International Journal of Advanced Research in Engineering and Technology (IJARET)
Volume 11, Issue 6, June 2020, pp. 175-183, Article ID: IJARET_11_06_016
Available online athttp://www.iaeme.com/IJARET/issues.asp?JType=IJARET&VType=11&IType=6
ISSN Print: 0976-6480 and ISSN Online: 0976-6499
DOI: 10.34218/IJARET.11.6.2020.016

MECHANICAL PROPERTIES OF AISI 316L FOR ARTIFICIAL HIP JOINT MATERIALS MADE BY INVESTMENT CASTING

R. A. N. Al Hakim
Center for Biomechanics, Biomaterial, Biomechatronics, and Biosignal Processing (CBIOM3S), Diponegoro University Semarang, Indonesia
Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia

O. Kurdi
Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia

R. Ismail
Center for Biomechanics, Biomaterial, Biomechatronics, and Biosignal Processing (CBIOM3S), Diponegoro University Semarang, Indonesia
Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia

S. Nugroho
Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia

J. Jamari
Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia

D.F. Fitriyana
Center for Biomechanics, Biomaterial, Biomechatronics, and Biosignal Processing (CBIOM3S), Diponegoro University Semarang, Indonesia
Department of Mechanical Engineering, Universitas Negeri Semarang, Semarang, Indonesia

M. Tauviqirrahman
Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia

A.P. Bayuseno*
Department of Mechanical Engineering, Diponegoro University, Semarang, Indonesia
*Corresponding Author Email: apbayuseno@gmail.com

ABSTRACT

The development of hip joint materials has improved rapidly in the fields of biomedical sciences. This is also accompanied by the advancement of the investment *casting process for making artificial hip joint materials. Recently, the use of steel alloys as biomaterials has grown. 316L stainless steel hip joint made using investment casting with duraluminum (Al-Cu alloy) molding was examined in the study. The purpose of this research was to evaluate the mechanical properties of AISI 316L material after the investment casting process. The mechanical characterization included tensile test, hardness test, and impact test. The results of mechanical property testing were compared to those of 316L stainless steel Ultra-Vision products and ISO 5832/1. Yield strength, ultimate tensile strength, elongation (%), hardness (HV) and impact strength for the investment casting product are 375 MPa, 579 MPa, 28 %, 126 HV and 95.06 J, respectively. In this study, the percent elongation for the investment casting product did not meet the minimum the percent elongation requirement specified by ISO 5832/1, but the hardness and strength of the investment casting product are greater than those of ISO 5832/1 standard. This investment casting approach may be adopted for making AISI 316L hip joint with the improved mechanical property.*

Key words: Investment casting, 316L stainless steel, material characterization, mechanical properties

Cite this Article: R.A.N. Al Hakim, O. Kurdi, R. Ismail, S. Nugroho, J. Jamari, D.F. Fitriyana, M. Tauviqirrahman, A.P. Bayuseno, Mechanical Properties of AISI 316L for Artificial Hip Joint Materials Made by Investment Casting, *International Journal of Advanced Research in Engineering and Technology*, 11(6), 2020, pp. 175-183.
http://www.iaeme.com/IJARET/issues.asp?JType=IJARET&VType=11&IType=6

1. INTRODUCTION

Stainless steel is commonly employed as implants for the replacement of diseased or worn joint parts. Additionally, the most common metals for use as biomaterials include titanium, and its alloys, cobalt-chromium-based alloys, tantalum, niobium, and gold [1]. Particularly, the inappropriate effect of implants in the human body may harm muscle tissues and bone. In this way, biomaterials must be biocompatible with the human body, on which they must have the ability to adapt the role of the body structure without generating the reaction that harms each other [2].

More recently, many metallic implants with better corrosion-resistance have been developed for a biomaterial that does not result in irritation, allergy, and infection on the human body. Specifically, 316L stainless steel is suitable for the implant materials on the human bones, such as artificial hip joint or artificial knee joint because of having mechanical properties, corrosion resistance and non-magnetic properties that meet the minimum criteria of the implant materials. In addition, this material is relatively low-cost and easily fabricated through a conventional casting method and the resulting products that have met the standards (Society for Testing and Materials Society for Testing and Materials-ASTM) (F138-04 and F139-03)) [1-4].

