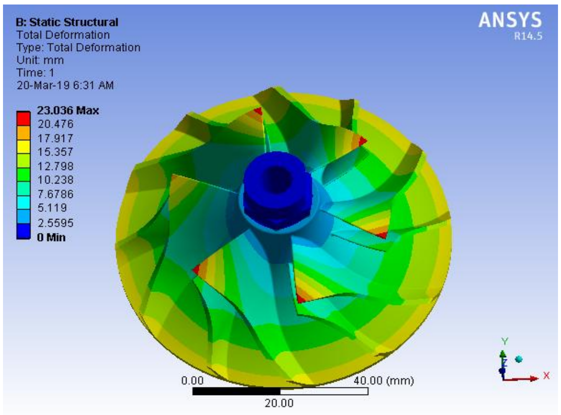

Figure 7. Total deformation for Structural steel

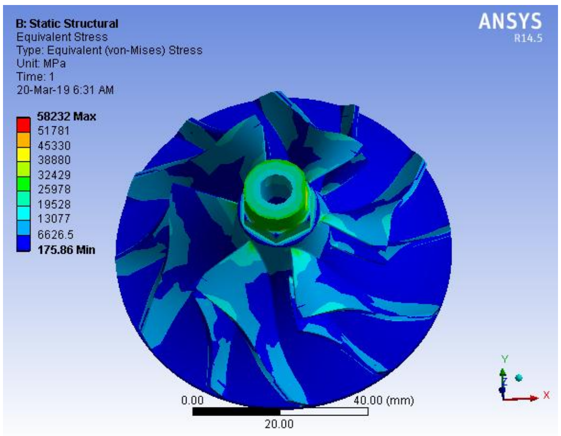

Figure 8. Equivalent stress for Structural steel

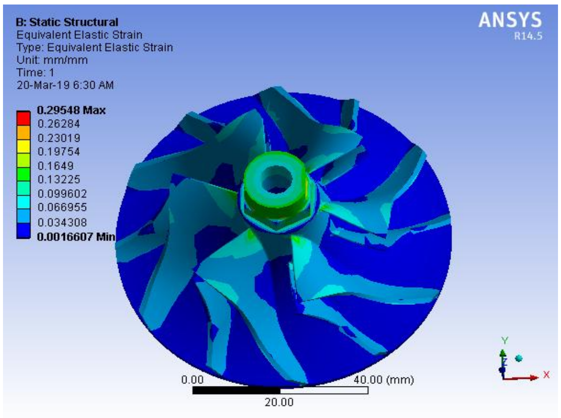

Figure 9. Equivalent strain for Structural steel

The total heat flux and directional heat flux analysis for the structural steel is shown in figure 10 and 11 respectively.

