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Modelling and Analysis of Centrifugal Impeller Using Composite Materials

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ABSTRACT

Centrifugal pump is a machine that imparts energy to a fluid. This energy can cause a liquid to flow or rise to ahigherlevel.Centrifugal pump is an extremely simple machine which consists of two basic parts: The rotary element or impeller and the stationary element or casing. A centrifugal pump is a rotational dynamic pump that uses a rotating impeller to increase the pressure of a fluid. An impeller is a rotating component of a centrifugal pump, usually made of iron, steel, bronze, brass, Aluminumorplastic,whichtransfersenergyfromthemotothatdrivesthepumptothefluidbeingpumpedbyacceleratingthe fluidoutwardsfromthecentreofrotation.Asignificantimprovementisrequiredforimpellerdesigntoresistcorrosion,erosion & lessweight.The aim of the project is to increase the life of the centrifugal impeller using composite materials. SOLIDWORKS software is usedfordesigningthecentrifugalimpellerANSYSsoftwareinusedforperformingthestaticandmodalanalysisusingcomposite materials (Carbon Fiber Reinforced Polymer, Glass Epoxy, Kevlar Epoxy). Finally, the effectiveness of suitable material for impeller is evaluated based on the stresses, strains, Total deformations in static structural analysis and total deformations at different frequencies in modalanalysis.

KEYWORDS: Centrifugal impeller, composite material, carbon Fiber Reinforced polymer, Glass Epoxy, Kevlar Epoxy.

1. INTRODUCTION

Centrifugal pump is a hydraulic machine which converts mechanical energy into hydraulic energy and are used extensively in a wide range of residential and industrial applications. Centrifugal pumps are used to transport fluids by converting rotational kinetic energy into hydrodynamic energy of the fluid flow. This rotational energy comes from an electric motor or engine. The fluid entersthepumpimpelleralongorneartotherotatingaxis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from whereitexits.Theyhaveapplicationsstartingfrom steam power plants, irrigation, sewages, water supply plants and ranging to hydraulic power services, mines and oil refineries. The pumps are divided into two categories basically and they are positive displacement pump and centrifugal pump. In centrifugal pump the mechanical energy is converted into pressure energy by means of centrifugalforceactingonthefluid.Theimpellerist hekey component of a centrifugal pump. It consists of a series of curved vanes. These are normally sandwiched between two discusssthe impeller increases kinetic energy ofliquidwhichiscomingfromsumpandflowofliqu idis inradialoutwarddirection.Fluidenterstheimpelle ratits axis (eye) and exits along the circumference between the vanes. The impeller, on the opposite side to the eye, is connected through a drive shaft to a motor and rotated at high speed. The rotational motion of the impeller accelerates the fluid out through the impeller vanes into the pump casing. The operation of pumps is driven by a mechanism which is supplied by many energy sources such as manual operation electricity, engines and wind power. This energy is used to perform the mechanical work to move fluids inside the pump by rotating the impeller inside the pump. Energy is added continuously in pumps in order to increase the fluid velocity within the machine.

2. REALATED WORK

Generally, centrifugal pump impellers are made of cast iron, cast steel, stainless steel, alloy steel, carbon structural steel, and non-metallic materials and the common material used for water pump impeller is cast iron. This results in the high weight of pump and also high corrosion and less fatigue strength. In the given context for ever-increasing need anddemand for higher and better pumping efficiencies, pump designers and manufacturers are seeking out for new and better ways of increasing the performance characteristics of pumps. Many factors affect centrifugal pump performance which includes cavitation, flow rate, static pressure head, dynamic pressure head, specific speed, poweretc.

Also, one of the main and crucial factors that affects the performance of a centrifugal pump is the type of impeller material used. Majority of the models in existence have been made of metallic materials and a few with non- metallic materials and they have their own share of backdrops contributing in affecting the performance. So, with the advancements and choices available, composite materials are a suitable alternative to the existing materials being used [4]. They have higher properties than regular materials and yield optimum results and help overcome the problems caused in existing impellers.

