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The role of Cu element and compaction pressure on microstructure and mechanical Properties of Al-Cu binary alloy synthesized by powder metallurgy

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ABSTRACT

Al-Cu alloys are promising material for engineering field due to their good mechanical properties. These characteristics could be obtained by addition of some elements and correct selected processes parameter. The purposes of this current study to investigate the effect of Cu contents and compaction pressure on microstructure evolution and mechanical properties of the Al-Cu alloy synthesized by powder metallurgy route. High purity Al and Cu elements are used as starting material with composition (21.0, 24.0, 27.0, 30.0, and 33.0) wt.%Cu with 210 MPa of compaction pressure. The varying compaction pressure 160, 180 and 180 MPa were carried for 15 minute holding time. Furthermore, a conventional sintering at 500oC for 1 hour holding time take place. The hardness test resulted that the increases of Cu contents was successfully improved the hardness, which is the maximum hardness 53.2 HV and 71.47 MPa of the compressive strength obtained by 33wt. Cu addition. On the other hand, the varying of compaction pressure resulted the maximum hardness and compressive strength are 25.6 HV and 60.8 MPa respectively for 200 MPa. The microstructure observation shows the increases of Cu promoted more Cu elements dispersed between the aluminum rinh matrix. The increase of compressive strength is encourages finer Al-Cu grain in the microstructure.

Keyword: Copper, Microstructure, Compressive Strength, Hardness

ABSTRAK

Al-Cu alloy merupakan paduan yang sangat menjanjikan dikarenakan memiliki sifat mekanis yang baik sehingga cocok untuk aplikasi bidang keteknikan. Sifat paduan ini dapat dicapai dengan penambahan elemen dan pemilihan parameter proses yang tepat. Penelitian ini bertujuan untuk melihat bagaimana pengaruh kandungan Cu dan tekanan kompaksi terhadap perubahan struktur mikro dan sifat mekanis paduan Al-Cu yang disintesis menggunakan teknik metalurgi serbut. Serbuk Al dan Cu dengan kemurnian tinggi dipergunakan pada penelitian ini dengan komposisi (21, 24, 27, 30 dan 33) wt.%Cu, tekanan kompaksi 210 MPa. Variasi kompaksi diambil tekanan 160, 180 dan 200 MPa dengan penekanan selama 15 menit. Proses sintering dilakukan pada suhu 500ºC selama 1 jam. Hasil pengujian kekerasan diperoleh bahwa peningkatan komposisi Cu cenderung meningkatkan kekerasan tertinggi yaitu sebesar 53,2 HV dan kekuatan tekan tertinggi 71,47 MPa pada komposisi 33wt.Cu. Pada bagian lain, variasi tekanan kompaksi kekerasan dan kekuatan tekan tertinggi 25,6 HV dan 60, 8 MPa dengan tekanan 200 MPa. Hasil pengamatan struktur mikro diperoleh peningkatan kandungan Cu mendorong lebih banyak Cu yang tersebar diantara matrik alumunium. Peningkatan tekanan kompaksi mendorong pembentukan butiran Al-Cu alloy yang lebih halus.

