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The effects of copper on the mechanical properties of Ti-10Mo alloy prepared by powder metallurgy method

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Abstract

Titanium alloys are currently widely explored and produced for applications in various engineering fields. Alloying metal elements such as Mo, Cu, and Mn bring more advantages among them to help improve the mechanical properties of titanium alloys. This study is intended for the evaluation of mechanical properties through compression and hardness testing performed on a Ti-10Mo alloy with copper addition by powder metallurgy. Ti-10Mo alloys with the addition of copper contents of 3 wt% Cu, 6 wt% Cu, and 9 wt% Cu were prepared to optimize the properties of Ti-10Mo-xCu alloys. With the addition of 3 wt% copper, the compressive strength increased to 577 MPa, which is the maximum compressive strength in this study. On the other hand, with 6 wt% and 9 wt% Cu addition, the compressive strength became 140 MPa and 201 MPa, respectively. A Ti-10Mo alloy with a 3 wt% copper content was able to achieve the maximum hardness of 576 HV. In short, the addition of 3 wt% copper successfully increased the compressive strength as well as the hardness of the prepared titanium alloys.

1. Introduction

Titanium alloy is an in a variety of engineering disciplines because it has good mechanical properties based on the alloy composition [1]. Titanium alloys are attracting plenty of interest in various uses of biodegradable materials mainly because of their outstanding durability and the density, anti-corrosion properties, and compatibility with the body [2]. Because it has an inferior modulus of elasticity between chromium - cobalt materials and stainless steel. Among the majority of popular biodegradable titanium compounds is Ti-6Al-4V [3,4]. Biomaterials used in orthopedics require a relatively small modulus of elasticity considering having high compatibility for bone tissue from a human. In cases where the modulus of elasticity of an implant is greater than that of bone structures, stress occurs because the implant carries more of the load than the bone [5]. As a result, producing a significant goal in the discipline of orthopedic to develop acceptable Ti-Mo alloys that have a small modulus of elasticity. Beside that, In the past decade, various alloys are being created for the purpose for solving toxicity issues associated with standard biocompatible alloys. Some examples include the development of Ti-Mn and Ti-Mo alloys, which serve as phase stabilizers for Mn and Mo elements in titanium alloys.

Many researchers have worked on the development of novel titanium alloys in order to improve their mechanical qualities. As an example, molybdenum and manganese are β-type titanium alloys with low cytotoxicity. Ti-10Mo-5Mn, Ti-15Mo-2.5Mn, and Ti-15Mo-5Mn alloys developed to produce the beta phase alloy structure FCC crystal structure and making use on Mo elements on Ti-15Zr composition, subsequently makes an effort to analyze the micro-structure characterization, state of the phase composition, micro-structure, and mechanical properties of alloys [6,7]. Molybdenum has the BCC crystal structure as β-stabilizer in titanium alloys. Arc-melting was used to prepare the samples, and the samples were analyzed using X-ray diffraction, optical and scanning electron microscopy. The Ti-20Zr-Mo (wt%) alloy was tested for mechanical properties by the vickers micro hardness and dynamic elasticity modulus. The results are shown the hardness of alloy was greater than pure titanium partly because of its inclusion of Mo and Zr elements as hardening agent, and a smaller elastic modulus than pure titanium [8].

Titanium offers a lot of possibilities as a titanium implant prospect, like as the addition of Cu into Ti-13Nb-13Zr composition provides a low yield of elastic property, antibacterial properties , due to the added copper element [9]. The other research, Ti-Cu alloys were analyzed based on the microstructure of grain growth, the formed intermetallic morphology of which was processed by powder metallurgy. Titanium alloys containing Cu have good mechanical properties, as well as suitable corrosion resistance due to the lower melting temperature [10]. The development of TiNi alloys with the addition of a percentage of Cu elements in the range of 1% to 10%, the result is a decrease in stress values compared to TiNi alloys without the addition of Cu. However, based on operating at increase temperature, when deformation occurs, the stress value is below 28 MPa [11]. Ti–6Al–7Nb was fabricated via mechanical milling at the temperature of sintering with variation of 1150°C tested against mechanical properties with the hardness test analyzed with X-ray diffraction to produce the lowest coefficient of friction and wear rate. The result are show to improved relative density and mechanical characteristics, with the smallest crystallite and pore sizes [12]. The context of this research, The Ti-10Mo composition was decided on as the fundamental alloys, and various proportions of Cu element had been added into the alloys. Cu content be considered for the human body, the Cu element has useful properties for human body. Furthermore, to investigate the influence of copper upon the modulus elasticity, copper addition has been contemplated with a 3 wt% Cu, 6 wt% Cu, and 9 wt% Cu element percentage. The primary goal of this research is to look into the conduct and consequences of including a Cu element on the Ti-10Mo alloy to produce titanium alloys has been a good mechanical properties on the compression test by prepared powder metallurgy, compaction, sintering process at variation temperature with sintering time to investigated by material characterization such as a X-ray diffraction, SEM-EDXS, and 3D optical microscopy.

