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Static, Dynamic and Life Evaluation of Submersible Pumps

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Abstract - *A pump is a device that mechanically transfers fluids (and gases). It's device that converts mechanical energy into water-powered energy. According to this method they employ to convey the liquid, pumps can be categorized into three distinct groups: direct lift, uprooting, and gravity pumps. The rotating component of a radiating pump is called an impeller. It is made up of a series of reverse-bent vanes. The present works goal is to design and perform static, modal analysis and life evaluation of submersible pump impeller utilizing a variety of materials mostly conventional ones such as CFRP and Al 2014 alloy. The Geometric CAD model of an impeller is done using CATIA and for analysis (FEA) ANSYS WORKBENCH is used. This work is projected to reduce the cost and to increase the weight to strength ratio.*

***Key Words*: Static analysis, Pump Impeller, FEA, Submersible Pump.**

1. INTRODUCTION

A pump is a device that mechanically transfers fluids (gases or fluids) or occasionally slurries. It's device that converts mechanical energy into water-powered energy. According to this method they employ to convey the liquid, pumps can be categorized into three distinct groups: direct lift, uprooting, and gravity pumps. Pumps operate using a variety of power sources including as motors, manual labor, wind control or electricity. Other words for pump include "water driven energy into mechanical energy" and "mechanical energy into pressure driven energy". The primary uses of submersible pumps are in agriculture, wind control, business ventures, water storage, and other applications.

The rotating component of a radiating pump is called an impeller. It is made up of a series of reverse-bent vanes. On a pole that is connected to the pole of an electric engine, the impeller is mounted. An impeller is a rotor that is placed inside a cylinder or channel and used to increase (or decrease, in the event that turbines are present) the weight and stream of a liquid.

The majority of centrifugal pump impellers are made of mild steel, which has a higher density. The main cause of the pump's weight is this. Moreover, it has low fatigue strength and a high rate of corrosion.

To reduce weight, enhance corrosion resistance and increase fatigue strength in comparison to other alloys and composite materials, alloy material (such as stainless steel, Inconel, aluminium alloys) can be used in place of mild steel. In comparison to composite materials and different alloys, the same material produces greater deformations since it has less stiffness.

1.1 Literature Review

A Syam Prasad, BVVV Lakshmipathi Rao et al [1] here in this work they have discussed various engineering application of alloys. This study examines the static and dynamic performance evaluation of a centrifugal pump impeller built of three distinct alloy materials (Warpaloy, Inconel alloy 803, and Inconel alloy 740). Structural analysis has been performed to investigate the strains, stresses, and displacements of the impeller, and a modal analysis has been used to investigate the frequency and deflection of the impeller. By comparing the outcomes achieved for three distinct alloys, an attempt is also made to recommend the optimal alloy for an impeller of a centrifugal pump.

Karthik Matta, Kode Srividya et al [2] here in this paper they have discussed the impeller, a rotating part of a centrifugal pump often made of iron, steel, bronze, brass, aluminum, or plastic, accelerates the fluid being pushed away from the center of rotation in order to transmit energy from the motor powering the pump to the fluid being pumped. It is suggested that a blower be designed utilizing composite material, and that its strength and deformation be examined using FEM software. Using packaged FEA (ANSYS), compare the performance of metal blower and impeller with composite materials. The first five natural frequencies are discovered using a modal analysis on a centrifugal blower impeller made of aluminum and composite.

G. Kalyan, K.L.N. Murty et al [3] here in their study they have discussed that it is essential for the cost-effective design of pumps to foresee their performance before constructing them, which necessitates knowledge of the flow behavior in various pump components. Aluminum and steel are the materials used in impeller. Both structural analysis and CFD analysis are carried out. By observing the outcomes of the analysis that was done, the impeller design is optimized. Results for stress, frequency, velocity, and pressure flow rates are taken into account. Analysis is performed through Ansys.

Pramod J. Bachche1, R.M. Tayade et al [4] here in this paper they have discussed that one of the oldest water-pumping devices in use is the centrifugal pump. Consider the Shaft of a Radial Pump for both static and dynamic analysis in this study. Two stages make up the entire project. The first stage is a static examination; this stage involves disassembling the pump shaft to check for tensions and redirection, and utilizing a graphical inclusion technique to confirm the same outcomes. Additionally, the results of the static inquiry are used at this point to calculate the dynamic powers entering the pump shaft for the dynamic examination. The least stream condition is created with the most redirection and stress. Maximum concerns for dynamic are obtained at 11% not exactly allowable diversion and 18% not exactly allowable elasticity, respectively, for the most severe unique avoidance.

