# Effect of Loading Rate and Thickness on Mechanical Properties of CP-Titanium Grade-2

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***Abstract-*** **Due to its adaptability to various environments, titanium is regarded as a good material for use in numerous sectors. Moreover, due to its remarkable resistance toward corrosion and high strength-to-weight ratio, CP-Titanium grade-2 is widely employed in aerospace and medical applications. There hasn't been a lot of in-depth experimental investigation on the impacts of loading rate and thickness. As a consequence, the impact of different thicknesses and loading rates on the mechanical properties of grade 2 CP Titanium is extensively considered in this study. The specimen was evaluated at room temperature under conditions ranging from quasi-static to high loading rates of 0.1, 1, and 10mm/min, with various thicknesses of 0.5, 1, 1.5, 2, and 2.5mm. The greatest mechanical values were attained at a strain rate of 10 mm/min, with a yield stress of 450 MPa and a maximum tensile strength of 471 MPa. The test specimen was prepared by the standard-ASTM B265. To assess the tensile qualities, the test was conducted using a tension fixture in a Universal Testing Machine (UTM).The findings indicate that mechanical characteristics like tensile stress and yield stress get influenced substantially by the loading rate, whereas, as the strength is influenced by thickness.**

***Key words*- Loading rate, Thickness, Mechanical Properties, CpTi, Tensile Test, Material.**

## I. INTRODUCTION

Contrary to cobalt-chromium-based alloys and stainless steel, commercially pure titanium (CpTi) and its alloys have emerged as the preferred metal for several biomedical devices, particularly orthopedic and dental applications. This is a result of its great qualities, including its high specific strength, excellent biocompatibility, lower density, superb resistance toward corrosion, and impressive fatigue resistance [1],[2],[3],[4]. When considering the physiological conditions that several of these implants could endure, such as cyclic loading, sliding wear, or simply the physiological factors that the human body experiences at rest, such as the pH level, these qualities are significant. Although CpTi is a biocompatible and non-toxic metal, it has significant drawbacks when it regards mechanical qualities, as seen in load-bearing implants [5, 6] with articulating surfaces, where strong wear resistance is required.

The mechanical characterization of structural materials must take into consideration tensile properties as index qualities. Tensile characteristics include ductility measures like elongation and area reduction as well as strength metrics such as ultimate tensile strength (UTS) and yield strength (YS) [7],[ 8]. A tiny rectangular tensile specimen must meet the ASTM criteria, which state that it must have a width of 6 mm, gauge length of 25 mm, and thickness of less than 3 mm [10]. The geometrical size and shape of the specimens used to evaluate the tensile characteristics can be determined using these specifications. [9],[26]. The majority of the time, however, the specimens do not meet the ASTM requirements, such as when samples are taken from structures and when their sizes are below the minimal ones required by the standard [10],[11].Even though the permissible specimen size exceeds the criterion, the ASTM standard does not define an exact thickness requirement. There is a large range of thicknesses [12],[13]. How can the findings of several tests be compared when they didn't use the same sample size if different specimen sizes don't provide the same results? So how are the results of one testing size transferable to another? These queries remain unanswered.

For many applications needing a somewhat high corrosion resistance and specific strength (strength-to-density ratio), sheets of commercially pure titanium have been utilized extensively. The majority of the sheets with a thickness higher than 0.5mmare produced in mills with high productivity. Nonetheless, the use of titanium sheets with a thickness of less than 0.3 mm is quickly spreading to more and more industries, including architecture, speaker diaphragms, corrosion protection panels for maritime steel structures, and fuel cell separators. Although it is anticipated that the in the upcoming years, the use of finer titanium sheets will increase even further. Their mechanical features have not been completely understood up until this point [14],[15],[16],[17].