2. Material and methodology

The powder element were used in this experiment were obtained from Zhok Material. Element powder of Ti (purity > 99.9%, particle size < 44 μm), Mo (purity > 99.2%, particle size < 25 μm), and Cu (purity > 99.9%, particle size < 25 μm), respectively. The alloy mixed together with each percentage composition stated on Table 1. Dry milling was performed in a shaker mill (PPF-Ultimate Gravity, Research Center for Advanced Materials-BRIN, Indonesia) for 1.5 h using steel balls with ball-to-powder ratio of 20:1 at room temperature. The milled powders were opened in atmospheric conditioning box supplied with argon gas with a high purity of 99.999%, which aims to reduce oxidation in the CCA (control contamination area). The mixed powder of Ti-10Mo-xCu was cold-compressed in pressure at 500 MPa for 5 min to form a green compact with cylindrical samples with a diameter of 10 mm and height 10 mm shown at Figure 1. The compaction process using zinc stearate lubricant as much as 1.5% of the total weight of the sample to reduce friction between the powder and the mold wall was performed.

The green samples were sintered using tube furnace (PPF-1300). The sintered operating parameter in inert environment at heating rate of $10°C \cdot s^{-1}$ with sintering temperature at 1000°C for 3 h and 1100°C for 2 h, respectively, and then brought to room temperature in the furnace. To avoid oxidation of the sintered sample, the sintering furnace is supplied with circulating high-quality argon gas with a steady flow of $120\ m \cdot min^{-1}$ (purity > 99.999%) through the sintering stage. The selection of temperature are based on the Ti-Cu binary system phase equilibrium diagram [13], due to the likelihood of precipitation of hard intermetallic phases at temperatures within 790°C and 890°C [14]. Eventually, this study compares the influence of the morphological structure and mechanical properties applying a higher sintering temperature in contrast to prior studies in metal systems.

The powder morphology and microstructure characteristics of sintered Ti-10Mo-xCu alloy were observed using SEM (SU3500 machine) of at 2000x magnification with EDXS mapping point. Sample were prepared using standard metallographic procedures, including a toning process with Dix Keller reagent solution. The intermetallic phase of the sintered Ti-10Mo-xCu alloy will be identified via XRD (x-ray diffraction) analysis with a HighScore Plus equipment. The x-ray diffraction parameters were used by the angle 2θ within 20° to 90° monochromatic CuKα radiation with a scanning speed of $0.5° \cdot min^{-1}$.

The principles of Archimedes was used to analyze the actual densities and porosity of Ti-10Mo-xCu alloys that corresponds with ASTM B961 - 08 standard. To calculate the value of density through the Equation (1), ρc is density value after sintering process.

$$\rho_c = \frac{\text{dry mass (g)}}{\text{wax mass (g) - mass in water (g)}} \times \text{density of water } (g \cdot cm^{-3}) \quad (1)$$

And then, to determine the theoretical density value (ρth) with Equation (3). But the first step must be calculate of theoretical volume (Vf_{Ti}) with the Equation (2).

$$Vf_{Ti} = \frac{\text{mass of element (g)}}{\text{density of elements } (g \cdot cm^{-3})} \quad (2)$$

$$\rho th = \rho_{Ti} Vf_{Ti} + \rho_{Mo} Vf_{Mo} + \rho_{Cu} Vf_{Cu} \quad (3)$$

Figure 1. Sample after the compaction process (in mm).

Table 1. Chemical composition.

Element	Composition (%)		
	Ti	Mo	Cu
Ti-10Mo-3Cu	Balance	10	3
Ti-10Mo-6Cu	Balance	10	6
Ti-10Mo-9Cu	Balance	10	9

Tabel 2. Sample size for compression test.

Element	Sintering temperature (°C)	Diamater (mm)	Height (mm)
Ti-10Mo-3Cu	1000 for 3 h	8	8.15
Ti-10Mo-6Cu	1100 for 2 h	8	8.06
Ti-10Mo-9Cu	1000 for 3 h	8.75	7.11

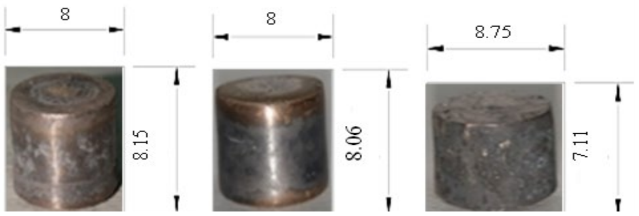

Figure 2. Samples after preparation Ti-10Mo alloy with addition of (a) 3 wt% Cu, 6 wt% Cu and (c) 9 wt% Cu.

If the theoretical density value is known, the next step is determining of the porosity value. The compressibility of an object is measured by its porosity. If the pores are very small, the porosity is low; conversely, the higher the porosity, the larger the pores [15]. This procedure is used to investigate the relationship between sintering temperature on the titanium, molybdenum, and copper element againts density and porosity. The sample porosity value (P_o) can be calculated with the formula Equation (4).

$$P_o = 1 - \frac{\rho c}{\rho th} \times 100\% \tag{4}$$

The compression test were used to evaluate the strength of the material properties of the alloy on the sample of Ti-10Mo-3Cu at 1000°C for 3 h, Ti-10Mo-6Cu at 1100°C for 2 h, and Ti-10Mo-9Cu at 1000°C for 3 h. Compression tests were conducted using a Tinius Olsen Universal Testing Machine at a strain rate 0.0001 s^{-1} at room temperature using standard ASTM E-9. The sample dimensions for preparation on the compression test are shown in Table 2 and Figure 2 for Ti-10Mo-xCu alloys. The fracture surface was observed using a Keyence 3D Optical Microscope with magnification X100 and X200 with size of 100 μm. Hardness measurement was conducted using microhardness (vickers indenter) at a load of 10 kg with a dwelling time of 15 s at room temperatures with ASTM E384-11 (Standard Test Method for Microindentation Hardness of Materials) at Center for Materials and Processing Failure Analysis (CMPFA). Average hardness values were obtained from five indents on the Ti-10Mo-xCu alloys samples were tested.

