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Development of Mechanical Properties of TC17 Titanium Alloy Shaft Based on the Stress-Strain State Based on the Dynamic Load

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ABSTRACT

In this study, the impact of a dynamic load on the mechanical properties of a TC17 titanium alloy shaft has been investigated by means of finite element analysis. This research's data was collected and analysed as an integral component of a larger investigation. In order to put the simulation approach into action, the Ansys software's static structure tool was utilised. Calculations were performed with a load ranging from 0 to 100 N during the duration of the experiment, which led to these results. Once the x, y and z-dimensional distortions have been fixed, the procedure may be considered finished. Deformation was greatest along the y-axis (8e-6 mm for the applied force) and it was least along the z-axis (0.006 mm for the applied load), according to the numerical study. The object's weight was crucial to each of these assessments. In addition, researchers have looked into vone-mises stressors, which are also called comparable stress. A stress level of 8.87 e10 Pa is considered to be the maximum equivalent stress, according to recent studies. Analysing the shear stress due to external loads over three separate planes yielded consistent results. Where studies have been conducted in all three perspectives (xy, xz and yz). A share stress peaking at 2.07e10 Pa was experienced by the xz plane at this spot.

1. Introduction

Several important metals were developed after the discovery of titanium alloys in the middle of the twentieth century. Titanium has superior properties than those of most other metals, including a lower density, greater resistance to corrosion and greater strength [1,2]. These materials are employed in the blades of compressors, integrated rotors and fans in aviation engines due to their great strength, low weight and strong resistance to heat [3].

A method to characterize tool-wear-related surface roughness was proposed by Sarma *et al.,* [4] as part of their study into the reliability of the ground surface of titanium alloys [5]. Using a collection

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of roughness process parameters, this method was utilised to assess surface integrity, processing dynamics and material properties [6]. All of these objectives were met by using this approach. Additionally, a combined machining/polishing model and a fractal model of the polishing-related wear process were developed [7,8]. In their research, Salman *et al.,* [9] examined how the make-up of the abrasive belt affected the final product. It also quantitatively described the process of improving component surfaces by using abrasive belts, which was done by investigating the physical principles underlying the grinding and polishing activities of the belts. Both classical statistical extraction approaches and state-of-the-art feature extraction strategies based on wavelet packet transforms [10,11] were used to polished sensor data, illuminating the level of surface roughness attained by the polishing process. According to Zhang *et al.,* [12], adaptable surfaces may be made by combining conventional methods of tool manufacture with cutting-edge robot-assisted polishing methods [13].

Therefore, an examination into the influence that temperature has on the mechanical characteristics of a shaft made of TC17 titanium alloy that has been subjected to a dynamic load was conducted with the assistance of finite element methods. The shaft was subjected to the load in a dynamic manner.

According to studies by Guo *et al.,* [14], the transportation, chemical and medical sectors rely heavily on titanium because of the metal's high specific strength, low melting point and good corrosion resistance. However, because to their high melting points and poor thermal conductivity, titanium alloys produce significant waste heat during the machining process. Low elasticity modulus, high machining temperatures and chemical interactions between tools and workpieces all contribute to the material's difficult machinability.

Many automotive components, including as engine parts, heat exchangers, chassis elements and exhaust systems, are made of titanium or titanium alloys, as stated by Yin *et al.,* [15]. Hydraulic pumps, propulsion shafts and main casings are just a few of the many uses for titanium alloys in the marine sector. A lot of underwater diesel engine mufflers, condensers and heat exchangers employ thin-walled pipes manufactured of high-grade titanium alloys [16]. This area can sustain temperatures more than 600 degrees Celsius due to the alloys utilised. Titanium alloys are highly regarded in many industries for their qualities such as biocompatibility and corrosion resistance. They find widespread use in compressor blades, fan housing, jet engine turbine discs and medical devices [17]. Because of its great strength-to-weight ratio and lack of toxicity, Ti-6Al-4V has discovered widespread application in the medical implant and surgical tool industries [18].

The possibility of creating unique titanium alloys with enhanced mechanical and chemical characteristics by heat treatments has been the subject of much investigation [19]. The detailed description of the thermomechanical approach may be found by Almagsoosi *et al.,* [20]. The objective is to alter the alloy's microstructure and macrostructure by means of controlled heating, annealing and cooling. Surface treatments like as thermal oxidation, anodization and chemical oxidation can be applied to titanium in addition to bulk treatments in order to enhance its mechanical properties [21]. Titanium alloy blades were subjected to the tests detailed by Salman *et al.,* [22] to determine their surface roughness, work hardening, metallographic structure and residual stress. The width of the abrasive belt and the intensity of the grinding process piqued the curiosity of the experts.

They built a regression model to predict surface roughness using their findings. Additional studies by Alwan *et al.,* [23], have forecasted the surface roughness of blades and improved the polishing parameters of flexible abrasive tools, leading to a 25% decrease in surface roughness. Raheemah *et al.,* [24] look at how adaptive belt grinding may be used to keep compressive stress in the material while reducing the surface roughness of aircraft blade edges to less than 0.25 micrometres. Machined a titanium alloy with microcrystalline corundum grinding wheels, showing that increasing porosity wheels gave superior results [25].

