Modal and Stress analysis of Centrifugal pump impeller produced with Al-3.7%Cu-1.4%Mg-1.5%wtRice husk ash nanoparticles composite

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Abstract

The stress analysis of developed Al-3.7%Cu-1.4%Mg/1.5%wtRice husk ash nanoparticles (RHAnp) composite for the production of pump impeller for industrial and agricultural applications has been investigated. Impeller speed of 1050, 1250, and 1450rpm were used for the stress analysis. The Al-3.7%Cu-1.4%Mg/1.5wt%RHAnp composite can be successfully used in the production of the pump impeller. It was observed that the maximum von misses' stress obtained is far lower than the yield stress in the materials. This result imply that using these developed materials in the production of the impeller is safe based on the judgment of the strength obtained in the work. Since the factor of safety is above one, it also indicates that failure may not occur before the design life is reached.

Keywords: Rice Husk, Aluminum alloy, Stress, Strain

1. Introduction

Centrifugal pump impeller has a significant role in the agricultural and industrial sectors [1]. The performance of this impeller depends on the design of the blade and the properties of the material (Lan-Ying and Yan-Lin, 2011). The most common materials used in the production of the centrifugal pump impeller are mild steel (Mane et al., 2017). The choice of mild steel is a result of high strength and low cost, however the high corrosion and less fatigue strength have lower the current use of mild steel in the production of pump impeller for industrials used (Srivastava et al., 2018). Aluminum alloys, stainless, and Inconel have been reported as candidate materials for the replacement of mild steel in the manufacturing of pump impeller for the enhancement of fatigue strength and lower of the corrosion rate (Rajanand, 2016). The use of stainless and Inconel in the production of pump impeller usually increases the cost of the pump impeller for the rural people to purchase for use in their agricultural purpose (Dadhich et al., 2012). To produce impeller that will be less expensive than stainless and Inconel and have better corrosion resistance and lightweight than mild steel that motivate interest in this current research. Hence the aim of this novel work is the modal and stress analysis of pump impeller produced from composites materials using agricultural waste.

2. Materials and Method

The modal and the stress analysis of the open centrifugal impeller were done with composites of Al-3.7%Cu-1.4%Mg/1.5%wtRice husk ash nanoparticles. The selection of this grade of composites was based on the previous work of the author and his co-worker (Atuanya and Aigbodion, 2014). In this work, the simulation of the open centrifugal impeller developed from Al-3.7%Cu-1.4%Mg/1.5%wtRice husk ash nanoparticles was conducted using Autodesk software. The prototype of the open centrifugal impeller and complete assembly used for the stress analysis is displayed in Figure 1. The mechanical properties of the composite used for the analysis are displayed in Table 1. The pump impeller was subjected to the speed of 1050, 1250, and 1450rpm as per the pumping rating recommended for ASME Class 300.

Table 1: Mechanical properties of the impeller

Density (g/cm^3)	Tensile Modulus(MPa)	Yield strength(MPA)	Tensile strength(MPa)	Fatigue strength(MPa)	Hardness values(HRB)	Impact energy(J)
2.64	5567.08	185.67	205.60	125.17	105.08	25.14

