National Conference on Recent Advances in Mechanical Engineering and Materials
International Journal of Scientific Research in Mechanical and Materials Engineering
2021 IJSRMME |Volume 4, Issue 7 |ISSN : 2457-0435

Design and Analysis of Centrifugal Pump Impeller by Finite Element Analysis

Abdul Rahman Faisal, Syeda Anjum, Dr. Nanjundaradhya N V*, Dr. Shivaraj B W*
Department of Mechanical Engineering, RV College of Engineering, Bengaluru 560059, Karnataka, India

ABSTRACT

The Centrifugal pump is a device which is mostly used for transporting liquid from lower level head to higher level head. Centrifugal pumps are used for, sewage, oil refineries, hydraulic power services, food processing factories, mines, chemical plants, irrigation, water supply plants and steam power plants because of suitability in various practical services. In centrifugal pumps the mechanical energy will be converted into hydraulic energy. The main components of centrifugal pump are casing and impeller therefore; they must be designed carefully for best performance of pump. The main goal of this work is to present design and analysis of centrifugal pump impeller by finite element analysis for four different materials Mild steel, Stainless steel, Aluminum alloy and Epoxy glass fiber composite material. Centrifugal pump impeller is modeled into 3D using Solid works 2015, using Ansys Software 2016 impeller material properties are given Stresses and Deformation in X, Y, Z directions are investigated. A structural analysis will be carried out to investigate the stresses, strains and displacements of the centrifugal pump impeller in Ansys Workbench. The paper gives static analysis of Impeller of different materials to check strength and deformation of Pump and found that the impeller with Epoxy glass fiber composite material is best compared to other material like MS, SS, and AA.

Index Terms - Centrifugal Pump Impeller, Design and Analysis, Weight Less Impeller, Ansys, Solid Works, Mild Steel EN-8, Stainless Steel 304, Aluminum Alloy 6064

I. INTRODUCTION

Centrifugal pump is rotor dynamic pump uses a rotating impeller to increase the pressure of fluids. Centrifugal pumps are mostly used to move liquids through piping systems. The fluid will enter the pump impeller near to the rotating axis will be accelerated by the impeller, which will flow radially outward into a diffuser volute chamber i.e. casing or diffuser. Its main purpose is to convert energy of a prime mover (an electric motor or turbine). First into velocity or kinetic energy and then into pressure energy of a fluid that is pumped. Centrifugal pumps are mostly used for large discharge through smaller heads. The Centrifugal pumps convert mechanical energy from a motor to energy of a moving fluid and some of the energy will go into kinetic energy of fluid motion and some into potential energy and will be represented by lifting the fluid against gravity to a higher level or fluid pressure.

[1] A Syam Prasad, B V V Lakshmipathi Rao, A Babji, Dr P Kumar Babu, “Static and Dynamic Analysis of a Centrifugal Pump Impeller” Alloys are playing one of major role in many engineering applications. They are offering outstanding mechanical properties, physical properties, flexibility in design capabilities and ease of fabrication. Few advantages include light weight,

impact resistance and excellent fatigue strength and corrosion resistance. This paper studies have carried out on static and modal analysis of a centrifugal pump impeller which is made of 3 different alloy materials. (I.e. Inconel alloy 740, Incoloy alloy 803, Warpaloy)

[2] Karthik Matta, Kode Srividya, "Static and Dynamic Response of an Impeller at Varying Effects" An impeller is a rotating component of a centrifugal pump, usually made of iron, aluminum, steel, bronze, brass, or plastic. The modeling of the impeller was done by using solid modeling software that is CATIA V5 software. It is proposed to design a blower with composite material, analyze strength and deformation using FEM software. In order to validate the effectiveness of composites and metal blower and impeller using FEA packaged i.e. ANSYS Workbench.

[3] G. Kalyan, K.L.N. Murty. "Design and Optimization of Centrifugal Pump Guide Vanes" In this paper an impeller of a centrifugal pump is designed and modelled in 3D modeling software. Materials used are steel and aluminum and the optimization of the impeller design is done by observing the results obtained from the analysis performed. The results considered are stress frequency velocity pressure flow rates. Analysis is done in ANSYS software 2016. The observered results shows the structural analysis result of stresses by increasing number of blades and increasing the angle of blade

[4] Pramod J. Bachche, R.M.Tayade "Finite Element Analysis of Shaft of Centrifugal Pump" In this paper study Shaft of centrifugal pump for static and dynamic analysis. The shaft is analyzed by using finite element analysis technique for stresses, strains and deflections. The total work is carried out in two stages in first stage is static analysis. In this stage pump the shaft is analyzed for stresses, strains and deflection and same results are verified using graphical integration method. And second stage for dynamic analysis, in this second stage result obtained by static analysis is used to calculate dynamic forces coming in pump shaft. Again shaft is analyzed in dynamic input condition and results are verified by using graphical integration method.

