Comparative Static & Frequency Case Analysis of Water Pump Impeller – A Case Study for Brass, Aluminium, Titanium and Plastic Material

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ABSTRACT

This paper addresses the modelling and static case analysis of Carbon Steel and Alloy Steel water pump impeller to inspect the deformation, stress, strain, vibrations and displacements. Water pump impellers are mostly manufactured with stainless steel or mild steel in which its relative high density has led to an increase in corrossion resistance, weight and a low tensile strength. A Brass, Aluminium, Titanium or Plastic material can be deployed instead of carbon steel to enhance decomposition, durability and also to create a lightweight pump impeller. For each of the material (Brass, Aluminium, Titanium and Plastic), the part geometry of the water pump impeller and its padding into 3D is done seperately using CATIA V5R20. Using finite element method, the mesh visualization is also done seperately, afterwhich moments are then taken to compute and display the von-misses stress (global extrema and global minima), displacements (translational displacements), and deformation. The primary goal of this paper is to investigate for the most favourable material to choose during material selection of the manufacturing process. A structural analysis has been carried out to investigate for the best stress and strain value between the materials as well as its displacments. This paper also explain the modal analysis in demonstrating how quick either of the materials get deformed with time with respect to its natural frequencies.

Keywords: CATIA V5R20, water pump, Impeller, static analysis, generative structural analysis, von-mises stress

iSTEAMS Proceedings Reference Format
Akinwande F.A., Kadiri S.O. & Ojo, A.O.. (2019): Comparative Static & Frequency Case Analysis of Water Pump Impeller – A Case Study for Brass, Aluminium, Titanium and Plastic Material. Proceedings of the 17th iSTEAMS Multidisciplinary Research Nexus Conference, D.S. Adegbenro ICT Polytechnic, Itori-Ewekoro, Ogun State, Nigeria, 21st – 23rd July, 2019.P 115-124. www.isteams.net - DOI Affix - https://doi.org/ 10.22624/AIMS/iSTEAMS-2019/V17N2P15

1. INTRODUCTION

Water pumps are cmmmonly used on construction sites for dewatering or removing excess water accumulation. Water can build up due to heavy rains or from a high water table, and pumps allow youto move the water quickly to minimize downtime. Water pumps suitable for this application come in two main types and can be electric, gas-powered, hydraulic or manual. There are two basic types of water pumps; centrifugal and positive displacement. Both types are designed to move water from one place to another continously. A centrifugal water pump uses a rotating impeller to move water into the pump and pressuirze the discharge flow. Centrifugal water pumps come in several different types, including standard, trash, and submersible models. All liquids can be pumped using centrfugal water pumps, even those with low viscosity.

Positive displacement water pumps also called rotary pumps deliver a fixed amount of flow through the mechanical contraction and expansion of a flexible diaphragm. Positive displacement pumps are used in many industries hat manage high-viscosiy liquids and where sensitive solids may be present. The primary drawback of positive displacement pumps is that they require a very small clearance between the rotating pump and the outer edge of the unit. As a result the rotation must occur at very slow speeds. If the pump is operated at higher speeds, the liquids can erode and eventually reduce the effiency of the water pump.

1.1 Impeller

An impeller is a rotating component of a cenrifugal pump which transfers energy from te motor that drives the pump to the fluid being pumped by accelerating the fluid outwards from the center of rotation. The velocity achieved by the impeller transfers into pressure when the outward movement of the fluid is confined by the pump casing. An impeller is usually a short cylinder with an open inlet (called an eye) to accept incoming fluid, vanes to push the fluid radially, and a splined, keyed, or threaded bore to accept a drive shaft. The impeller made out of cast material in many cases maybe called a rotor. The rotor usually names both the spindle and the impeller when they are mounted by bolts.
There are two types of impellers depending on the flow of regime created:

- Axial flow impeller
- Radial flow impeller

Impellers can be further classified principally into three subtypes; Propeller, paddlea and turbines. In this paper, semi open impeller type of the centrifugal pump is taken into consideration for the design. The types of material used in manufacturing impeller goes a long way in determining its durability, strength and efficiency. A Syam Prasad, BVVV Lakshmipathi Rao, A Babji, and Dr P Kumar Babu have carried out a computational analysis on a centrifugal pump impeller in which Inconel alloy 740, Incoloy alloy 803 and Warpaloy were used as materials. They observed that the best suggested material for the design of impeller is inconel alloy 740. B.Sajjan, A. Santhosh, M.Jaya ram and K. Anusha have also carried out a computational anaysis on impeller type centrifugal pump and realize that the natural freqencies and strength of structural steel is higher compared to cast iron and polyethylene. They suggested from thier work that the best material for impeller design is structural steel.