Furthermore, 316L stainless steel is for the clinical use of metal-on-plastic hip joint replacement surgeries. In addition, this material can be used in the process of osteoarthritis healing and rheumatoid arthritis. In this way, osteoarthritis and rheumatoid arthritis for aiding healing require hip joint replacement of the femoral head and acetabular sockets [5]. Nevertheless, there is a potential risk of using stainless steel in the medical material due to its nickel and chromium elements. Nickel ions could be a source of allergens, which can manifest in several ways of cutaneous inflammations such as swelling, reddening, eczema, and itches on skins. The allergy reactions may also involve teratogenicity and carcinogenicity in the human body [1]. If these alloying constituents are in trace amounts, however, they could be tolerated by the body. Accordingly, they are still biocompatible to the body environment due to their corrosive resistance on the surface.

Generally, the manufacturing of biocompatible materials includes classical casting and machining methods (turning, milling, and drilling), whereas the manufacturing process must consider the economic and precision of the geometrical product. Here investment casting (IC) is a precision casting process using a lost wax method to make the artificial hip-joint in metal cast alloys with the exact form and size of the components (precision) by minimizing porosity and other defects [6]. Moreover, the IC can produce metallic implants with complicated models, and provide reliability, better tolerance compared to the sand casting method. Additionally, the method can provide a product with smooth surface finishes and reduce machining and finishing. However, this method has the limitations of yielding accurate sizes of the component, and tend to be long lead time [6-8].

Correspondingly, for achieving the quality of investment casting, there are key parameters of investment casting related to oversized mold versus the shrinkage after cooling. In this manner, the total expansion of the investment mold could be established by considering the allowance of die tool-making, on which some parameters should be controlled through setting behavior of tank and block temperatures for the molding machine, cooling time for the wax pattern, primary coating and secondary coating composition, viscosity factor of the coating and shell firing temperature.

Several researchers have investigated the key parameters influencing on investment casting such as (1) number of liners in the ring, (2) position of liners, (3) position of the wax pattern in the ring, and (4) water/powder ratios of investments [7]. Clinical experience has suggested that other factors may also be significant in determining the setting expansion of investment and in the subsequent regulation of casting size [7]. Thus, accurate setups of casting phase development and need to better monitor the key parameters are required to yield a competitive product to the market.

This present research was aimed to investigate the investment casting product of 316L stainless steel for hip-implants through mechanical property evaluation. The casting results were then compared with that of 316L stainless steel ultra-vision and ISO 5832/1 products to determine the quality of investment casting products. It is expected that the best tensile and impact properties of the implant can be reached for use in advanced biomedical applications.

2. MATERIALS & EXPERIMENTAL PROCEDURES

2.1. Investment Casting of 316 L Stainless Steel

The raw material (316L stainless steel) selected in this experiment is presented with the chemical composition in Table 1. This raw material was purchased from PT Itokoh Ceperindo, Indonesia. Evidently, the stainless steel sample contains the main constituent alloy of Cr and Ni in addition to Fe and C. The design of the geometrical patterns for casting material is presented in Figure 1. The initial process of this experiment was to make a pattern by injecting the wax into the duralumin molding (Al-Cu alloy). The purpose of this process was to make a wax pattern. The molding used in this study was shown in Figure 2. The experimental procedures of investment casting are presented in Figure 3. After the injection molding, the next process made the assembling wax into the pattern tree attached by wax sprue. This process aims to facilitate the flow path of the molten material to fill out the void created by the wax pattern. Prior to casting, the wax tree was coated by sand with 7 layers using the slurry coating. The next process is dewaxing to remove wax from the mold using a furnace. Before being used for the casting process, the preheating process was carried out on the mold at a temperature of 1060^{O}C for 30 minutes. This preheating process was carried out to avoid crack or any damage to the mold during the material casting process [9]. Subsequently, the 316L stainless steel material was initially melted in the electric furnace and poured into the mold and left to room temperature.

