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Static and Dynamic Analysis of a Centrifugal Pump Impeller

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Abstract— Alloys are playing major role in many engineering applications. They offer outstanding mechanical properties, flexibility in design capabilities, and ease of fabrication. Additional advantages include light weight and corrosion resistance, impact resistance, and excellent fatigue strength. Today alloys are routinely used in such diverse applications as automobiles, aircraft, space vehicles, offshore structures, containers and piping, sporting goods, electronics, and appliances. This paper deals with the static and dynamic analysis of a centrifugal pump impeller which is made of three different alloy materials (viz., Inconel alloy 740, Incoloy alloy 803, Warpaloy) to estimate its performance. The investigation has been done by using CATIA and ANSYS13.0 softwares. The CATIA is used for modeling the impeller and analysis has been done by using ANSYS. ANSYS is dedicated finite element package used for determining the variation of stresses, strains and deformation across profile of the impeller. HYPER MESH 9.0 is also used to generate good and optimum meshing of the impeller to obtain accurate results. A structural analysis has been carried out to investigate the stresses, strains and displacements of the impeller and modal analysis has been carried out to investigate the frequency and deflection of the impeller. An attempt is also made to suggest the best alloy for an impeller of a centrifugal pump by comparing the results obtained for three different alloys.

Index Terms— CATIA V5, ANSYS 13.0, FEM, HYPERMESH 9.0

1. Introduction

An alloy is a mixture or metallic solid solution composed of two or more elements. An alloy will contain one or more of the three: a solid solution of the elements (a single phase); a mixture of metallic phases (two or more solutions); an intermetallic compound with no distinct boundary between the phases. Solid solution alloys give a single solid phase microstructure, while partial solutions give two or more phases that may or may not be homogeneous in distribution, depending on the thermal (heat treatment) history of the material. An intermetallic compound will have another alloy or pure metal embedded within another pure metal. Khin Cho Thin et. al. [1] have carried out computational analysis of a centrifugal pump and predicted performance for off-design volume flow rate and calculated impeller volute disc friction loss, slip, shock losses, recirculation losses and other friction losses. E.C. Bcharoudis et. al. [2] have contributed to reveal the flow mechanisms inside centrifugal impellers and studied performance by varying outlet blade angle. They observed a gain in head more than 7 % with increase in outlet blade angle from 20o to 45o. Motohiko Nohmi et. al. [3] have developed two types of cavitation CFD codes for centrifugal pump. They observed that at the cavitation, there is a breakdown of flow rate as throat is choked by cavities on both suction surface and pressure surfaces. Vasilios A. et. al. [4] studied computational analysis of c ent r i fugal pump impeller by optimising blade inlet geometry. John S. Anagnostopoulos [5] solved RANS equations for the impeller of centrifugal pump and developed fully automated algorithm for impeller design. M.H.Shojaee Fard and F.A.Boyaghchi [6] have carried out computational analysis on a centrifugal pump handling viscous fluids. They observed performance improvements in centrifugal pump with increase in the outlet blade angle due to decrease of wake formation at the exit of the impeller. S.Rajendran et.al [7] describes the simulation of the flow in the impeller of a centrifugal pump. VSRM Kishore et.al [8] has design the impeller of a turbocharger for a diesel engine to increase its power and efficiency, and showing the advantage of designing comparing with the turbocharger by varying the materials. Mohd Zubair Nizami et.al [9] has suggested that composites are the best alternatives to control the vibrations in impellers because of their superior damping characteristics.

In this paper the finite element method has been adopted for predicting Von Mises stress and strains for three different alloy materials (viz., Inconel alloy 740, Incoloy alloy 803, Warpaloy) by using static analysis, also an attempt is made to predict the frequency modes of three different alloy materials by using dynamic analysis.

2. Finite Element Analysis

Finite element analysis is a computer based numerical technique for calculating the strength and behaviour of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behaviour and many other phenomena. It can analyze elastic deformation or “permanently bent out of shape” deformation. The computer is required because of the astronomical number of calculations needed to analyze a large structure. The power and low cost of modern computers has made finite element analysis available to many disciplines and companies.