Keyword: Tembaga, Mikrostruktur, Kekuatan tekan, Kekerasan

1. Introduction

The Al-Cu alloy are promising material for engineering application due to their good characteristics, such mechanical properties which are strongly influenced by composition of the Cu between Al matrix. This alloys have many intermetallic phases at most of the region in their binary diagram. The increases of the Cu content are promoted the intermetallic phases which is at temperature of 550ºC the solubility limit of Cu in Al about 2.5at. And conversely, 18.5 at. with 566.7ºC of the temperature for Al in Cu [1]. Furthermore, intermetallic phases are found in the wide range of different alloys system such as Al-Mg, Al-Fe, Al-Ni, and Al-Cu alloys [1][2][3][4]. The formation of intermetallic phase probably correlated with their misfitch of basic characteristics element each other. The presence of intermetallic are important role to improve mechanical properties of Al alloys like hardness and tensile strength [4]. Nevertheless, more intermetallic phase formed are reduced the ductility and brittle of the alloys [4][5]. Al alloys which have good ductility could be produced by different method such casting and powder metallurgy (PM). J.Sena, et al. was reported that aluminum based alloys can be synthesized by casting route which is an intermetallic phase formed in the microstructure [6]. The second method is PM, due to their advantages this technique has been widely used to synthesize light metal alloy, like Al-Si and Al-Fe [3][7]. It is believed that the hardness of Al-Fe alloy influenced by the presence of intermetallic phase [8]. I. Aatthisugan, et al. was reported that Al6Cu-xMg based alloy was successfully synthesized by PM, in which Al6Cu based alloy shows a better both of density and hardness in comparison with Mg addition [9]. The solubility limit and mechanical properties of Al-Cu improved by ultrasonic treatment were reported [10]. The higher Cu contents and heat treatment, further, subsequently quenching process contributed to enhancing the hardness through grain refinement of the Al-Cu alloy [11]. However, the increase of Cu content to exceed the solubility limit promotes the Cu-based phase segregated between microstructures, and thus reduced the hardness of the CoCrCuFeNi HEA [12]. On the other hand, the correctly selected parameter processes of Al-Cu synthesized by bed fusion with laser beam are important for obtaining denser and free cracks of alloys [13]. Powder metallurgy is a promising way to synthesize alloys, in which one of the important parameters is compaction pressure. N.Kumar, et al. reported that the increase of compaction pressure can increase both hardness and electrical conductivity of a Cu-based alloy [14]. It is believed that the strength of materials is correlated with their powder size and density, in which the higher compaction pressure is the less porosity of such iron base powder obtained [15]. Particle size and their segregation have a significant effect on the tensile strength of the Inconel 718 alloy, so that correct parameter processes are important to be considered [16]. It was reported that the hardness and compression strength of the aluminum 6061 alloy are influenced by particle size [17]. The investigation of characteristics of alloys with Cu elements was carried out by many researchers, but the role of Cu with 15~33wt.% in the Al-Cu binary system and compaction pressure are limited. The aim of this current study is to investigate the effect of Cu contents and compaction pressure on mechanical properties of the Al-xCu alloy. Microstructure evolution due to difference of composition is also observed in this research.

2. Method

High purity of commercial aluminum and copper elemental powder with particle size below 40 µm were used as starting material in this study. The differences in Cu content and compaction pressure were carried to synthesize the Al-Cu alloy, the sampel parameters as shown in Table 1. Furthermore, each powder is subsequently done by cold die compaction with different pressures for 15 minute holding time to obtain a green body of material. A conventional sintering at 500oC for 60 minutes was carried out. These samples were made according to ASTM B925-03, which are 25.4 mm and 7.11±0.25 mm in diameter and compact thickness respectively in the compressive test samples. The compressive test was conducted at room temperature with compressive strength and crack morphology, which indicated the strength of the material.

Table 1. The parameters of the synthesis of Al-Cu alloy mixing by V- mixer type.

No.	Cu (wt.%)	Compaction Pressure (MPa)	Mixing Time (min.)	Speed of mixer (RPM)	Sinte-ring (ºC)	Holding time of sintering (min.)	Al (wt.%)
1	21	210	60	115	500ºC	60	bal.
2	24	210	60	115	500ºC	60	bal.
3	27	210	60	115	500ºC	60	bal.
4	30	210	60	115	500ºC	60	bal.
5	33	210	60	115	500ºC	60	bal.
6	15	160	60	115	500ºC	60	bal.
7	15	180	60	115	500ºC	60	bal.
8	15	200	60	115	500ºC	60	bal.

