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The Influence of Cold Rolling Treatment on the SS 316L Surface Properties

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ABSTRACT

The biomedical engineering is increasingly developing with the creation of biomaterial dental crown products that can be used if teeth are damaged from an aesthetic perspective. 316L stainless steel is a biomaterial because it has good corrosion resistance and high mechanical characteristics. However, the corrosion resistance and mechanical strength of 316L stainless steel still need to be improved so that it can be a better dental crown material. This research objective is to increase the mechanical value of 316L stainless steel by cold rolling treatment. Variations in reducing thickness by cold rolling consist of 0%, 5%, and 12%. After that, the specimen will be tested for Vickers hardness on the specimen surface and wettability. The results obtained after the treatment were carried out that the greater the variation in reducing the thickness of the specimen, the greater the Vickers hardness value. However, in the wettability test, the contact angle value decreased along with increasing variations in thickness reduction. The increase in surface hardness value is due to the granules becoming denser due to the influence of cold rolling. This reduces the contact angle value so that the value of all variations becomes less than 90˚.

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INTRODUCTION

One of the systems in the human body is the digestive system. The function of the digestive system is to process food and beverages so that nutrients can be absorbed by the body to be used as energy. In the digestive system, there is a role for the body's organs such as mouth and teeth. The role of these oral organs is the main thing before the process of digestion and absorption of nutrients is carried out. The process of breaking down the food and beverages will be carried out by the teeth after it enters the mouth. Food and beverages that come into direct contact with teeth, if not cleaned regularly, will cause plaque on teeth. The interaction that occurs between plaque and food that enters the mouth will cause dental caries because the tooth enamel layer is dissolved. Cavities often occur due to dental caries that are not treated immediately so that the human digestive system can be disrupted (Davis et al., 2020; Sensoy, 2021).

The biomedical field which continues to develop has created a dental crown product that can be used if teeth are damaged (Sun et al., 2023). Materials used in biomedicine can use biomaterials. The properties that biomaterials must have in the human body is able to accept the implanted biomaterial without any side effects according to the organ being replaced and not release carcinogenic or toxic ions in the body. Stainless steel 316L (SS 316L) is one of the biomaterials because it has durability, good corrosion, and high mechanical properties (Goharian & Abdullah, 2017; Shahmir et al., 2024). In the biomedical field, SS 316L is used for bone implants, dental crowns, and braces because it has good biocompatibility, low price, high mechanical strength, and is easy to shape. However, the corrosion resistance and mechanical strength properties of SS 316L still need to be improved to be able to be a better material for biomaterials (Agarwal et al., 2020; Zahir et al., 2022).

One method that can be used to improve the physical and mechanical quality of SS 316L is cold cold-working (Singh, 2020). High oxygen consumption can fail a material due to a corrosion reaction, thereby endangering patients who use the material. Therefore, surface treatment must be carried out to improve the mechanical properties, wear, and corrosion of SS 316L. The cold working applied in this study is cold rolling. Cold rolling is the process of reducing the thickness of a material using a rolling machine which is carried out below the recrystallization temperature. The cold rolling process will create residual stress in the material, thus increasing the mechanical value (Jacobs et al., 2023; J. Liu et al., 2024). In the research of Mohammadzehi et al., (2023), unidirectional and cross-rolling treatments were carried out with variations in thickness reduction of 12.5-75% on SS 316L material. The results of this research show that with a thickness reduction variation of 25% with rolling direction in the same direction the mechanical value increases due to the growth of grain dislocations in the SS 316L material. Then, after all variation specimens have been mechanically tested, the results will show an increasing trend. Thus, cold rolling has the potential to increase mechanical strength values. In the research of Aghamohammadi & Jamaati, (2024), the mechanical properties of AISI 430 with cold rolling treatment were investigated. The specimens used have a thickness of 4 mm with thickness reduction variations of 20%, 40%, and 60%. After tensile testing, the 60% thickness reduction variation had yield stress and ultimate strength values of 823 MPa and 833 MPa respectively. This is due to the strain occurring in the grains of AISI 430, resulting in the creation of dislocations. The increasing thickness reduction will increase the strain and compact the grain dislocations so that the thickness reduction has a significant effect on rolling. Therefore, this research aims to increase the mechanical value of SS316L material in low-thickness reduction variations by cold rolling.