[5] S.Rajendran and Dr. K Purushothaman "Analysis of centrifugal pump impeller using ANSYS-CFX" In this paper analysis of centrifugal pump impeller design is carried out using ANSYS-CFX. It is most common pump used in industries and domestic application. The complex internal flow in centrifugal pump impeller can predict by ANSYS-CFX. The centrifugal action of impeller accelerates the liquid to high velocity, transferring mechanical energy to the liquid. The flow pattern, pressure distribution in blade passage and blade loading of centrifugal pump impeller. Centrifugal pump impeller without volute casing is solved at a designed mass flow rate is high. The total efficiency of pump will increase by 30%.

II. OBJECTIVES OF STUDY

1. Modeling of Centrifugal Pump Impeller using Solid works software 2015.
2. To check strength of centrifugal pump impeller and weight reduction by static analysis utilizing Ansys workbench 2016 for different materials Mild Steel EN8, Stainless Steel 304, Aluminum alloy 6061 and Epoxy Glass Fiber.

III. METHODLOGY

Modelling of centrifugal pump impeller by utilizing CATIA V5 Software

- **ASSEMBLY OF CENTRIFUGAL PUMP IMPELLER**

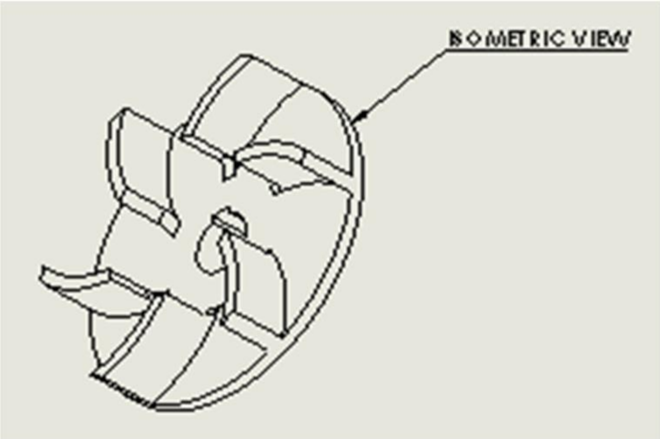

Fig. 1 Assembly of Centrifugal Pump Impeller

- **GEOMETRY OF CENTRIFUGAL PUMP IMPELLER**

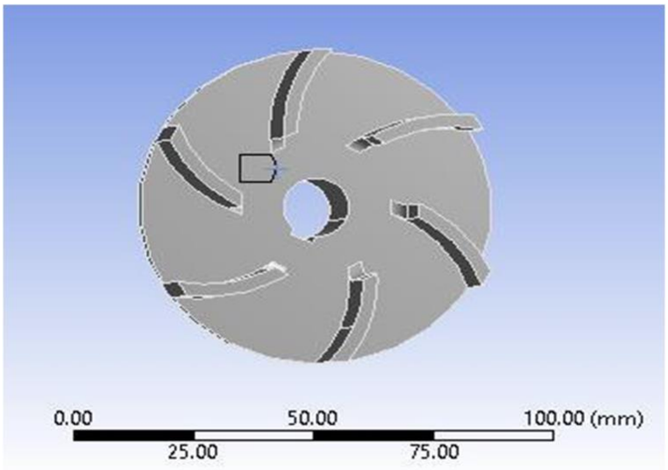

Fig. 2 Geometry of Centrifugal Pump Impeller

- **FEA MODEL OF CENTRIFUGAL PUMP IMPELLER :**

In Mesh Generation: Finite element analysis is carried out; the model used compulsory divided into a number of small parts which is known as finite elements. Since the model will be separated into various discrete parts, Finite element analysis can also be called as discretization method. In different terms, a mathematical net or mesh will be required to carry out a finite element analysis. If the system under validation is 1Dimensional in nature, we use line elements to represent geometry and to carry out analysis. If the problem can be described in two dimensions, then a 2Dimensional mesh will be required. Then, correspondingly if the problem is complex and a 3Dimensional representation of the continuum is required, then we 3Dimnesional mesh is used. Area elements can also be triangular or quadrilateral in shape. The selection of the element order and shape is mainly based on considerations relating to the complexity of nature and the geometry of the problem being modelled in Ansys Workbench. Membrane elements will not have thickness. As a result there will not be bending stiffness. The loads can only be carried in the element plane. There are special elements, which can facilitate accurate modeling of thick plates. If the deflection is greater than the plate thickness, then the membrane action should be considered and so shell elements should be considered. Shell element nodes have five degrees of freedom the missing is the in-plane rotational freedom (also called as the drilling freedom). Solid elements come in different varieties. Axi- symmetric elements are used to describe the cross- section in an axially symmetric part.

- **VOLUME MESHING**

3Dimensional elements take the form of cubes called hexahedrons, 3Dimensional triangles called tetrahedrons and 3Dimensional wedges known as pentahedrons. Decisions on element selection hinge on understanding the role of the element order of interpolation and shape. The Modeling of 3D-Elements is the most flexible approach. These types of elements are used for thick structures that have neither an axis of symmetry nor a constant cross section. The Solid modeling will almost make analysis preparation a bit easier. Meshing and solving can take a long time particularly if the structure is thin-walled i.e. large number of elements are required to produce a mesh in FEA.