Bulk materials which have a flat surface and are 25.4 mm in diameter and 7.11±0.25 mm thickness are prepared for micro Vicker hardness, and it was conducted with 100 gr for 10 second penetration. The sintered samples for microstructure observation were prepared by a polishing machine with grinding paper from 100~2000 in size. Furthermore, the optical microscope has been used to observe the microstructure with different magnification. The density of model Al-Cu alloys was measured using the Archimedes principle.

3. Result and Discussion

3.1. Microstructures of model Al-Cu alloy

The 85Al15Cu alloy synthesized by powder metallurgy is presented in Fig. 1. Green body material shows the surface morphology, which consists of Al area and Cu with gray and yellow colors respectively, see Figs. 1a-b. These elements are separated as individual elements due to their unhomogeneous mixing obtained by the V-mixer processing method. Fig. 1c-d shows a sintered alloy with some porosity clearly observed at the surface bulk material. The pore formation usually correlated with the entrapped of oxygen or some contaminant in the powder stage, which is generate porosity in the microstructure. During high temperature sintering, the interaction between atomic species occurs. A small amount of Cu is dissolved into the Al matrix to form a solid solution. Aluminum which is fitted with oxygen at high temperatures can generate the Al-oxides formation, see Fig. 1d.

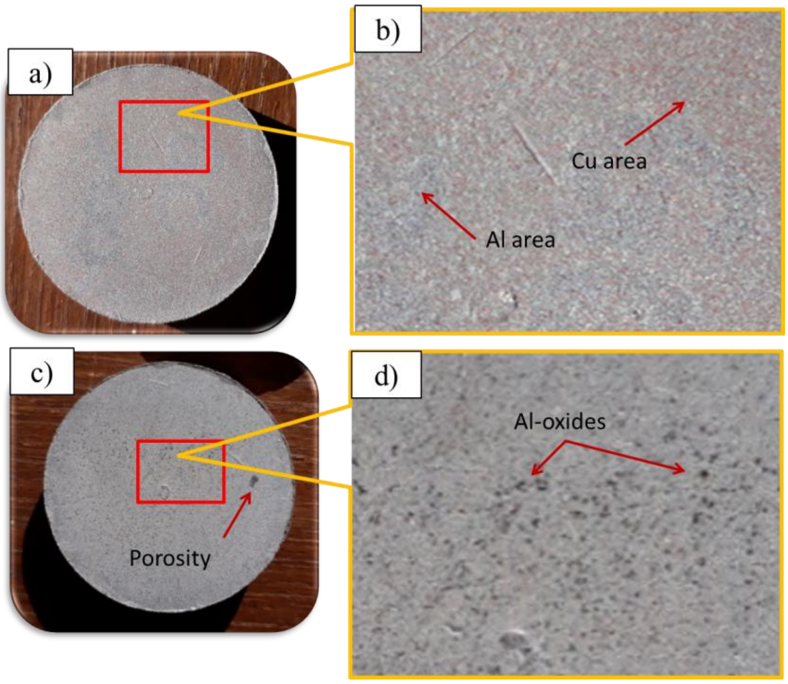

Fig. 1 Surface morphology of (a-b) green body, (c-d) bulk material of the 85Al15Cu allloy

Fig. 2 shows the microstructure of an 85Al15Cu alloy for different compaction pressures. It was clearly observed that the microstructure consists of α- aluminum acting as a matrix. A larger grain, more than 50μm, is obtained at low compaction pressure. Further, the partial Cu element pushed out from the Al matrix is segregated near the grain boundary which is probably associated with its solubility limit. In which the solubility limit between Al-Cu elements is very low [18]. However, at low compaction pressure, large pores and oxides were clearly visible among α-aluminum, which is the presence of defects causes reduced mechanical properties of the aluminum alloys [19]. The increase in compaction pressure successfully reduced the Al grain and porosity, see Fig. 2b-c. The compaction parameters contributed to increased hardness, atomic diffusion behavior and contact point [20].On the other hand, a small oxide phase observed dispersed between Al matrix which confirmed that the compaction paramater unable to fully avoid Al-oxide formation due to Al and oxygen have good affinity to fom oxide particularly at high temperature sintering. The microstructure of an Al-Cu alloy with different Cu contents is shown in Fig. 3..

