The Effects of The Degree of Deformation In The Work Hardening Process on Microstructure, Hardness, and Phase Transformation of The Material Structure of Nickel-Free Austenitic Stainless Steel

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Abstract - Stainless steel is one of the materials used for biomedical implants in medical field since it is resistant to corrosion under various environmental conditions, high plasticity, and has an excellent fatigue endurance and toughness. One such stainless steel used for biomedical implant is nickel-free austenitic stainless steel. In recent years, this material has been developed in medical field due to its low toxicity level in human bodies. Several methods have been used to improve the quality of nickel-free austenitic stainless steel and one of them is by using the work hardening method. Resulting data from the material test shows that the degree of deformation variation applied in work hardening process in the amount of 15 %, 30 %, 45 %, and 54 %, is able to change the grain structure and increase the material hardness significantly. The work hardening process is able to change the mechanical properties and the shape of the grain structure without changing the phase of the nickel-free austenitic stainless steel's crystal structure. Based on the X-Ray Diffraction (XRD) test, it can be concluded that the phase of the test specimen's crystal structure remains unchanged from its initial crystal structure, i.e. an austenitic phase with fcc (face centered cubic) crystal structure.

Keywords : ***nickel-free austenitic stainless steel, work hardening, microstructure, hardness, phase transformation***

I. INTRODUCTION

In recent years, the development of biomedical implant technologies has rapidly grown. The material commonly used for implants to support or substitute the function of human's bones is the austenitic stainless steel. The austenitic stainless steel consists of iron-chromium as its main composition (16-28 %), while 35 % of it is nickel. This composition gives some advantages to the austenitic stainless steel, for instance, it is resistant to corrosions under corrosive environments. The chromium element in the austenitic stainless steel is able to form a passive oxidant layer, that is the Cr_2O_3 layer, which protects the surface of the material from corrosions [1].

While nickel and chromium are resistant against corrosions, they have a drawback, i.e. they are potentially harmful for human's body when applied to the implant material, stainless steel. In some cases, nickel causes allergic reactions to human's body. The Ni ion is an antigenic ion which might cause inflammations on skins in the form of rash, itching, and eczema [2].

One way to reduce the risks of allergy caused by biomedical implants is to decrease the effect of Nickel in biomaterials. Type of implant materials with a very low nickel concentration is nickel-free austenitic stainless steel, in which its nickel content is 0.3 % maximum. Nickel-free austenitic stainless steel is an implant biomaterial have been developed in medical field recently. It has very low nickel content but very high nitrogen concentration, yielding high corrosion resistance and mechanical strength. This type of material is prospective to be developed since it is relatively safe and biocompatible to the human's body [3-5].

Several methods have been used to improve the quality and the mechanical strength of nickel-free austenitic stainless steel, one of them is the work hardening method [6-7]. The work hardening process is able to increase the mechanical strength by using the principle of deformation and grain dislocation. This research aims to investigate the effects of the work hardening method on microstructure, hardness, and phase transformation of the material structure of nickel-free austenitic stainless steel.

II. RESEARCH METHODS

As testing specimen, this research uses stainless steel BioDur 108 with chemical composition : (54.54 % Fe, 21.85 % Mn, 20.43 % Cr, 0.025 % Ni, 0.67 % Mo 0.0673 % Si, and 0.95 % Ni). The dimension of the material sheet used in the work hardening test is 15 mm (length) x 15 mm (width) x 3 mm (thickness). In the work hardening process, an amount of load is applied on the test specimen using hydraulic machine with load variations of 15 %, 30 %, 45 %, and 54 %. The objective of the work hardening process is to increase the mechanical strength of the stainless steel BioDur 108 by means of changing the grain structure through a deformation process.

The resulting material from the work hardening process is subjected to several tests including the microstructure, hardness, and XRD (X-Ray Diffraction) test to examine the increase of its hardness, the microstructure shapes, and the crystal structure's phase of the stainless steel BioDur 108. Microstructure test is carried out using an optical microscope. Before being applied to the microstructure test, an etsa process is applied to the material using a chemical solution which is a mix of Hidrocloric Acid (HCl), Nitric Acid (HNO_3), and alcohol of 96 % concentration. The hardness test is performed using the Micro Vickers method with a load of 0.3 $Kg_{f,}$, while the XRD test is performed using a Shimadzu *X-Ray* Diffractometer equipment to examine the phase of material crystal structure after the work hardening process.