2. RESEARCH GAP

Water pump impellers are mostly manufactured with stainless steel or mild steel in which its relative high density has led to an increase in corrossion resistance, weight and a low tensile strength. This stainless steel or mild steel can be replaced with other materials (e.g. brass, titanium, aluminium, bright plastic) to improve corrossion resistance, reduce the weight and increase the tensile strength. Brass, titanium, aluminium and bright plastic are the chosen materials to be used as a case study in this paper to determine the material with the minimum deformation, highest strength and natural frequencies.

The materials selected to be used have been chosen as a result of the following reasons

a) Aluminium: Is a non-ferrous metal, very lightweight, approximately one third as much as steel. It exihibits excellent atmospheric corrossion resistance.
b) Brass: It comes with good strength and has good bearing properties, low magnetic permeability, excellent high temperature ductility and reasonable cold ductility.
c) Titanium: It has an excellent strength-to-thickness ratio.
d) Bright plastic: It provide broad chemical resistance and are less costly and lighter in weight than metal.

3. METHODOLOGY

The stages involved in this research work are listed below

1) 3D Modelling of the impeller using CATIA V5 R20
2) Meshing visualization using CATIA V5 R20
3) Creating a distributed force load
4) Creating a static case solution
5) Viewing displacement, von-mises stress, and deformation results
6) Computing the frequency case solution and viewing of the frequency results.