Table 1 Chemical composition of 316L stainless steel

C%	Si%	Mn%	P%	S%	Cr%	Ni%	Mo%	N%	Fe
0.029	0.55	0.92	0.033	0.007	17.18	12.81	2.47	0.06	Balance

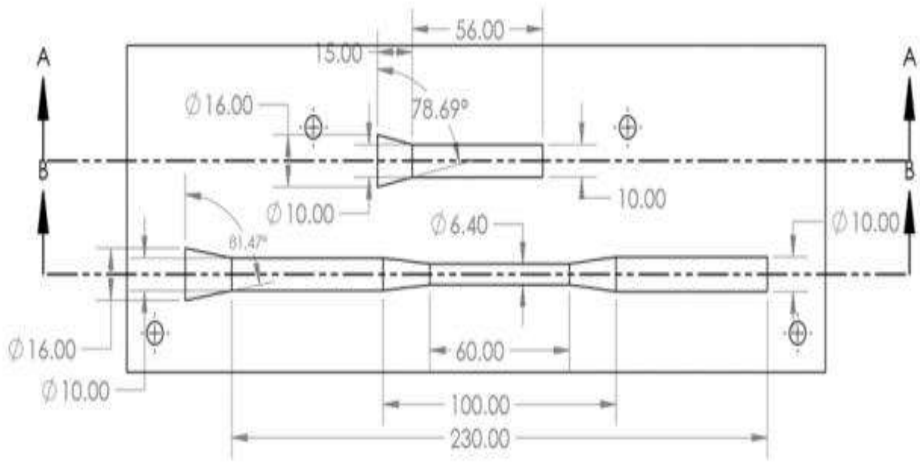

Figure 1 Design molding investment casting of 316L stainless steel samples

Figure 2 Metal dies of investment casting

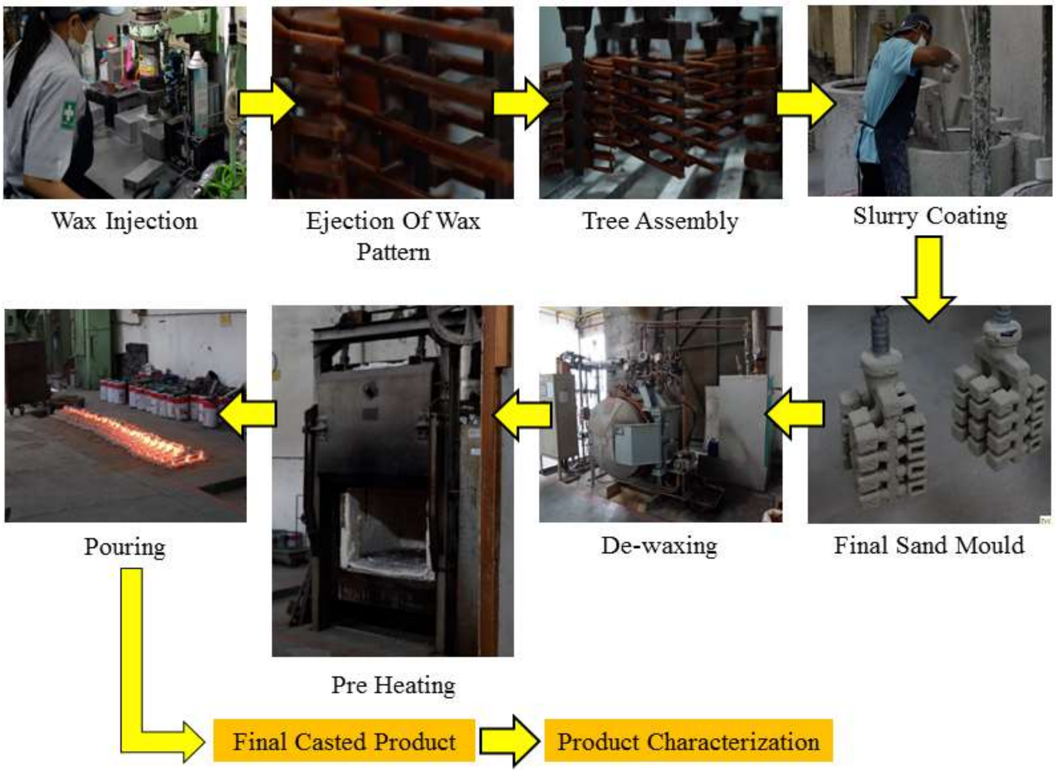

Figure 3 Experimental procedures of investment casting for 316L stainless steel

2.2. Mechanical Characterization of the Sample

Mechanical characterization of iinvestment casting products included tensile, hardness and impact tests. Specimens were manufactured according to the ASTM D3039 for tensile testing to determine the tensile strength, elastic modulus, and the failure strain of the 316L stainless steel. The tensile tests (Shimadzu UH) were set up at a load cell of 1000 kN gauge, whereas a 60 mm gauge length extensometer was selected to determine the strain from the measured data. Moreover, the hardness and impact test of the specimens were performed by Vickers and Charpy method respectively. Mechanical properties of investment casting products compared to 316L stainless steel Ultra-Vision products and ISO 5832/1 (Standards for Iron base alloys used for artificial hip joints).