S. Rajendran, Dr. K Purushothaman et al [5], in this paper discussed using the ANSYS software, a three-dimensional, completely turbulent model of the compressible flow past an impeller with a complicated shape, similar to those seen in centrifugal pumps, was created. In their work, the flow of a centrifugal pump impeller is simulated. ANSYS-CFX is used to analyze the design of the impeller for a centrifugal pump. ANSYS-CFX can accurately estimate the complicated internal flows in the centrifugal pump impellers. The standard incompressible Navier-Stokes equations in three dimensions are numerically solved on an unstructured grid using an ANSYS-CFX. This study discusses the flow pattern, blade loading, pressure graphs, and pressure distribution throughout the blade passage.

Sampath Kumar, Dsvsra Vara prasad et al [6] in their study discussed centrifugal blowers is used in engines that have high noise levels and in maritime applications. This paper examines outward blowers using composite materials using static and model analysis. The current study investigates if using E-Glass instead of metal will improve vibration management. E-Glass, which is renowned for its unmatched dampening qualities, is also encouraging in terms of vibration reduction when compared to metals. The E-Glass/Epoxy blower concerns discovered during the static inspection are within the acceptable pressure range. Because of the higher firmness, the typical recurrence of E glass blowers is decreasing from 16.6% to 27.7%.

Gundale V.A., Joshi G.R. [7] in this paper they discussed the complete picture of the radial type vane profile design method. . In this work, the vane profile was constructed without changing the overall dimensions of an existing impeller. The 3D model was made using commercial 3D CAD software. This strategy will motivate pump designers to improve the functionality of both current and future versions.

Shyam Karanth, V. K. Havanur [8] in their work discussed how to improve the model G554T pump's efficiency and hence its overall efficiency. Pump efficiency and motor efficiency together make up the overall efficiency. Analyzing the current model G554T and figuring out its current overall efficiency comes first. The second phase entails redesigning the pump such that more power can be produced for the same amount of power input. SOLIDWORKS has a model of the new pump design. In order to increase overall efficiency, the modeled pump is examined using ANSYS, and then the newly developed pump is assessed and approved.

Farah Elida Selamat,Wan Hariz Iskandar Wan Izhan [9], This paper focuses on the idea of centrifugal pump design & research to enhance pump performance within the pump parameters. ANSYS CFX was used for design and simulation, with the Navier-Stokes equation. For this project, the shear stress transport (SST) turbulence model was employed. As the impeller's rotational speed increases, the pressure inside the impeller rises, as can be seen from the simulation results. From the impeller inlet to the impeller outlet, the pressure rises gradually. Additionally, it is evident that as rotational speed rises, impeller efficiency rises. When a result, as efficiency rises, so does the impeller's performance. The performance of the impellers was compared based on the inlet and outlet power, impeller performance, pressure distribution, and static head pressure produced.

S.Mayakannan, V. Jeevabharathi et al [10] in this paper they discussed that in order to boost the power and efficiency of a centrifugal caustic slurry pump, the impeller should be designed. The impact of temperature, pressure, and induced stresses on the impeller has been attempted to understand. Long-term stability and extended service life are guaranteed by defining the true design characteristic. The heat flow and direction of the impeller's heat flux have been investigated by a thermal study. By contrasting the outcomes for two distinct materials .Inconel alloy 783 and Inconel alloy 740 for centrifugal is to be manufactured and an attempt is also made to suggest the optimum material for an impeller. The ideal material for a turbocharger impeller is suggested based on results.

1.2 Objectives

This works main objective is to perform structural analysis under static and dynamic load circumstances and pump life evaluation.

- Geometric modelling is developed to validate the stress and deformation using analytical equations.
- Static structural evaluation of the submersible pump impeller.
- Modal analysis of submersible pump impeller.
- Modal analysis of submersible pump impeller.
- Life evaluation of impeller (Fatigue analysis).

2. Methodology

The impeller is made in accordance with the requirements established by SiTarc, a renowned educational organization that provides information on pumps. Prior to starting the design process, the performance data for the pump's motor is gathered. The design factors presented are based on a theoretical framework and extensive data collection over many years involving thousands of performance testing.

The blade needs to be built to handle 2100GPM of discharge and a head that is 450 feet long and rotating at 3600RPM. Some of the necessary data are presumptive. The impeller blade is created as shown below.