With the rapid advancement of technology, the complexity of the problem to be dealt by a design engineer is also increasing. This scenario demand speedy, efficient and optimal design from an engineer. To keep pace with the development and ensure better output, the engineer today resorting to numerical methods. For problems involving complex shapes,

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material properties and complicated boundary conditions, it is difficult and in many cases interactive to obtain analytical solutions. Numerical methods provide approximate but acceptable solutions to such problems.

Finite element analysis is one of such numerical procedure for analyzing and solving wide range of complex engineering problems (may be structural, heat conduction, flow field) which are complicated to be solved satisfactorily by any of the available classical analytical methods.

The computer intervention is the backbone of the procedure since it involves the solution of many simultaneous algebraic equations, which can be solved easily by the computer. Actually Finite Element Method was originated as a method of stress analysis. But today the applications are numerous. Now days, each and every design is developed through Finite Element Analysis. The numerous applications include the fields of Heat transfer, Fluid flow, Lubrication. Electric and Magnetic fields, Seepage and other flow problems. The various areas of applications include design of buildings and bridges, electric motors, heat engines, aircraft structures, spacecrafts etc. With the advances in Interactive CAD systems complex problems can be modeled with relative ease. Several alternative configurations can be tried out on a computer before the prototype is built.

3. Modeling and Meshing of Centrifugal Pump Impeller

The solution procedure of this project work involves the following steps:

1. Modeling by using CATIA V5 R19
2. Meshing by using HyperMesh 9.0
3. Analysis using ANSYS 13.0

3.1 Modeling by Using CATIA V5 R19

A centrifugal pump impeller with outward curved impeller blades positioned in housing. Modeling of the Centrifugal pump impeller is done using CATIA V5 R 17. In order to model the centrifugal blower it is necessary to model the parts of the impeller which are blades including guided blades and the hub then it was assembled to get the total component. The solid model of the centrifugal blower is as shown in the figure 3.1.

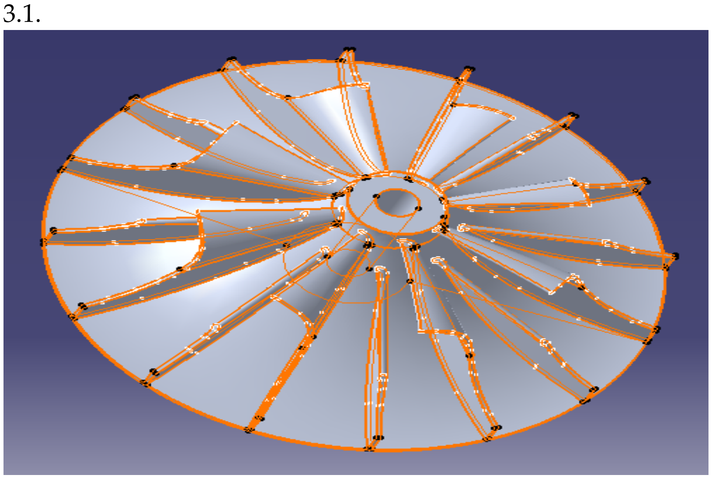

Figure 3.1: Solid model of Centrifugal pump impeller.

3.2 Meshing by Using HYPERMESH 9.0

The solid model is imported to HYPERMESH 9.0 and hexahedral mesh is generated for the same. The meshing was done by splitting it into different areas and the 2D mapped mesh was done and then it was converted into 3D mesh using the tool linear solid. There are 8 quality check parameters in HYPERMESH to get optimum meshing. They are Jacobian, warpage, aspect ratio, skew, chordal deviation, length, taper angle, triad angles. Out of these 8 parameters any 5 has to be within permissible limits. Then the meshed model is imported into the ANSYS. The meshed model imported to ANSYS is shown in figure 3.2.