3. Results and discussion

The SEM image on the Ti-10Mo-3Cu powder are show in Figure 3 has an irregular morphological microstructure. The powder shape morphology during 1.5 h mill on Ti-10Mo-3Cu alloy can be seen in Figure 3. Ball-to-wall and ball-to-ball interaction throughout the milling operation permit all of the particles to make contact with each other, which results in three phenomena: fracture, cold welding, and deformation. The particle can be damaged and deformed from their original shape morphology such as the fracture shown at Figure 3. The solid-state welding process is performed by applying high pressure between two workpiece surfaces that are in contact with each other. During the milling process, this phenomenon occurs continuously and repeatedly [16].

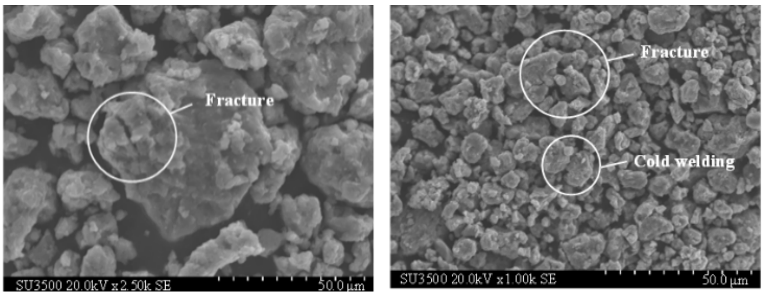

Figure 3. The microstructure of the powder after milling 1.5 h on the Ti-10Mo-3Cu.

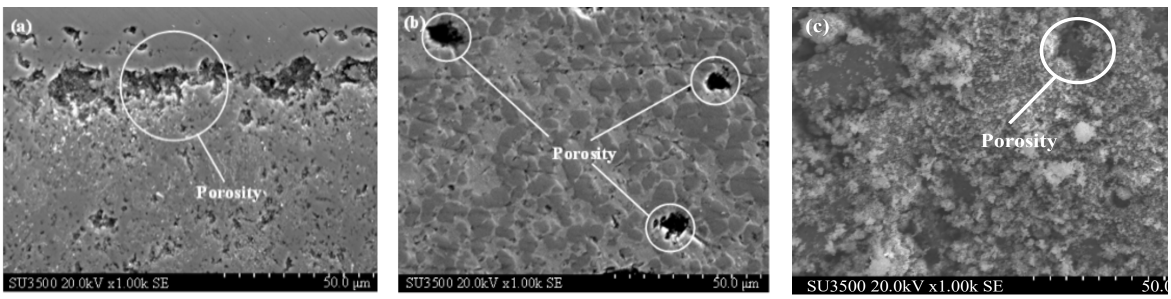

Figure 4. SEM results after sintering on the Ti-10Mo alloy (a) 3Cu, (b) 6Cu and (c) 9Cu element.

Figure 4 shows SEM image after sintering based on the microstructure of (a) Ti-10Mo-3Cu, there are many large flat pore with in the sample is lamellar, because of its plate-like particle shape is randomly spread throughout the surface of the alloy. Figure 4(b), As for the morphology molybdenum is small particle and the shape an irregular and almost round which can be said to be a type of granular particle with a small number of pores. For morphology, the copper element has a small particle size, round and irregular (nodular). The influence of the alloys sintering time (Table 5), where the longer the sintering time, have a high the sinter density value and the lower the porosity and the discovered on the microstructure is in the form of pores. The pores are formed by evaporated amounts of Cu holding substance, and their physical form has evolved through the morphology on Cu powder. The small pores are caused by disparities between powders, as well as impurity evaporation in green compact pores [17]. In Figure 6, The distribution of molybdenum and copper particles is very uniform. The mapping of the arranged EDXS point is categorized by brightly color which is indicated as the formed intermetallic element.

In Figure 4(b), the Ti-10Mo-6Cu alloy produces a shape morphology such as showing a round flat surface dominated by the titanium element. Figure 4(c) are shown a produces with platy shape morphology dominated by the Mo element. As the 3% to 9% Cu element are added, the stress value decreases, but the use of molybdenum (Mo) and copper (Cu) is intended as a good β-stabilizer in titanium alloys [8,11].

Because the intermetallic phase has different properties than the constituent components, further characterization is required to detect the new phase formed after sintering on the sample.