Table-1: Dimensions

Sl no	Parameters	Dimensions
1	Eye diameter(D_1)	137.15
2	Outlet Diameter(D_2)	219.67
3	Shaft diameter(D_s)	80mm
4	Inlet angle(β_1)	23^0
5	Outlet angle (β_2)	20^0
6	Impeller Width (b_2)	30mm
7	Thickness	4mm

2.2 Modeling of Submersible pump Impeller using CATIA

Fig-1: Geometric model of Submersible Pump Impeller

Meshing of the model

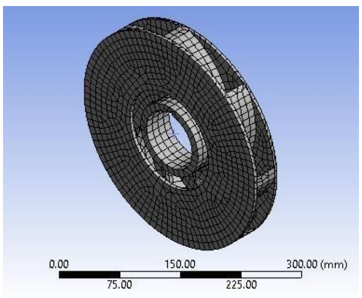

Fig-2: Meshing of submersible pump impeller

The above figure shows meshing on impeller of submersible pump. Meshing used is hexagonal mesh metric, statistic nodes is 57644 and elements 18015. Using Analysis software ANSYS WORK BENCH.

Statistics	
Nodes	57644
Elements	18015
Mesh Metric	None

Table-2 Number of elements and nodes

Boundary Condition

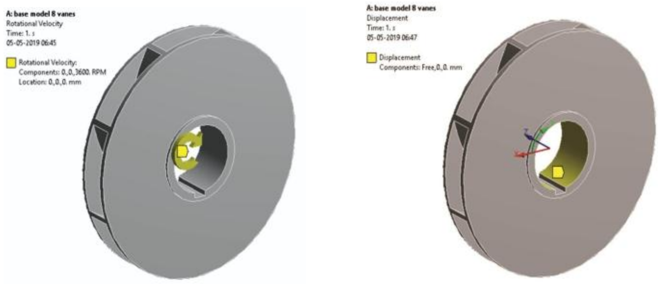

Fig-3: Impeller displacement in x axis and y axis and constrain in z direction.

Apply load condition is Rotational velocity and the displacement. The water pressure should emerge in pump, to create pressure impeller must be in ratio certain RPM as per analytical calculation, and rotational velocity is 3600RPM.