METHOD

The material used in this research was an SS316L plate with dimensions of 200 mm length, 100 mm width, and 3 mm thickness. The variations in cold rolling thickness reduction applied are 0%, 5%, and 12%. The research flow chart is shown in Figure 1. The rolling procedure is carried out at room temperature. Surface hardness testing uses the Vickers hardness method with a Buehler Micromet series. The indentation load for testing the surface hardness of the specimens is carried out at 3 different points with a force load of 200 grams for 15 seconds. Wettability testing uses several tools such as a camera, alcohol, distilled water, and dropper pipettes. The size of the specimens carried out in this test is 20 mm long and 20 mm wide with a thickness according to the variation in thickness reduction that has been given. Before carrying out a wettability test, the surface of the specimens must be cleaned using alcohol, so the dirt does not stick to the surface of the specimen. This test is carried out by calculating the average value of the contact angle between the droplet and the surface of the specimens. The process of taking the wettability value is carried out twice at each different point on the center surface of the specimen. The wettability schematic experiment is shown in Figure 2.

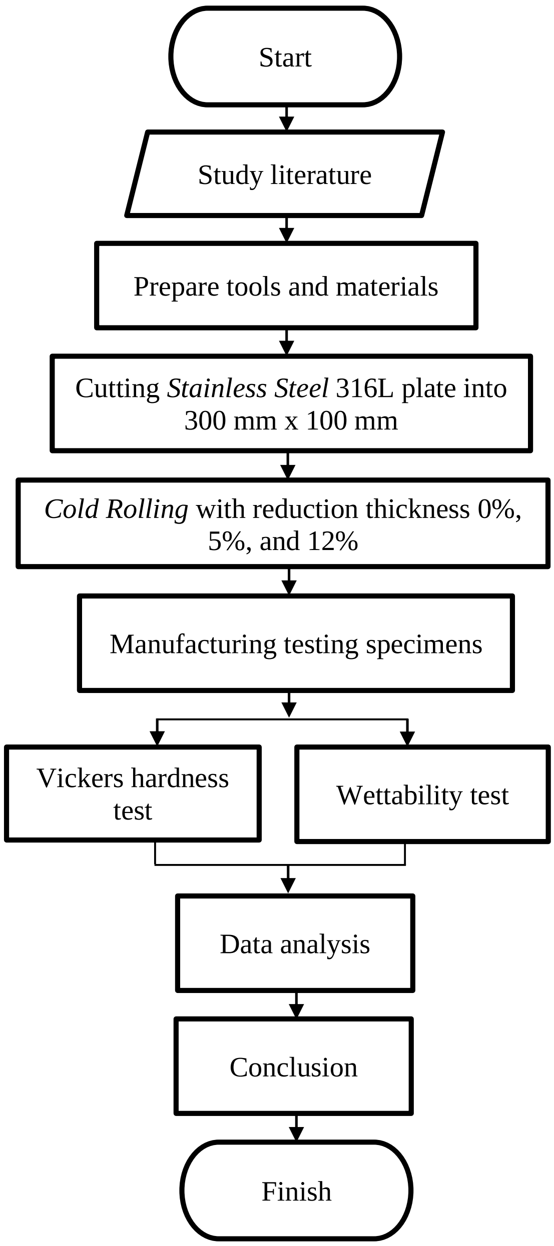

Figure 1. Flow Chart

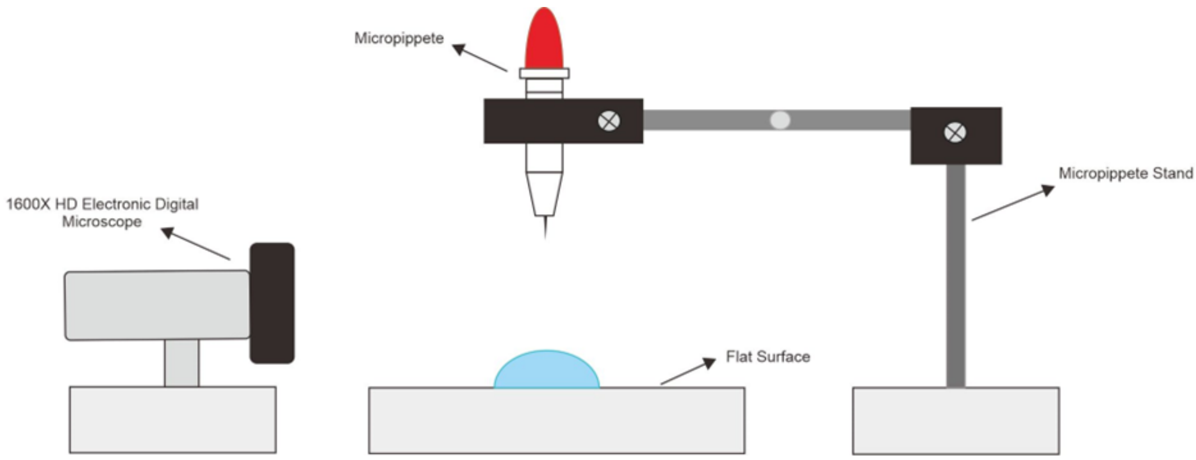

Figure 2. Wettability schematic experiment

RESULTS AND DISCUSSION

Surface Hardness Test

Hardness testing on specimens is carried out using the Vickers method (HV). HV is obtained from the results of calculating the diagonal length value from the indentation test.

$$\mathrm{HV} = \frac{2P\sin(\frac{136}{2})}{d^2/1} = \frac{1.8544P}{d^2} \quad (1)$$

In the surface hardness test, a diagonal indentation length test was carried out at 3 center points with an indentation load of 200 gf within 15 seconds. The data obtained from the test is calculated from the average of each point to become the HV value on the following Table 1.

Table 1. Surface Hardness SS316L

Thickness Reduction (%)	HV Average (kgf/mm^2)
0	275.25
5	485.48
12	532.76

From the test results data, the HV value obtained shows that the thickness reduction specimens that occur, the greater HV value obtained on the following chart in Figure 3. This means that SS316L which is treated by cold rolling will encounter plastic deformation causing the material to become harder. The increases in HV value are caused by dislocation growth due to plastic deformation. Grain dislocations will grow and trigger interactions between the other grains, causing the dislocation density to be denser and inhibit each other, which can lead to increased hardness values (L. Liu et al., 2024; Poojari et al., 2024; Zhu et al., 2024).