Bachi Al-Fahad *et al.,* [26] found a few flaws in the machined surface of a titanium alloy (Ti-6Al-2Sn-4Zr-2Mo) while studying the fatigue life and surface integrity of the alloy. On the other hand, titanium alloys can have their surface integrity improved, which could mean that the components last longer. The reason behind this is because titanium alloys do retain a little amount of compressive stress. A machinable titanium-aluminium alloy was found and studied by Mantle and colleagues to have microcracks [27]. The impact of roughness on contact fatigue has been investigated using mesoscopic methods in recent studies by Mouhmmd *et al.,* [28]. They discovered that fatigue properties changed significantly at roughness levels greater than 0.4 micrometres. Subhi *et al.,* [29] found that the quantity of residual stress is directly proportional to the number of cycles a material can endure before exhibiting fatigue symptoms. Most notably, this occurs when the mean stress is kept below the yield point of 20 MPa.

A group of researchers headed by Kadhim *et al.,* [30] looked into the GH33A superalloy's low and high cycle fatigue lifetimes. This discovery might potentially be used to improve the design of turbine discs. Mohammed *et al.,* [31], the researchers looked studied how surface working conditions affected the fatigue life of a high-strength titanium alloy. According to the research, fatigue strength was increased by almost one-third using a compressive stress coating that was 250 micrometres thick. The researchers found that fatigue resistance rose by about 70% when the surface was totally smooth and undamaged. A TC4 titanium alloy's surface was wet shot peened to shift the fatigue fracture initiation point [32]. So that they could get where they were going, this was done.

Research on the effects of surface integrity on abrasive belt grinding of titanium alloys [33] showed that factors like temperature and surface roughness are important to improve the surface texture. By investigating the connection between residual stress and ground titanium alloy finish quality, this study sought to address a gap in our understanding [34]. By examining the relationship between grinding and residual stress, this study aimed to address the issue, "How does grinding affect the fatigue life of titanium alloys?" on an empirical level.

Therefore, the dynamic load and temperature effects on the mechanical characteristics of a TC17 titanium alloy shaft were investigated using the Finite Element Methods.

2. Methodology

2.1 Mechanical Properties

According to the generally accepted standard, the tc 17 titanium alloy has been described in a number of investigations. In this study, in order to carry out the simulation analysis of the existing model, it is necessary to address all of the relevant information that is included in Table 1.

Table 1
Mechanical characteristics of TC17 alloy

Ultimate tensile strength	Modules of elasticity	Density	Passion ratio
1108 MPa	111.5 MPa	4.5 g/cm^3	0.31

Four parameters have been considered in order to determine the given titanium alloy in the material library of the software. Theses parameters are necessary to perform the simulation process.

2.2 Primary Boundary Conditions

Tc17 alloy has been heavily used in this investigation; in fact, it is the main material for the model that is now being used. A force of one hundred newtons is being exerted to meet the conditions of this experiment. Because of its cantilever design, it has been worked with one side supported and the other side loaded. The model's prototype, which is now in use, has already accomplished this. All of the shaft's geometry has been locked down in the Ansys software. Additionally, the beam's opposite side has experienced loads.

2.3 Meshing and Modelling

We have implemented and statistically investigated the geometry in AutoCAD. The plain segment starts and finishes at a gap in the centre.

A company called ANSYS, Inc. This problem necessitated the use of mesh generation in order to correctly execute the meshing process. Mesh creation limits the previously uncontrollable number of particles in a model to a more manageable range. A very small mesh was created utilising a strict grid to guarantee the accuracy of the simulations. This allows for the construction of the mesh. Face meshing and coarse meshing were used to carefully manage the element size and curvature size, respectively, in order to achieve the necessary fine mesh. The result was a mesh that could be as fine-grained as required. The ability to produce the necessary tiny mesh was thus enabled. So far, 553,345 binary nodes have been constructed throughout the whole wedge. This kind of mesh is seen in Figure 1 in two dimensions. Due to the symmetrical nature of the three-dimensional wedge, studies and models have only been carried out on one side until now. One of the unforeseen results was the finding of three-dimensional wedge symmetry.

