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Structural Analysis, Material Optimization using FEA and Experimentation of Centrifugal Pump Impeller

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Abstract: ***In general the Efficiency of a centrifugal pump (ηo) = Mechanical efficiency (ηm) × Volumetric efficiency (ηv). Most of the study has been done in the improvement of Hydraulic efficiency but overall efficiency depends on both factors Hydraulic and Mechanical. Mechanical components – for example, impeller weight and structure produce a mechanical loss that reduces the power transferred from the motor shaft to the pump or fan impeller. Also, the strength of the pump reduces due to stress corrosion problems in impeller which can be minimized using an alternate material having same/more strength. The modelling of the impeller will be done by using solid modelling software, CATIA. The meshing and boundary condition application will be carried using Hypermesh, it is also used to produce good and optimal meshing of the impeller to obtain accurate results and analysis has been done by using ANSYS.***

A static analysis on 3HP pump impeller has been carried out to examine the stresses and displacements of the centrifugal impeller. Conventional MS material is replaced with glass fiber composite material. After getting safe results from the analysis, the model will be fabricated and testing will be done on UTM.

Keywords: Centrifugal Pump Impeller, Fea, Static Analysis, Material Optimization, Glass Fiber.

I. INTRODUCTION

Centrifugal pumps are very well-known equipment used in residence, agriculture and industrial applications. It is necessary for a pump manufactured at low cost and consuming less power with high efficiency. It is the most used pump in the world. The centrifugal pumps are well described, tested and robust and also inexpensive to manufacture.

A centrifugal pump is a dynamic device. Fluid pressure increases from pump inlet to the pump outlet when the pump is working. In the centrifugal pump pressure increases on the fluid by receiving mechanical energy from the motor to the fluid with the help of rotating the centrifugal impeller. The fluid flows from the inlet to the center of the impeller and goes out along the impeller blades. The centrifugal force on the fluid increases the velocity of the fluid. As the kinetic energy is converted to pressure/ hydraulic energy, stress generates in the impeller, therefore, it is necessary to do an analysis of the impeller strength which depends on the material used for the impeller. Also, the strength of the pump reduces due to stress corrosion problems in impeller which can be minimized using an alternate material having same/more strength.

II. LITERATURE SURVEY

1. V. Jose Ananth Vino, "Analysis of Impeller of Centrifugal Pump"

The study in this paper regards to linear structural analysis of centrifugal pump impeller. Here they have assembled 5 parts of an impeller of Centrifugal pump and primary goal is to apply preload of 100 N in the belt and to check that impeller is not getting deflected to a maximum of 0.0075 mm. They have applied the material to pump whose elastic limit is not exceeded then the elastic limit. The variation of von-misses stress, von-misses strain, and deformation factor for different materials can be taken into consideration. The CATIA is used for modeling the impeller and analysis is done in ANSYS. ANSYS is dedicated finite element package used for determining the variation of stresses, strains, and deformation across the profile of the impeller. An attempt has been made to investigate the effect of temperature, pressure and induced stresses on the impeller. By identifying the true design feature, the extended service life and long term stability are assured.A structural analysis has been carried out to investigate the stresses, strains, and displacements of the impeller for different materials.

2. A Syam Prasad, BVVV Lakshmipathi Rao, A Babji, Dr P Kumar Babu, "Static and Dynamic Analysis of a Centrifugal Pump Impeller".

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 CAT-IA and ANSYS13.0 software. 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 the 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 have 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 (viz., Inconel alloy 740, Incoloy alloy 803, Warpaloy).

The best material for the design of impeller is Inconel 740. Specific modulus of Inconel 740 obtained in static analysis is 10 % higher than other material. The natural frequency in the modal analysis is 6% higher than other material. The deformation of Inconel 740 in static analysis is reducing by 12%.