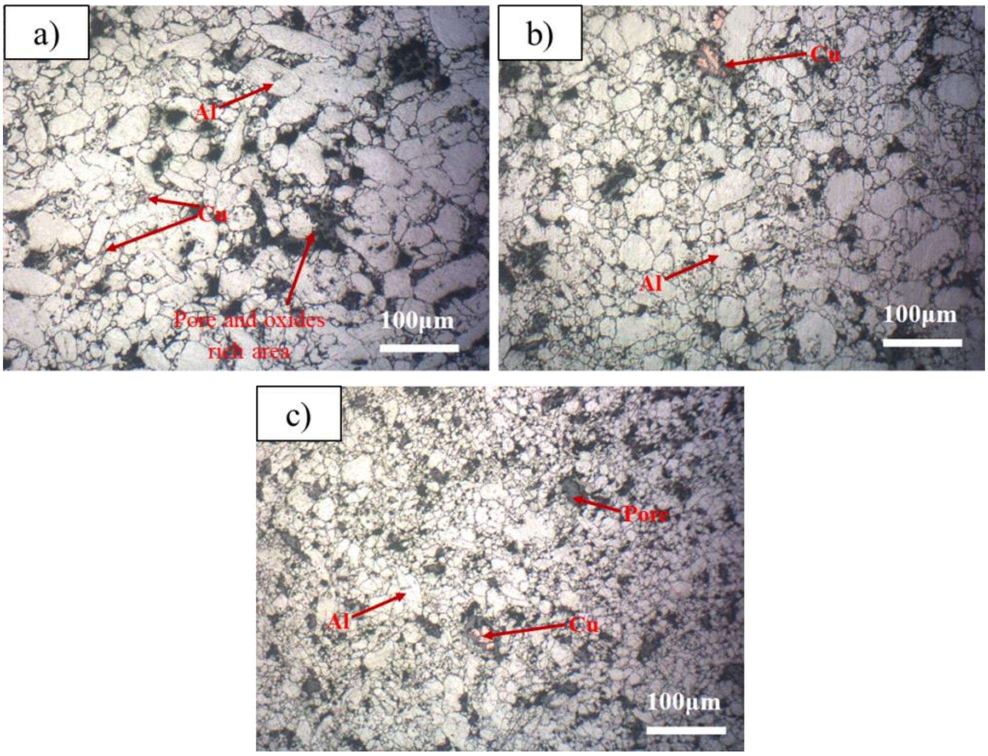

Fig. 2 Microstructure of 85Al15Cu for different compaction pressure (a) 160, (b) 180, and (c) 200 MPa.

It is clearly observed that the increases in the Cu content encourage the Cu element to be segregated between the Al matrix, in which the red and gray colors are identified as Cu and Al-rich phase resepectively. The phenomenon Cu segregated in the Al alloy system was reported by other research group [21][22]. Aluminum has a good affinity with oxygen, the formation of oxides can not be avoided in the microstructures in this current study, see Figs. 3a-d. However, the addition of a Cu element successfully reduces the oxide content, which is probably caused by this element being more stable from oxide formation upon high temperature sintering.