3. RESULTS AND DISCUSSION

3.1. Result of Investment Casting

The hip joint made from 316L stainless steel by investment casting process resulted in products with a good surface property (Figure 4), while the result of investment casting product for chemical composition is comparative with the 316L stainless steel (Ultra-Vision) and ISO 5832/1 (Table 2). The ISO standard specifications mainly cover the chemical composition, structure and mechanical properties of Fe alloys material that are used as artificial hip joint material [10]. Evidently the products of investment casting meets the ISO 5832/1 standard because the chemical composition is a range within the specified values. Apparently, the surface roughness of casting product was very good and no subsequent machining was required. Also no defect of the product could be found during the experiments.

Figure 4 Investment casting product

Table 2 The chemical composition of several 316L stainless steel products

Chemical composition	C%	Si%	Mn%	P%	S%	Cr%	Ni%	Mo%	N%	Fe
Investment casting material	0.029	0.55	0.92	0.033	0.007	17.18	12.81	2.47	0.06	Balance
Ultra-Vision [11]	0.025	0.42	1	0.032	0.0311	17.12	10.13	2.11	0.06	Balance
ISO 5832/1 [10]	<0.03	<1	<2	<0.25	<0.015	16-19	10-16	2-3.5	-	Balance

3.2. Result of Mechanical Properties Testing

The tensile testing on iinvestment casting products was performed at the universal testing machine for 3 specimens. Figure 5 shows the obtained specimens broken into two pieces. Moreover, the results of the mechanical properties of the Investment casting products are compared with those of 316L stainless steel Ultra-Vision products and ISO 5832/1 (Table 3). The percentage (%) of elongation produced in the specimens was 28%, which did not meet the minimum percent elongation specified by ISO 5832/1 (% elongation of 40%). Conversely, the 316L stainless steel product (Ultra-Vision) has % elongation of 48.9%, which has fulfilled the minimum % elongation specified by ISO 5832/1. Importantly, the % elongation of material represents the ductility of a material and its capability of undergoing deformation without breaking. The higher the ductility refers to the higher % elongation of the material [12]. It was found in the study that the ductility of the Investment casting products is smaller than 316L stainless steel (Ultra-Vision) products and that it does not meet the minimum requirements of ISO 5832/1.

Figure 5 Speciment after tensile testing

Table 3 Mechanical properties of investment casting, Ultra Vision, and ISO 5832/1 products

Mechanical Properties	Investment casting	Ultra vision [11]	ISO 5832/1 [10]
Yield strength (MPa)	375	Not specified	170 min
Ultimate Tensile Strength (MPa)	579	651	480 min
Elongation (%)	28	48.9	40 min
Hardness (HV)	126	248	Not specified
Impact Strength (J) (Charpy)	95.06	278	Not specified

Further, the mechanical strengths of the investment casting products are higher than those specified by ISO 5832/1. The minimum yield strength and ultimate tensile strength of 316L stainless steel used for artificial hip joints according to ISO 5832/1 are 170 MPa and 480 MPa respectively. Obviously ultimate tensile strength of iinvestment casting products is lower than that of 316L stainless steel Ultra Vision products (579 MPa < 651 MPa). This low ultimate tensile strength for 316L stainless steel investment casting products may relate to the higher Ni content than that in 316L stainless steel Ultra-Vision products (12.81% versus 10.13%). Moreover, Ni content in the stainless steel may improve its strength and toughness, through triggering the formation of austenite that makes stronger and more stable at high temperatures, provides oxidation resistance, carburization, nitriding, and thermal fatigue, and increases fracture toughness. However, there are several disadvantages to high nickel concentration which makes a reduction of the tensile strength of the material [13]. Obviously the Ni content on 316L stainless steel investment casting products (12.81%) is quite high to relate the ultimate tensile strength of 579 MPa. In comparison to the Ni content of the 316L stainless steel investment casting products, the Ni content of the Ultra-Vision products is lower (10.13%), while the ultimate tensile strength is higher (651 Mpa). The lower nickel content may also increase the yield strength and ultimate tensile strength of this material. Additionally, the low nickel content makes the product becoming more economical [13-15]. It is shown that the yield strength and ultimate tensile strength of investment casting products has fulfilled the minimum requirements specified by ISO 5832/1 (Figure 6).