3.1 3D Modelling of the impeller using CATIA V5 R20

The solid model of the water pump impeller is shown in shown below in figure 3.1

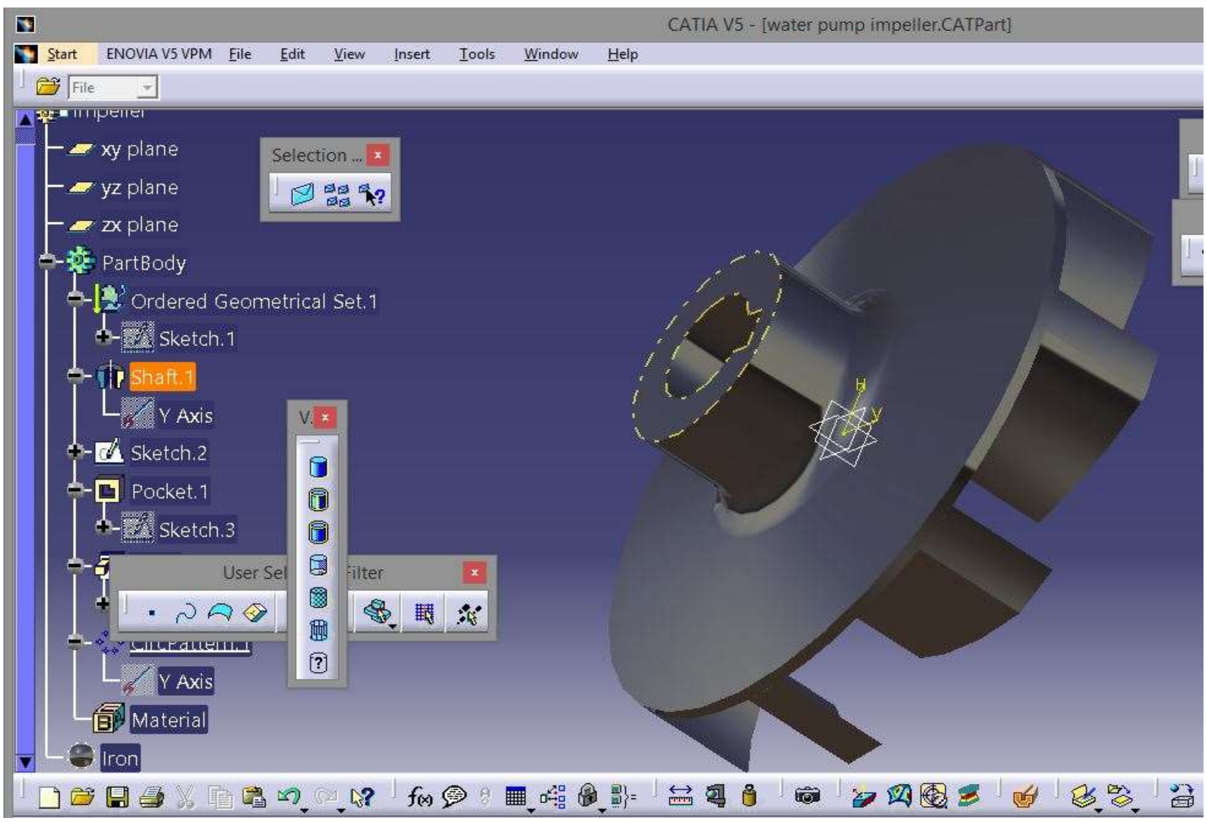


Figure 3.1: Solid model of the water pump impeller.

3.2 Meshing visualization using CATIA V5 R20

After the solid model of the water pump impeller, the meshing visualization is achieved by selecting Start > Analysis and Simulation > Generative Structural Analysis workbench. Once the New Analysis Case box appears, the Static Analysis is selected while we also click on the OK. The mesh is