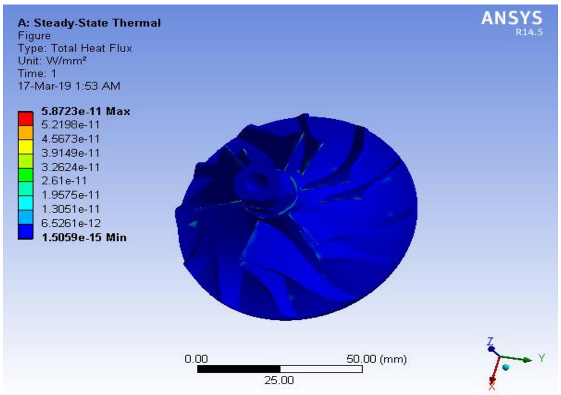

Figure 10. Total heat flux for Structural steel

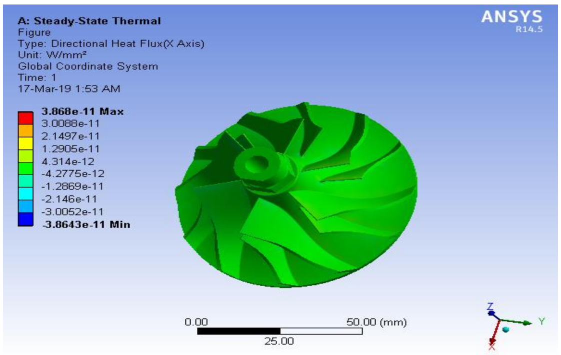

Figure 11. Directional heat flux for Structural steel

FEA RESULTS OF TITANIUM ALLOY

The total deformation, equivalent stress analysis, equivalent strain analysis for the titanium alloy is shown in figure 12, 13, and 14 respectively. The total heat flux and directional heat flux analysis for the titanium alloy is shown in figure 15 and 16 respectively. The same procedure was followed for the static structural analysis and the thermal analysis of the titanium alloy as like the structural steel. The same constraint and rotational velocity is considered.

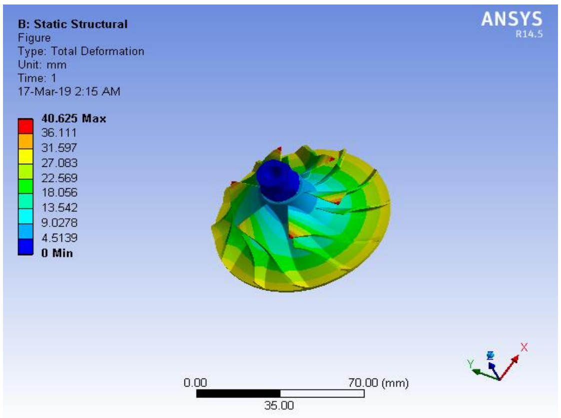

Figure 12. Total deformation for Titanium alloy

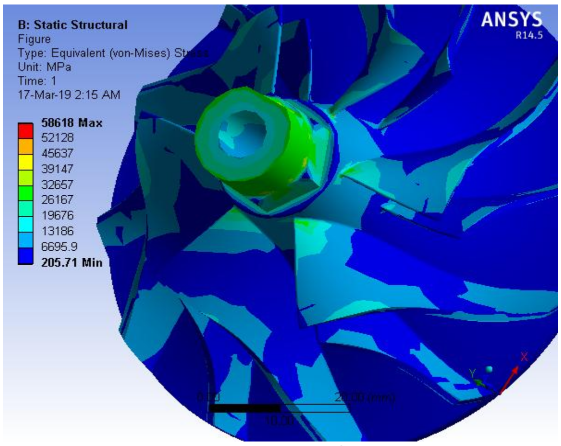

Figure 13. Equivalent stress for Titanium alloy

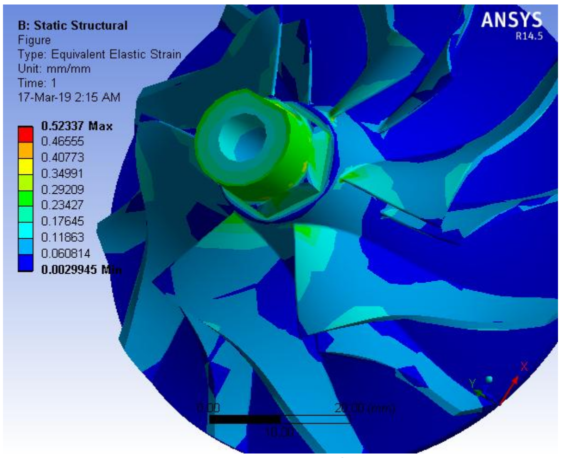

Figure 14. Equivalent strain for Titanium alloy

FEA RESULTS OF NICKEL ALLOY

The total deformation, equivalent stress analysis, equivalent strain analysis for the Nickel alloy is shown in figure 17, 18, and 19 respectively. The total heat flux and directional heat flux analysis for the Nickel alloy is shown in figure 20 and 21 respectively. The same procedure was followed for the static structural analysis and the thermal analysis of the Nickel alloy as like the structural steel and Titanium alloy. The same constraint and rotational velocity is considered.