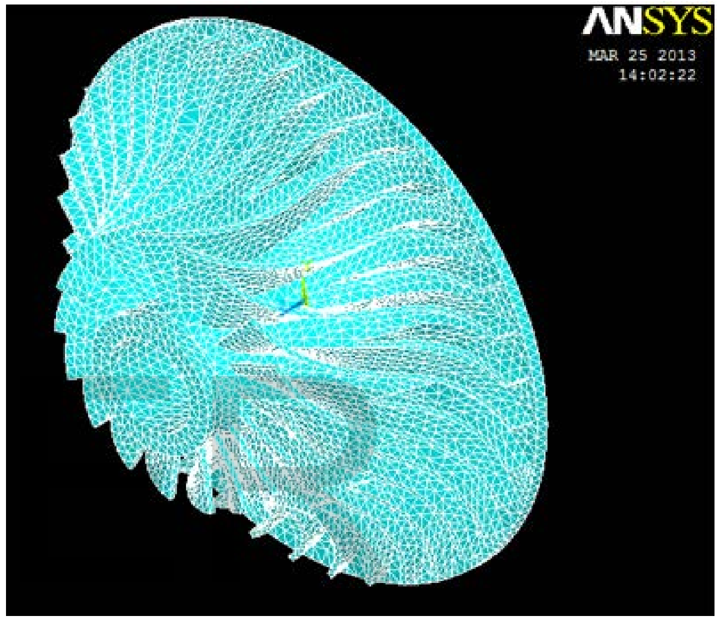

Figure 3.2: The FE model of Centrifugal impeller imported to ANSYS.

3.3 Boundary Conditions using in ANSYS

Centrifugal pump impeller is fitted on motor shaft. So, the nodes at the interface of the impeller and shaft are fully constrained.

3.4 Material Properties

Table.1: Typical properties of alloys

Material	Density	Young's Modulus	Poisson's Ratio
Inconel alloy 740	8050 Kg/m^3	221 GPa	0.35
Incoloy alloy 803	7860 Kg/m^3	195 GPa	0.32
Warpaloy	8290 Kg/m^3	211 GPa	0.30

4. Results and Discussions

4.1 Static Analysis on Centrifugal pump impeller:

4.1.1 Incoloy Alloy 803:

Static analysis has been carried out to predict the stress and displacement. Figure 4.1~4.3 shows the variations of Von Mises stress, Von Mises strain and deformation of Inconel alloy 803 and the results are tabulated mentioned in Table 2.

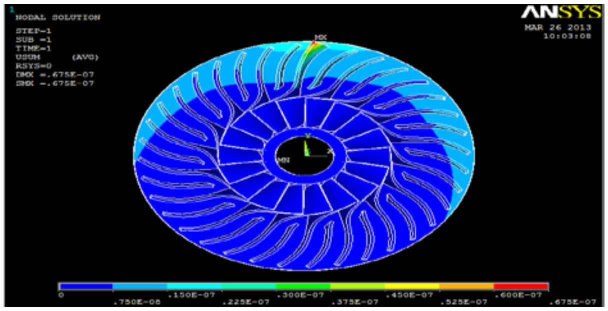

Fig 4.1: deformation of Incoloy alloy 803

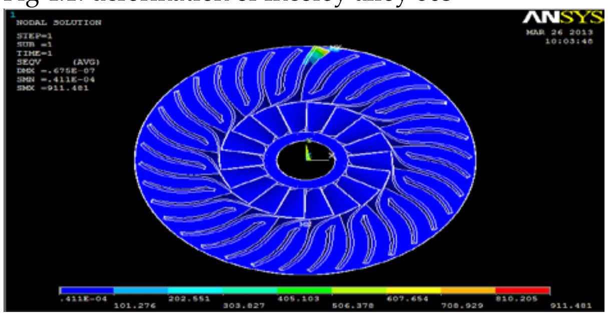

Fig 4.2: von misses stress of Incoloy alloy 803

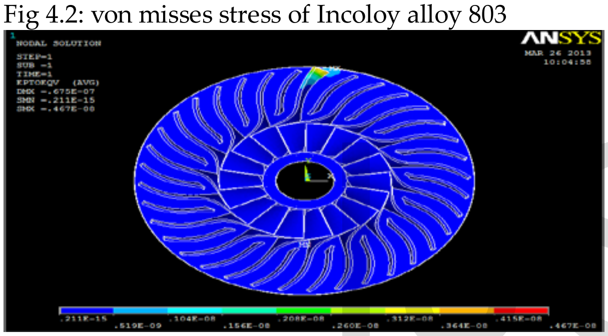

Fig 4.3: von misses strain of Incoloy alloy 803

4.1.2 Incoloy Alloy 740:

Static analysis has been carried out to predict the stress and displacement. Figure 4.4~4.6 shows the variations of Von Mises stress, Von Mises strain and deformation of Inconel alloy 740 and the results are tabulated mentioned in Table 2.