seen by right clicking on Nodes and Elements in the design tree and click Mesh Visualiation. The meshed model is shown in figure 3.2.

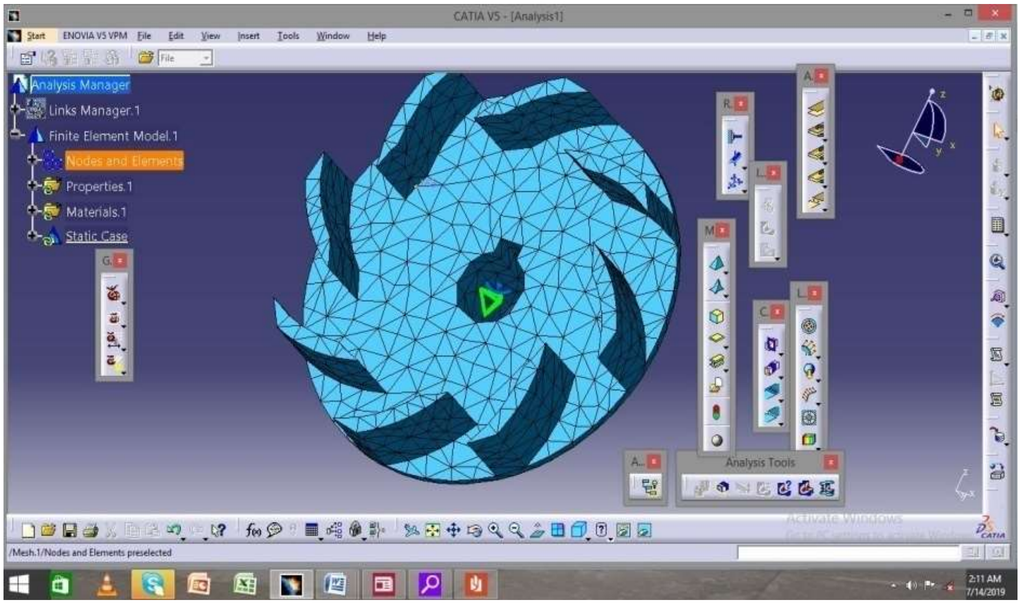


Figure 3.2 Meshed model of the impeller using CATIA V5 R20

Table 3.3.1 Material Properties

Material selected	**Young Modulus**	**Density**	**Poisson Ratio**	**Yield Strength**
Aluminium	7E+010N/m^2	2710Kg/m^3	0.346	9.5E+007N/m^2
Brass	1.31E+011N/m^2	8216Kg/m^3	0.35	3.5E+008N/m^2
Titanium	1.14E+011N/m^2	4460Kg/m^3	0.34	8.25E+008N/m^2
Bright Plastic	2.2E+009N/m^2	1200Kg/m^3	0.38	0N/m^2