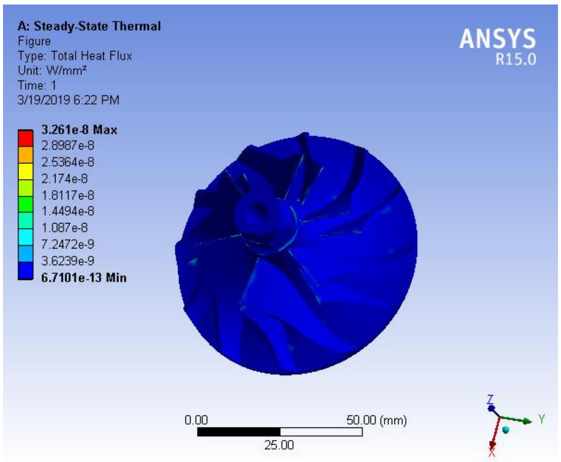

Figure 15. Total heat flux for Titanium alloy

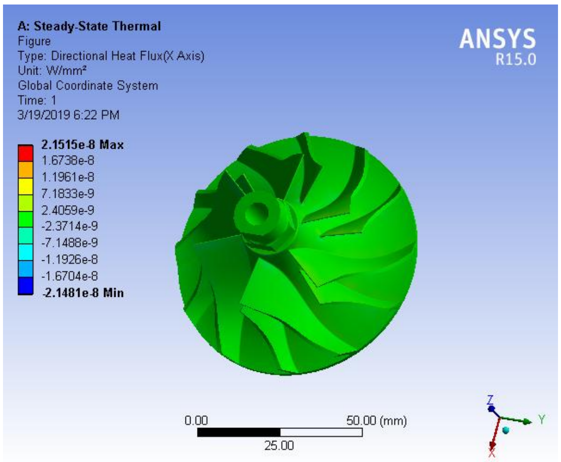

Figure 16. Directional heat flux for Titanium alloy

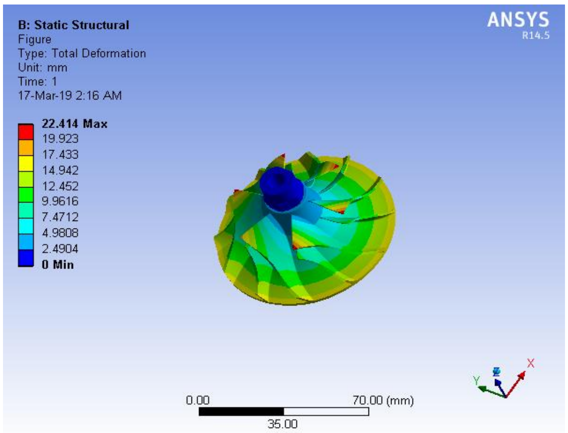

Figure 17. Total deformation for Nickel alloy

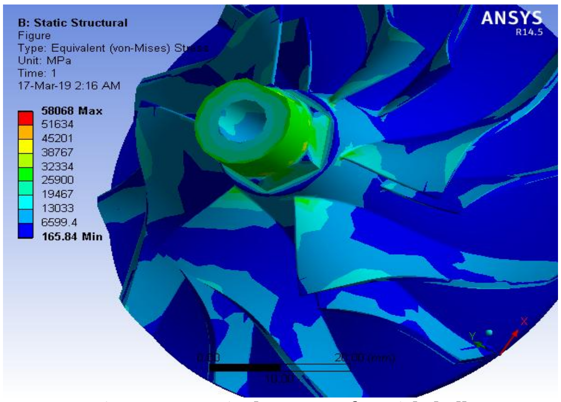

Figure 18. Equivalent stress for Nickel alloy

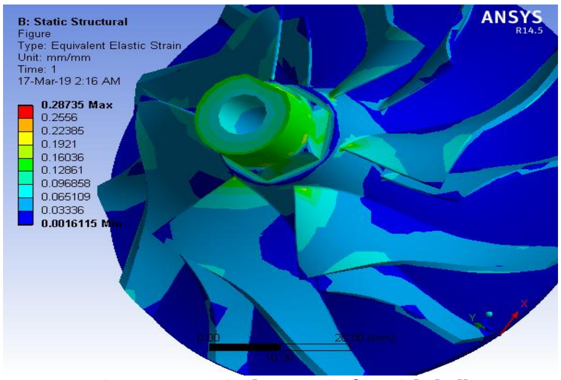

Figure 19. Equivalent strain for Nickel alloy

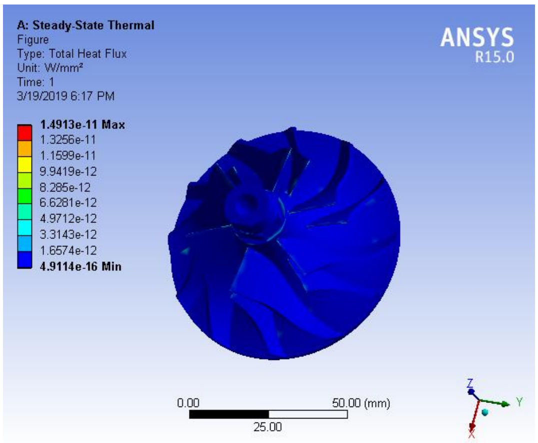

Figure 20. Total heat flux for Nickel alloy

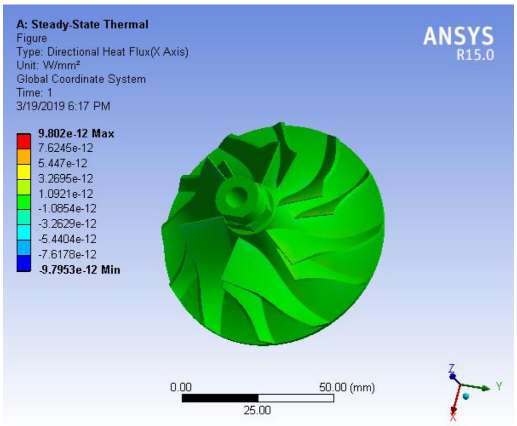

Figure 21. Directional heat flux for Nickel alloy

The table 4 and 5 shows the comparison static structural analysis results and thermal analysis results of all the three materials considered in this study. The comparison graphs of all the five parameters analyzed in this study is shown in figures 22 to 26 respectively.

Table.4 Static structural analysis comparison

Sl. No	Parameters	Structural steel	Titanium alloy	Nickel alloy
1	Total deformation(mm)	23.036	40.625	22.414
2	Equivalent elastic strain(mm)	0.29458	0.52337	0.28735
3	Equivalent stress (Mpa)	58232	58618	58086

Table.5 Thermal analysis comparison

SL.NO	Material	Total Heat flux (Q) (W/mm2)	Directional Heat Flux (W/mm2)
1	Structural Steel	$5.8723*10^{-11}$	$3.868*10^{-11}$
2	Titanium Alloy	$3.2602*10^{-11}$	$2.152*10^{-11}$
3	Nickel Alloy	$1.491*10^{-11}$	$9.802*10^{-11}$