3. PROPOSED WORK OF THE IMPELLER

The dimensions [5] for modelling the pump impeller are chosen as the following:

Table 1: Dimensions

Outer Diameter	238 mm
Inner Diameter	112 mm
Shaft Diameter	18 mm
Rotational velocity	2880 RPM
Fin width	40 mm
Number of blades	06

In this project, we are proposing a better alternative material to make centrifugal pump impellers to improve the characteristics and efficiency of the system. Here, the impelleristakenintoconsiderationforsimulationandt he simulation involves static structural and modal analysis. ThecadmodelisdesignedinSOLIDWORKS2021SP2.0 . Theimpellerusedhas6bladesandaspeedof2880rpm. Upon designing the impeller, the cad model is then imported to ANSYS workbench for simulation,where properties of the materials are set which include young's modulus, density, and Poisson's ratio of the material. In the pre-processing process, the simulation requires boundary conditions such as fixed supports and load applied on the impeller. The model is meshed with tetrahedral elements. In solution phase the fixed supports are given followed by the application of forces. The rotational velocity is given as 2880 rpm. In post- processing, the analysis model is selected and they are equivalent stress, equivalent strain and total deformation. In modal analysis we can observe the natural frequencies and totaldeformationbecause ofvibrations producedatdifferentnodes. Results of this simulation are compared among themselves to choose a suitablematerial.

4. RESULTS AND MODELLING

The design of the impeller is slightly altered by curving the blades so that higher output is obtained. The front view, top view and isometric view are obtained as follows:

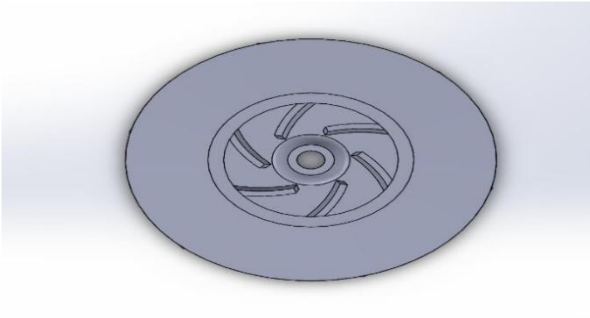

Figure 1.Top view of the impeller

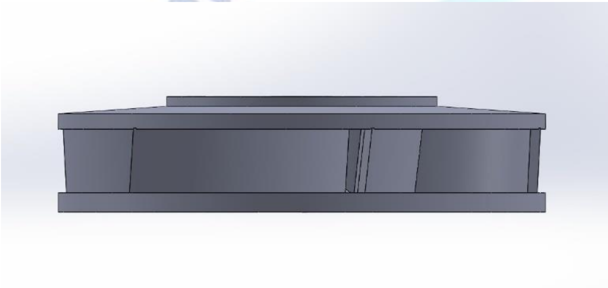

Figure 2: Side view of theimpeller

The materials chosen for the impeller to perform analysis are S glass epoxy, Kevlar epoxy, carbon fiber reinforced polymer (CFRP) and their properties are listed below:

S.NO	PROPERTIES	VALUES
1	Density	2.49e-06 kg/mm³
	Young's modulus	80000 MPa
3	Poisson's ratio	0.27
4	Bulk modulus	57971 MPa
5	Shear modulus	31496 MPa
6	Tensile ultimate strength	4750 MPa
7	Tensile yield strength	3680 MPa

Table 2: Properties of S-glass/Epoxy

S.NO	PROPERTIES	VALUES
1	Density	1.235e-06 kg/mm³
2	Young's modulus	93000 MPa
3	Poisson's ratio	0.28
4	Bulk modulus	70455 MPa
5	Shear modulus	36328 MPa
6	Tensile ultimate strength	1693 MPa
7	Tensile yield strength	1306