3. Static Analysis of Centrifugal Blower Using Composite Material Mr M. Sampathkumar, Mr Dsvsra Varaprasad, Mr Vijaykumar

This paper deals with the static and model analysis of centrifugal blowers using composite materials. Centrifugal blowers are used in marine applications which have high noise levels. The noise generated by a rotary part is mostly due to random loading force on the blades and periodic iteration of incoming air with the blades of the rotor. The Contemporary blades in marine applications are made up of Aluminium or Steel and generate noise that causes disturbance to the people working near the blower. This paperwork aims at observing the choice of E-Glass as an alternative to metal for better vibration control. E-Glass, known for their superior damping characteristics are more promising in vibration reduction compared to metals. The stresses of E-Glass/Epoxy blower obtained in the static analysis are within the allowable stress limit. The natural frequency of E glass blower is reducing by 16.6% to 27.7% because of high stiffness. The weight of the E-Glass blower is 15 kg which is less than the Aluminium blower with a weight of 19 kg. From the results of the harmonic analysis, the damping effect is more in E-Glass blower which controls the vibration levels. From the above results, we can conclude that E-Glass blower is preferable than Aluminium blower and based upon frequency values can be reduced.

III.PROBLEM IDENTIFICATION AND PROBLEM DEFINITION

As the present centrifugal pump impeller is made up of material MS, the weight of the impeller is high because of material density. As the kinetic energy is converted to pressure/ hydraulic energy, stress generates in the impeller, therefore, it is necessary to do an analysis of the impeller strength which depends on the material used for the impeller. Also, the strength of the pump reduces due to stress corrosion problems in impeller which can be minimized using an alternate material having same/more strength.

Due to following conditions, mechanical efficiency reduces and power requirement of the pump increases.

- Non-optimized size of the impeller
- Weight of the pump impeller
- Impeller axial forces acting on side walls and internal blades
- Water head and pressure acting on impeller profile.

SCOPE AND OBJECTIVES OF WORK:

SCOPE:

• An axial flow centrifugal pump impeller 3 HP rating will be taken for reference and its parameters and loading parameters henceforth will be calculated.

• Literature Survey

• Design of pump impeller by using Solidworks CAD Software

• Analysis of impeller for materials like MS, Al, Glass fiber, etc.

• The solution proposed here will be through material optimization with glass fiber based epoxy composite material which is having great mechanical property.

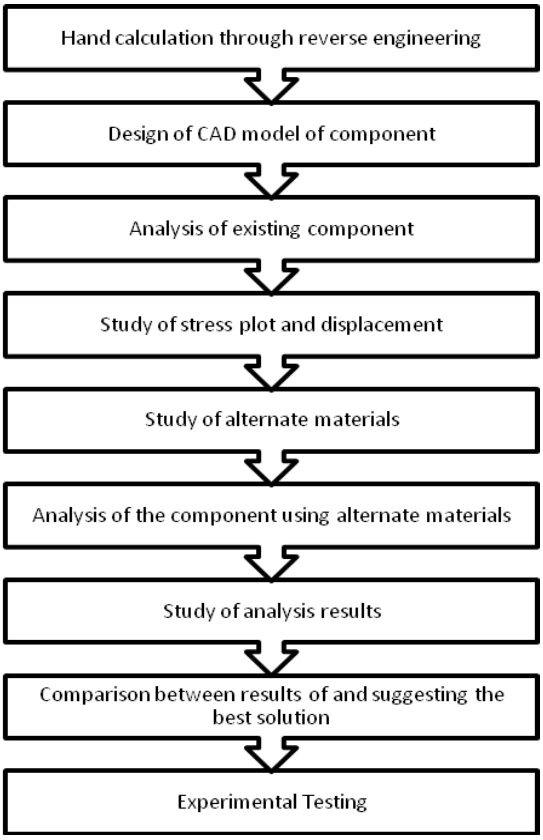
OBJECTIVES:

The main objective of the project is to weight optimize the impeller. This can be done by replacing conventionally used MS material with glass fiber composite material.