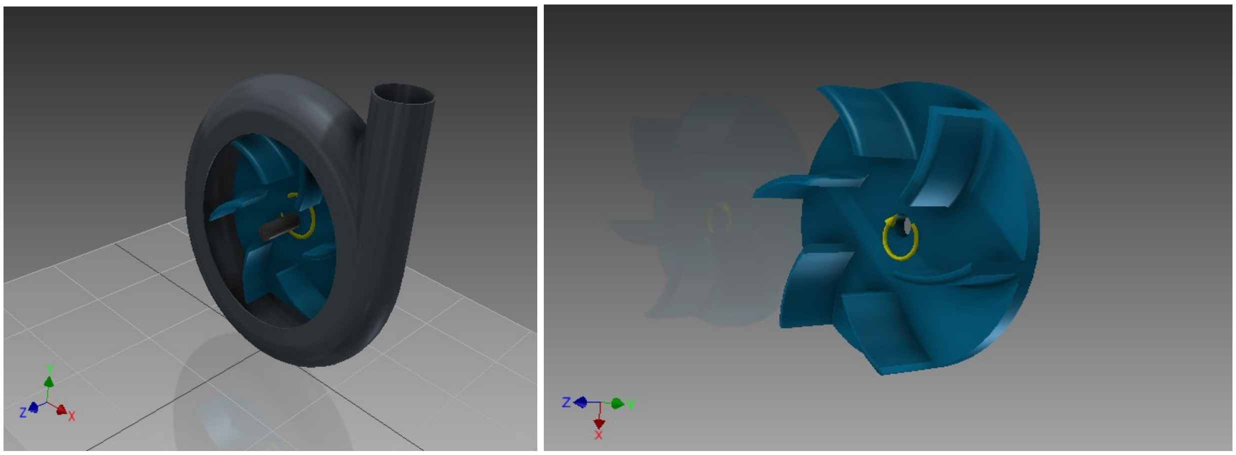

Figure 1: Photograph of the complete assembly and open centrifugal pump impeller

The boundary condition applied was the restraining of the displacement in x and z direction and support at the center location in y-displacement (see Figure 1). For the meshing, the average element size of 0.1 fraction model diameter and 0.05 shells, 60o maximum turning angle, 1.5 grading factor, and 0.2 minimum element sizes were used. The impeller is free to move either in the radial (X) or tangential (Z) direction, this provides impeller rotation and the exact behavior of stress in the impeller. The simulation involves the modeling of the impeller under the speed of operation to determine the stress, deformation, strain, and factor of safety of the materials.

3. Results and Discussion

Figures 2-6 and Table 2 displayed the Von mises stress, strain, displacement, factor of safety, and contact pressure results from the simulation. Von mises stress was used to determine the yielding of the materials in question. The effect of speed on the stress analysis on the developed impeller was evident. Operating speed is chosen in this work because of the relevance of working speed on the performance and failure of centrifugal pump impeller in service. It observed that in Figures 2-3 the higher the speed of operation results to an increase in the von mises stress and the strain. For example, the maximum stress of 1.8128 MPa, 2.56902 MPa, 3.45705 MPa, and strain 0.000020355, 0.0000288467, and 0.0000388176 were recorded at speed of 1050, 1250, and 1450 rpm respectively (see Figures 2-3). It was expected because increasing the impeller making increases the straining of the materials and hence large the deformation of the materials. The maximum deformation occurs at the point of application of the speed, this could be attributed to the fact that bending of the impeller may happen. High deformation of the impeller was observed at higher speed, due to high compression as a result of the bending of the impeller.

Table 2: Simulation results obtained

	1059rpm		1250rpm		1450rpm	
	Min.	Max.	Min.	Max.	Min.	Max.
Von Mises Stress	0.0114027 MPa	1.8128 MPa	0.0161251 MPa	2.56902 MPa	0.0216877 MPa	3.45705 MPa
Displacement	0.00mm	0.0058279 mm	0 mm	0.00825936 mm	0 mm	0.0111135 mm
Strain	0.000000131346 ul	0.000020355 ul	0.000000185779 ul	0.0000288467 ul	0.000000249825 ul	0.0000388176 ul
Factor safety	1.99318	15ul	1.39659	15 ul	1.0546	15 ul
Contact pressure	0 MPa	0.817613MPa	0 MPa	1.15948 MPa	0 MPa	1.56064 MPa