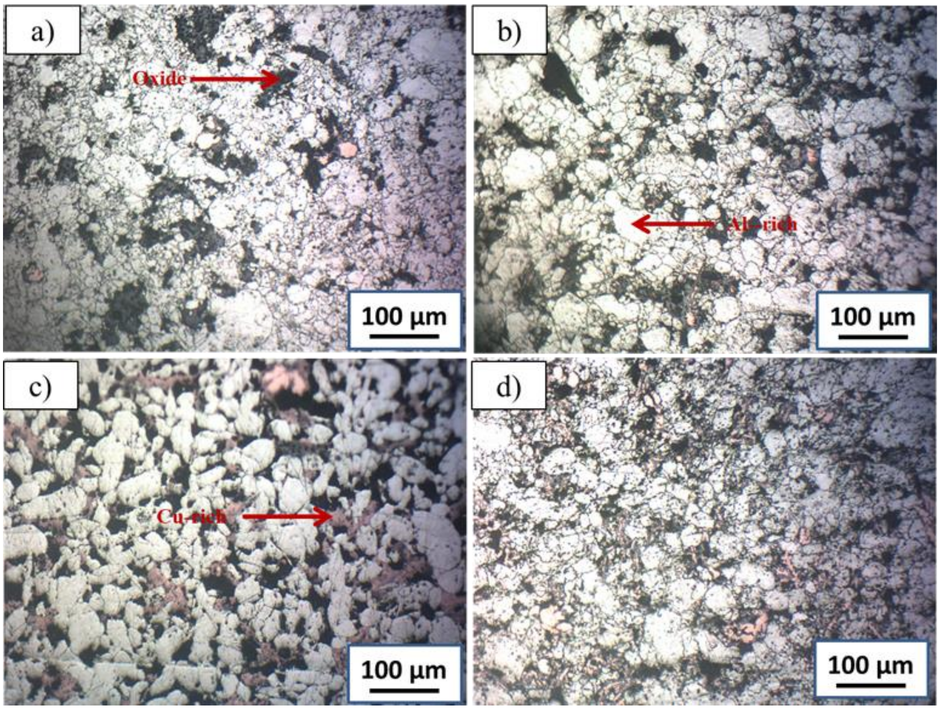

Fig. 3 Microstructure of model alloy with different Cu content (a) 21wt.%Cu, (b) 27wt.%Cu, (c) 30wt.%Cu, and (b) 33wt.%Cu.

3.2. Density of the model Al-Cu alloy

Table 2 shows the relationship between the density of the model Al-Cu alloy with different Cu contents and compaction pressure. It is clear that the density increases with the increase of compaction pressures of both green body and sintered material. The higher densities were achieved from the sintered alloy, which is correlated with the densification processes during high temperature sintering. However, these results are below the theoretical density of the Al-Cu alloy. The low density of alloys is probably influenced by oxide and porosity formation between microstructures, see Fig.2. .

Table 2. The difference of the density of the compaction pressure and Cu content in the Al-Cu alloy

No.	Variation of Compaction Pressure			Variation of composition	
	Compaction (MPa)	ρ, Green body (gr/cm^3)	ρ, Sintered alloy Green body (gr/cm^3)	Cu-Elements (wt.%)	ρ, sintered alloy (gr/cm^3)
1	160	1.3391	1.5560	21	1.6149
2	180	1.3903	1.5686	24	1.6419
3	200	1.4240	1.6211	27	1.6578
4				30	1.8633
5				33	1.9873

On the other hand, the increase in Cu content successfully increased the actual densities of model alloys. The maximum density of 1.9873 gr/cm3 was achieved by 33wt.% Cu. Even though the increases in densities are achieved, these numbers are still low, which is caused by oxide or porosity formation as seen in Fig. 3. Oxides, porosity and density are influence on mechanical properties of different aluminum alloys system which were reported in other study [23][24].

3.3. Mechanical properties of the model Al-Cu alloy

The hardness of model Al-Cu alloys for different Cu contents and compaction methods are demonstrated in Figs.4a-b. It was clearly observed that the Cu contents play an important role in improving the hardness of the Al-Cu alloy, which is that the increases of the hardness can be achieved by addition of the Cu from 21 to 33 wt.%.