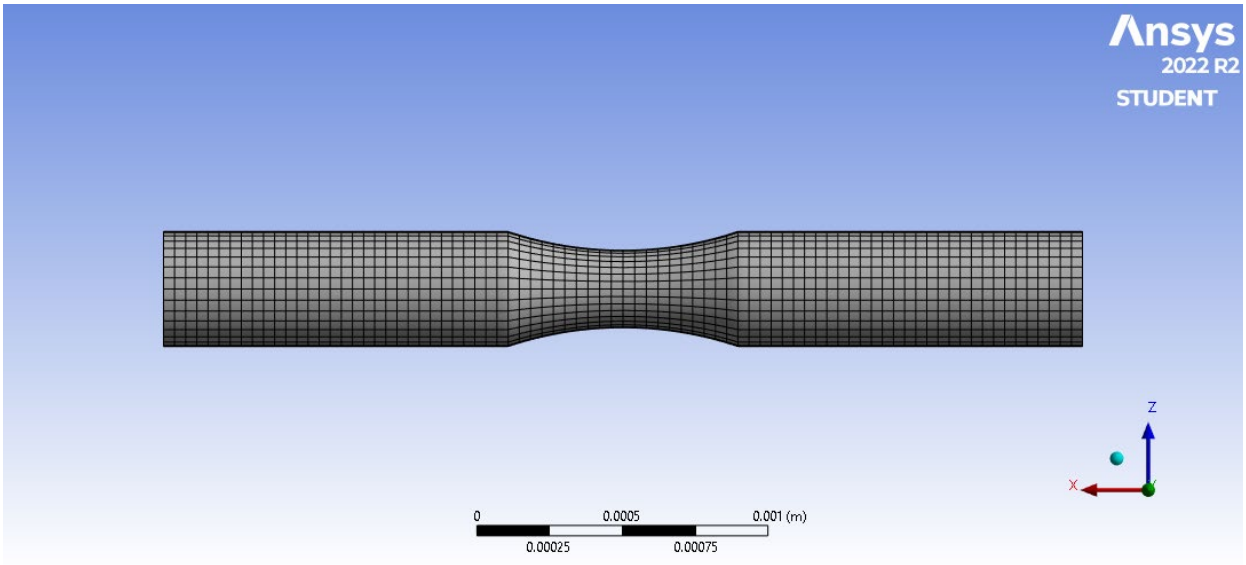

Fig. 1. The meshed model of TC 17 Titanium alloy

2.4 Mesh Convergence

In the research, the total deformation was employed as the principal metric as an equivalent for the convergence technique of the composite single stranger plate. This was done so that the results could be compared. The purpose for doing this was to get further knowledge on the convergence approach. After the mesh that was used to simulate the existing geometry was improved, it was found that a deflection of 3.32e5 millimetres could be achieved. As can be seen in Figure 2, the absolute least amount of variance that is required to reach convergence is 2.9 e5 millimetres.

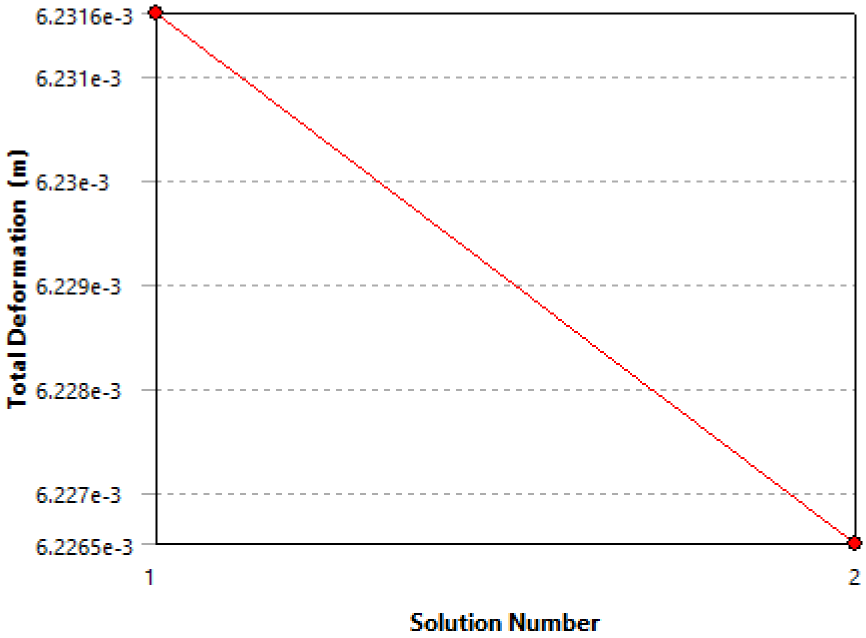

Fig. 2. Process of convergence in the present investigation

3. Results and Discussion

3.1 Investigate Mechanical Properties Based on the Load-Deflection Test

The TC 17 titanium ally has had load-deflection applied to it while the temperature was being held constant. The whole operation was carried out from a single vantage point. In this instance, the sample has been modelled as a straightforward cantilever. The load that was applied was equal to 100 n. The results of the numerical analysis, which can be seen in Figure 3, show that the free end of the specimen had the greatest amount of deflection. 0.0062 is the value that has been reached for the highest amount of deflection.