Figure 5 shows an XRD (x-ray diffraction) graph that shows the different characteristics of the peaks formed by each titanium alloy. Each constituent element has a major component (base), such as titanium, which is stabilized by copper and molybdenum. Aside from that, the addition of the 3 wt% Cu element has the potential for enhancing material of mechanical qualities. Mechanical qualities that include as ductility and strength are imperative to provide Ti-Cu alloys. The formed intermetallic Ti-10Mo-3Cu alloy is $Mo_132Ti_{0.66}$ and $CuTi_3$ guaranteeing that the Ti-Cu alloyed retains its mechanical properties [18] with the addition Mo element has strong β-stabilizer properties in titanium [29]. From Figure 9 shows that the 3 wt% Cu content creates the highest value of stress (577 MPa) when compared to 6 wt% Cu and 9 wt% Cu. The molybdenum element has good properties for maintaining a certain surface shape [19]. According by Yi *et al*. [20] the compression strength and elastic modulus change as the Cu content increases with higher compressive strength and lower elastic modulus. When compared to other Ti-10Mo-Cu alloys, that Ti-10Mo-3Cu alloy has a higher compression strength, because of the production of an intermetallic compound in the form of $CuTi_3$ via XRD analysis. Intermetallic formation is forming in the alloys Ti-10Mo-6Cu (at 1100°C for 2 h), Ti-10Mo-9Cu (at 1000°C for 3 h), namely $Cu_3O_1Ti_1$ and Mo_1Ti_1 belonging to the category of titanium alloys appear of oxygen at room temperature as a phase stabilizer on alloys containing titanium. The presence contains formed intermetallic phase will affect for mechanical qualities on the titanium alloys like as the yield strength value [21].

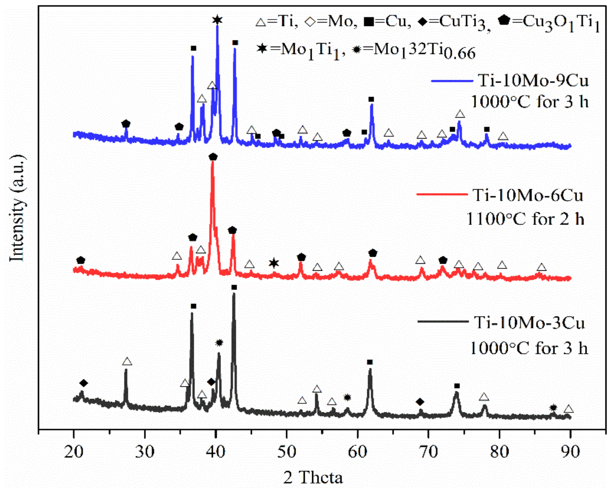

Figure 5. Graph of XRD after sintering process on Ti-10Mo alloy with Cu addition.

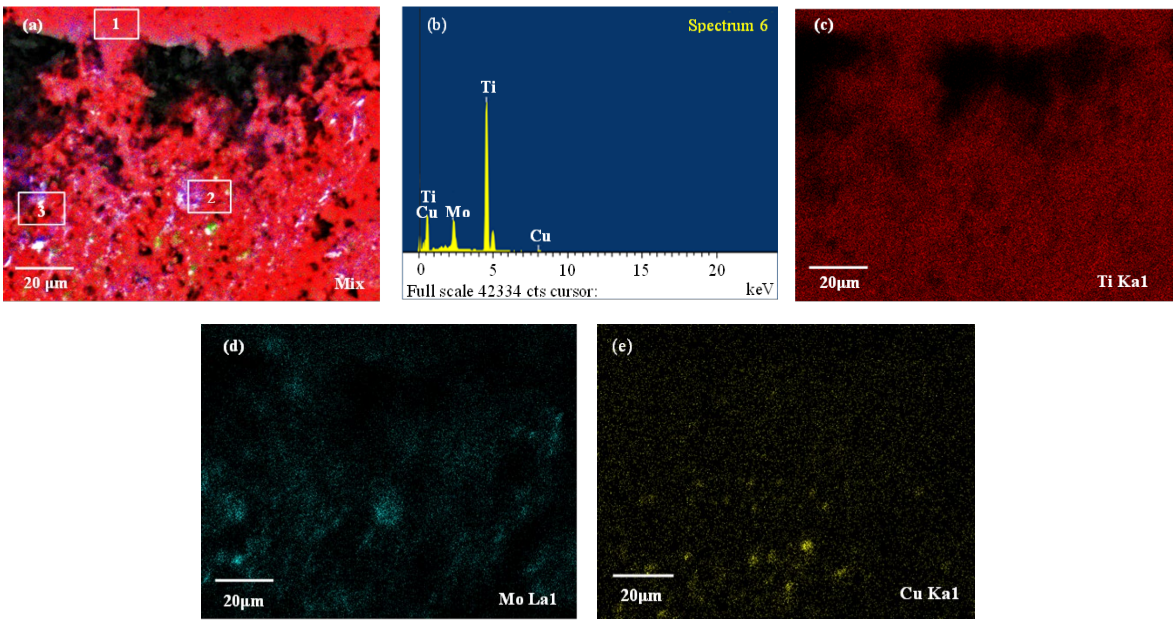

Figure 6. The EDXS result of Ti-10Mo-3Cu sample (a) EDXS point locations, (b) EDXS mapping spectrum, with color gradient (c) Ti, (d) Mo, and (e) Cu.

The findings of the X-ray diffraction analysis show that the different effects of the peaks that occur on the properties of the intermetallic phase formed are not influencing by variations in the sintering process time. This shows that the influence of the addition of the Cu element is more dominant in forming the intermetallic phase, which will decrease the strength of the Ti alloy [9]. During sintering, the oxide in Cu and produces oxygen, which can become trapped in the material, generating closed holes. As a result, the sintered density is low [22]. It can be seen that there is not $Cu_3O_1Ti_1$ phase in Ti-10Mo-3Cu, which is a phase that should avoid because an oxygen will reduce the strength of the Ti alloy.