3. Static Analysis of Submersible Pump Impeller

3.1 Static Analysis of Structural Steel

- **Maximum Equivalent (von-mises) Stress**

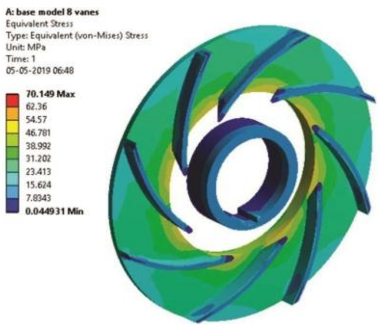

Fig-4: Maximum Equivalent Stress of SS Pump

- **Maximum Principal Stress**

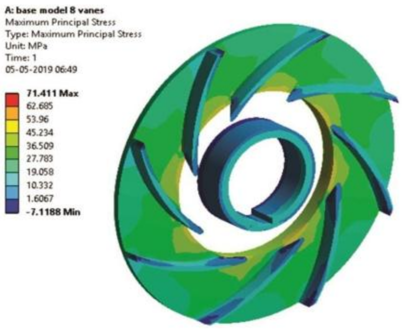

Fig-5: Maximum Principal Stress of SS impeller

- **Minimum Principal Stress**

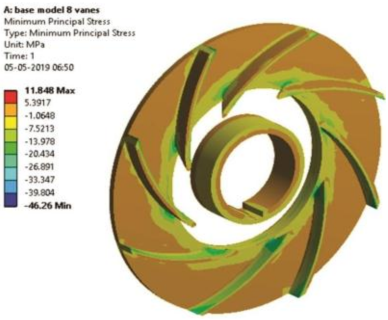

Fig-6: Minimum Principal Stress of SS impeller

- **Total Deformation**

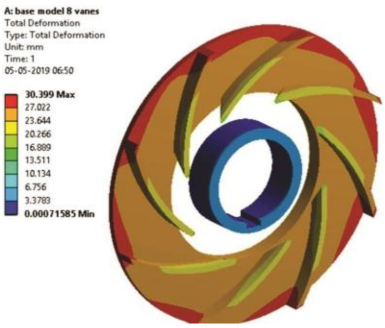

Fig-7: Maximum Total deformation of SS Impeller

3.2 Static Analysis of Aluminum 2014 alloy

- **Maximum Equivalent (von-mises) Stress**

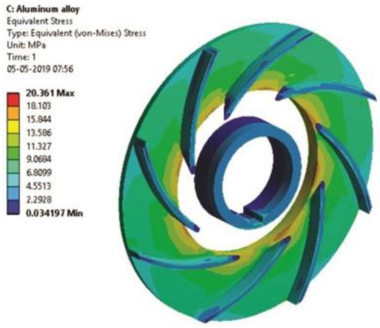

Fig-8: Maximium Equivalent stress for Al 2014 Impeller

- **Maximum Principal Stress**

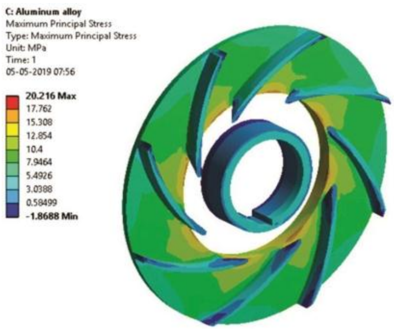

Fig-9: Maximum Principal Stress of Al 2014 Impeller

- **Minimum Principal Stress**

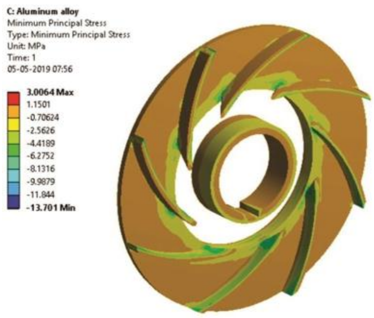

Fig-10: Minimum Principal Stress of Al 2014 Impeller

- **Total Deformation**

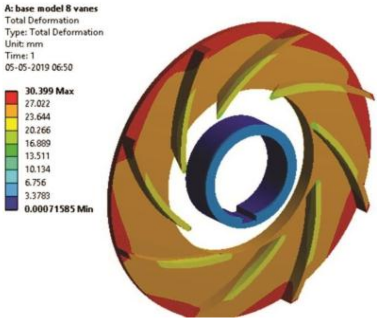

Fig-11: Maximum Total deformation of Al 2014 Impeller

3.3 Static Analysis of CFRP Impeller

- **Maximum Equivalent (von-mises) Stress**

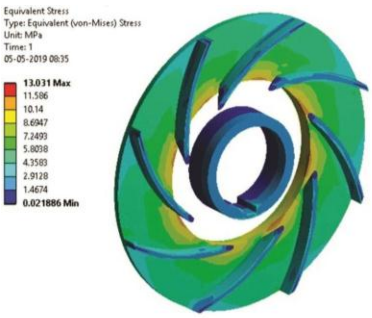

Fig-12: Maximum Equivalent Stress of CFRP Impeller

- **Maximum Principal Stress**

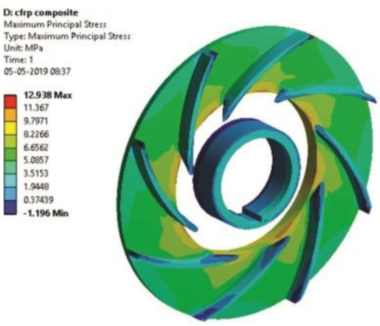

Fig-13: Maximum Principal Stress of CFRP impeller

- **Minimum Principal Stress**

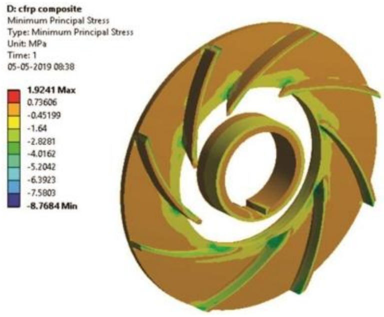

Fig-14: Minimum Principal Stress of CFRP impeller

- **Total Deformation**

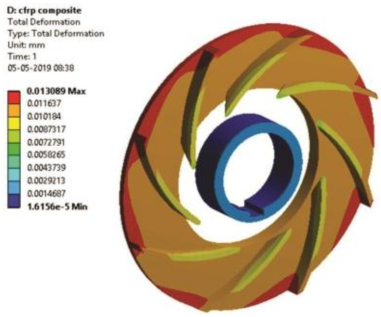

Fig-15: Maximum Total deformation of CFRP Impeller

3.4 Results and Discussion

Sl no	Material	Max Equivalent stress (MPa)	Max principal stress (MPa)	Min Principal stress (MPa)
1	SS	70.114	71.411	11.848
2	Al 2014	20.361	20.216	3.0064
3	CFRP	13.031	12.938	1.9241

Table-3: Evaluation of Max & Min Principal Stress and equivalent stress.