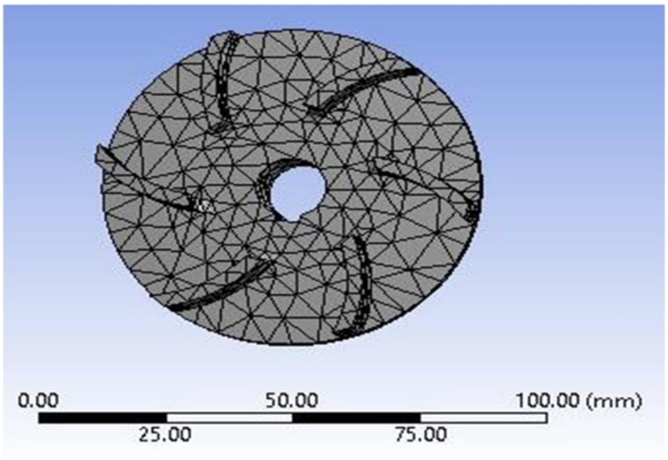

Figure 3 FEA Model of Centrifugal Pump Impeller

Table 1 Number of Nodes and Elements of Centrifugal Pump Impeller

Statistics	
Nodes	3491
Elements	1662
Mesh Metric	None

- **SUPPORT**

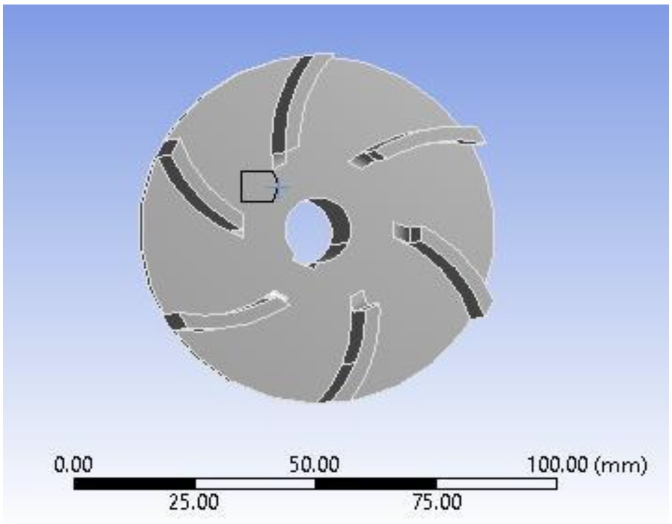

Fig 4 Fixed Support of Impeller

- **MOMENT**

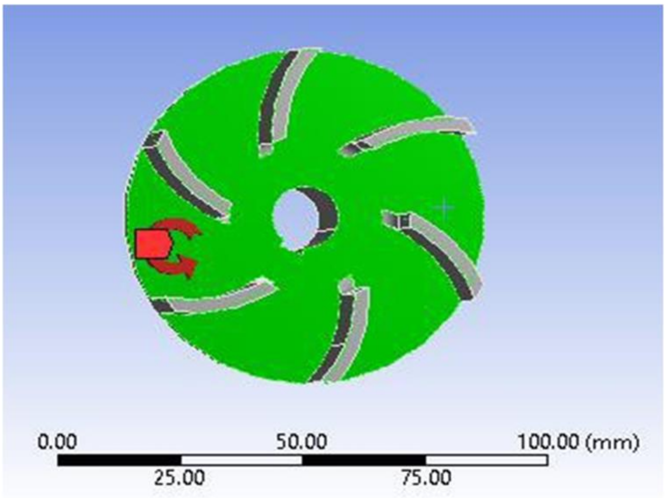

Fig 5 Moment applied at Impeller

IV. STATIC ANALYSIS OF CENTRIFUGAL PUMP IMPELLER

- **Procedure For Static Analysis In Ansys 2016 Software:**

1. Build the FE model
2. Define the material properties such as young's modulus, density and poisson ratio etc.
3. Apply boundary condition and pressures.

- **ANSYS 2016:**

ANSYS Work bench is a software platform where analysis is carried out i.e. Finite Element Analysis activities. The workbench allows organizing all related analysis files, databases under the same frame work.

The ANSYS Workbench platform provides users to create new, faster processes and efficiently interact with other tools like update Computer Aided Drawings systems. In this particular platform working on Metaphysics simulation would become easy. Those performing a structural simulation use a graphical interface i.e. called the ANSYS Workbench Mechanical application which employs a tree like navigation structure to define all parts of their simulation, geometry, mesh, loads, boundary conditions, connections, and results. By using ANSYS workbench 2016 the user can save time in many of the task performed during simulations. The bi-directional links with major update Computer Aided Drawings systems offer an efficient way to update Computer Aided Drawings geometries along with design parameters.

- **Static Analysis For Equivalent (Von-Misses) Stress:**

Static analysis of centrifugal pump impeller is done using Finite Element Analysis which is the main part of centrifugal pump. The, Impeller is chosen as main part of centrifugal pump for the static analysis because Centrifugal Pump Impeller is core part of centrifugal pump and all the performance of blower is depended upon it . The Analysis is done for the material like MS EN-8, SS 304, Al Alloy 6064 and Glass fiber in order to check Equivalent stresses and its corresponding deformations induced in each material. Analysis is done for the material MS EN-8, SS 304, Al Alloy 6064 and Glass fiber respectively, in order to check deformations induced in each material and check equivalent stresses.