III. RESULTS AND DISCUSSION

The results of the microstructure test of the stainless steel BioDur 108, with the variations of the work hardening treatment of 15 %, 30 %, 45 %, and 54 %, are shown in Figure 1.

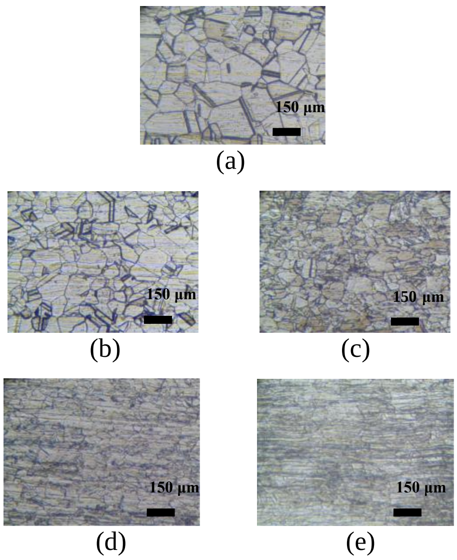

Figure 1. Microstructure of (a) *Raw Material*, (b) Work Hardening 15 %, (c) Work Hardening 30 %, (d) Work Hardening 45 %, (e) Work Hardening 54 %

The results of microstructure test shows that the grain structure was changed due to the work hardening treatment. In the material pressing process with deformation's scale 15 %, 30 %, 45 %, and 54 %, yields a grain elongation and material compression process. The microstructure also shows the existence of dislocation lines in the middle of the specimen. The higher degree of deformation scale in work hardening process, the more the resulting grain dislocations.

Figure 2 illustrates the distribution of the hardness level due to the work hardening process.

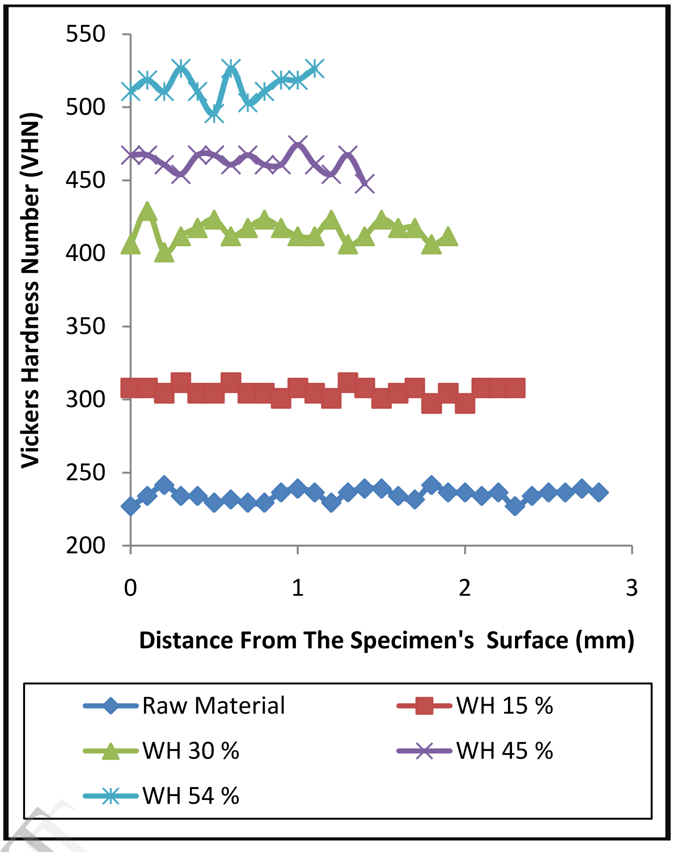

Figure 2. The Hardness Distribution of The Testing Material's Cross Section of *Nickel-Free Austenitic Stainless Steel*

Based on the graph of the hardness test's result using the Micro Vickers method, a data is obtained, which shows that the resulting hardness after the work hardening process increases with the increase of the stress scale. The initial hardness level of raw material is 235 HVN on average. Using work hardening with 15 % degree of deformation, this hardness level increases to, on average, 30 % of that of the raw material. Work hardening with 30 % treatment results in the hardness level 77 % on average of that of the raw material. Similarly, work hardening with 45 % and 54 % degree of deformation increase the hardness level 77 % and 119 % on average of that of the raw material, respectively. These improvements in hardness level occur since the work hardening, because of the existence of an amount of dislocation density results in strain hardening.