Figure 6 depicts the SEM-EDXS images obtained after sintering at 1000°C for 3 h on the Ti-10Mo-3Cu alloy, indicating the most beneficial variables of the alloy. The SEM micrograph reveals a variety of colors in varying sizes and shapes. It has previously been noticed that the titanium structure, as the primary material, has been identified with white gray with an irregular lamellar structure [23]. There are two other colors visible, notably light gray alongside dark gray. Copper are indicated with dark colors, whereas molybdenum are represented with light gray colors. It can be observed in the EDS point analysis that each of these factors has a significant weight to percent compared to other points (Table 3). To take one example, it has been shown in the EDXS point analysis that point 1, which is a Ti element, has a high weight percentage when compared to point 2 and 3, which is formed of the elements Cu and Mo. The morphology of the mixture is shown in Figure 6(a) EDXS point locations, (b) EDX mapping spectrum, color gradient on each element (c) Ti is red, (d) Mo is blue, and (e) Cu is yellow.

The increased of sintering time produces in higher density values, especially for Ti-10Mo-3Cu (2 h) and (3 h), which range from 2.866 g·cm^{-1} to 3.079 g·cm^{-1} and Ti-10Mo-9Cu (2 h) and (3 h) with range from 2.876 g·cm^{-1} to 3.362 g·cm^{-1} (Table 5). This refers to basically the higher the temperature applied to material, the more energy it possesses. However, the density of Ti-10Mo-6Cu alloy is decreases from sintering time of 2 h into 3 h with the density value of 3.098 g·cm^{-3} to 3.042 g·cm^{-3}. Furthemore, the increasing of sintering temperature causes the alloy to have higher porosity, which indicates a drop in density. At sintering temperature of 1100°C, the porosity values of the Ti-10Mo-3Cu and Ti-10Mo-9Cu alloys were 41% and 42.7%, respectively (Table 4). However, the porosity of Ti-10Mo-6Cu decreased at 1000°C to 1100°C of 38.4% into 37%. This demonstrates an inverse relationship between porosity and density, with the lowest density sample having the largest porosity (Table 5). This phenomena is likewise similar to what occurred in the investigation by Li *et al.* [24] particularly, due to the excess zinc stearate content so that when heated, porosity will form from the areas left by the vaporized zinc stearate and the majority of the Cu melts dispersed out of the sample resulting with low density and high porosity.

Table 3. The EDXS results correspond to the point locations.

Element	Weight (%)	Point
Ti	79.45	1
Cu	3.27	2
Mo	17.28	3
Total	100.00	

Table 4. Effect sintering temperature on porosity of the Ti-Mo-xCu alloys.

Element	Sintering temperature (°C)	
	1000	1100
Ti-10Mo-3Cu	36.6	41
Ti-10Mo-6Cu	38.4	37
Ti-10Mo-9Cu	33	42.7

Table 5. Effect sintering time on density of the Ti-10Mo-xCu alloys.

Element	Density (g·cm^{-3})	
	2 h	3 h
Ti-10Mo-3Cu	2.866	3.079
Ti-10Mo-6Cu	3.098	3.042
Ti-10Mo-9Cu	2.876	3.362

Table 6. Theoretical and experimental density on Ti-10Mo-xCu alloy after sintering.

Element	Sintering temperature (°C)	Theoretical density (g·cm^{-3})	Experimental density (g·cm^{-3})
Ti-10Mo-3Cu	1000	4.854	3.079
Ti-10Mo-6Cu	1100	4.92	3.098
Ti-10Mo-9Cu	1000	5.015	3.362

Table 7. Result of porosity value on the Ti-10Mo-xCu alloys.

Element	Sintering temperature (°C)	Porosity (%)
Ti-10Mo-3Cu	1000	36.6
Ti-10Mo-6Cu	1100	37
Ti-10Mo-9Cu	1000	33

Table 8. The result of compression test on the Ti alloys.

Element	Diameter (mm)	Height (mm)	Area (mm^2)	Stress (MPa)
Ti-10Mo-3Cu	8.00	8.15	50.24	577
Ti-10Mo-6Cu	8.00	8.06	50.24	140
Ti-10Mo-9Cu	8.75	7.11	60.1	201