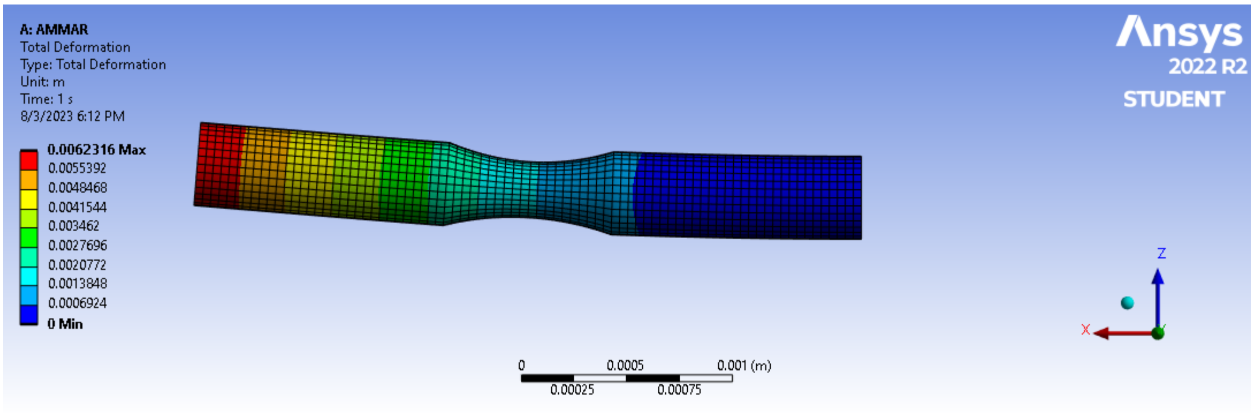
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Fig. 3. Graphical depiction of the overall deformation that was caused by the load that was applied

In consideration of this data, it has been hypothesized that directional deformation has become apparent. A representation of the deflection along the X axis may be seen in Figure 4. When the maximum deformation reached 0.00063 mm and where the minimum deformation reached –

0.00063 mm under the same force in the other region on the spaceman. It can be seen from these figures of the deformation that the effect of load is exclusive to the spacemen.

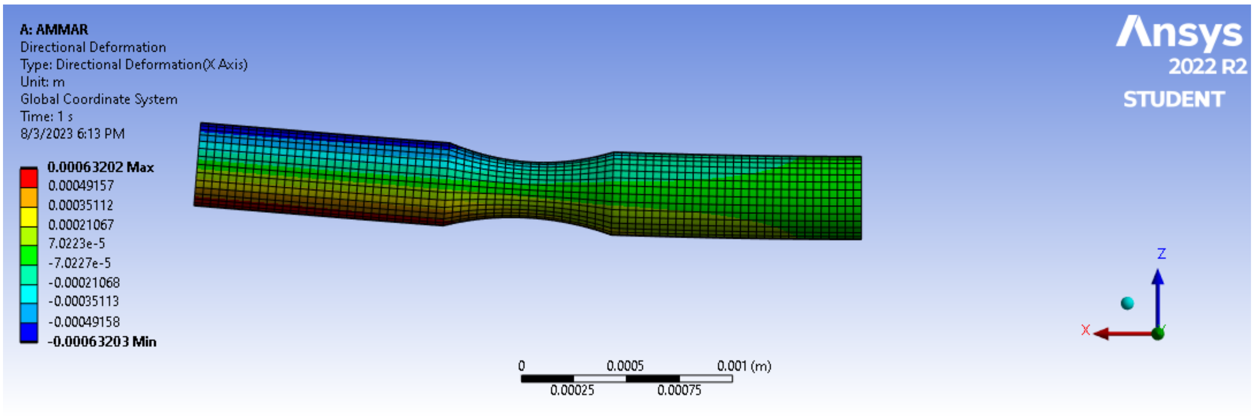

Fig. 4. Graphical depiction of the overall deformation on the X axis

This analysis has been taken into consideration as having identified directional deformation. The deflection along the Y axis is illustrated in Figure 5. where the highest distortion reached 8E-6 mm millimetres and at the same load in the other location on the spaceman, the minimum deformation was 8E-6 MM. These figures of the deformation show that the effect of load is particular to the astronauts.