For this following objectives needs to be achieved:

- To study the existing model.
- Calculate forces and boundary conditions.
- Carryout meshing and analysis
- To carryout material optimization
- Testing on the fabricated model.

IV. METHODOLOGY



CAD MODEL OF PUMP IMPELLER

For the reference, we are using Kirloaskar pump of following specifications
Head H = 13m
Q Discharge = 515LPM or 0.00858 m3/sec
3 HP motor 2800 rpm
CAD model is prepared by doing design calculations based on given specifications and using CATIA CAD software

DIMENSIONS OF A PUMP IMPELLER ARE
D_{outer} = 216mm
D_{shaft} = 16mm
D_{hub} = 20mm
D_{eye} = 107.6mm
Width = 13mm
No. of blade = 8 no.s
Width of blade = 12.5mm
β_1 = 26.89 degree
β_2 =19.29 degree

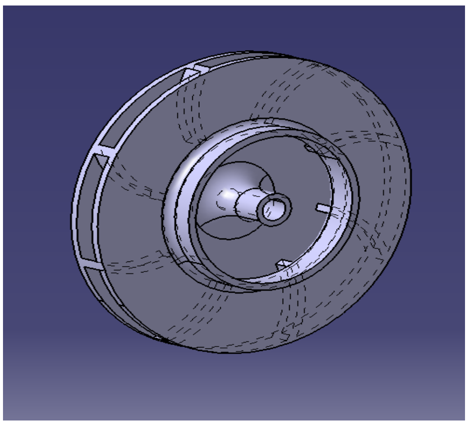


Fig: CAD Model

V. FINITE ELEMENT ANALYSIS OF PUMP IMPELLER

The meshing and boundary conditions are applied for pump impeller CAD model by using Hypermesh. After completing the meshing and defining the boundary conditions the static structural analysis is done by using ANSYS R15.0 FEA software for the different materials.

The analysis is done for the material MS, Aluminum Alloy, and SS304L (Food Grade Steel) respectively, in order to check Equivalent Stresses and its corresponding deformations induced in each material.

The 3D CAD model of 3HP pump impeller is imported in Hypermesh and the surface was created and meshed. Here we are using 3D elements called as tetrahedral elements for meshing as all the dimensions of the pump impeller are measurable.

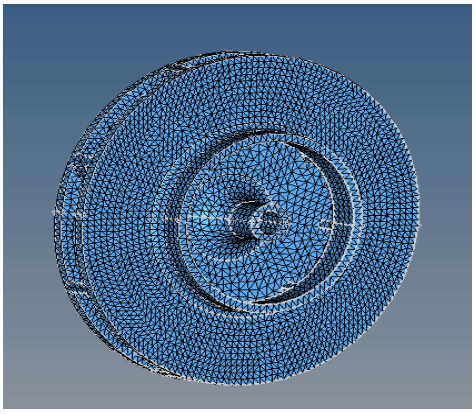


Fig: Tetrahedral meshing on 3HP pump impeller

Table: No. Nodes & Elements

No. of Nodes	No. of Elements	Element Size	Type of Meshing
9638	28716	2 mm	Tetrahedral

After completing the meshing boundary conditions are applied to the meshed model of pump impeller
These boundary conditions are used to calculate the results of analysis