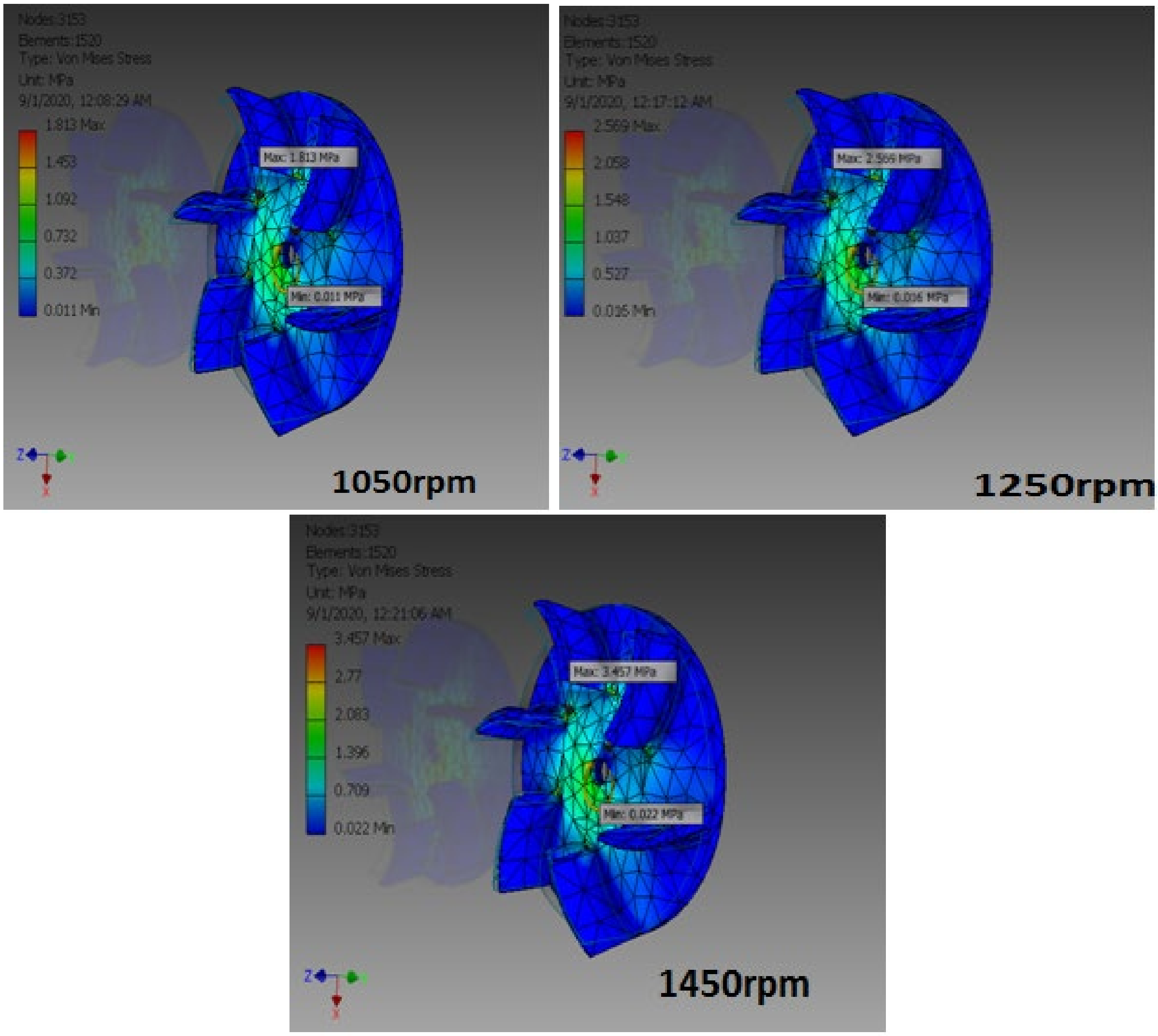

Figure 2: Von mises stress obtained at different operating speed

Maximum displacement value of 0.0058279 mm, 0.00825936 mm, and 0.0111135 mm (see Figure 4), while of the factor of safety of 1.99318 ul to 15 ul, 1.39659 ul to 15 ul, 1.0546 ul to 15ul (see Figure 5) were obtained in this stress analysis of the composite impeller at speed of 1050, 1250 and 1450 rpm respectively (see Table 2). The displacement is more at the blade that the center of the impeller. The higher the speed, the more the displacement and lower the von Misses stress and factor of safety. The higher deformation observed at a higher speed of 1450rpm was attributed to the greater force which tends to stretch the impeller apart.