There have been many researchers who have explored their studies in this scope of subject. Due to its exceptional mix of resistance toward corrosive acid, biocompatibility, seawater, and mechanical qualities, such as high strength, and low specific gravity, up until now, the most widely utilized metal for orthopedic implants has been pure titanium (Ti)

[18],[19],[20]. However, compared to human bone, pure titanium has a substantially greater Young's modulus (110 GPa) (12–23 GPa). There are still significant issues unaddressed as a result of the elastic modulus mismatch between human bone and implants. To address the difficulties of pure Ti, Young's modulus can be decreased in one way by including holes, minimizing damage to the tissues around the implant and thus increasing device life [21],[ 22].
The author reports the creation of sintered porous Titanium compacts with Young's moduli similar to that of the bone of humans [23]. Porous compacts with a porosity of 19 to 35 vol% were made using pure Titanium powder which has particle sizes of 300–500 μm. Porosity-graded Ti compacts were also studied by the author [24] using Titanium powders with three distinct particle sizes: 374, 189, and 65μm.According to Miyazaki et al., the yield stress is bound to reduce with an increase in thickness and is connected to the thickness-to-grain ratio of thin sheets of pure iron and copper alloy that vary in thickness (t) from 0.045 to 1.84 mm. They claimed that in the range of t/dgs smaller than roughly 10 and 5, respectively, yield strength in pure copper and iron alloy sheets diminishes with decreasing thickness. The author [25] showed that As the number of grains falls across the width of a thin aluminum sheet, maximum load and yield strength do as well. The loading rate in the prior investigation had an impact on the material's mechanical characteristics. According to the loading condition, the yield value and maximum tensile stress will rise, but the modulus of elasticity will remain relatively constant. Investigating the material's deformation properties at various loading rates is crucial. The author [9] investigated the hypothesis that when the strain rate increases, the value of the specimen's hardness surface decreases.
To characterize yield behavior, many researchers have researched phenomenological and physical-based models, but experimental research on the effects of loading rate and thickness has lagged. Therefore, experimental research was done in this work to determine how thickness and loading rate affected pure titanium grade 2. Understanding the mechanical characteristics of CP-Titanium Grade-2 at room temperature and different loading rates of 0.1, 1 and 10 millimeters per minute is the goal of this study.

## II. MATERIAL AND EXPERIMENT

In the current study, sheet thicknesses of 0.5 mm to 1.5 mm and 2 mm to 2.5 mm of commercially pure titanium grade 2 (CpTi) were used. Jay Steel Corporation provided the material. Table 1 contains a list of the material's chemical composition. The mechanical properties/characteristics of the material are illustrated in table 2. The test specimen geometry is determined according to ASTM B265 as illustrated in Fig. 1.

Table 1- Chemical Composition (ASTM B265)

| Element | Iron | Oxygen | Hydrogen | Nitrogen | Carbon | Titanium |
|---|---|---|---|---|---|---|
| Wt | 0.30% | 0.25% | 0.015% | 0.030% | 0.080% | Remainder |

Table 2: Mechanical Characteristics (ASTM B265)

| Tensile strength | Yield strength | Elongation | Modulus of elasticity |
|---|---|---|---|
| 344MPa | 275-410MPa | 20% | 105GPa |