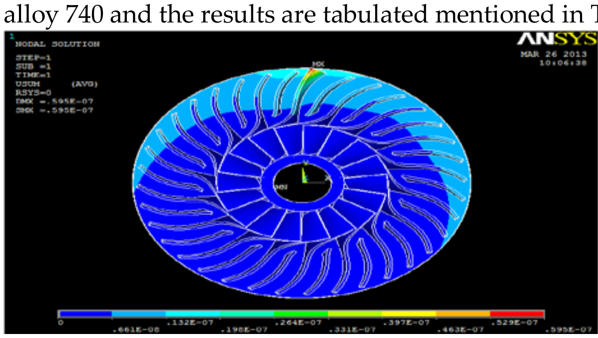

Fig 4.4: deformation of Incoloy alloy 740

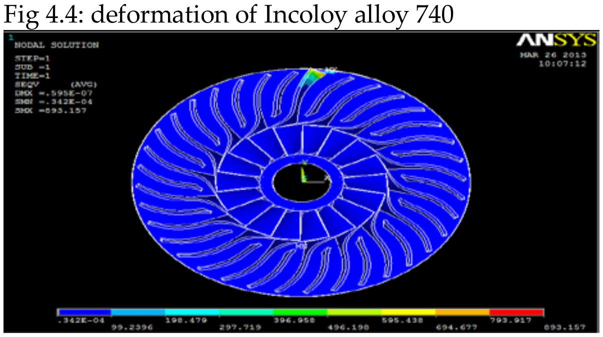

Fig 4.5: von misses stress of Incoloy alloy 740

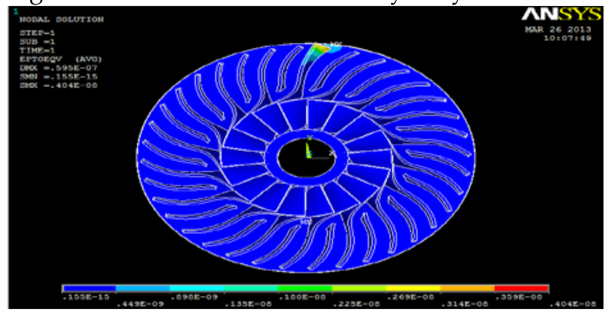

Fig 4.6: von misses strain of Incoloy alloy 740

4.1.2 Warpaloy alloy:

Static analysis has been carried out to predict the stress and displacement. Figures 4.7~4.9 shows the variations of Von Mises stress, Von Mises strain and deformation of Warpaloy alloy and the results are tabulated mentioned in Table 2.