4. RESULTS AND DISCUSSIONS

4.1 For 500N Aluminum Material

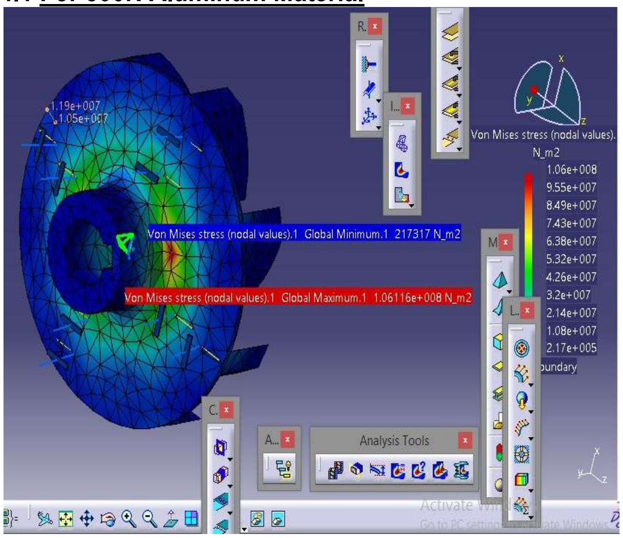


Figure 4.1.1: von-mises stress of water pump impeller

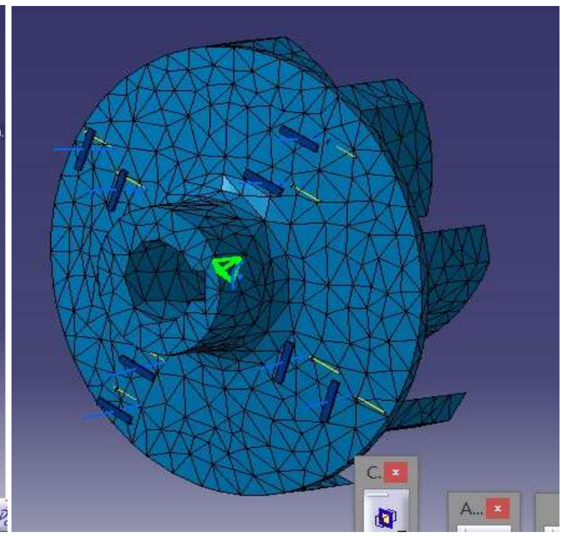


Figure 4.1.2 deformation of water pump impeller

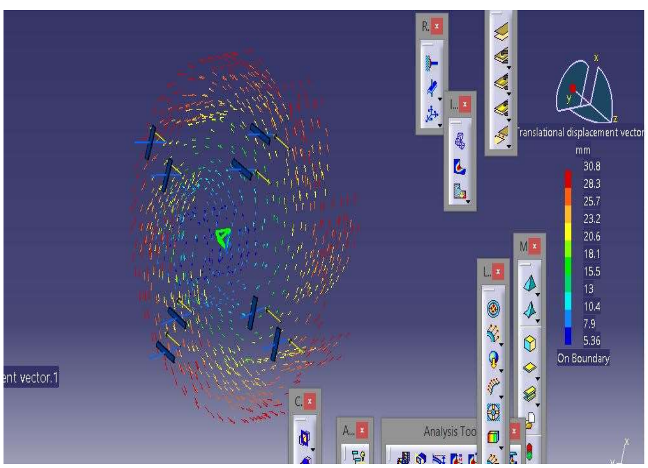
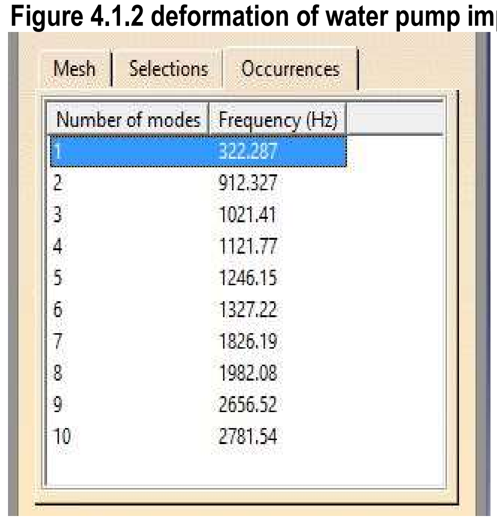