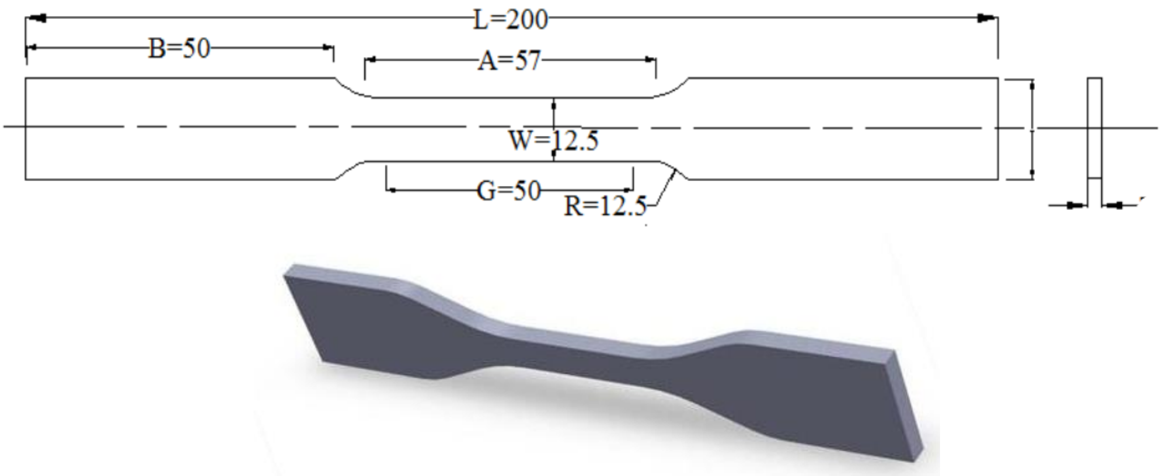


Fig. 1- ASTM B265 Tensile specimen (in mm)

To get material parameters includes Young's modulus, yield strength, % elongation, and ultimate strength, a uni axial tensile test was conducted. Evaluating the behaviour of CP-Titanium grade-2 under stress and strain is the primary objective of tensile testing. It is tugged until flat, uniform-cross-section specimen ruptures. Before executing the test,

the original cross-section area and gauge length are determined. Using comfort-based data gathering, the applied load and gauge displacement are continually monitored throughout the test. The specimen's length and surface quality are such that both ends can be tightly grasped during testing.
To assess the tensile qualities, the test was conducted using a tension fixture in a Tinius Olsen 50 KN-capable Universal Testing Machine (UTM) and test speeds ranging from 0.001 mm/min to 500 mm/min (Fig. 2). In the tensile test, six specimens of the same thickness are also employed, making a total of thirty specimens prepared for five different thicknesses as illustrated in Fig 3. At room temperature, samples of varying thickness were evaluated at 0.1 mm/min, 1 mm/min, and 10 mm/min loading rates.


Fig. 2 - Tinius Olsen Universal Testing Machine

Fig. 3- Standard tensile specimens

### III. Results and Discussion

The material specimens are made by ASTM B265 and put through a tensile test. Since there are five different types of specimens used in the tensile test i.e., 0.5mm, 1mm, 1.5mm, 2mm, and 2.5mm, each specimen is put through three different loading rates i.e., 0.1mm/min, 1mm/min, and 10mm/min.
The stress-strain curve of CpTi grade-2 undergone a uniaxial tensile test is shown in Fig. 3(a-e) at various loading rates and thicknesses. Some of the most crucial qualities can be gathered from the outcome. The maximum mechanical values were seen in Fig. 4 at a loading rate of 10 mm/min, whereas the mechanical properties with the least values were observed during a loading rate of 0.1 mm/min for all specified thicknesses. Table 3 displays the mechanical property value for each loading rate value. The results of testing with an increased loading rate reveal that the value of the loading rate corresponds to the increased yield and maximum tensile stress.

Table 3- Mechanical characteristics under various loading rates

| **Thickness (mm)** | **Loading rate (mm/min)** | **Tensile Strength (MPa)** | **Yield stress(MPa)** |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 0.5 | 0.1 | 232 | 220 |
| | 1 | 252 | 250 |
| | 10 | 269 | 280 |
| 1 | 0.1 | 318 | 255 |
| | 1 | 339 | 310 |
| | 10 | 360 | 323 |
| 1.5 | 0.1 | 404 | 370 |
| | 1 | 441 | 400 |
| | 10 | 471 | 450 |
| 2 | 0.1 | 325 | 235 |
| | 1 | 337 | 290 |
| | 10 | 358 | 320 |
| 2.5 | 0.1 | 380 | 290 |
| | 1 | 390 | 380 |
| | 10 | 405 | 420 |