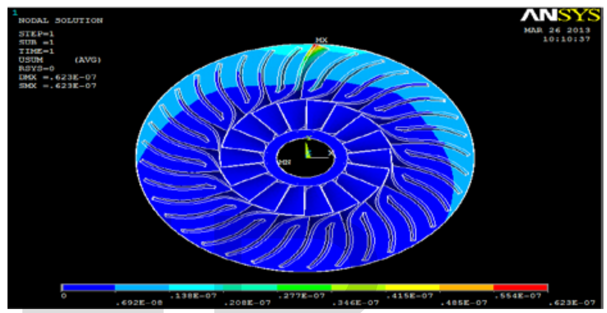

Fig 4.7: deformation of Warpaloy alloy

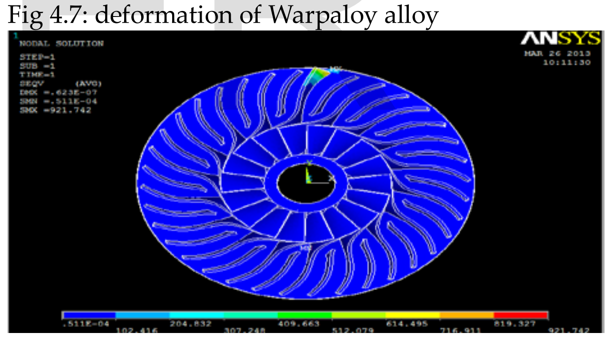

Fig 4.8: von misses stress of Warpaloy alloy

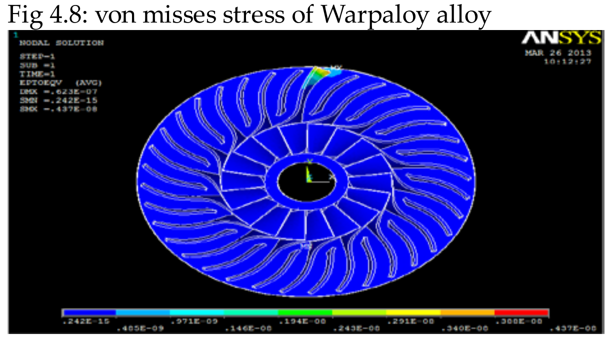

Fig 4.9: von misses strain of Warpaloy alloy

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Table 2: Static analysis of alloy materials

Properties	Incoloy alloy 803	Inconel alloy 740	Warpaloy
Von misses Stress (MPa)	911.481	893.157	921.742
Von misses Strain	0.0000467	0.0000404	0.0000437
Deformation (mm)	0.0675	0.0595	0.0623

4.2 Dynamic Analysis on Centrifugal pump impeller:

4.2.1 Incoloy alloy 740:

Model analysis has been carried out to estimate the variations in frequency for various sets. Figures 4.10~4.12 shows the variations of frequency of Incoloy alloy 740 and the results are tabulated in Table 3.