Figure 4.1.3 Translational displacement vector of impeller



Mesh | Selections | Occurrences

Number of modes	Frequency (Hz)
1	322.287
2	912.327
3	1021.41
4	1121.77
5	1246.15
6	1327.22
7	1826.19
8	1982.08
9	2656.52
10	2781.54

Fig 4.1.4 Impeller Freq at different modes

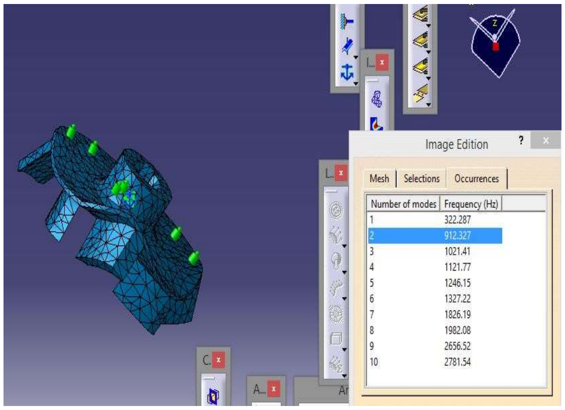


Figure 4.1.5 Shape of the 2nd mode

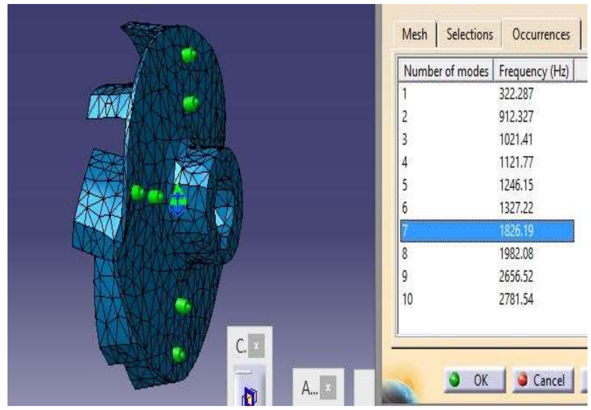


Figure. 4.1.6 Shape of the 7th mode

4.2 For 500N Brass Material

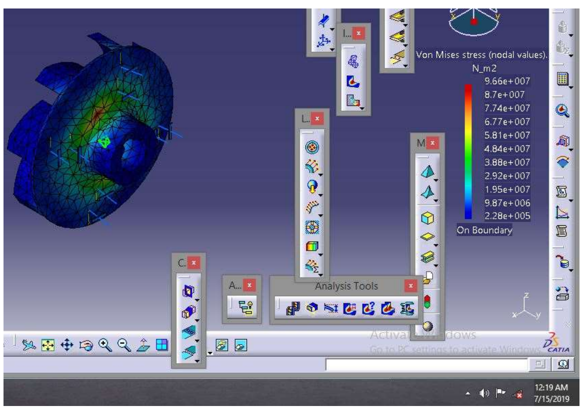


Figure 4.2.1 von-mises stress of water pump impeller

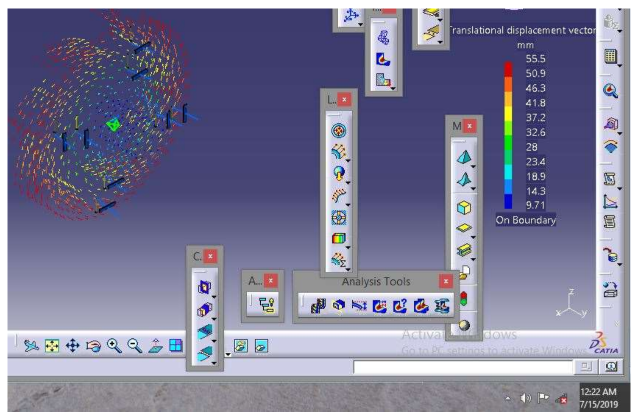


Figure 4.2.2 Translational displacement