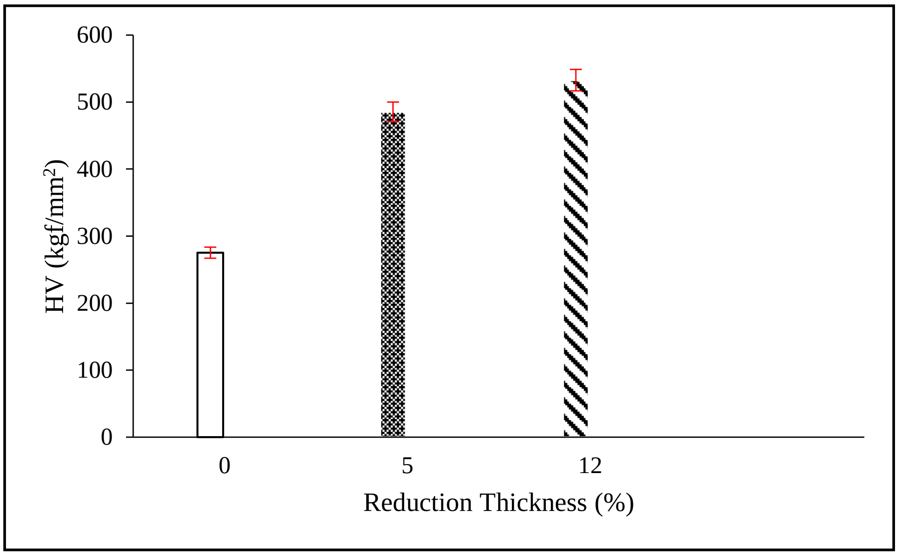

Figure 3. Bar chart of HV surface SS316L

Wettability

Wettability testing is carried out to determine the wetting properties of a material surface after being treated with cold rolling. The contact angle value between the surface and the droplet is the result of wettability testing. The contact angle value will be visible after distilled water is dripped onto the surface of the test material at a predetermined point (Sajid & Kiran, 2018). The help of a micro camera will make it easier to analyze the contact angle value after the image-taking process. Then, contact angle analysis can be determined from the material that has been tested. Data values for calculating droplet contact angles on test materials with cold rolling treatment can be observed in Table 2.

Table 2. Surface Wettability SS316L

Thickness Reduction (%)	Contact Angle Average (°)
0	88.07
5	80.32
12	75.01

The data values contained in Table 2 show that the droplet contact angle value for each material surface shows a decrease in value with each variation. This decrease in value shows that cold rolling treatment is able to improve the material-wetting properties of each specimen tested. The 0% or raw specimen was tested first with a test value obtained of 88.97°. The next process is testing on each variation starting with a thickness reduction variation of 5% and 12%. The contact angle values obtained in each variation respectively are 80.32° and 75.01°. The following is a graph of the contact angle values for each specimen which can be seen in Figure 4.

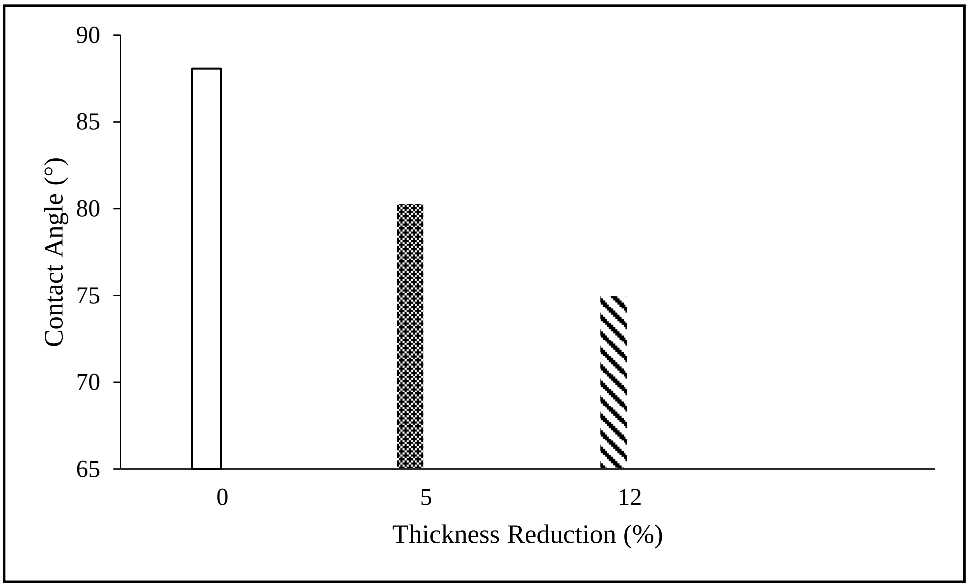

Figure 4. Bar chart of wettability SS316L

All wettability values obtained for each specimen indicate that all specimens have hydrophilic properties (Cui et al., 2018). This is because the value of each specimen has a droplet contact angle of less than 90° (Gao et al., 2023; Lu et al., 2021). The trend of decreasing contact angle values in the graph in Figure 4 shows that cold rolling treatment is able to increase the wettability properties of the specimen surface. In biomedical materials, especially implants, wettability has a significant impact on the level of protein adsorption. Biomaterials with hydrophilic properties increase protein absorption and material biocompatibility (Bagherifard et al., 2016; Pathote et al., 2023).