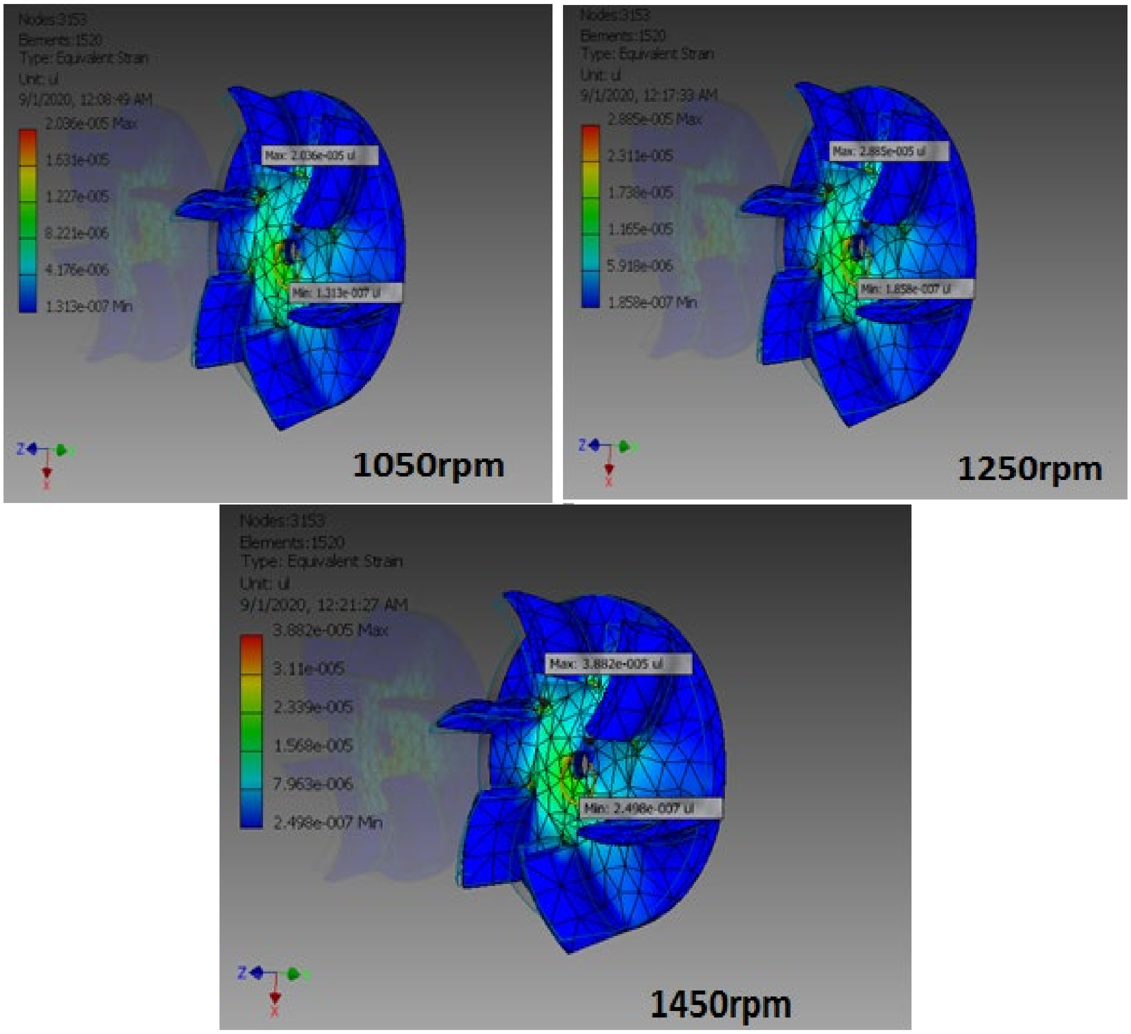

Figure 3: Equivalent strain obtained at different operating speed