BOUNDARY CONDITION CALCULATION

$P = \rho\, g\, h$

Where, P = Pressure of water, N/m^2

ρ = mass of density of fluid = 103 Kg/m^3

H = height of fluid = 13m

g = 9.81 m/s^2

$\therefore$ P = 127530 N/m^2

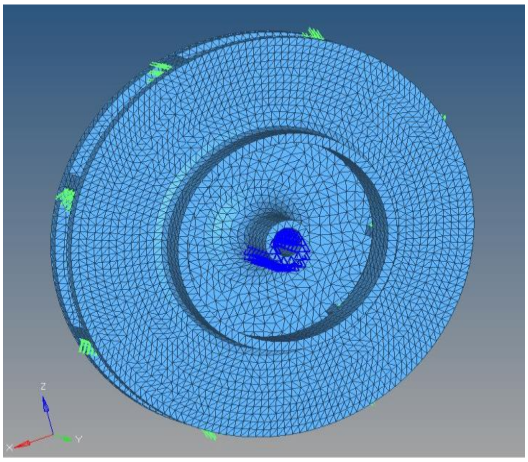


Fig: Constraints and forces applied on model in Hypermesh

MATERIALS ANALYSED

1. Mild Steel:

The existing impeller is made up of mild steel material. Therefore first analysis is done using MS as material.
The properties of mild steel are listed below

Property	Value
Young's Modulus, E	210 GPa
Poisson's Ratio ,ν	0.3
Density, ρ	7850 kg/m^3
Yield Stress, σ_{yield}	250 MPa
Ultimate Tensile Stress, σ_{uts}	410 MPa

Results for MS are as follows:

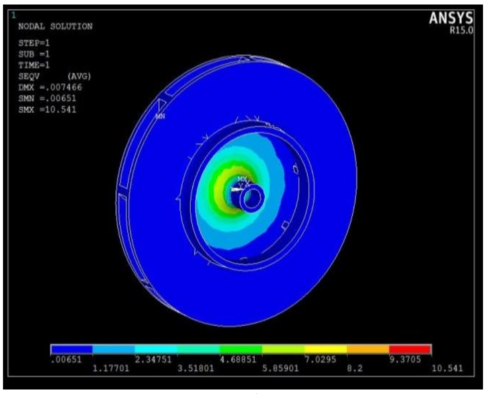


Fig: Von-mises stress for pump impeller

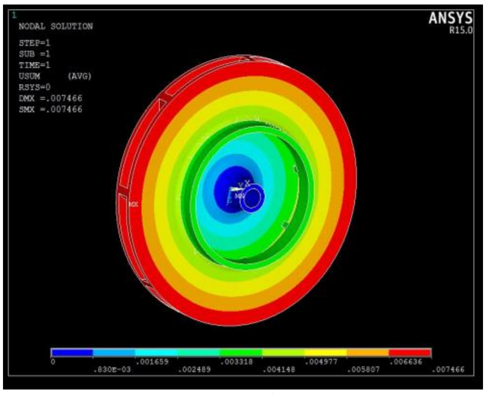


Fig: Displacement result for pump impeller

2. Aluminum Alloy
   The properties of Aluminum Alloy are listed below:

Property	Value
Young's Modulus, E	68.9 GPa
Poisson's Ratio ,ν	0.33
Density, ρ	2700 kg/m^3
Yield Stress, $\sigma_{\mathbf{yield}}$	214 MPa
Ultimate Tensile Stress, $\sigma_{\mathbf{uts}}$	241 MPa

Results for Aluminum Alloy are as follows:

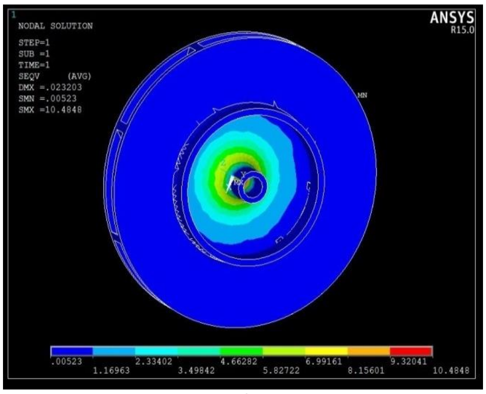


Fig: Von-mises stress for pump impeller

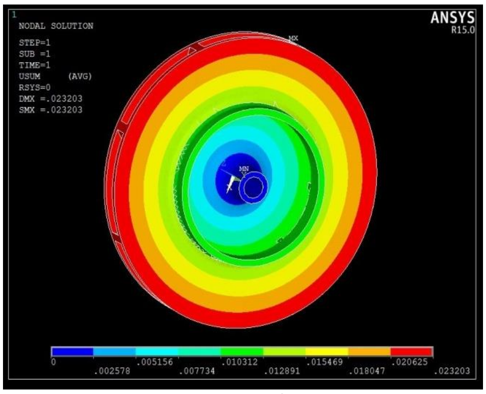


Fig: Displacement result for pump impeller

3. Composite Material (E-Glass/Epoxy)

Property	Value
Young's Modulus, $E_X = E_Y$	40 Gpa
Young's Modulus, E_z	6.2 Gpa
Poisson's Ratio ,NUXY	0.2
Poisson's Ratio ,NUYZ=NUXZ	0.39
Density, ρ	1900 kg/m^3
Shear Modulus G_{XY}	3.0 Gpa
Shear Modulus G_{YZ}	2.3 Gpa
Shear Modulus Gzx	1.5 Gpa

Results for Composite Material are as follows:

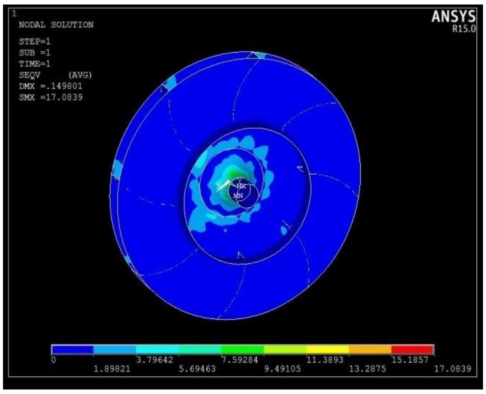


Fig: Von-mises stress for pump impeller

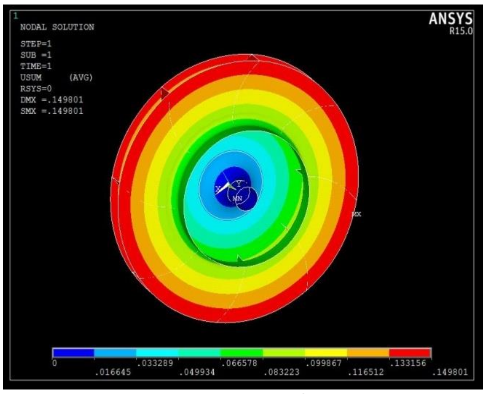


Fig: Displacement result for pump impeller

RESULT TABLE:

The analysis of pump impeller has been done for all the three materials viz. steel, aluminum alloy 6063 and Composite material (E-glass fiber). The comparison of properties and analysis results is shown in the table.

S.No.	Material	Max. Stress	Max. Displacement	Weight (Kg)
1.	**Steel**	10.54 MPa	0.007 mm	3.09
2.	**Aluminum Alloy 6063**	10.48 MPa	0.023 mm	1.06
3.	**Glass Fiber**	17.08 MPa	0.149 mm	0.75