CONCLUSION

The study results show that the cold rolling treatment influences the surface properties of SS 316L. The greater variation in the cold rolling thickness reduction increases the surface Vickers hardness value. The highest surface Vickers hardness value was found in the specimen with a 12% thickness reduction of 532.76 MPa and the lowest value in the 0% specimen was 275.25 MPa. Then, the cold rolling treatment of the specimen was able to reduce the droplet contact angle value on the material. The results obtained from the wettability test showed that all specimens were hydrophilic. However, as the variation in thickness reduction increases, the value will decrease. The lowest contact angle value for the wettability test was found on the specimen with a thickness reduction of 12%, namely 75.01° and the highest contact angle value was 88.97° on the 0% specimen.

REFERENCES

Agarwal, K. M., Singh, P., Mohan, U., Mandal, S., & Bhatia, D. (2020). Comprehensive study related to advancement in biomaterials for medical applications. *Sensors International*, *1*(November), 100055. https://doi.org/10.1016/j.sintl.2020.100055.

Aghamohammadi, H., & Jamaati, R. (2024). Effect of cold single-roll drive rolling on the microstructural evolution and mechanical properties of ferritic stainless steel. *Journal of Materials Research and Technology*, *29*(February), 2679–2688. https://doi.org/10.1016/j.jmrt.2024.02.016.

Bagherifard, S., Slawik, S., Fernández-Pariente, I., Pauly, C., Mücklich, F., & Guagliano, M. (2016). Nanoscale surface modification of AISI 316L stainless steel by severe shot peening. *Materials and Design*, *102*, 68–77. https://doi.org/10.1016/j.matdes.2016.03.162.

Cui, C., Duan, X., Collier, B., & Poduska, K. M. (2018). Fabrication and wettability analysis of hydrophobic stainless steel surfaces with microscale structures from nanosecond laser machining. *Journal of Micro and Nano-Manufacturing*, *6*(3), 1–8. https://doi.org/10.1115/1.4040469.

Davis, K. A., Mountain, R. V., Pickett, O. R., Den Besten, P. K., Bidlack, F. B., & Dunn, E. C. (2020). Teeth as Potential New Tools to Measure Early-Life Adversity and Subsequent Mental Health Risk: An Interdisciplinary Review and Conceptual Model. *Biological Psychiatry*, *87*(6), 502–513. https://doi.org/10.1016/j.biopsych.2019.09.030.

Gao, D., Li, C., Zhang, C., Yang, B., Lin, T., Chen, L., Si, X., Qi, J., & Cao, J. (2023). Microstructure and wettability of the micro-laminated Ti6Al4V/304 stainless steel composite fabricated by diffusion bonding. *Journal of Materials Research and Technology*, *27*(October), 3788–3796. https://doi.org/10.1016/j.jmrt.2023.10.219.

Goharian, A., & Abdullah, M. R. (2017). Bioinert Metals (Stainless Steel, Titanium, Cobalt Chromium). In *Trauma Plating Systems: Biomechanical, Material, Biological, and Clinical Aspects*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-804634-0.00007-0.

Jacobs, L. J. M., Atzema, E. H., Moerman, J., & de Rooij, M. B. (2023). Quantification of the In fluence of anisotropic plastic yielding on cold rolling force. *Journal of Materials Processing Technology*, *319*(February), 118055. https://doi.org/10.1016/j.jmatprotec.2023.118055.

Liu, J., Dong, L., Li, C., Fang, J., Chen, Y., & Cui, J. (2024). Quasi-static and dynamic tensile behaviour of 316L stainless steels: Rolled versus laser-powder bed fusion (LPBF) fabricated samples. *International Journal of Impact Engineering*, *190*(April), 104972. https://doi.org/10.1016/j.ijimpeng.2024.104972.