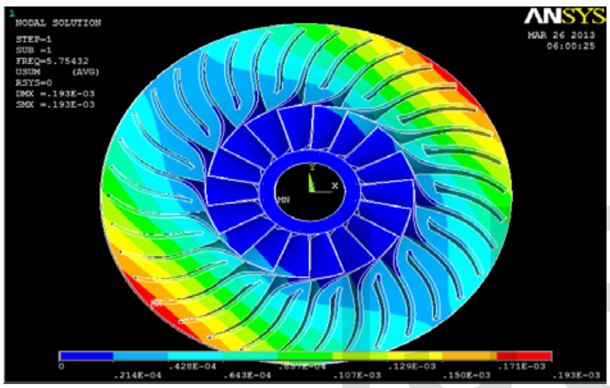

Fig 4.10: Incoloy alloy 740 frequency[1] deflection

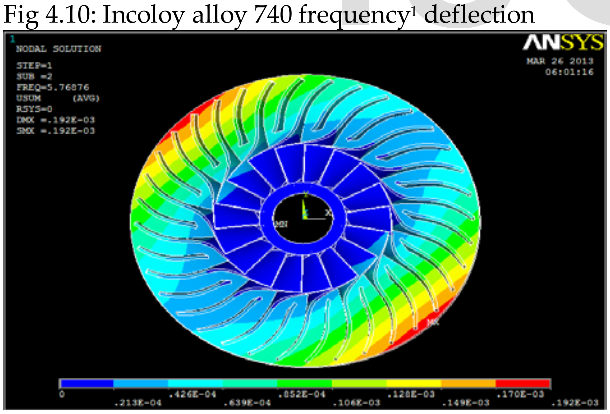

Fig 4.11: Incoloy alloy 740 frequency[2] deflection

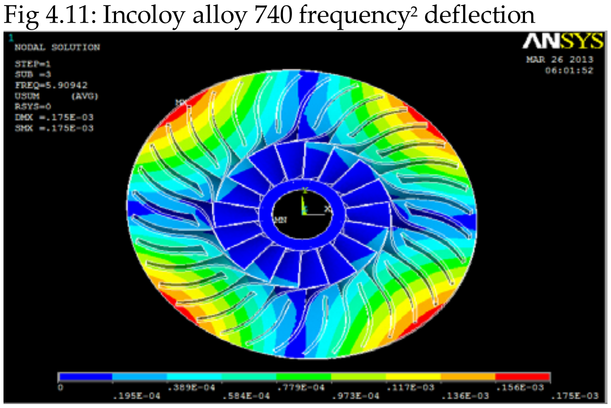

Fig 4.12: Incoloy alloy 740 frequency[3] deflection

4.2.2 Incoloy alloy 803:

Model analysis has been carried out to estimate the variations in frequency for various sets. Figures 4.13~4.15 shows the variations of frequency of Incoloy alloy 803 and the results are tabulated in Table 3.

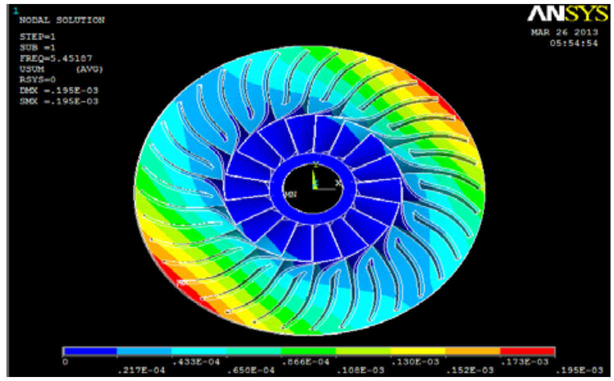

Fig 4.13: Incoloy alloy 803 frequency[1] deflection

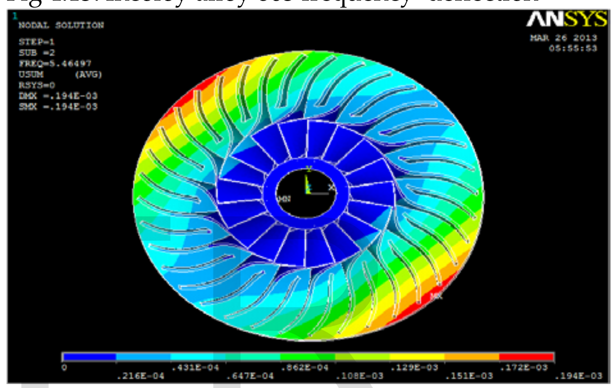

Fig 4.14: Incoloy alloy 803 frequency[2] deflection

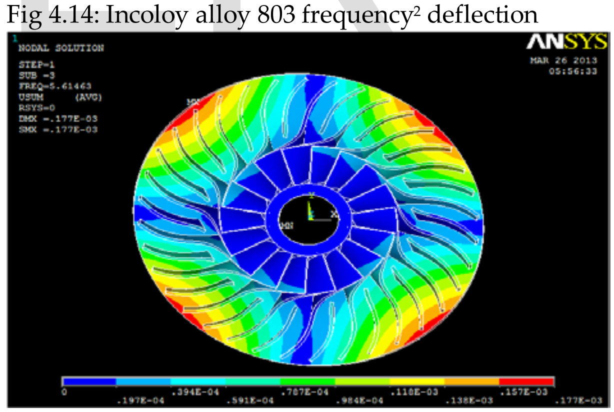

Fig 4.15: Incoloy alloy 803 frequency[3] deflection

4.2.3 Warpaloy alloy:

Model analysis has been carried out to estimate the variations in frequency for various sets. Figures 4.15~4.17 shows the variations of frequency of Warpaloy and the results are tabulated in Table 3.