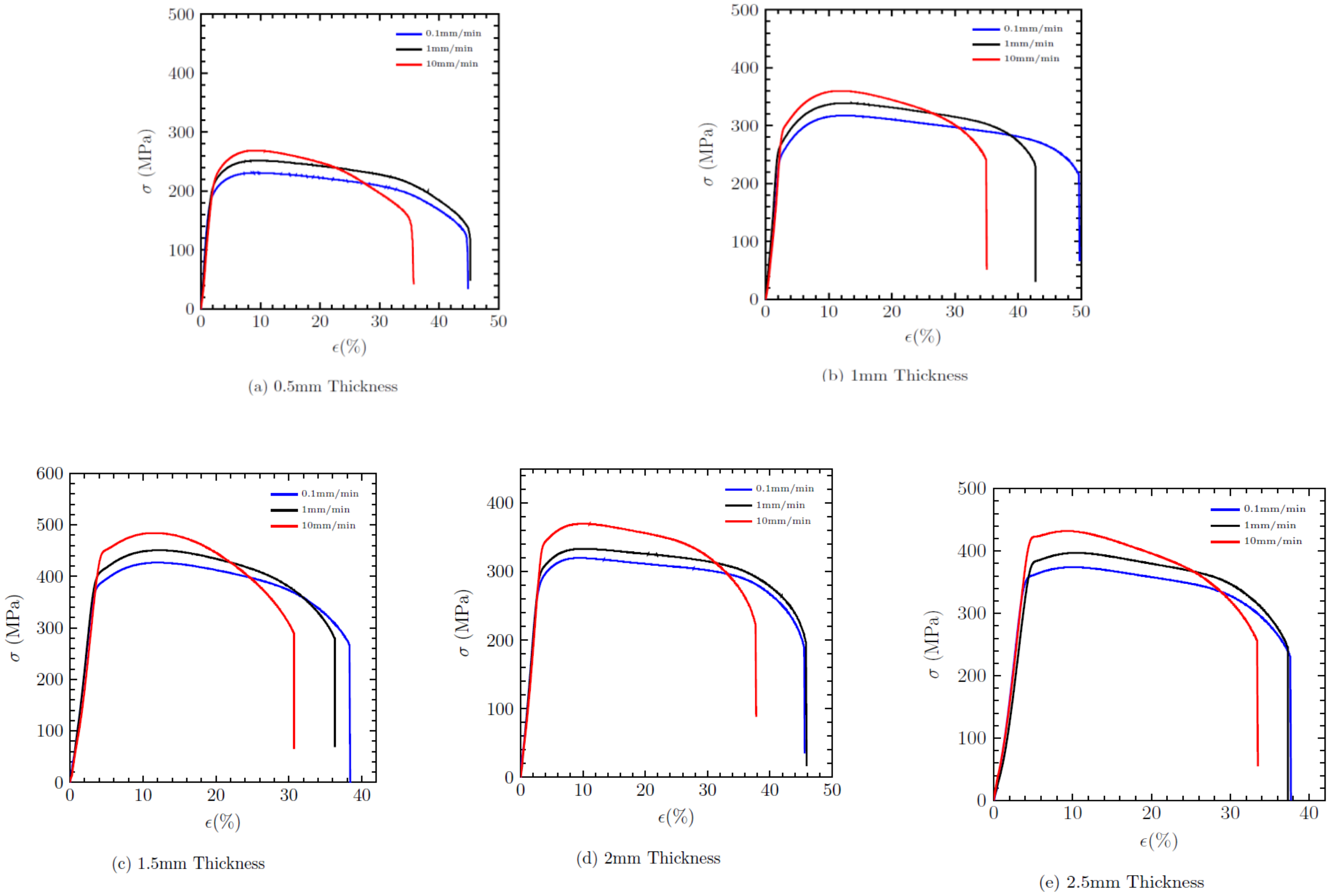


Fig. 4- CP Titanium grade-2 Stress-Strain curves at different loading rates and thickness (a) 0.5 mm thickness, (b) 1.0 mm thickness, (c)1.5 mm thickness, (d)2.0 mm thickness, and (e) 2.5 mm thickness