TABLE 3: PROPERTIES OF KEVLAR EPOXY

S.NO	PROPERTIES	VALUES
1	Density	1.61e-06 kg/mm³
2	Young's modulus	1.269e+05 MPa
3	Poisson's ratio	0.28
4	Bulk modulus	96136 MPa
5	Shear modulus	49570 MPa
6	Tensile ultimate strength	1170 MPa
7	Tensile yield strength	896 MPa

TABLE 4: PROPERTIES OF CFRP

4.1 ANALYSIS:

The required boundary conditions are applied and the static structural and modal analysis is performed on all the 3 composite materials and results are obtained as follows:

4.2 BOUNDARY CONDITIONS FOR IMPELLER

A cylindrical support is provided to the shaft to impart rotation to the impeller and the fixed support is provided at the point where shaft and impeller is connected so that the impeller moves in concentric manner and remains fixed in its position. A pressure of 2.5 Mpa is applied along the vanes of the impeller and a rotational velocity of 2880 RPM is supplied in Y-axis in order to perform analysis and obtain the total deformation, stress and strain acting on the impeller. Tetrahedral meshing is done to the impeller.

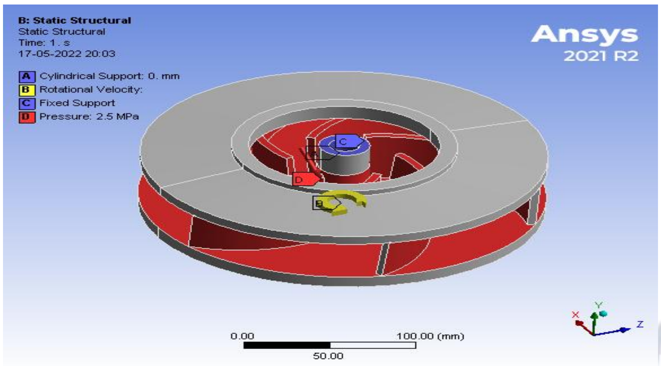

Figure 3: Boundary Conditions

NODES	44291
ELEMENTS	24187

TABLE 5: STATISTICS OF MESHING

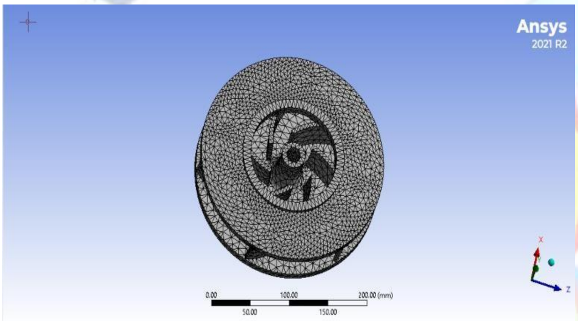

Figure 4:Meshing

STATIC STRUCTURAL ANALYSIS:

4.3 Ansys results for Sglass/Epoxy

Upon giving the boundary conditions to the impeller, static structural analysis is performed. S glass/Epoxy is the material chosen and the the effect of total deformation, equivalent stress and equivalent stress on different areas of the impeller with respect to particular values are observed and found out to be as given below.