Sl no	Material	Total Deformation(mm)	Weight (kg)
1	SS	30.399	8.1225
2	Al 2014	0.020452	5.5802
3	CFRP	1.9241	3.9802

Table-4: Evaluation of deformation and weight reduction.

If we look at the results above and compare the corresponding deformation of the SS material to the corresponding deformation of the Al 2014 alloy and the CFRP composite material, the CFRP composite material has the least amount of deformation, so there are fewer chances that the pump impeller will fail than with the SS and aluminum materials. As a result, the CFRP composite material increases the pump's strength. Because the CFRP composite material pump impeller (3.9 Kg) weighs less than the SS (5.58 Kg) material, the weight of the pump impeller was reduced. Hence, the pump impeller's weight is significantly decreased.

3.5 Modal Analysis of CFRP Pump Impeller

It is common for specifications for rotating equipment with significant dynamic loads to demand that no structural modes exist within a given frequency range. It is frequently quite difficult to do dynamic analysis of complex floor systems using computer finite element methods. During the design of the pump in a different process, rotating equipment was a worry. These pumps needed a lot of free space underneath them because they were going to be subject to strong dynamic forces. For each of the impellers, a range of support and restraint systems were modeled using finite element analysis.

Tabular Data

	Mode	Frequency [Hz]
1	1.	686.66
2	2.	691.73
3	3.	1189.9
4	4.	1535.3
5	5.	1538.7
6	6.	2254.7