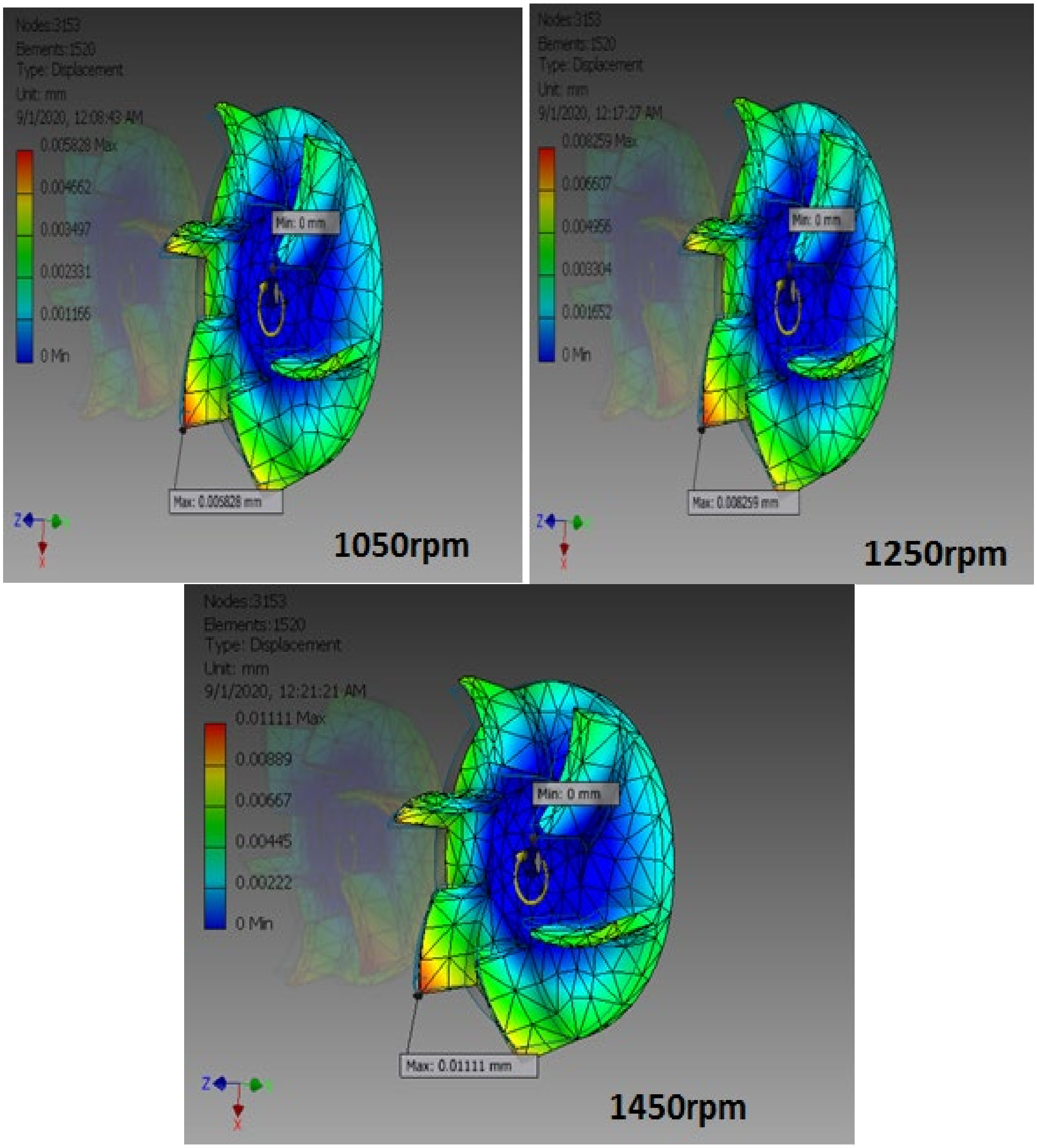

Figure 4: Displacement obtained at different operating speeds.