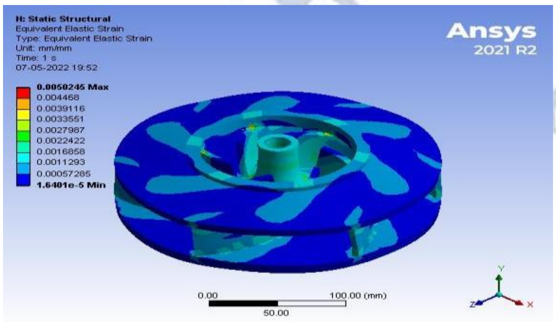

Figure 5: Equivalent Elastic Strain

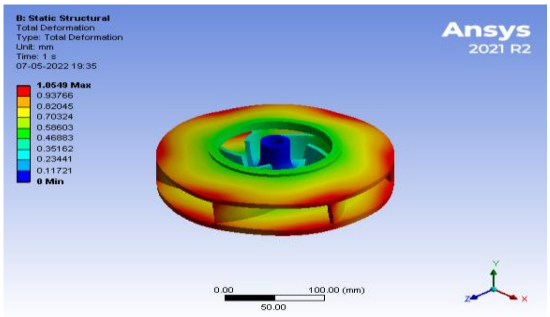

Figure 6: Total deformation

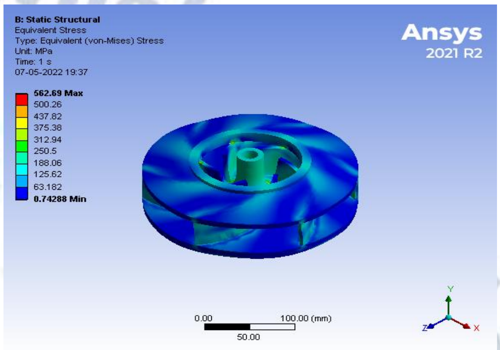

Figure 7: Equivalent Stress

4.4 ANSYS RESULTS FOR KEVLAREPOXY

Similarly, Kevlar epoxy is chosen as the material of choice and analysis is performed on ANSYS and the same procedure is applied. The result with respect to the material is obtained and are given as shown in the figures.

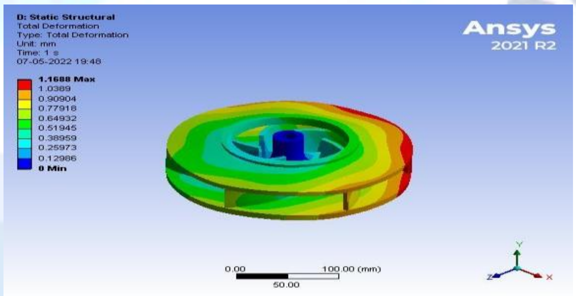

Figure 8: Total deformation

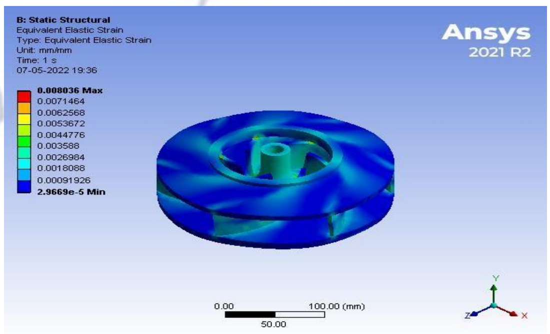

Figure 9: Equivalent Elastic Strain

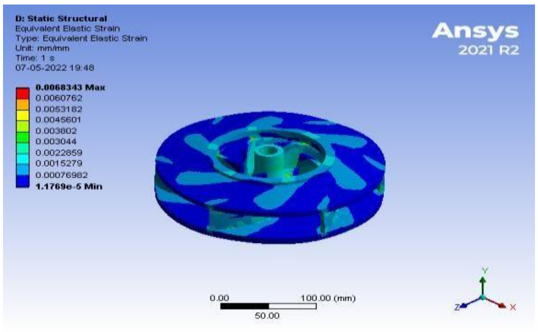

Figure10: EquivalentStress

4.5 Ansys results for CFRP

Finally, Carbon fibre reinforced polymer (CFRP) is selected as the third material and the process of analysis is perfomedas in the remaining two materials. The obtained results are given in the below figures.