Table-5 Frequency

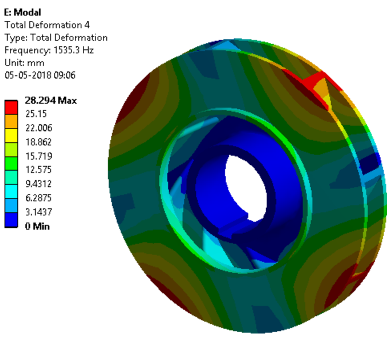

Fig-19: Fourth mode of impeller

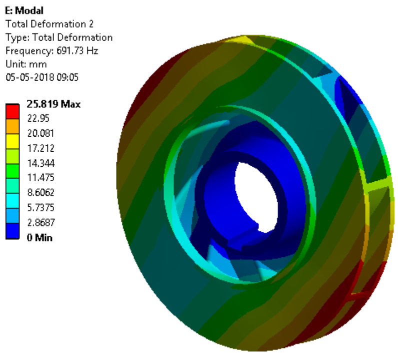

Fig-17: Second mode of impeller

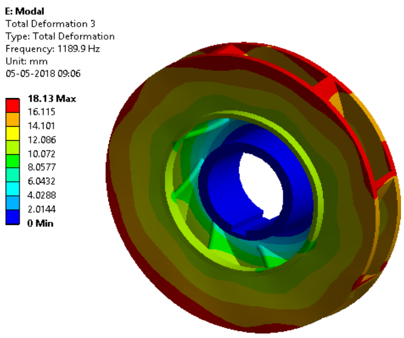

Fig-18: Third mode of impeller

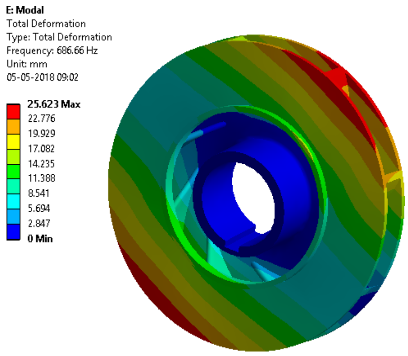

Fig-16: First mode of impeller

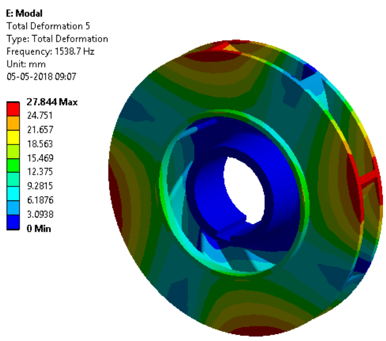

Fig-20: Fifth mode of impeller

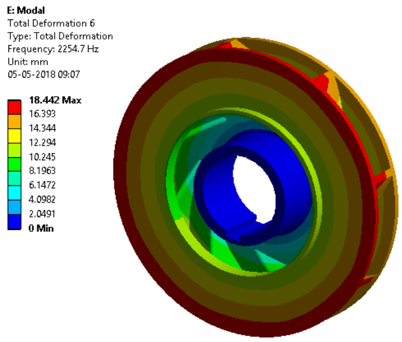

Fig-21: Sixth mode of impeller

Mode Number	Natural Frequency in Hz	Total Deformation (mm)
1	686.66	25.623
2	691.73	25.819
3	1189.9	18.13
4	1535.3	28.294
5	1539.7	27.844
6	2254.7	18.442

Table-6 Natural Frequency corresponding to its deformation

3.6 Life Evaluation Results

The fatigue life of a specimen is the total number of cycles of loading (stress or strain) it can withstand before failing. Low cycle fatigue is defined as the region between 10^4 and 10^5 load cycles. High cycle fatigue is the highest stress that a material can endure under repeated cyclic loading without immediately failing.

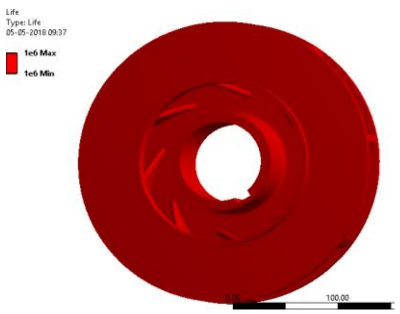

Fig-22: Life evaluation of impeller is 1000000 cycles

The figure-21 indicates the life evaluation of the pump impeller done using ANSYS which is 10^6 cycles.
Mean stress can be calculated from

$$\sigma_{mean} = \sigma_{von}/2$$

Where

σ_{von} = Equivalent Stress

$\sigma_a = (\sigma_1 + \sigma_2)/2$

σ_{mean} = 49.76 Mpa

$\sigma_a = (\sigma_1 - \sigma_2)/2$

= 29.96 Mpa

Where

σ_1 = Maximum principal Stress

σ_2 = Minimum Principal Stress

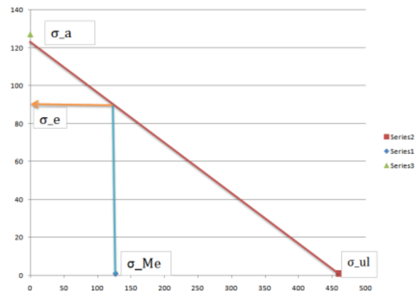

Fig-23: Goodman diagram

$$N_f = \frac{\left[\sigma_{ult} - \sigma_{ult}\left(\frac{1}{fos} - \frac{\sigma_a}{\sigma_e}\right)\right]^{\frac{1}{0.08}}}{\sigma_a}$$

Where,

N_f=Fatigue life

σ_{utl}=Ultimate stress

fos=Factor of Safety

σ_e=Endurance limit

b = Fatigue strength exponent

σ_a=Alternating stress

$N_f = 1.554 \times 10^6$

The resulting fatigue life obtained by analytical method is greater than 10^5 Cycles hence it is high cycle fatigue.

3. CONCLUSIONS

According to static and modal analysis of the pump impeller, the maximum deflection that can be caused in a metallic pump impeller made of SS material is 3.00mm, which is within working limits. With consideration of working limit, the maximum induced stress for the SS material is 71.02 Mpa, which is less than the permitted stress (340Mpa). Therefore, based on strength the design is secure. With consideration of working limit, the maximum induced stress for the SS material is 71.02 Mpa, which is less than the permitted stress (340Mpa). Therefore, based on strength the design is secure. If we look at the results above and compare the corresponding deformation of the SS material to the corresponding deformation of the Al 2014 alloy and the CFRP composite material, the CFRP composite material has the least amount of deformation, so there are fewer chances that the pump impeller will fail than with the SS and aluminum materials. As a result, the CFRP composite material increases the pump's strength. Because the CFRP composite material pump impeller (3.9 Kg) weighs less than the SS (5.58 Kg) material, the weight of the pump impeller was reduced. Hence, the pump impeller's weight is significantly decreased.

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