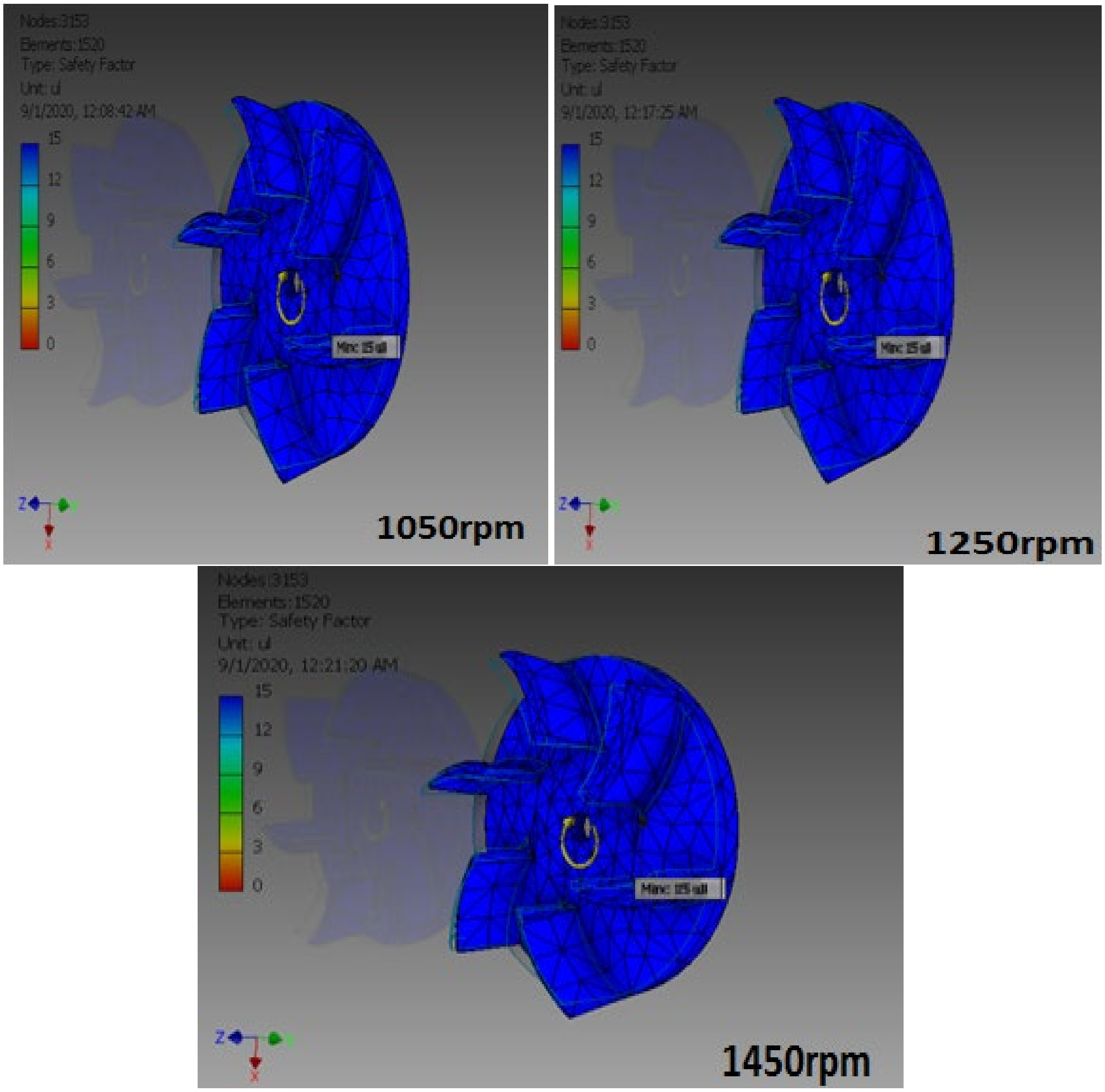

Figure 5: Factor of safety obtained at different operating speeds

The Kirlosakar pump specification of the head (13m), three horsepower machines, and 0.00858m3/s discharge speed was used to determine the contact pressure in the assembly work. Figure 6 displayed the results of the contact pressure with speed. It was observed that the higher the speed the more the contact pressure in the system (see Table 2). It was observed that the pressure in the blade increase from the inner to the outer part of the impeller which leads to complicated pressure distribution as a result of the complex of the flow.