The specimen has undergone the greatest amount of stress possible. The greatest ultimate stress i.e., 471 MPa is derived from a specimen with a thickness of 1.5 mm and a loading rate of 10 mm per minute. UTS is determined for all types of strain rates as well as for various specimen thicknesses. The UTS of the specimen is also influenced by the strain rate and the thickness of the specimen. A material's ability to endure loads without breaking down from severe stress under pulling forces is known as yield strength. It is removed from the stress-strain curve of materials with varying thicknesses that depends on the specimen's area. A high loading rate offers better yield strength than low and medium loading rates, while medium-thickness specimens deliver yield strength that is superior to other thickness specimens. The UTS and Yield stress v/s loading rate curves are shown in Fig. 5. It demonstrates that the specified material's load-carrying capacity is higher at higher loading rates.

The experimental findings for the yield stress and ultimate tensile stress for loading rates of 0.1mm/min, 1mm/min, and 10mm/min, respectively, with varied thicknesses, are shown in Fig. 6(a),(b), and (c).According to Fig. 5, as the thickness rises from 0.5mm to 2.5mm, the yield stress calculated from the experimental stress-strain graph of CP-Titanium grade-2 changes from 220 to 370 MPa for 0.1mm/min loading rate, 250 to 400 MPa for 1mm/min loading rate, and 280 to 450 MPa for 10mm/min loading rate. As the thickness grows from 0.5mm to 2.5mm, the ultimate tensile strength changes from 232 to 404 MPa for 0.1mm/min loading rate, 252 to 441 MPa for 1mm/min loading rate, and 269 to 471 MPa for 10mm/min loading rate.