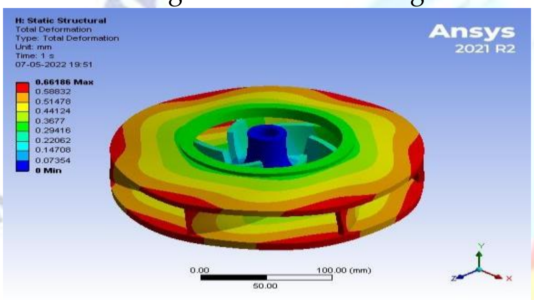

Figure 11: Total deformation

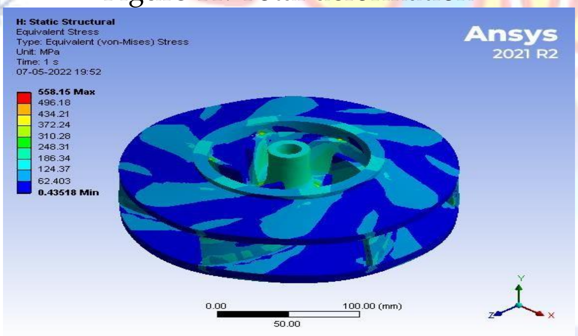

Figure 12: Equivalent Elastic Strain

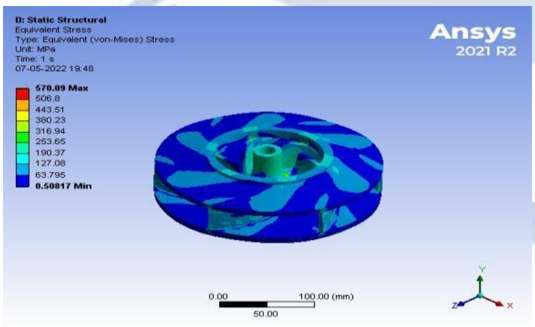

Figure 13: Equivalent Elastic stress

4.6 MODAL ANALYSIS:

Here, the total deformation of the impeller for all the composite materials at different frequencies is analyzed and tabulated as below.

After performing the analysis of centrifugal pump impeller on ANSYS WORKBENCH, i.e., STATIC STRUCTURAL ANALYSIS which include total deformation,equivalent(Von-Misses)stresses,equi valent elasticstrainandMODALANALYSISwhichinclude total deformation at different frequencies. An analysis is performed on selected composite materials and the results are compared with other two materials to propose a suitable material for the impeller which helps overcome the problems raised by the existing impellers. Upon performing the analysis and comparing the results, it can be clearly seen that the total deformation, equivalent elastic strain and equivalent stress of the impeller made by Carbon fibre reinforced polymer are very low compared to other materials under same conditions.Also, in S-glass/epoxy and Kevlar epoxy although the static structural analysis results are quite similar but in modal analysis Kevlar epoxy showed low deformation at higher frequenciesascomparedtoS-glass/epoxy.So,compa ring all the three materials, carbon fiber reinforced polymer is the best suitable material forimpeller.

Mode	Frequency (Hz)	Total Deformation
1	573.81	42.605 mm
2	574.31	42.601 mm
3	903.06	32.241 mm
4	1297	33.181 mm
5	2530.7	50.339 mm
6	2531	51.429 mm

Table 6: Modal analysis of S-glass/Epoxy

Mode	Frequency (Hz)	Total Deformation

1	879.45	60.912 mm
2	87.8	60.049 mm
3	1378.1	45.739 mm
4	1988.5	47.114mm
5	3868.3	73.858 mm
6	3869.1	69.076 mm

Table 7: Modal analysis of Kevlar Epoxy

Mode	Frequency (Hz)	Total Deformati-on
1	900	52.993 mm
2	900.8	2.965 mm
3	1409.9	40.042 mm
4	2035.3	41.254 mm
5	3958	62.707 mm
6	3958.4	64.23

Table 8: Modal analysis of CFRP

5. CONCLUSION

In this paper the impeller is analyzed for different materials and suggested an efficient materialas alternativeforexistingmaterialsi.e.,castironorcaststeel to make impeller. It is found that CFRP composite material has better and efficient properties under same conditions compared to Kevlar epoxy and S-glass epoxy composite material.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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