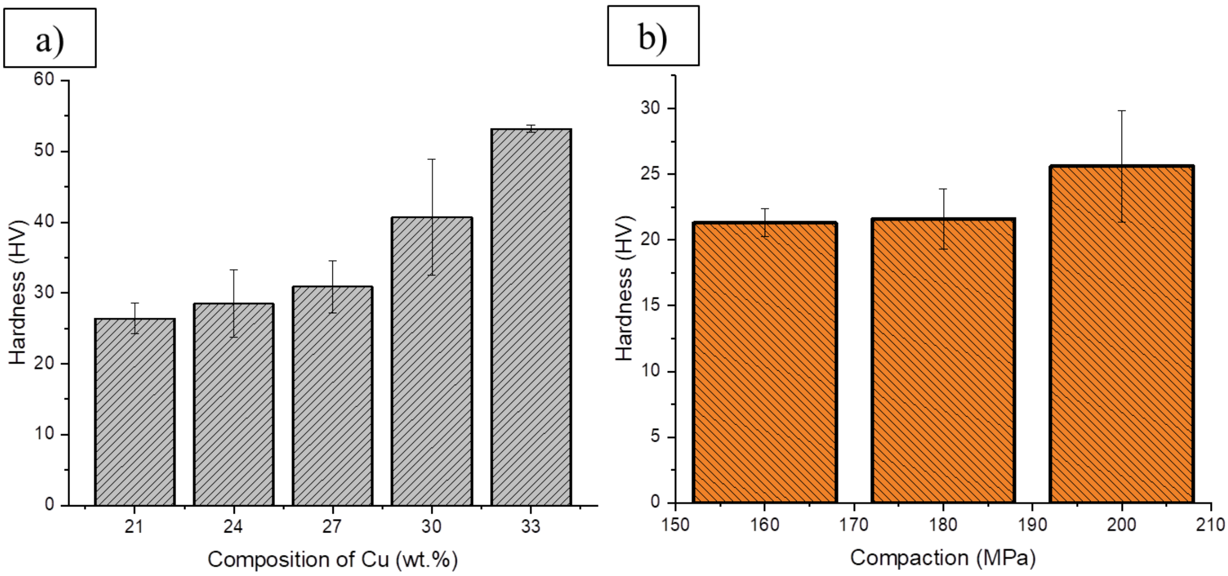

Fig. 4 The hardness of model Al-Cu alloy (a) variation of Cu content and (b) hardness of the 85Al15Cu for different compaction pressure

The highest hardness is 53.2 HV obtained with maximum Cu content in this current study, see Fig. 4a. The presence of the Cu could improve the hardness, and compaction pressure does not significantly increase the hardness of the sintered 85Al15Cu alloy, see Fig. 4b. The increases in pressure during compaction might correlated with densification, in which only slightly increase of density for sintered alloy obtained as shown in Tabel 2.

Fig. 5 shows the compressive strength of model Al-Cu alloy for different Cu contents. The addition of Cu into Al clearly improved the compressive strength, which is the maximum strength of 71.47 MPa obtained by addition of 33wt.%Cu. The Al-Cu alloy usually consists of many intermetallic phases with increases in Cu content, thus 33wt.% Cu elements are potentially to form some θ phase in their microstructure. This phase with an Al_2Cu structure is intermetallic, which has good hardness and strength [25].Furthermore, the compaction parameters influence the compressive strength of the 85Al15Cu alloy, see Fig. 6.