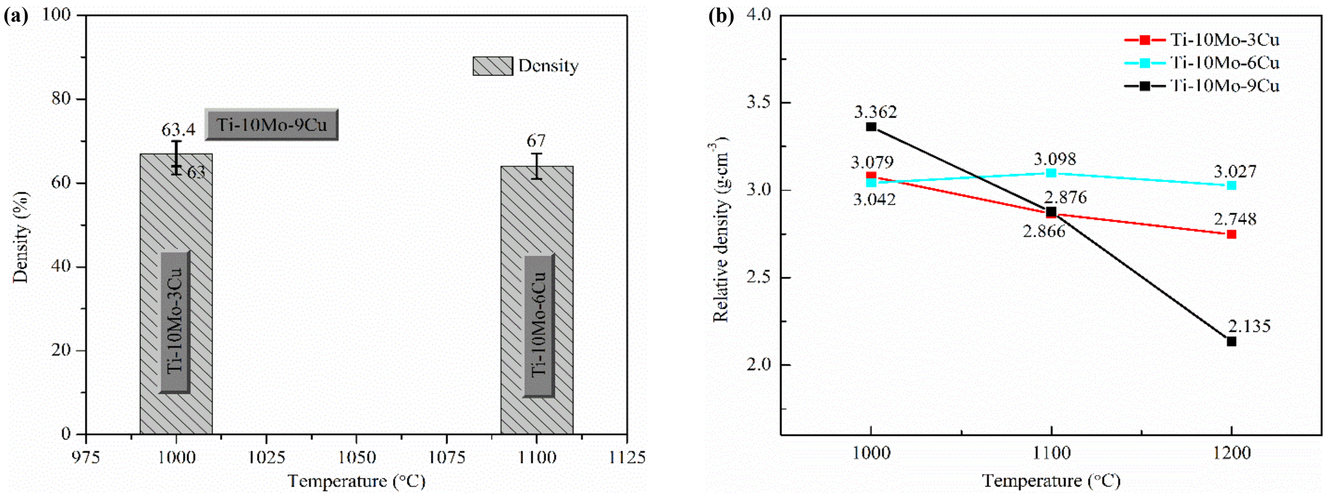

Figure 7. Density graph (a) after sintering and (b) the relative density relationship with sintering temperature.

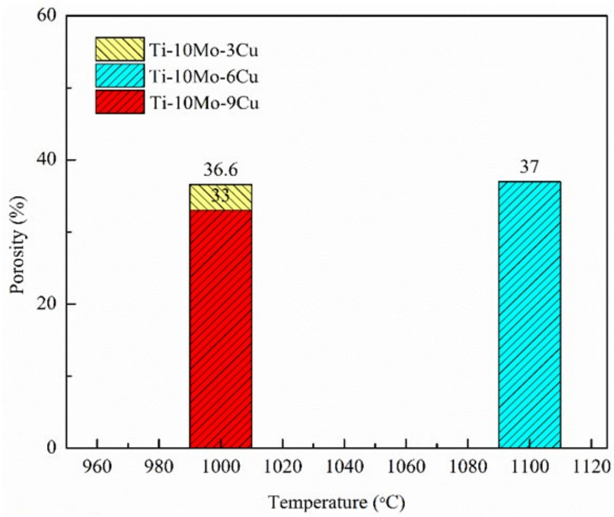

Figure 8. The porosity results on the Ti-10Mo alloys with Cu addition.

However, if it is related with the effect of the inclusion of the element Cu in the titanium-molybdenum alloy, it decreases their mechanical properties found in the alloy, especially maximum stress value are shown in Figure 9, this is similar to the results of research conducted previously by Mao *et al*. [9]. As a result, the titanium alloy with the low porosity value from each Ti-Mo-xCu alloy will be used for compression test (Table 7) of the Ti-10Mo-3Cu (1000°C for 3h), Ti-10Mo-6Cu (1100°C for 2h) and Ti-10Mo-9Cu (1000°C for 3h).

Table 6 represents, the results of the theoretical and experimental density on Ti-10Mo-xCu alloy after the sintering process.

The demonstrates reveals a sample structure is overlapping ue to an excessively high sintering temperature can be seen in Figure 7(a) and Figure 7(b). The gap caused by the sintering temperature which is too high is caused by the melting point of Cu, which is 1083°C, causing Cu elements in samples with sintering temperatures of 1100°C and 1200°C to melt which causes a porosity gap to be created due to the expansion of the sample, and reduces the value of the density. Figure 8 show, this is a state in which the sintering density drops due to a considerable amount of liquid phase and grain development, which causes particle aggregation and the formation of porosity, also known as the Ostwald Ripnning phenomena [25].

3.1 Mechanical behavior

Based on Figure 9, the Ti-10Mo with addition of 3 wt% Cu element failed to fracture at a force load of 29000 N have a value of stress 577 MPa, 6 wt% Cu element at a force load of 7100 N, with the value of stress 140 MPa and 9 wt% Cu element at a force value of 12000 N until fracture occurs with 201 MPa. The results of the maximum stress value are classified as the strength value that the material can withstand againts to its mechanical properties in the Ti-10Mo with the addition of Cu element, the result can be shown in Table 8. The addition of Cu reduces the yield of the maximum stress on the compression test [9].

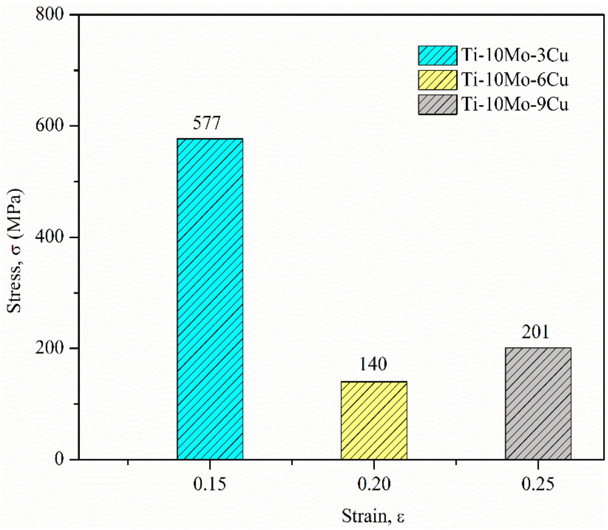

Figure 9. Graph of stress vs strain on the Ti-10Mo with Cu addition of compression test.