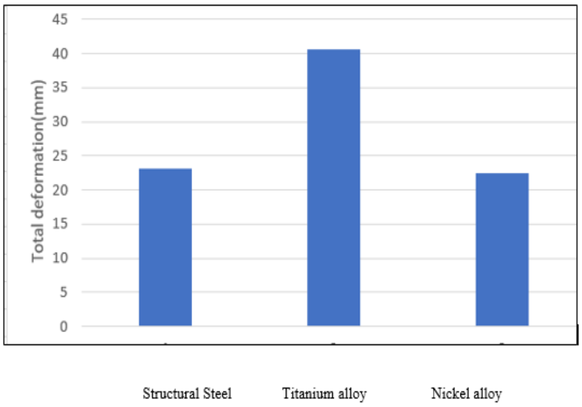

Figure 22. Comparison of total deformation

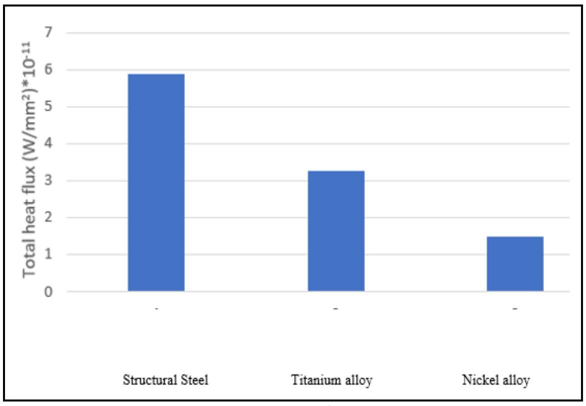

Figure 25. Comparison of Total Heat Flux

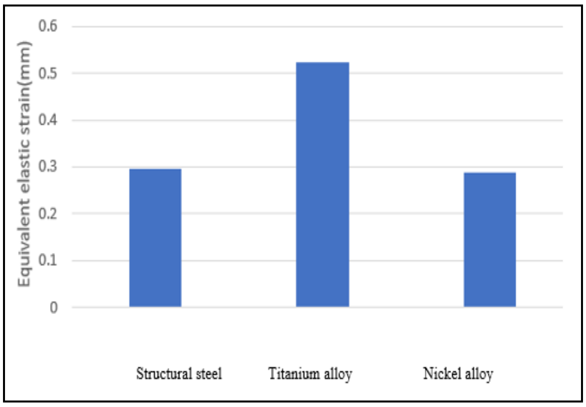

Figure 23. Comparison of Equivalent elastic strain

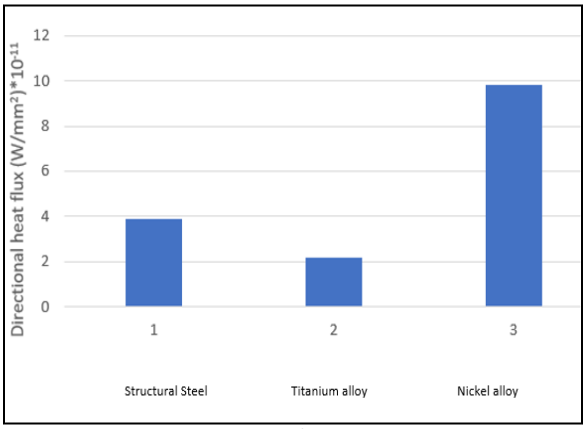

Figure 26. Comparison of Directional Heat Flux

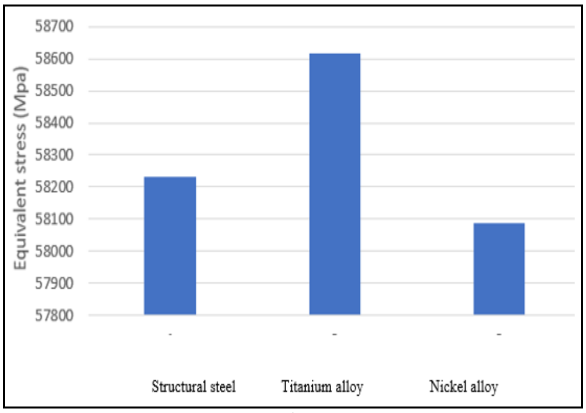

Figure 24. Comparison of Equivalent elastic stress

The above shown graphs clearly show the comparison among the structural properties between the three materials. Out of the three materials Titanium seems to undergo more deformation compared to Nickel alloy and Structural steel. The above shown graphs clearly shows the comparison among the thermal properties of the three materials. The directional heat flux for Nickel alloy is the highest among the three materials but since the total heat flux is least for Nickel alloy when compared to Titanium alloy and Structural Steel.

CONCLUSION

The analysis was carried out for the impeller of the turbocharger using ANSYS. In the analysis part the model of the impeller was created using CREO and the files were saved in STEP format and imported to ANSYS. The analysis is carried out on the redesigned model with different materials (Structural Steel, Nickel alloy and Titanium alloy) and the results were compared. From the above result summary table we conclude that Nickel alloy was found better than Structural Steel and Titanium alloy. From the above data we observed that minimum stress and deformation is obtained for Nickel alloy. Also the total thermal flux induced on the impeller was low for the material Nickel alloy. Thus the impeller could withstand more stress and temperature if Nickel alloy is used. So we conclude that Nickel alloy is the most apt material among the three chosen materials for the impeller of the turbocharger.

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