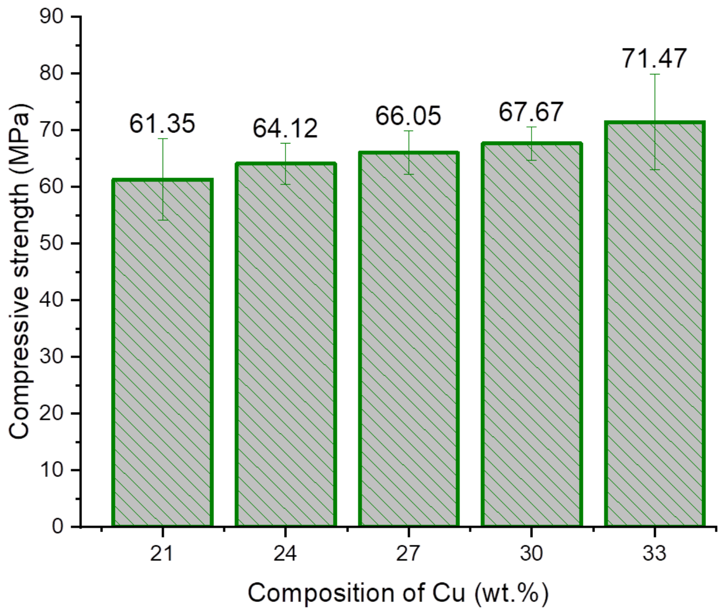

Fig. 5 Compressive strength of the model Al-Cu alloys for varying Cu contents

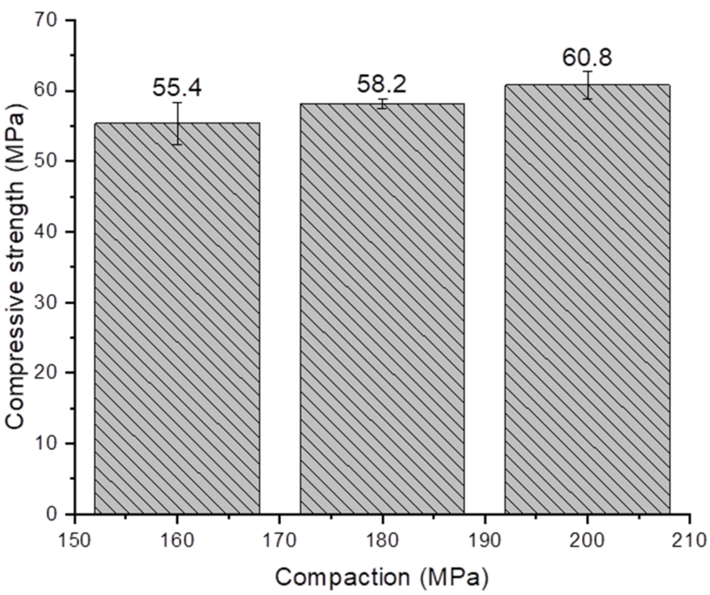

Fig. 6 Compressive strength of the model 85Al15Cu alloy for varying compaction pressure

A slight increases in compressive strength was obtained with the increase of pressure. The 60.8 MPa was achieved by introducing 210 MPa of compaction pressure. This result revealed that the pressure has not significantly improved the compressive strength of the sintered Al-Cu binary alloy, several phenomena such as oxides and porosity formation during sintering probably also influence the strength.

Fig. 7-8 shows the fracture surface of the compressive test of the model Al-Cu alloys. It was clearly observed that the fractures were mainly located at the outside diameter of model alloys. The crack propagation initially occurred from the top side to the bottom side as shown in Fig. 7b. The crack surface of a sample with varying compaction process also demonstrates similar crack characteristics with different Cu content, see Fig.8. It can be seen that until 30% strain the model alloys did not fully fracture, which indicated that the model Al-Cu alloy still has ductility.