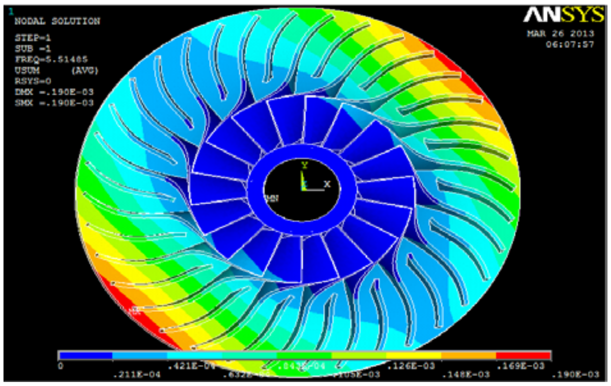

Fig 4.16: Warpaloy frequency1 deflection

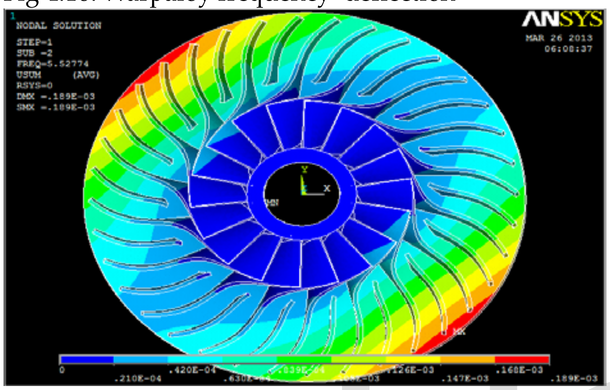

Fig 4.17: Warpaloy frequency2 deflection

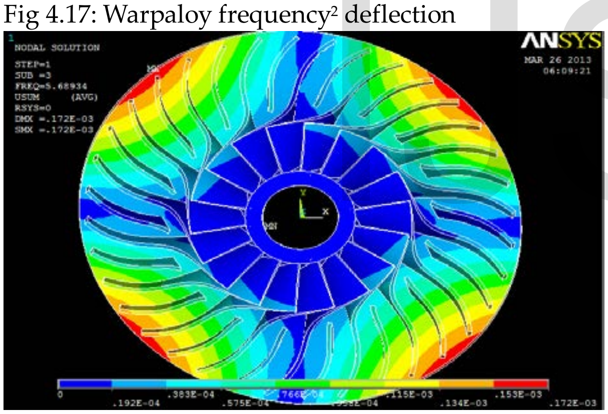

Fig 4.17: Warpaloy frequency3 deflection

Table 3: Variation of frequency and deflection for different materials using Model Analysis

Material	Frequency (HZ)			Displacement (mm)		
	1	2	3	1	2	3
Incoloy alloy 803	5.45	5.47	5.61	0.195 e-3	0.194 e-3	0.177 e-3
Inconel alloy 740	5.75	5.77	5.91	0.193 e-3	0.192 e-3	0.175 e-3
Warpaloy	5.52	5.53	5.69	0.190 e-3	0.189 e-3	0.172 e-3

4.3 Analysis of Results

4.3.1 Static Analysis

- From the Figures it can be seen that the induced Von Mises stress in Warpaloy alloy are maximum when compared to Incoloy alloy 803 and Inconel alloy 740.
- From the Figures it can be seen that the induced Von Mises strain in Incoloy alloy 803 are maximum when compared to Warpaloy and Inconel alloy 740.
- The displacement induced in Incoloy alloy 803 is maximum when compared to Warpaloy and Inconel alloy 740.

4.3.2 Model Analysis

- In case of Incoloy alloy 803 maximum displacement is observed at the frequency 5.4519 HZ i.e 0.195 e-03 mm.
- In case of Inconel alloy 740 maximum displacement is observed at the frequency 5.7543 HZ i.e 0.193 e-03 mm.
- In case of Warpaloy maximum displacement is observed at the frequency 5.5148 HZ i.e 0.190 e-03 mm.

5. Conclusions

For impeller the minimum Von Mises stress obtained for the material Inconel alloy 740, also the maximum frequency is obtained for the same material. The maximum specific modulus is 27.46 MPa for the material Inconel alloy 740, for Incoloy alloy 803, specific modulus is 24.83 MPa and for Warpaloy is 25.44 MPa. Comparing the results of three alloy materials (viz., Inconel alloy 740, Incoloy alloy 803, Warpaloy) of impeller, maximum Von Mises stress, natural frequency and specific modulus obtained for Inconel alloy 740 is optimum compared to other materials like Incoloy alloy 803 and Warpaloy. So, the best suggested material for the design of impeller is Inconel alloy 740. Hence finite element method is a viable alternative to perform better analysis of engineering structures.

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