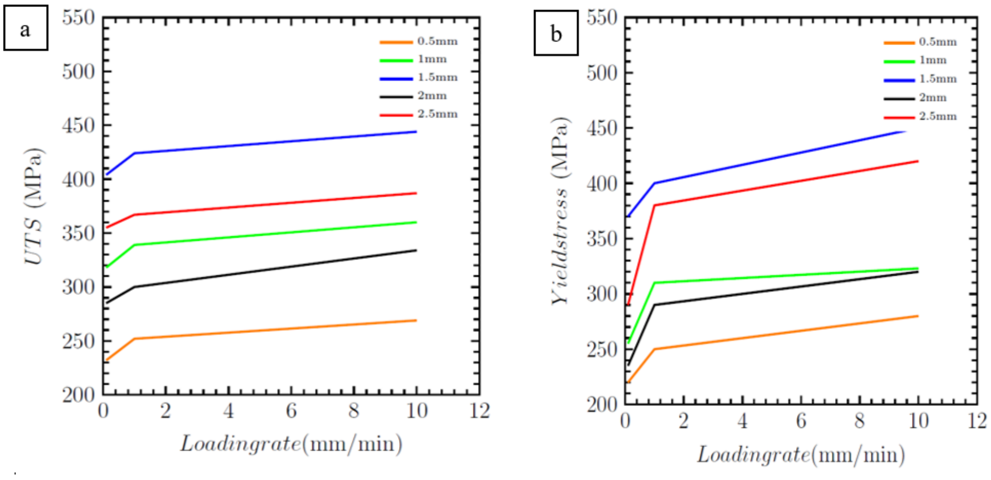


Fig. 5 - Effect of loading rate on ultimate tensile strength and yield stress

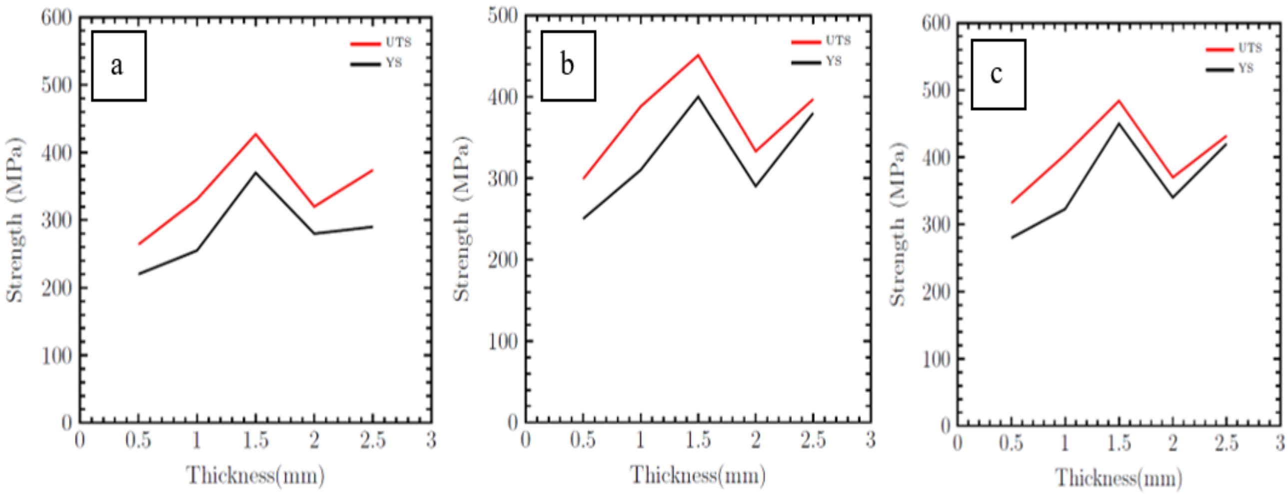


Fig. 6 - Dependency of the yield stress (YS) and the ultimate tensile stress (UTS) on the thickness of specimen for loading rate (a) 0.1mm/min (b) 1mm/min (c) 10mm/min

## IV. Conclusion

The mechanical characteristics of CP-Titanium grade-2 at various loading rates and thicknesses was examined in this study. The material was characterized at different loading rates of 0.1mm/min, 1mm/min, and 10mm/min with various thicknesses of 0.5mm, 1mm, 1.5mm, 2mm, and 2.5mm. The findings of the uniaxial tensile test support the following assertions:

Based on the result from uniaxial tensile test, It may be concluded that as the loading rate value increases, the material's mechanical properties similarly rise in proportion to the loading rate value.

The greatest mechanical values were attained at a loading rate of 10 mm/min, with a yield stress of 450 MPa and a maximum tensile strength of 471 MPa.

The least mechanical values were attained at a loading rate of 0.1 mm/min, with a yield stress of 220 MPa and a maximum tensile strength of roughly 232 MPa.

Finally, it was determined that thickness variations affected mechanical properties such as mechanical strength.