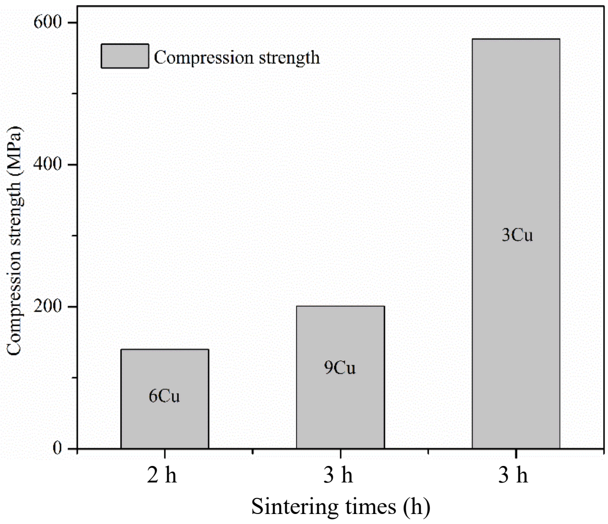

Figure 10. Effect sintering time for the compression strength of titanium alloy.

Sintering time affects the compressive value of the material, the more extended the sintering duration, the greater duration the period of time for diffusion of Mo, Cu into the Ti lattice, which can then improve the phase transformation of alloy bonding energy, thus improving the compressive strength of the material [26]. In Figure 10, based on the relationship between compression test result and sintering time on the Ti-10Mo-6Cu (for 2 h), Ti-10Mo-9Cu (for 3 h), and Ti-10Mo-3Cu alloy (for 3 h), the compression strength value of the alloy continues to increases with the values of 140 MPa, 201 MPa, and 577 MPa, respectively.

3.2 Results of compression test cracks on TiMoCu alloy

The stress values were determined using the reaction force (compressive strength) values generated by the universal testing machine and implemented to the samples cross-sectional surface area. According to Figure 11(a), the results of the cracks that occur can be seen with a magnification of X100 and a size of 100 µm at a force value of 29000 N, the initial crack appears from the center of the pressured and has three directions of propagation until it reaches a break distance in the amount of 0.852 mm with the damage localization of the structure cracked on two of the sides. Figure 11(b) with magnification X100 with a size of 100 µm, the crack occurs at a force value of 7100 N with two directions of propagation until break distance 1.656 mm with damage localization on the center of sample. Figure 11(c) are shown as in the previous test, the crack that occurs of 12000 N on the two directions of propagation until it reaches a breaking distance of 2.39 mm with magnification X200 and a size of 100 µm with structure cracked on two of the sides.

3.3 Vicker hardness

Based on the Figure 12 shows the relationship between hardness and variations in Cu content in Ti-Mo alloys. It can be seen that the addition of Cu to titanium-molybdenum decreases the hardness of the alloy. In comparison to other elements with elemental contents of 6 wt% Cu and 9 wt% Cu, 3 wt% Cu had the maximum hardness with the value is 576 HV. According to our findings, the hard phase of $CuTi_3$ intermetallic compound produced in Ti-10Mo-3Cu alloy has the greatest hardness value of 576 HV. However, the addition of copper content reduced mechanical qualities on hardness from 3 wt% Cu, 6 wt% Cu and 9 wt% Cu added to Ti-10Mo alloy. The Ti-Cu alloy were created had good mechanical characteristics such as high micro-hardness and acceptable toughness [13,27] and adding copper element to titanium will increase the melting heat on the Ti-Cu alloys [28]. Mo has excellent β-stabilizer capabilities in titanium. Ti-Mo alloys are responsive to Mo content, and a minimum proportion of 10 wt% is required to stable the β-phase for Ti-Mo alloys at ambient temperature [14,29]. The Ti-Cu binary alloy equilibrium phase diagram reveals when adding more than 3 wt% copper to the alloy of titanium produces in an intermetallic phase, such as Ti_2Cu intermetallic compound, which can improve mechanical qualities such as hardness [27,30]. The hardness value obtained is high, it will offer superior wear resistance [31]. The Ti-10Mo-3Cu alloy has the maximum hardness value is achieved at sintering on the 1000°C for 3 h with producing the intermetallic compound of $CuTi_3$.

Figure 13 are shows, the relationship of the compression strength and hardness (micro vickers) was findings from the Ti-10Mo alloys evaluated at room temperature. The findings from experiments demonstrated the existence with intermetallic phase on the alloys, this can be linked to one of the causes for the improvement in compression strength, particularly Ti-10Mo-3Cu element. By raising a copper proportion by weight towards to 6 wt% and 9 wt%, X-ray diffraction investigation on the Ti-10Mo-6Cu element indicated the possibility of considerable crack expansion and decrease strength, and this observation was also confirmed on the 9 wt% Cu element. According to the result of the hardness test on Ti-10Mo alloy with Cu addition, the Hardness (HV) value is decreased for every Ti-10Mo-xCu alloy. The fraction of phases generated at room temperature is a key factor for assessing the variation overall strength that occur [32].