The results of XRD test of the raw material and specimen subjected to the work hardening process are depicted in Figure 3 – 7.

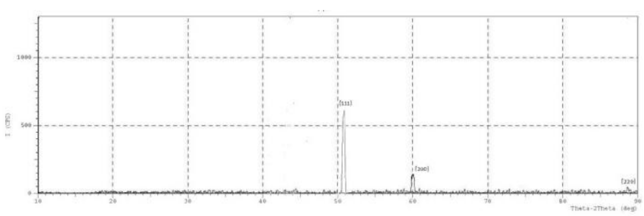

Figure 3. Result of XRD Test of Raw Material

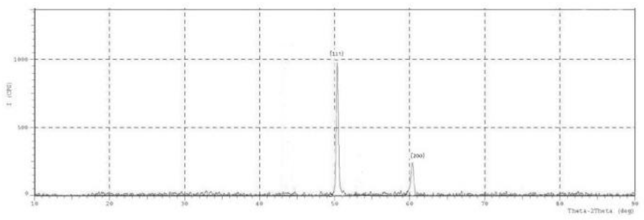

Figure 4. Result of XRD Test of Work Hardening 15 %

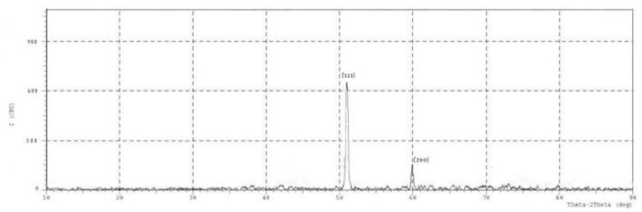

Figure 5. Result of XRD Test of Work Hardening 30 %

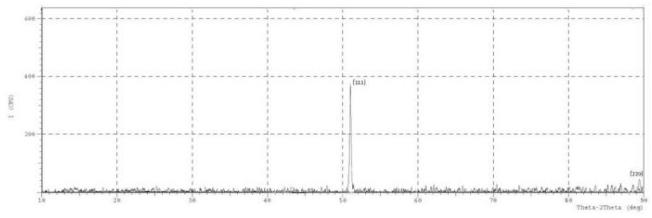

Figure 6. Result of XRD Test of Work Hardening 45 %

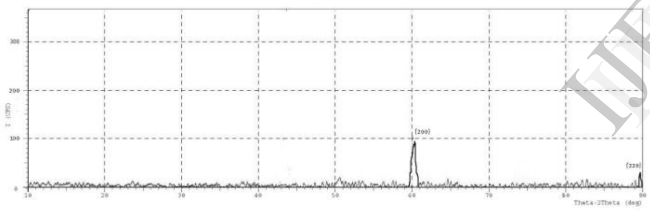

Figure 7. Result of XRD Test of *Work Hardening* 54 %

The XRD test is intended to analyze the phase transformation of the test specimen's structure. The resulting data indicates that the graph showing peaks of the initial and work hardening test specimens do not result in angle shifting nor changes in the pattern of crystal planes. The initial and the end phase of the material resulting from the work hardening process is the austenitic phase with fcc (face centered cubic) crystal structure.

IV. CONCLUSION

Over the last few decades, nickel free austenitic stainless steel has become a prospective implant material to be developed in medical field. The reason is nickel free austenitic stainless steel is an implant biomaterial with very low nickel concentration yet very high nitrogen concentration, resulting in high corrosion resistance as well as mechanical strength. Several methods have been used to improve the mechanical strength of nickel free austenitic stainless steel and one of them is the work hardening method. The results of this research show that the degree of deformation in the work hardening process is able to increase the hardness of BioDur 108 without changing its chemical compositions nor the phase of its crystal structure. Work hardening process results in dislocations, so that yields strain hardening that increases the hardness of nickel-free austenitic stainless steel.

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