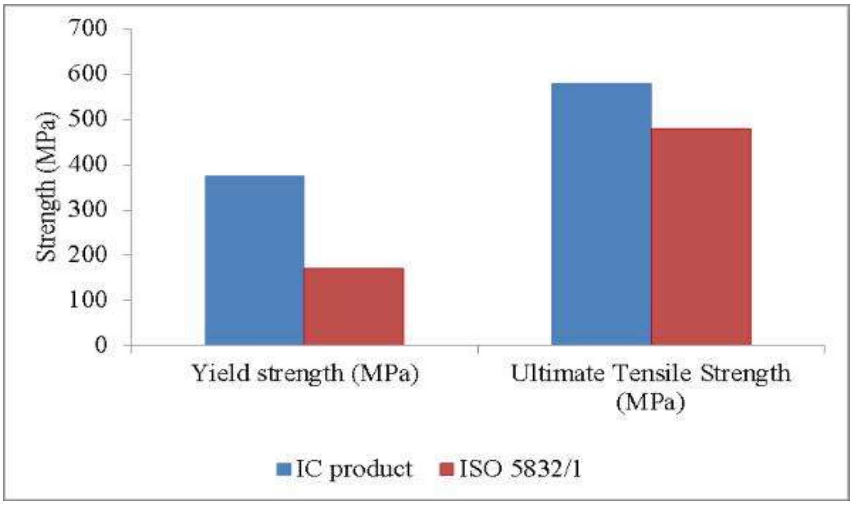

Figure 6 Mechanical strength of investment casting products and ISO 5832/1

In this study, investment casting products of 316L stainless steel and 316L stainless steel (Ultra-Vision) products have the same nitrogen content and are in accordance with the standards specified by ISO 5832/1. Moreover, the content of manganese (Mn) on 316L stainless steel investment casting products and 316L stainless steel (Ultra-Vision) products are 0.92% and 1% respectively. Here Mn content based on ISO 5832/1 should be less than 2 %. Mn in stainless steel can contribute to its hot ductility. However, its positive impact on the ferrite/austenite balance depends on the temperature: in that at low-temperature Mn could stabilize austenite, but at high temperature, Mn makes stable ferrite [16]. Increased levels of Mn in alloys increases the tensile strength, strain, hardness and toughnes [17-18]. This study demonstrated that the ultimate tensile strength, hardness and impact strength of 316L stainless steel investment casting products were 579 MPa, 126 HV and 95.06 J. respectively. These values were lower than the ultimate tensile strength, hardness and impact strength of 316L stainless steel Ultra-Vision products which is 651 MPa, 248 HV and 272 J. Reasonably, Mn content the Ultra-Vision products are greater than that of the investment casting product. The higher the manganese solubility in stainless steel leads to the more solubility of nitrogen contents in austenitic stainless steels. This is also the reason that the hardness and impact strength of the Ultra-Vision products is greater than that of investment casting products [17-20]. These results also provided the advanced knowledge for designing of 3D-artificial prosthetic leg system [21].

4. CONCLUSION

It can be concluded that the chemical composition of investment casting products meets with the standard of ISO 5832/1. The investment casting product has a higher yield strength and ultimate tensile strength compared to ISO 5832/1 product. Higher Ni content in 316L stainless steel IC products results in lower yield strength and ultimate tensile strength than those of the Ultra-Vision product which has lower Ni content. The lower Mn content in the IC products resulted in lower hardness and impact strength than that of the Ultra-Vision products which have a higher Mn content. In this study, the % elongation of the IC product was 28 %, which did not meet the minimum % elongation requirements specified by ISO 5832/1 (40 % elongation). The results proposed the advancement of investment casting for further increase in the tensile characteristics of a hip joint material.

ACKNOWLEDGEMENTS

This work is supported by Master's Research Grant provided by Institutions and Community Service (DRPM DIKTI) Indonesia under contract of number: 258-22/UN7.P4.3/PP/2019.

CONFLICTS OF INTERESTS

The authors declare no conflict of interest.

REFERENCES

[1] Yang, K. and Ren, Y. (2010) Topical Review : Nickel-free austenitic stainless steels for medical applications *Sci. Technol. Adv. Mater,* 11, pp. 13

[2] Anwar, I. B., Saputra, E., Jamari, J., & van der Heide, E. (2015) Preliminary Study on the Biocompatibility of Stainless Steel 316L and UHMWPE Material, *Advanced Materials Research*, 1123, pp. 160–163.