V. STATIC ANALYSIS OF MS EN-8 PUMP IMPELLER:

- **Total Deformation:**

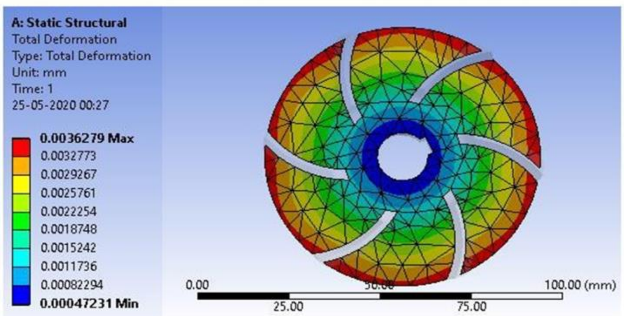

Fig 6 Total Deformation of MS EN-8 Pump Impeller

- **Equivalent Stresses:**

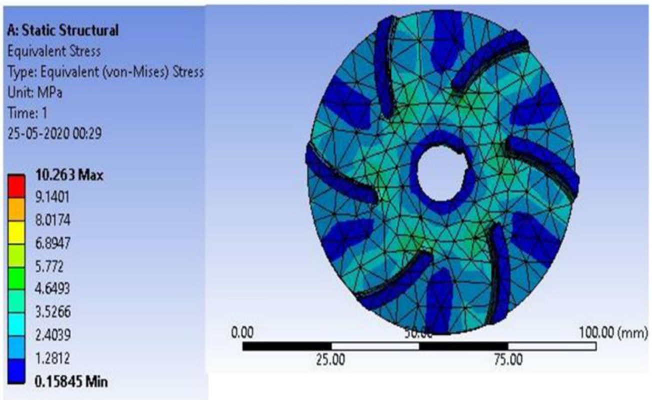

Figure 7 Maximum Stress induced in MS EN-8 Pump Impeller

VI. STATIC ANALYSIS OF Al PUMP IMPELLER

- **Total Deformation:**

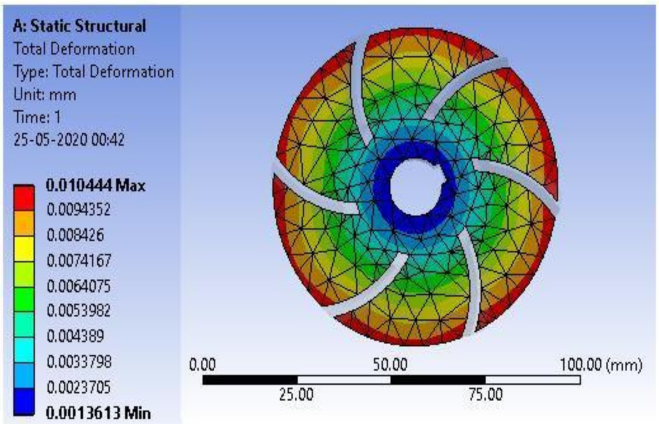

Figure 8 Total Deformation of AA Grade-6064 Pump Impeller

- **Equivalent Stresses:**

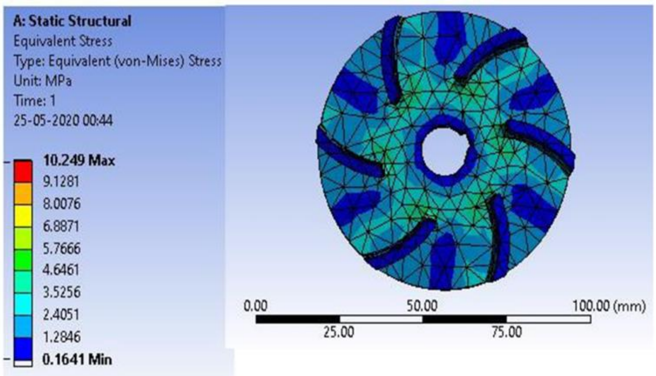

Figure 9 Maximum Stress induced in AA Grade-6064 Pump Impeller

VII. STATIC ANALYSIS OF STAINLESS STEEL PUMP IMPELLER

➢ **Total Deformation:**

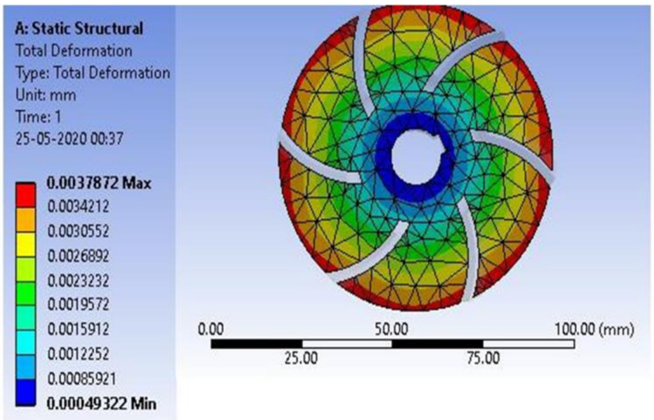

Figure 10 Total Deformation of SS Grade-304 Pump Impeller

➢ **Equivalent Stresses:**

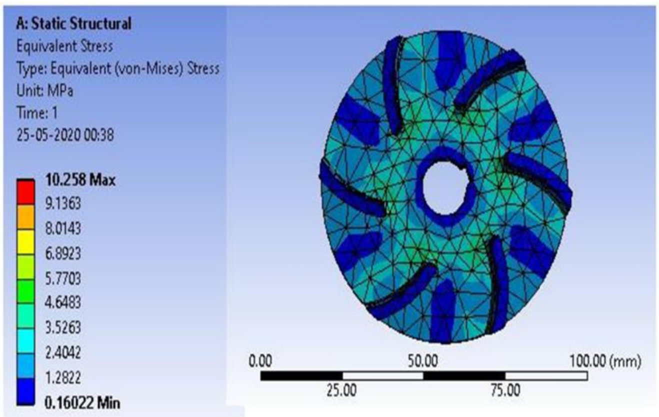

Figure 11 Maximum Stresses in SS Grade-304 Pump Impeller

VIII. STATIC ANALYSIS OF COMPOSITE MATERIAL (E-GLASS/EPOXY) PUMP IMPELLER

➢ **Total Deformation:**

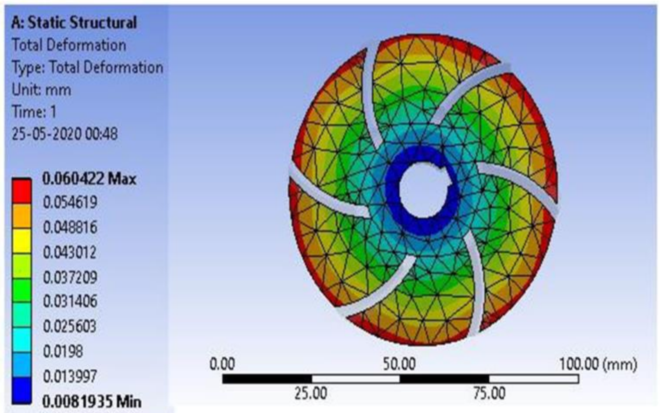

Figure 12 Total Deformation of E-Glass Pump Impeller

➢ **Equivalent Stresses:**

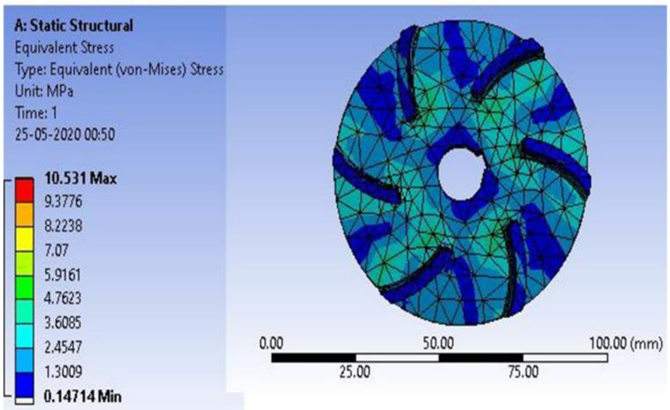

Figure 13 Maximum Stresses induced in E-Glass Pump Impeller

IX. RESULTS & DISCUSSIONS:

The analysis of centrifugal pump impeller has been done for all the four materials viz. MS EN-8, SS Grade-304, aluminum alloy Grade 6064 and Composite material (E- glass fiber). The comparison of properties and analysis results is shown in the table 2.