FINITE ELEMENT ANALYSIS CONSIDERING LOAD ON SINGLE BLADE OF 0.12 N/mm2

1. Mild steel

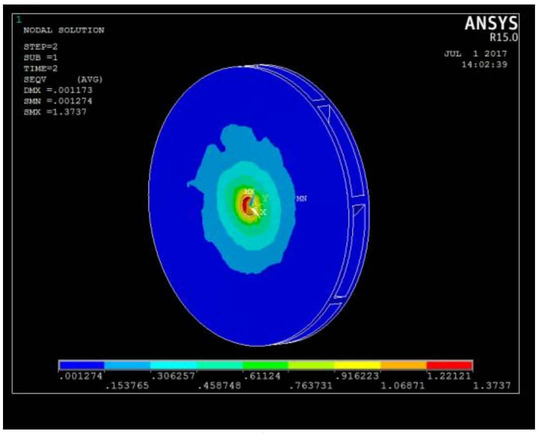


Fig: Von-mises stress for pump impeller

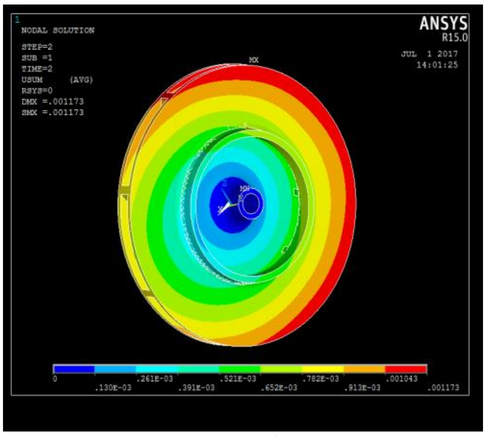


Fig: Displacement result for pump impeller

2. Aluminium Alloy

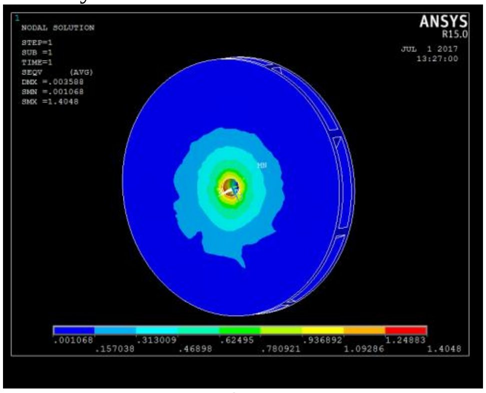


Fig: Von-mises stress for pump impeller

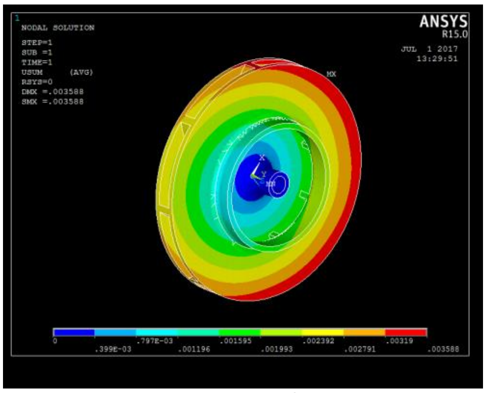


Fig: Displacement result for pump impeller

3. Glass Fiber(E-Glass/Epoxy)

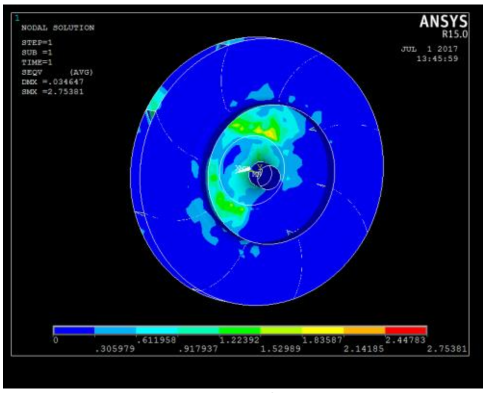


Fig: Von-mises stress for pump impeller

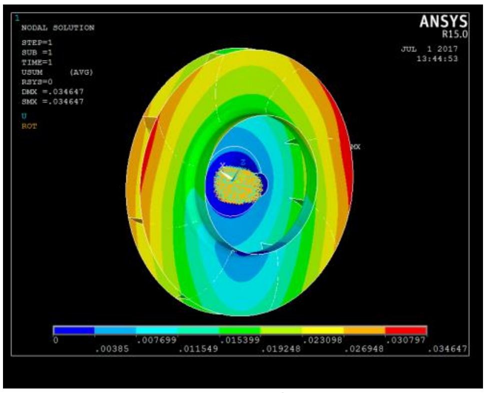


Fig: Displacement result for pump impeller

S.No.	Material	Max. Stress	Max. Displacement	Weight (Kg)
1.	**Steel**	1.37 MPa	0.0011 mm	3.09
2.	**Aluminum Alloy 6063**	1.40MPa	0.0035 mm	1.06
3.	**Glass Fiber**	2.75MPa	0.0346 mm	0.75

VI. EXPERIMENTATION

Based on the analysis results the pump impeller is manufactured using Glass Fiber (E-Glass/Epoxy) and tested on UTM.