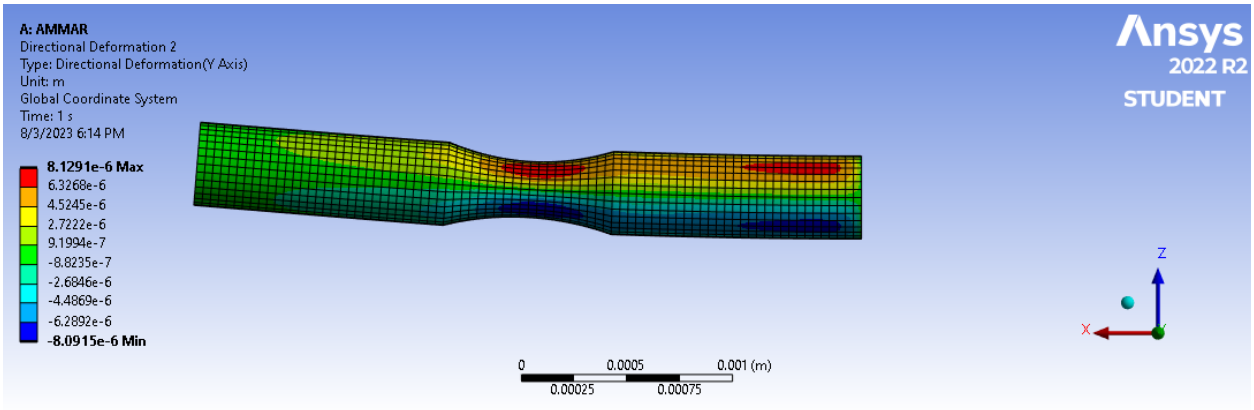

Fig. 5. Graphical depiction of the overall deformation on the Y axis

In basis of this investigation, it has been determined that directional deformation has been shown. A representation of the deflection along the Z-axis may be seen in Figure 6. There the highest deformation reached 0.006 mm, while at the same load in the other place on the spaceman the minimum deformation reached 0.0 mm. It can be seen from these figures of the deformation that the effect of load is particular to the spacemen.

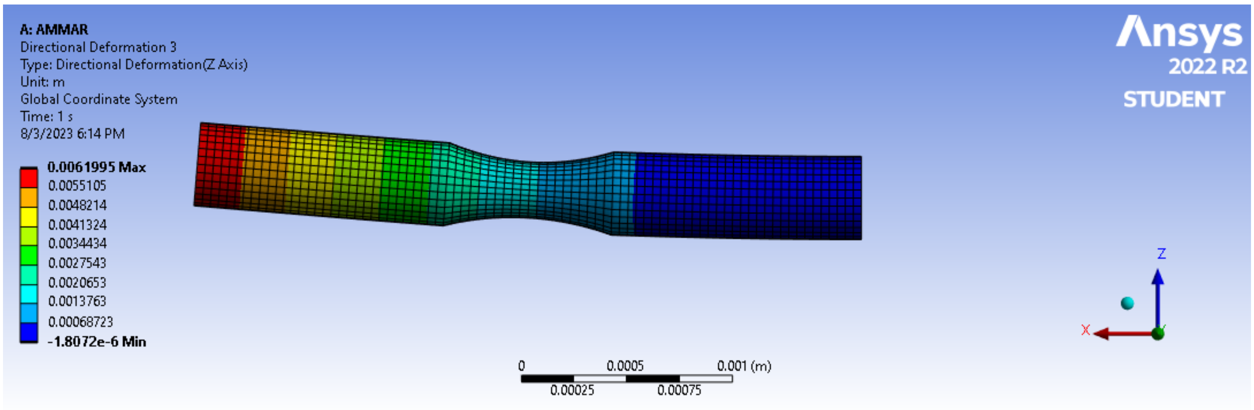

Fig. 6. Graphical depiction of the overall deformation on the Z axis

The effect of the load on the three-dimensional deformations is depicted graphically in Figure 7, which may be found below (x, y, z). When compared to the other axes, the axis of Z has been subjected to much deformation. The point on the same graph where the greatest value of the deflection reached 0.006 mm is also the point on the Y axis when the deformation along that axis hits zero. This indicates that the Y axis has undergone the least amount of distortion. This is because there is no effect of load along that axis, as the explanation goes. In a manner analogous to that of the x-axis, where the maximum load reached 0.0006 millimetres.