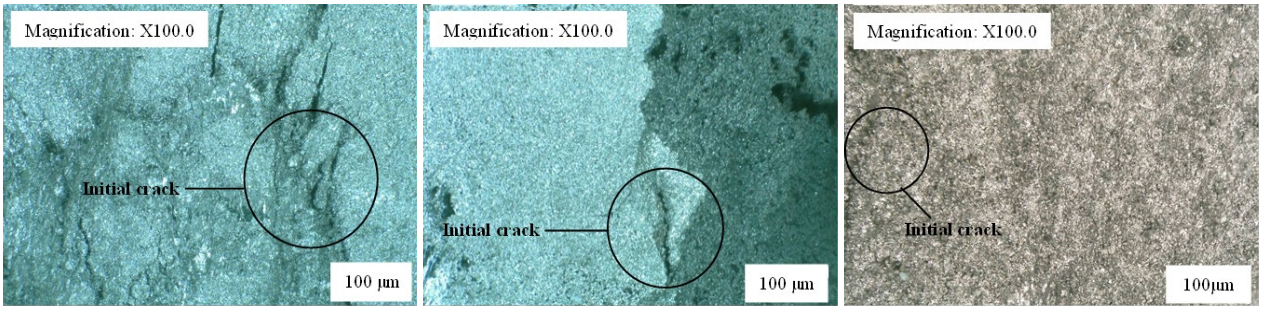

Figure 11. The fracture results from 3D OM on Ti-10Mo alloys with addition (a) 3Cu, (b) 6Cu, and (c) 9Cu.

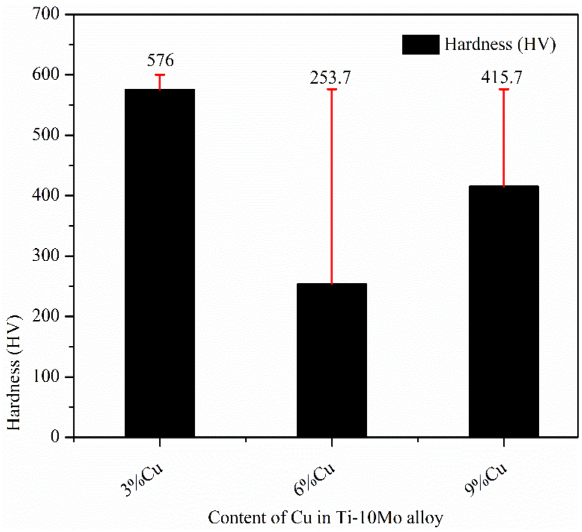

Figure 12. Microhardness (vickers) of the Cu content in Ti-10Mo sample.

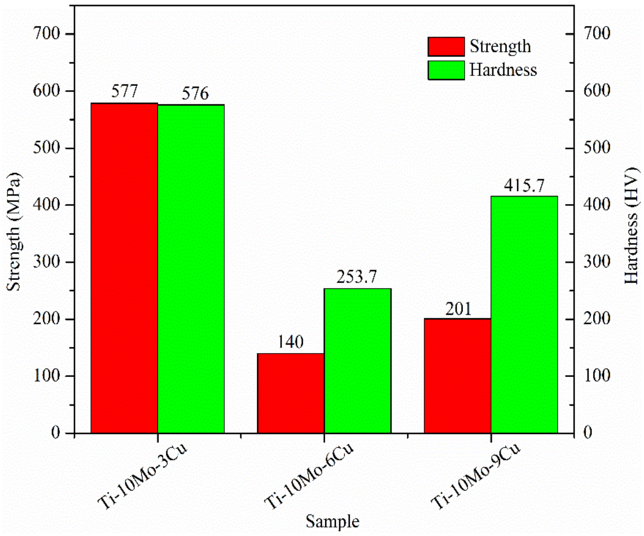

Figure 13. Relationship between hardness and strength of Ti-10Mo is change when Cu is added.

4. Conclusions

In these studies, effect of copper on the mechanical qualities on the titanium-molybdenum alloys is has been evaluated. Our study findings have significant ramifications for the fabrication and practical application of metallic alloys on the mechanical properties. The mechanical qualities of Ti-Mo alloys can be develop from understanding a influence with various compositions on those qualities can perform more effectively with adding the copper element. It is important to note, nevertheless, may the research contains limitation which means there are several regions that need to be explored extensively. Furthermore, more research is required to investigate the impact of varied mixtures, fabrication variables, and testing conditions on the mechanical characteristics of Ti-Mo alloys. The outcomes are outlined below:

1. Ti-10Mo-xCu alloy may produce an extensive lineup of mechanical properties. The inclusion of cooper elements at 3 wt% to 9 wt% inside the Ti-10Mo alloy reduces stress with the value of 140 MPa for Ti-10Mo-6Cu, 201 MPa for Ti-10Mo-9Cu, and the highest stress value of 577 MPa which occurs on the Ti-10Mo-3Cu alloy.
2. The vickers hardness decreased as the Cu addition to Ti-10Mo alloys. The Ti-10Mo-3Cu alloy shows a maximum hardness of 576 HV.
3. On the compression test, fracture deformation occurs in localization, with damage to the crack structure on two side (Ti-10Mo-3Cu and Ti-10Mo-9Cu alloys). The localized damage occurs at the middle of the sample until it becomes two sections on the Ti-10Mo-6Cu alloy. The strain is greatest in the central area of the sample and orthogonal to the direction of the applied compressive strength.

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