[3] Suprihanto A., Fitriyana D.F., Armila, Caesarendra W. (2020) An Application of High Temperature Gas Nitriding (HTGN) Method to Improve the Quality of Implant Materials 316L and 316LVM. In: Murakami RI., Koinkar P., Fujii T., Kim TG., Abdullah H. (eds) NAC 2019. Springer Proceedings in Physics, vol 242. pp. 131-142.

[4] Martinesi, M., Bruni, S., Stio, M., Treves, C., Bacci, T., & Borgioli, F. (2007) Biocompatibility evaluation of surface-treated AISI 316L austenitic stainless steel in human cell cultures, *Journal of Biomedical Materials Research Part A*, 80A(1), pp. 131–145.

[5] M. Sivasankar, S. Arunkumar, V. Bakkiyaraj, A. Muruganandam, S. Sathishkumar, (2016) A Review on Total Hip Replacement, *International Research Journal in Advanced Engineering and Technology* (IRJAET), 2 (2), pp. 589-642.

[6] Singh, S., & Singh, R., (2015) Precision investment casting: A state of art review and future trends, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 230(12), pp. 2143–2164.

[7] Singh, R., Singh, S., & Kapoor, P., (2014) Development of Biomedical Implant (Hip Joint) by Combining Fused Deposition Modelling and Investment Casting, Proceedings of the International Conference on Research and Innovations in Mechanical Engineering, 204, pp. 225–232.

[8] Kumar, P., Ahuja, I. S., & Singh, R. (2016) Experimental investigations on hardness of the biomedical implants prepared by hybrid investment casting, *Journal of Manufacturing Processes,* 21, pp. 160–171.

[9] Singh, S., & Singh, R. (2015) Precision investment casting: A state of art review and future trends. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 230(12), pp. 2143–2164.

[10] Semlitsch, M., and Willert, H. G., (1980) *Med. & Biol. Eng. & Comput*, 18 (4), pp. 511-520.

[11] Fiawoyife, D.E., (2012) Effect of Temperature and Carbonaceous Environment on the Fatigue Behaviour of AISI 316l Austenitic Stainless Steel, Master of Science in Engineering Dissertation, Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg.

[12] Callister, William D., (2007) Materials Science and Engineering: An Introduction 7th ed.

[13] Rimac, M., Beganović, O., (2012) Optimization of Nickel Content In Aisi 316 Steel Alloyed With Nitrogen, 16th International Research/Expert Conference ”Trends in the Development of Machinery and Associated Technology” TMT 2012, pp. 183 – 186.

[14] Oruč M., Rimac M., Beganović O., Muhamedagić S., (2011) Alloys with modified characteristics, *Materials and technology,* 45(5), pp. 483-487.

[15] Oruč M., Rimac M., Beganović O., Delić A., (2009) New materials for development of modern industrial technologies, 13th International Research/Expert Conference “Trends in the development of Machinery and Associated Technology”, pp. 133-136.

[16] Leffler, B., STAINLESS-stainless steels and their properties https://www.tf.uni-iel.de/matwis/amat/iss/kap_9/articles/stainless_steel.pdf

[17] I. Toor, (2014) Effect of Mn Content and Solution Annealing Temperature on the Corrosion Resistance of Stainless Steel Alloys, *Journal of Chemistry*, pp. 1-8.

[18] Kartikasari, R. (2015) Effect of Mangan Content on Mechanical Properties and Corrosion Behavior of as Cast Fe-7.5Al-0.6C Alloy, *International Journal of Applied Engineering Research,* 10 (13), pp. 32884 – 32887.

[19] Yunxiu Xu, You Yang, (2018) Microstructure and Corrosion Properties 0Cr21Mn17Mo2N0.8 High Nitrogen Austenitic Stainless Steel, IOP Conf. Series: Materials Science and Engineering, 423, pp. 1-7.

[20] Ghosh, D., (2016) Effects of Grain Size and Nitrogen Content on Tensile Flow Properties of 316LN Stainless Steel at 300 K and 823 K, Master of Technology in Steel Technology Dissertation, Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology Bombay.

[21] Anggoro, P.W., Saputra, E., Tauviqirrahman, M., Jamari, J., Bayuseno, A.P., (2017) A 3-dimensional finite element analysis of the insole shoe orthotic for foot deformities, *International Journal of Applied Engineering Research* 12 (15), pp. 5254-5260.