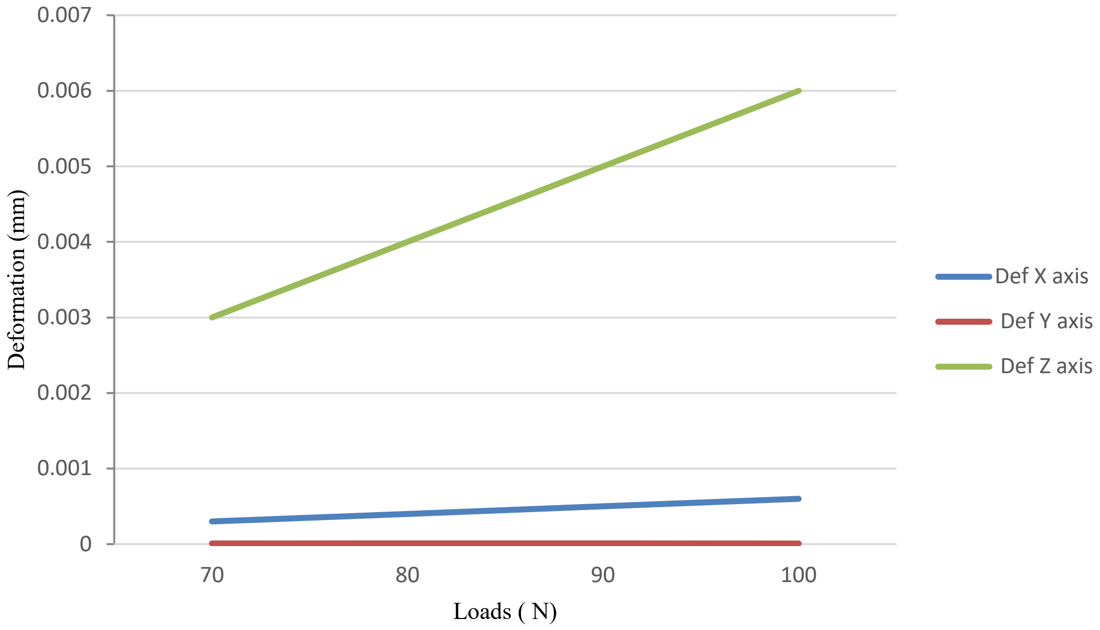

Fig. 7. Deformations to the three-axis

3.2 Investigation Based on Von Mises Stresses (Equivalent Stress)

The numerical finding uncovered evidence of the existence of equivalent stress. Figure 8 is an illustration of the effect that the stress had on the astronauts and it can be viewed here. The neck was subjected to the greatest amount of stress, which reached 8.8710 Pa at its maximum point. It was seen that the greatest concentration of tension was located in the centre of the sample (at the neck). The phrase "where it has been noted that" The fact that the neck is the part of the sample that has the lowest cross-sectional area is what may be pointed to as the cause of the stress concentration that can be seen there.

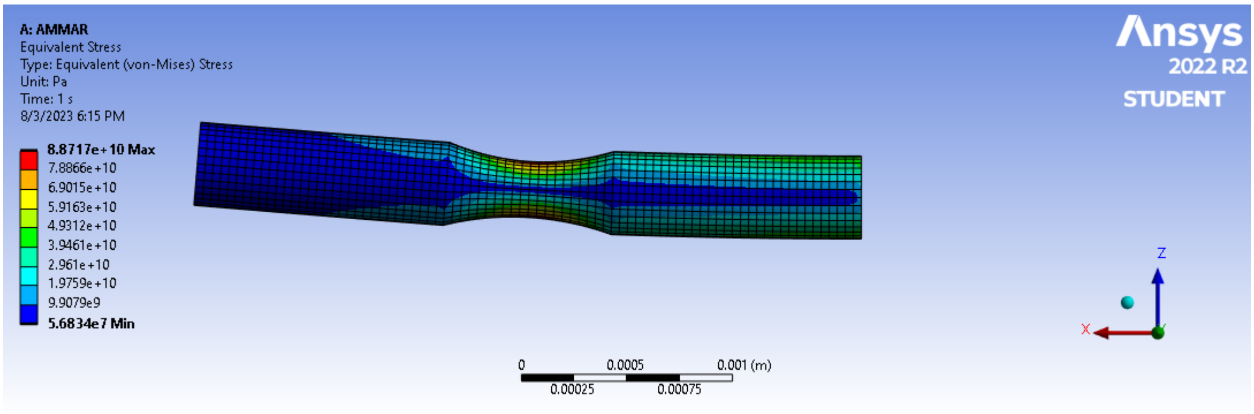

Fig. 8. Graphical illustration of Vone-mises stress

Figure 9 demonstrates that a comparable stress can be obtained with respect to a variety of various ranges of applied forces. These forces have been applied in a series of orderly steps. (70,80,90,100 N). The maximum stress registered at 8.87x10 Pa when a force of 100 N was applied to the material. After multiplying the load by 70 N, the stress level reached 8.5e10 Pa, which was the absolute minimum that it was capable of reaching.