Liu, L., Fei, R., Sun, F., Bi, H., Chang, E., & Li, M. (2024). Effect of cold rolling deformation on the pitting corrosion behavior of high-strength metastable austenitic stainless steel 14Cr10Mn in simulated coastal atmospheric environments. *Journal of Materials Research and Technology*, *29*(December 2023), 1476–1486. https://doi.org/10.1016/j.jmrt.2024.01.230.

Lu, L., Yao, W., Xie, Y., Li, K., & Wan, Z. (2021). Study on the wettability of biomimetic stainless-steel surfaces inspired by Bauhinia Linn. leaf. *Surface and Coatings Technology*, *405*(November 2020), 126721. https://doi.org/10.1016/j.surfcoat.2020.126721.

Mohammadzehi, S., Mirzadeh, H., Sohrabi, M. J., Roostaei, M., & Mahmudi, R. (2023). Elucidating the effects of cold rolling route on the mechanical properties of AISI 316L austenitic stainless steel. *Materials Science and Engineering: A*, *865*(August 2022), 144616. https://doi.org/10.1016/j.msea.2023.144616.

Pathote, D., Kumari, P., Singh, V., Jaiswal, D., Gautam, R. K., & Behera, C. K. (2023). Biocompatibility evaluation, wettability, and scratch behavior of Ta-coated 316L stainless steel by DC magnetron sputtering for the orthopedic applications. *Surface and Coatings Technology*, *459*(January), 129392. https://doi.org/10.1016/j.surfcoat.2023.129392.

Poojari, G., Kumar, H., Sampreeth, S., Tharian, T., Makineni, S. K., Singh, S. B., & Kar, S. K. (2024). Effect of prior cold rolling and aging temperature on PH martensitic stainless steel: Evolution of microstructure, micro-texture and austenite stability. *Materialia*, *33*(February), 102040. https://doi.org/10.1016/j.mtla.2024.102040.

Sajid, H. U., & Kiran, R. (2018). Influence of corrosion and surface roughness on wettability of ASTM A36 steels. *Journal of Constructional Steel Research*, *144*, 310–326. https://doi.org/10.1016/j.jcsr.2018.01.023.

Sensoy, I. (2021). A review on the food digestion in the digestive tract and the used in vitro models. *Current Research in Food Science*, *4*(April), 308–319. https://doi.org/10.1016/j.crfs.2021.04.004.

Shahmir, H., Al-Asadi, N. K. F., & Bani-Asad, Z. J. A. A. (2024). Comparison of microstructure, mechanical properties and biocompatibility of CoCrFeNiMn high-entropy alloy with 316L stainless steel. *Intermetallics*, *167*(February), 108215. https://doi.org/10.1016/j.intermet.2024.108215.

Singh, R. (2020). Working with metals. *Applied Welding Engineering*, 93–96. https://doi.org/10.1016/b978-0-12-821348-3.00009-4.

Sun, J., Jiang, J., Xue, Z., Ma, H., Pan, J., & Qian, K. (2023). Mechanical properties of cracked teeth with different dental materials and crown parameters: An in vitro proof-of-concept. *Journal of the Mechanical Behavior of Biomedical Materials*, *145*(July), 106045. https://doi.org/10.1016/j.jmbbm.2023.106045.

Zahir, A., Mahmood, U., Nazir, A., Hussain, T., & Abid, S. (2022). Biomaterials for medical and healthcare products. In *Medical Textiles from Natural Resources*. Elsevier Ltd. https://doi.org/10.1016/B978-0-323-90479-7.00013-0.

Zhu, L., Li, K., Yang, X., He, J., Fang, J., Zhang, Z., Guo, M., & Zhang, J. (2024). Tailoring the formability and planar anisotropy of Al-Mg-Si-Cu-Zn alloys via cross hot rolling and two-stage cold rolling. *Journal of Alloys and Compounds*, *985*(February), 174089. https://doi.org/10.1016/j.jallcom.2024.174089.