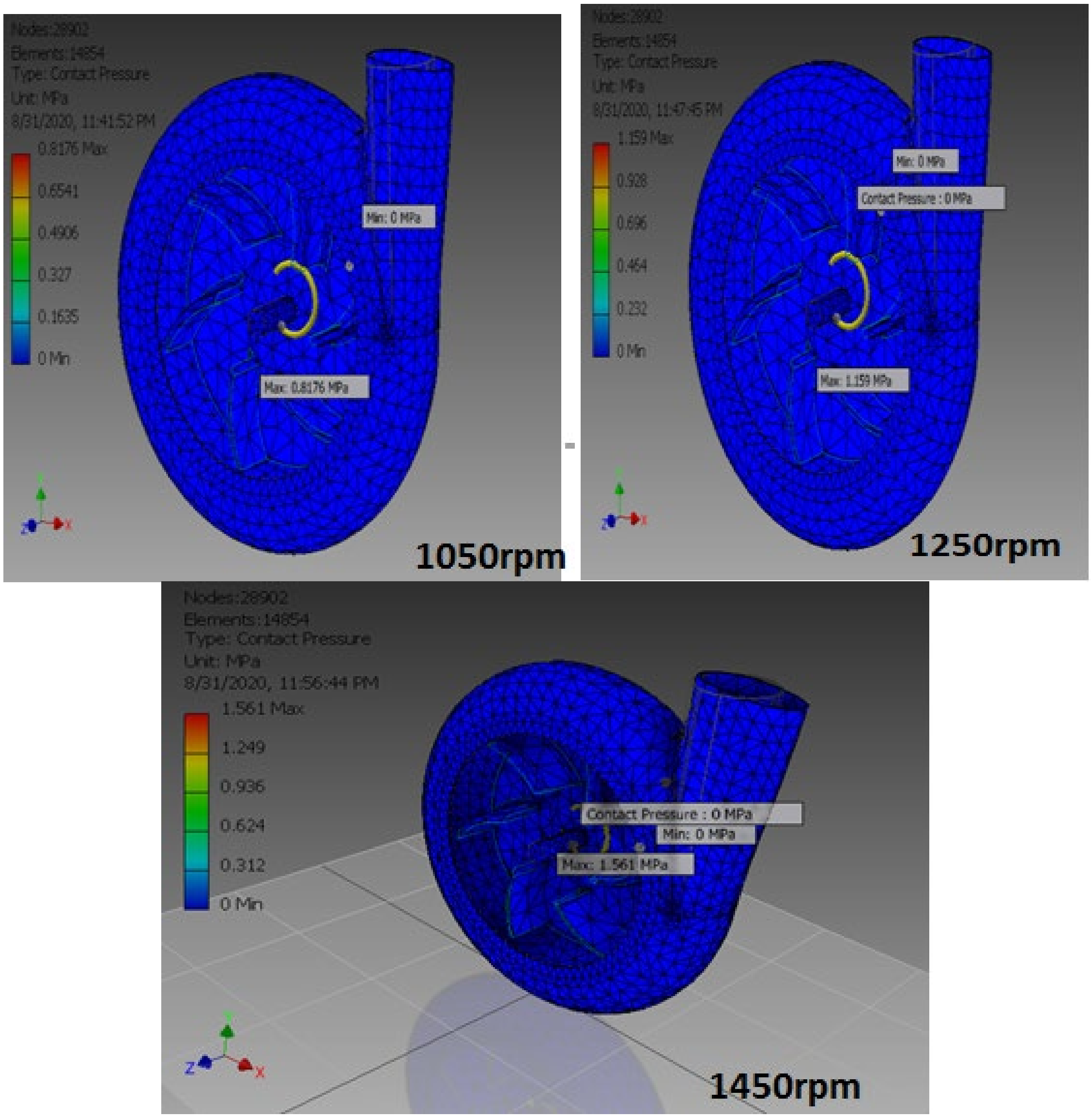

Figure 6: Contact pressure obtained at different operating speeds

The good linear structural analysis of the developed impeller with composite material was attributed to the stiffness and strength obtained in this composite which resulted in high toughness obtained by the reinforcement that gives a minimum factor of safety. The tensile strength and factor of safety obtained are within the recommended standard for impeller application it was observed that the maximum von misses' stress obtained in this work is far lower than the yield stress in the materials by using the factor of safety. This can be concluded that using these developed materials can be used in the production of the impeller is safe based on the judgment of the strength obtained in the work.

4. Conclusions

New information was obtained in using the developed composite in the production of pump impeller for industrials and agricultural applications. The Al-3.7%Cu-1.4%Mg/1.5%wtRice husk ash nanoparticles composite can be successfully used in the production of the pump impeller. The tensile strength and factor of safety obtained are within the recommended standard for the impeller application. It was observed that the maximum von misses' stress obtained in this work is far lower than the yield stress in the materials. This can be concluded that using these developed materials can be used in the production of the impeller is safe based on the judgment of the strength obtained in the work. Since the factor of safety is above one indicates that failure may not occur before the design life is reached.

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Biographies