Table 2 Results of Centrifugal Pump Impeller

Sl. No	Material	Deformation (mm)	Max. Stress (MPa)	Weight (Kg)
1	Mild Steel EN8	0.0036	10.26	2.85
2	Stainless Steel Grade- 304	0.0037	10.25	2.73
3	Aluminium Alloy Grade-6061	0.0104	10.24	1.24
4	Composite material (E-glass fibre)	0.0604	10.53	0.87

Most of the centrifugal pump impellers are made up with Mild Steel EN8 which results in density. This is the main cause for high weight of the pump. It is observed from finite element analysis results that the stresses will be maximum at the shaft location.

From the comparison of Finite Element Analysis, it is observed that glass fiber is the material which is having the less weight, good strength and non-corrosive properties compared to other materials analyzed shown in table. Epoxy Glass Fibre is best suited alternative material for centrifugal pump impeller and is expected to perform better with a good amount of weight reduction
i.e. (0.87 Kg).

X. CONCLUSION

It is observed that all the materials will have stress values less than their respective permissible stress values. By doing static analysis of pump impeller it is observed that, the maximum deflection induced in Epoxy glass fiber material is 0.0604 mm, which is in permissible safe limits. The maximum induced stress for the Epoxy glass fiber is 10.53 MPa which is less than the allowable stress i.e. working stress by considering factor of safety (72 GPa).Hence the design is safe based on strength.

From the table 2 results above it is observed that weight of the Epoxy Glass Fiber (0.87 Kg) impeller material is minimum as compared to Mild Steel EB-8 (2.85 Kg), Stainless Steel 304 (2.73 Kg) and Aluminum Alloy material 6064(1.24 Kg), hence weight of the centrifugal pump impeller is reduced (optimized). It is observed that

maximum deformation takes place at the periphery of the centrifugal pump impeller (10.53 MPa). The deformation in Alloy Material is less (10.24 MPa). The Epoxy Glass fiber material which is having the less weight (0.87 Kg), deformation (0.0604) it is best suited alternate material for centrifugal pump impeller and is expected to perform better with constructive amount of weight reduction.

XI. FUTURE SCOPE

- Dynamic analysis can be performed for pump impeller.
- Modal analysis can be performed for pump impeller for determining natural frequency.
- Computational Fluid Dynamics analysis of the centrifugal impeller can be performed.
- Different way of development is by increasing the number of vanes.
- In this design as the numbers of vanes on diffuser were six, impeller with three, impeller with four vanes could be used.

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