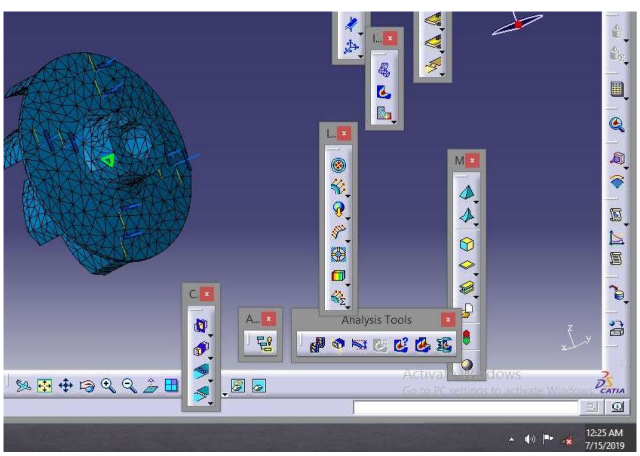


Fig 4.2.3 deformation of water pump impeller

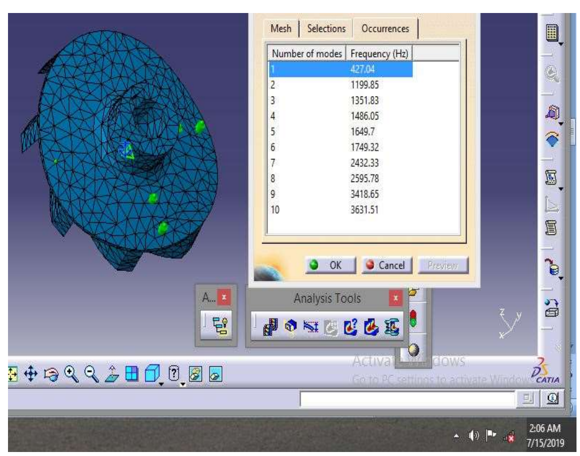


Fig 4.1.2 Freq of the impeller at different modes

4.3 For 500N Titanium Material

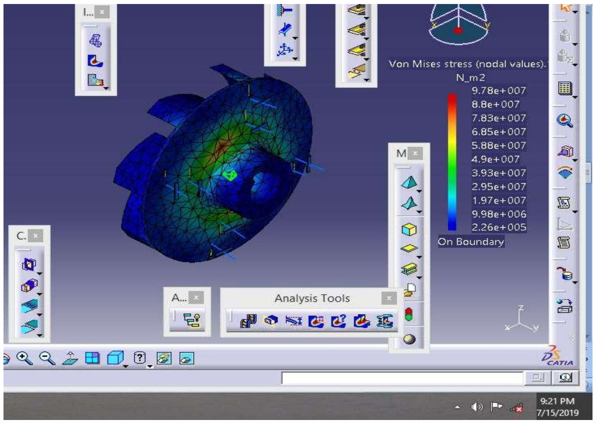


Figure 4.3.1 von-mises stress of the impeller

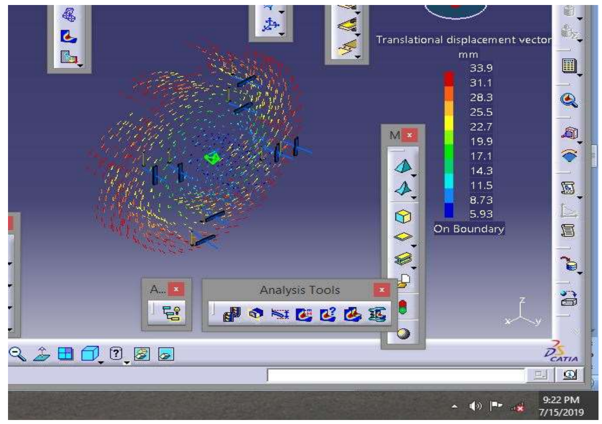


Figure 4.3.2 Translational displacement

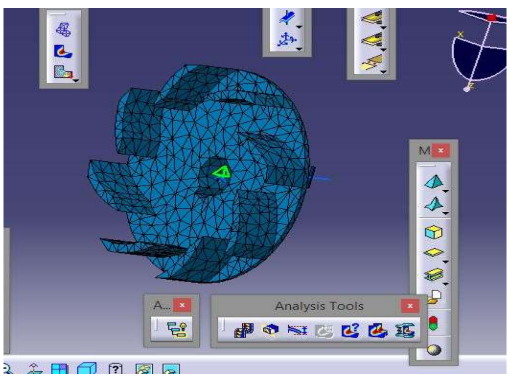
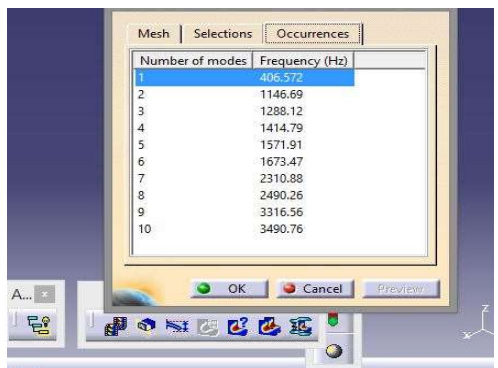


figure 4.3.3 Deformation of impeller



Number of modes	Frequency (Hz)
1	406.572
2	1146.69
3	1288.12
4	1414.79
5	1571.91
6	1673.47
7	2310.88
8	2490.26
9	3316.56
10	3490.76