**REFERENCES:**


1. ASTM B557M-10. American Society for testing and Materials, Philadelphia.
2. EOS GmbH (2010). Material Properties Polyamide, 12, pp. 2.
3. Rose J.H. Universal Binding Energy Curves for Metals and Bimetallic Inter- faces. The American Physical Society 1981; 47: 675-1981.
4. Kushwah, S., Parekh, S., Mistry, H. et al.(2022) A methodological study of leaf spring by material comparison and Taguchi's DOE: 239–252. https://doi.org/10.1007/s12008-021-00831-8
5. EOS GmbH (2015), EOS PEEK HP3.
6. FDA (2013). FDA 510k Clearance Oxford Medical PEKK.
7. Takebe H, Mori K, Takahashi K, Fujii H. (2016). Effects of thickness and grain size on tensile properties of pure titanium.:491-494.
8. Tan H., Liu C. et al.( 2006). The cohesive law for the particle/matrix interfaces in high explosives. Journal of Mechanics and Physics of Solids; 53: 1892-1917.
9. Raulea L V, Goijaerts AM, Govaert LE, Baaijens FPT (2001). Size effects in the processing of thin metal sheets.;115:44-48
10. Rachman M, Machmud MN (2018). The Influence of Strain Rate To Mechanical Properties OnLow Alloy Steel ASTMA36.;050003. doi:10.1063/1.5046276
11. Suh CH, Jung Y, Kim YS (2010). Effects of thickness and surface roughness on mechanical properties.;24(10):2091-2098. doi:10.1007/s12206-010-0707-7
12. Thongpin C, Srimuk J. (2016). Effect of loading rate on tensile properties and failure behaviour of glass fibre / epoxy composite Effect of loading rate on tensile properties and failure behaviour of glass fibre / epoxy composite. doi:10.1088/1757-899X/115/1/012017
13. Sciences T. Effects of Temperatures and Strain Rate on the Mechanical Behaviour of Commercial Aluminium Alloy AA6061. 2019;1(1):21-26.
14. Ravikumar Patel et al. (2022). A review article on FDM process parameters in 3D printing for composite materials, Materials Today: Proceedings, Volume 60, Part 3, Pages 2162-2166, https://doi.org/10.1016/j.matpr.2022.02.385
15. Sandyal P, Sreenath N, Sandyal A (2019). Effect of strain rate and thickness on mechanical properties of jute / glass hybrid fiber composites.:269-275.
16. Yuan WJ, Zhang ZL, Su YJ, Qiao LJ, Chu WY (2012). Influence of specimen thickness with rectangular cross-section on the tensile properties of structural steels.532:601-605. doi:10.1016/j.msea.2011.11.021
17. Kushwah, S (2021). An Oscillating Water Column (OWC): The Wave Energy Converter. J. Inst. Eng. India Ser. C 102, 1311–1317. https://doi.org/10.1007/s40032-021-00730-7
18. Srinivasan N, Velmurugan R, Kumar R, Kumar S (2016). Materials Science & Engineering A Deformation behavior of commercially pure ( CP ) titanium under equi-biaxial tension. Mater Sci Eng A. 674:540-551. doi:10.1016/j.msea.2016.08.018
19. Gibson, L. J. and Ashby, M. F. (1988), Cellular Solids – Structure and Properties, Pergamon Press. Greene, C. D. and Heaney, D. F. (2007), 'The PVT effect on the final sintered dimensions of powder injection molded components', Materials and Design, 28, 95–100.
20. Saxena, A., Kumaraswamy, A., Sethi, S., Madhusudhan Reddy, G. and Madhu, V.(2018). Microstructural characterization and high strain rate plastic flow behavior of SMAW Armox500T steel joints from spherical indentation experiments. Journal of Materials Engineering and Performance, 27, pp.4261-4269.
21. Heaney, D. F. and German, R. M. (2001). 'Porous stainless steel parts using selective laser sintering', Advances in Powder Metallurgy and Particulate Materials, 8, 73.
22. Heaney, D. F., Gurosik, J. D., and Binet, C. (2005). Isotropic forming of porous structures via metal injection molding, Journal of Material Science, 40, 973–981.
23. Jena, A., Gupta, K., and Sarkar, P. (2003). 'Porosity characterisation of microporous small ceramic components', American Ceramic Society Bulletin, 82(12), 9401–9406.
24. Rajpurohit, A., Patel, K., Naik, J., Bhatt, M., Sondagar, M., Kushwah, S. (2022). Design and Analysis of Piston Comparing Different Materials. In: Kumar, S., Ramkumar, J., Kyratsis, P. (eds) Recent Advances in Manufacturing Modelling and Optimization. Lecture Notes in Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-16-9952-8_59
25. Lefebvre, L. P. and Thomas, Y. (2003). 'Method of making open cell material', US Patent 6660224.
26. Miyasaka, K., Manabe, T., and Konishi, M. (1976). 'A modified penetration rate method for measuring the wettability of magnesium oxide powders', Chemical and Pharmaceutical Bulletin, 24(2), 330–336.
27. Sushant Merai et al (2022). A study and design of standing wheelchair, Materials Today: Proceedings, ,https://doi.org/10.1016/j.matpr.2022.06.485