Dr Paul A. Ozor obtained a bachelor's degree (B.Eng) in Mechanical/Production Engineering at Enugu State University of Science and Technology, Nigeria in 2001. He worked as project manager with some engineering companies before proceeding to Department of Mechanical Engineering, University of Nigeria Nsukka (UNN), where he specialized in Industrial Engineering and Management. He obtained both Masters and PhD degrees in 2008 and 2015, respectively from UNN. Dr Ozor is a winner of the prestigious TWAS-DST-NRF fellowship to University of Johannesburg, South Africa, and had been awarded the Association of Common Wealth Universitie's (ACU) early career scholarship in 2014. His research interests include Industrial Operations modelling, Quality management, Systems Analysis, Reliability Engineering, with special emphasis on Maintenance, Failure mode effects and criticality analysis (FMECA), Safety and Risk assessment (SRA) as well as Environmental (Waste) influence modelling. Dr Ozor has over fifty peer reviewed publications and has visited countries in North America, Europe, Asia and Africa on research grounds.

Professor Sunday Victor Aigbodion work with the Department of Metallurgical and Materials Engineering, University of Nigeria, Nsukka, Nigeria. He is a scholar of international repute and currently a visiting Professor to the University of Johannesburg as well as University of Benin Nigeria. Prof Aigbodion has published over one hundred and eighty-four (184) research papers in several local, international journals and conferences. He has also served as an external assessor to many international bodies among which are the National Center of Science and Technology Evaluation Ministry of Education and Science Astana, Republic of Kazakhstan, Anna University Centre for Research Chennai, India, University of Johannesburg, Nova Science Publishers Inc Hauppauge USA, National Research Foundation (NRF), South Africa, just to mention a few. Prof Aigbodion has headed and also a member of many accreditation teams in University and Polytechnic, Member, Council of Engineering and Regulation of Nigeria professional Registration interview team. **Prof Aigbodion is a National Research Foundation (NRF) South Africa C3 rated researcher.**