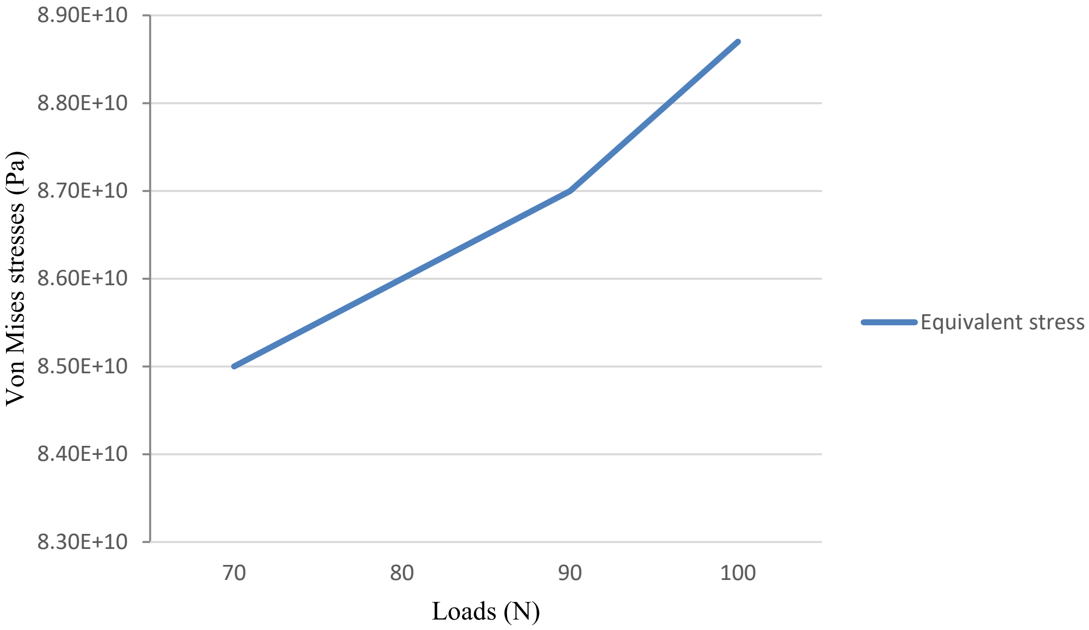

Fig. 9. Equivalent stress due to the load

3.3 Shear Stress Analysis Due to the Applied Loads

The simulation method for the shear stress that was caused by the imposed force in the XY plane has been presented in Figure 10. Where the load that was applied was 100 and the highest shear stress was 1.4e10. The graphical representation provided an illustration of the distribution of the stress that was caused by the applied load along the sample.

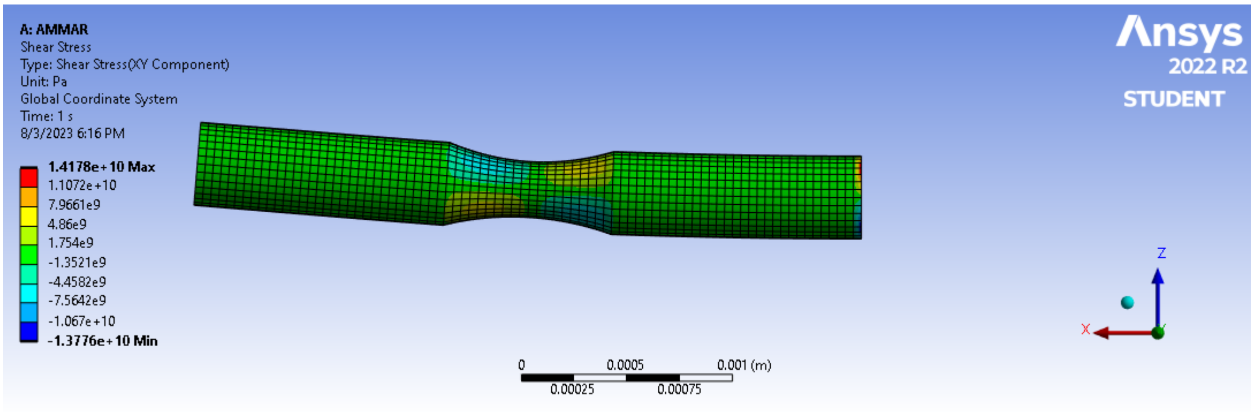

Fig. 10. Graphical illustration of shear stress in xy plane

The procedure of simulating the shear stress in the XY plane that is caused by the imposed load has been demonstrated in Figure 11. Where the load that was applied was 100 and the highest shear stress was 2.07e10. Because of the load that was applied, the graphical depiction was able to show how the stress was distributed along the sample.

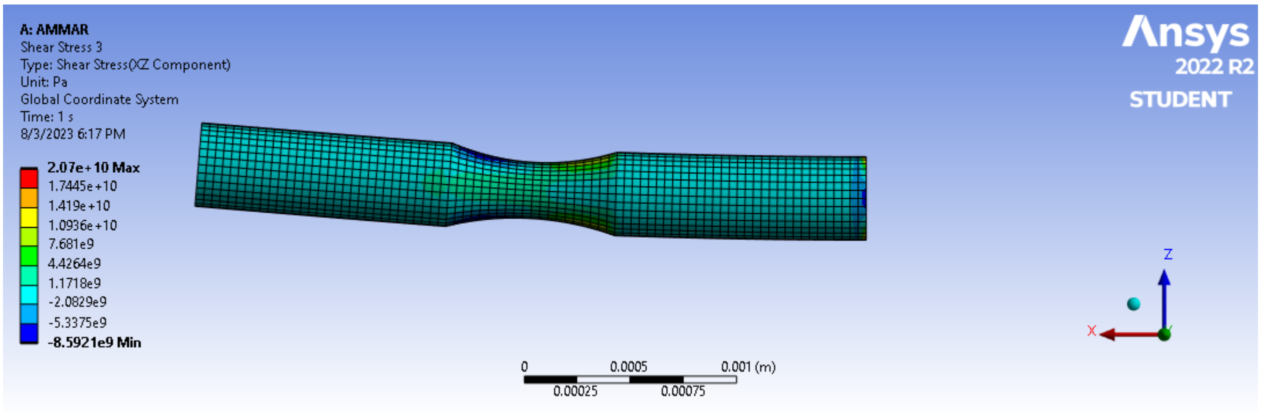

Fig. 11. Graphical illustration of shear stress in xz plane

The simulation process for the shear stress caused by the conducted force in the YZ plane has been displayed in Figure 12. Where the load that was applied was 100 and the highest shear stress was 3.5e9. Because of the load that was applied, the graphical depiction was able to show the distribution of the stress along the sample.