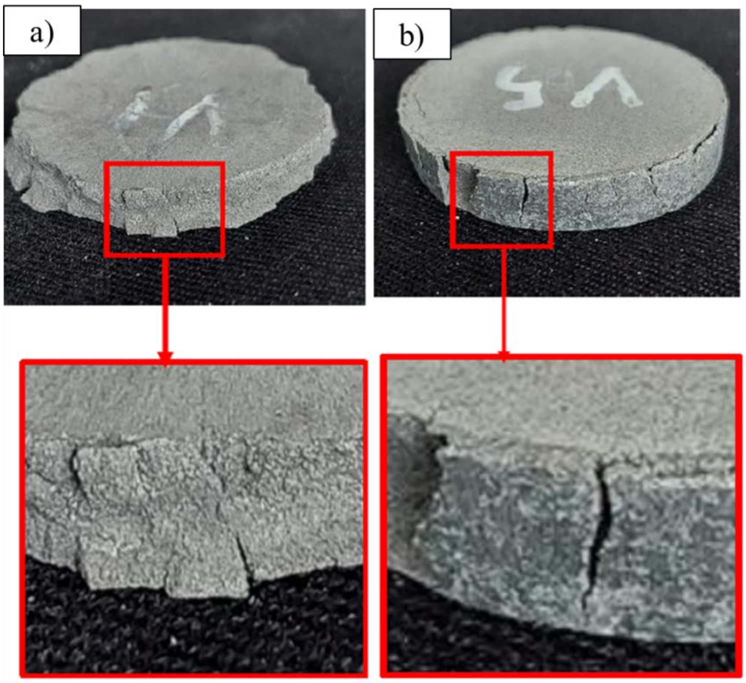

Fig. 7 Fracture surface of the compressive test for different Cu contents (a) 21wt.% and (b) 33wt.%

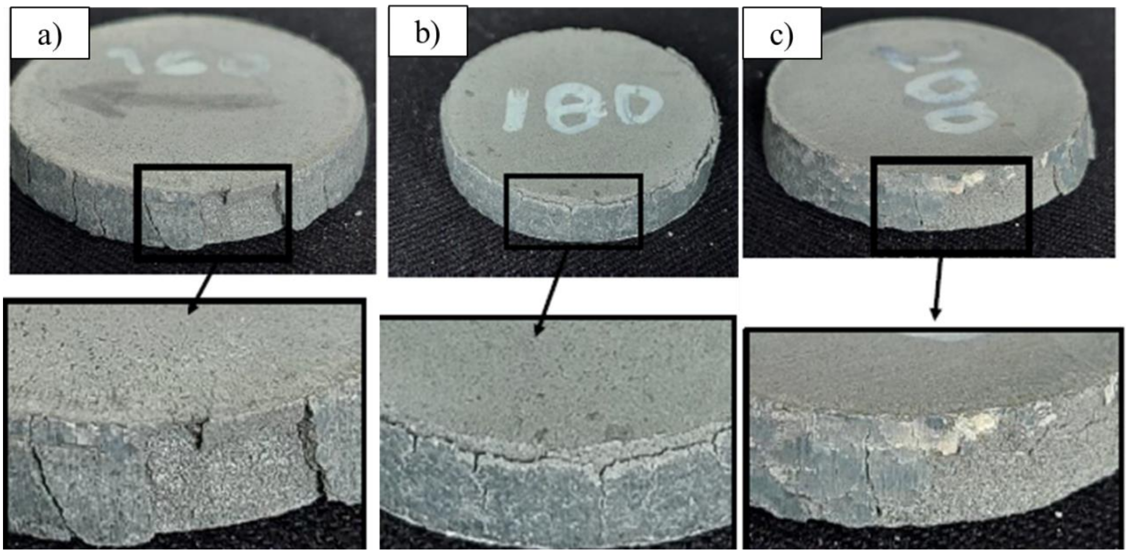

Fig. 8 Fracture surface of compressive test of the different compaction (a) 160 MPa, (b) 180 MPa, and (c) 200 MPa.

4. Conclusions

The effect of Cu contents and compaction parameters on mechanical properties and microstructure of Al-Cu alloy was investigated using different routes. The following conclusion can be drawn:

1. The addition of the Cu element (21-33wt.%) successfully enhanced the hardness and compressive strength of 26.4 HV~53.2 HV and 61.35 MPa~71.47MPa respectively.
2. A slight increase in the hardness and compressive strength was obtained with the increase of compaction pressure.
3. The increase of the Cu content encourages the Cu dispersion between the Al matrix in the microstructure and also reduces the oxides or porosity formation.
4. The increase of compaction pressure promotes a fine Al-Cu grain and reduces the porosity in the microstructure of the 85Al15Cu allloy.

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6. Conflict of Interest

The authors declare no conflicts of interest correlated with data, financial support, and personal relationships in this paper.

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