Figure 4.3.4 Frequency at different modes

4.4 For 500N Bright Plastic Material

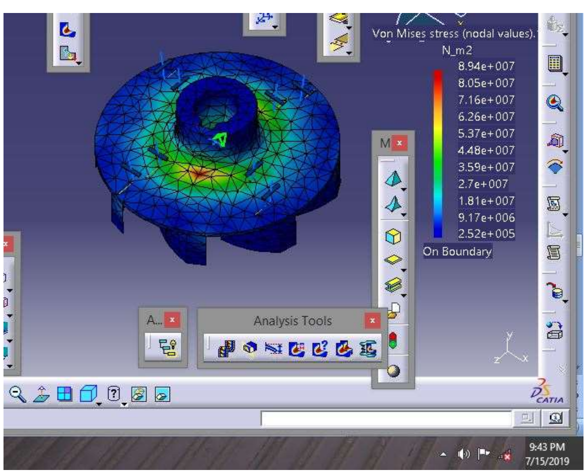


Figure 4.4.1 von-mises stress of the impeller

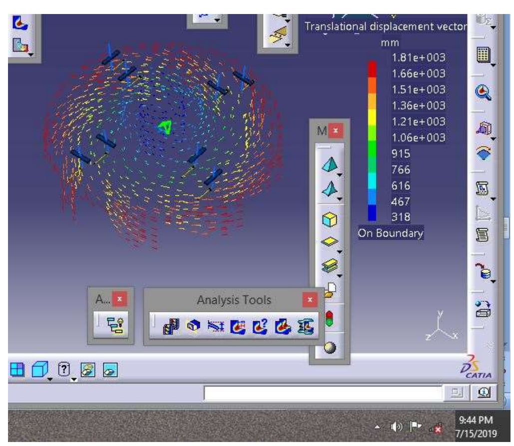


Figure 4.4.2 von-mises stress of the impeller

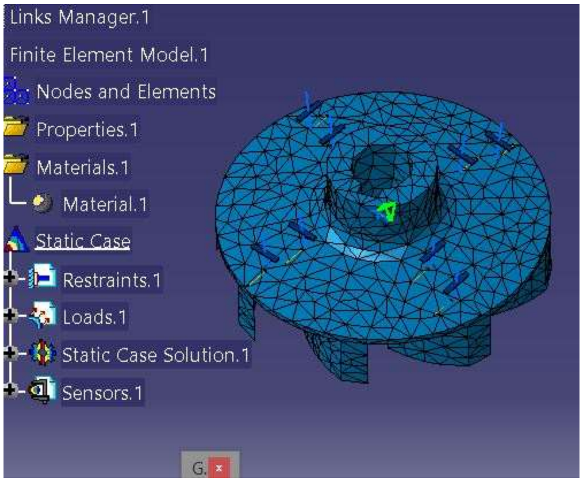


Figure 4.4.3 deformation of the impeller

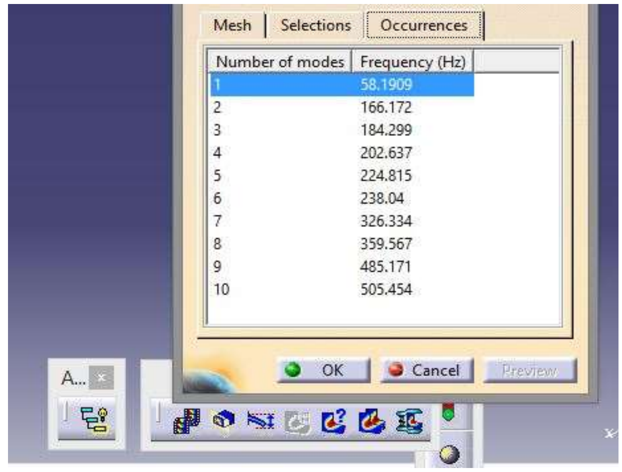


Figure 4.4.4 Frequency at different modes

Table 4.1 Static analysis of the materials

Properties	Aluminium	Brass	Titanium	Bright Plastic
Von mises stress (MPa)	106	96.6	97.8	89.4
Deformation (mm)	0.0235	0.0215	0.0242	0.850s
Displacement (mm)	0.0308	0.0555	0.0339	1.81
Load	500N	500N	500N	500N

Table 4.2 Natural frequencies of the materials at different modes

Mode Number	Natural Frequency of Aluminium (Hz)	Natural Frequency of Titanium (Hz)	Natural Frequency of Brass (Hz)	Natural Frequency of Bright Plastic (Hz)
1	322.287	406.572	427.04	58.1909
2	912.327	1146.69	1199.85	166.172
3	1021.41	1288.12	1351.83	184.299
4	1121.77	1414.79	1486.05	202.637
5	1246.15	1571.91	1649.7	224.815
6	1327.22	1673.47	1749.32	238.04
7	1826.19	2310.88	2432.33	326.334
8	1982.08	2490.26	2595.78	359.57
9	2656.52	3316.56	3418.65	485.171
10	2781.54	3490.76	3631.51	505.454

4.5 Analysis of the Results

4.5.1 Static case Analysis

- From the figures and table it can be deduced that the von mises stress in aluminium is maximum when compared to brass, titanium and bright plastic.
- From the figures and table, it can be deduced that the deformation is minimum in brass when compared to aluminium, titanium, and bright plastic.
- From the figures and table, it can be deduced that the displacement is maximum in bright plastic when compared to aluminium, titanium and brass.
- From the figures and tables, it can also be affirmed that maximum specific modulus is brass is maximum when compared to aluminium, titanium and bright plastic.

4.5.2 Frequency case Analysis

- From the figures and table, it can be deduced that brass has the highest natural frequencies when compared to aluminium, titanium and bright plastic.

5. CONCLUSIONS

Comparing the results of the static and frequency case analysis done for the water pump impeller for the four materials (aluminium, brass, titanium and bright plastic), it can be deduced that brass is the material with the minimum deformation when compared with aluminium, titanium, and bright plastic which implies an increase in the strength (also justified by its maximum specific modulus) of the pump and that chances of failure of the water pump impeller is less. From the results shown above, it can also be affirmed that the natural frequencies of brass is higher compared to aluminium, titanium and bright plastic, hence brass has higher strength compared to aluminium, titanium and bright plastic. From this work, Brass iss the best suggested material for the design of impeller.

Acknowledgment

It is my privilege to acknowledge the valuable support and encouragement of Professor O. G Akanbi and Dr. Bolarinwa of the University of Ibadan for their immense contribution.

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