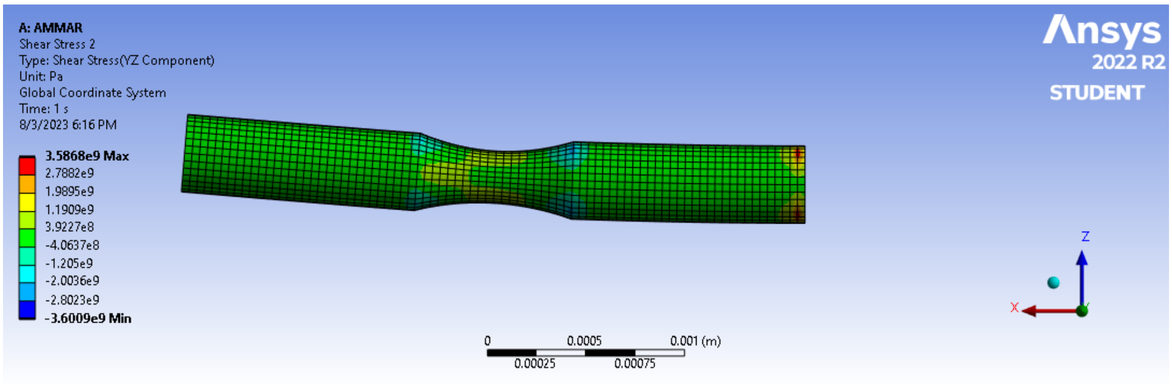

Fig. 12. Graphical illustration of shear stress in the YZ plane

Shear stress in three separate planes (XY, XZ and YZ) has been computed by the use of numerical analysis. It has been discovered that the shear stress lies somewhere in the range of force that is comprised of (70.80.90.100 N). The evidence presented in Figure 13 proves beyond a reasonable doubt that the XZ plane was the site of the highest shear stress. The XZ plane has been subjected to a maximum stress of 2.07e10 pa as a finding of the 100 N of external force that was conducted. The shear stress is currently at its absolute minimum on the yz plane, which was the location where it achieved its maximum value of 3.5e9 earlier.

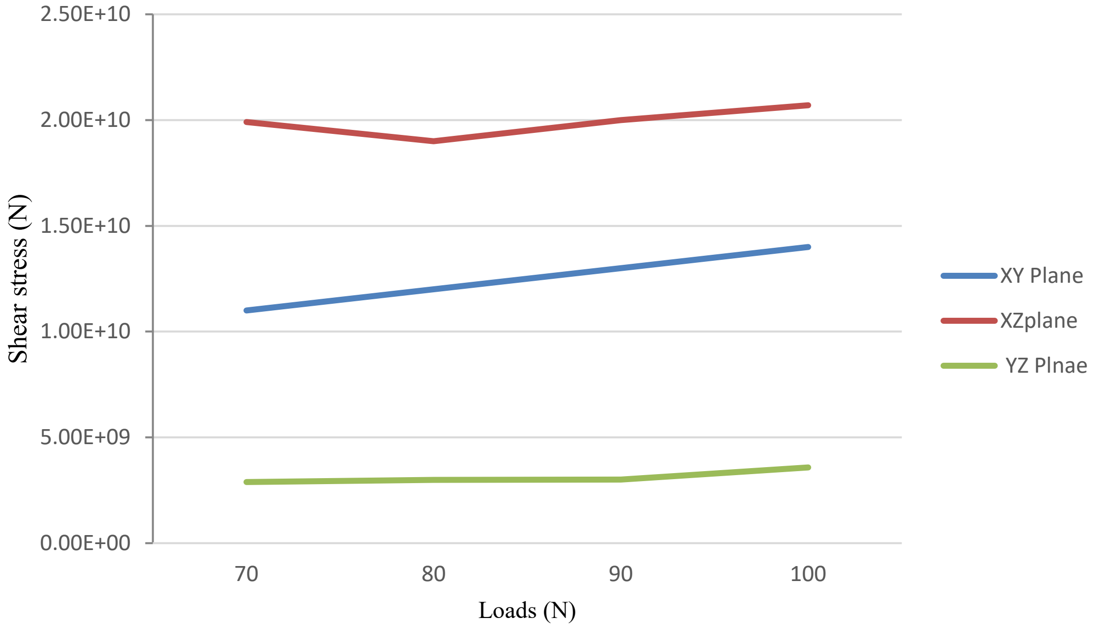

Fig. 13. Shear stresses to the three different planes

4. Conclusions

In conclusion, the research of mechanical characteristics based on the load-deflection test has been carried out in three different directions. The findings indicate that the z-axis exhibited the highest value of the deflection, which was 0.006 millimetres.

We estimated the von mises stress, which is also known as the equivalent stress, based on the load that was being applied and the numerical findings demonstrated that the stresses reached their highest possible value of 8.87 e10 Pa.

The shear stress analysis that came about as a result of the loads that were applied in different planes (XY, XZ and YZ) has been computed. During the course of the examination, it was discovered that the XZ plane experienced the highest possible amount of shear strains, which was 2.07 Pa.

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