Fig: Pump Impeller made up of Glass-fiber (E-Glass/Epoxy)

Fig: Experimental Setup (UTM)

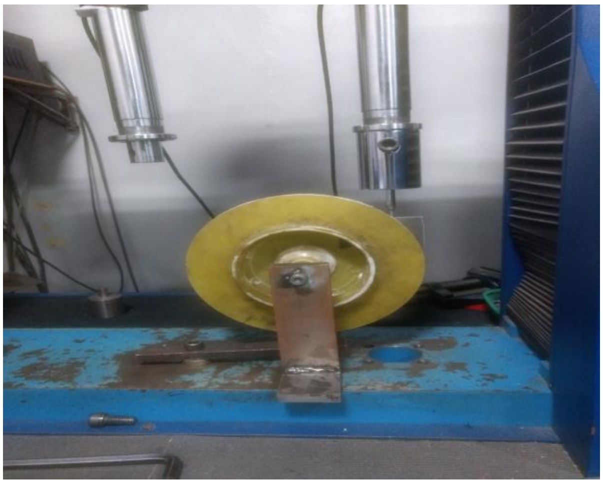
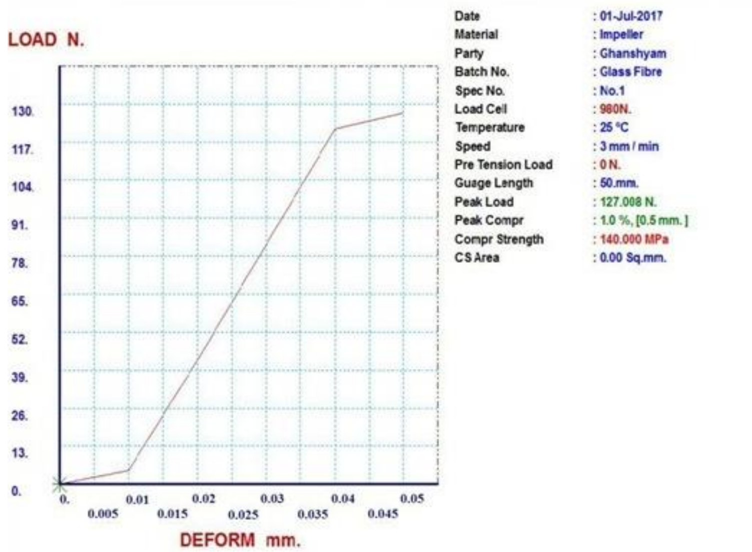


Fig: Specimen Mounted on UTM with proper fixtures

Experimental Test Result:



COMPARISON OF EXPERIMENTAL AND FEA RESULTS FOR PRESSURE OF 0.12 N/mm2 ON SINGLE BLADE FOR GLASS FIBER SPECIMEN

Sr. No.	Type of Analysis	Max. Displacement	% Error
1.	FEA	0.0346 mm	5.88
2.	Experimental	0.032 mm	

CONCLUSION

It is observed from the finite element analysis results that the stresses are maximum at the shaft location. It is also observed that all the materials have stress values less than their respective permissible stress values.

From the comparison of FEA and experimental testing results, it is observed that glass fiber is the material which is having the less weight, good strength and non-corrosive properties it is best suited alternate material for pump impeller and is expected to perform better with a satisfying amount of weight reduction. Also, it is easily available.

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