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Effects of aluminum addition on the characteristics of Cu-28Zn brass produced by gravity casting

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Abstract. Brass has an attractive combination of strength, ductility, and good corrosion resistance, which are required in many components, such as cartridge cases, valves, and fittings. In all of these components, brasses are usually fabricated through casting, rolling, deep drawing, and other mechanical deformation processes. Alloying elements were added in order to improve strength without sacrificing the ductility of brass. In this research, aluminium was added to Cu-28Zn brass of 1.9, 5.7, and 6.2 wt. % addition. Alloys were fabricated by gravity casting followed by homogenization at 800 ^{o}C for 2 h. Material characterizations were done through microstructural analysis using optical microscope and Scanning Electron Microscope – Energy Dispersive X-Ray (SEM-EDX), Rockwell B and Micro Vickers hardness testing methods, and tensile testing. The results showed that Al addition improved the mechanical properties of Cu-28Zn alloy. Hardness, tensile strength, and yield strength increased, but the elongation decreased.

1. Introduction

Cartridge brass is a 70Cu-30Zn wt. % alloy that has an exceptional mechanical strength and ductility. It is widely utilized in applications requiring high mechanical properties such as heat exchangers, pipelines, and cartridge cases. In the previous research, it was found that the alloy exhibited optimal strength and ductility properties at the composition of 28 wt. % Zn [1]. Further attempts in optimizing the mechanical properties of Cu-28Zn were then done through alloying. Basori, et al. [2] concluded that the addition of 0.22, 0.41, and 0.80 wt. % Bi did not contribute significantly in improving hardness of the alloy, instead, the presence of 0.41 and 0.80 wt. % Bi in the alloy will result in lenticular and network morphology, respectively. Both of the morphologies had negative impacts on elongation, tensile, and yield strength of the cartridge brass alloy. Pratiwi [3] then showed that Mn addition of 1.26, 3.23, and 5.83 wt. % could increase the hardness of Cu-28Zn alloy through solid solution strengthening and formation of β' second phase in Cu-28Zn-5.83Mn alloy composition. A research by Ovat, et al. [4] suggested that addition of up to 10 wt. % aluminium could enhance the hardness, strength, and elongation of Cu-15Zn brass. Optimum combination of ultimate tensile strength, elongation, and hardness was found in samples with 5 wt. % Al addition, while optimum toughness resulted from addition of 2 wt. % Al. However, the research did not provide any results of microstrucural observation.

In mathematical Al-Cu-Zn thermodynamic systems presented by Liang and Fetzer [5] that included a vertical phase diagram sections of the alloy at constant 2, 4, and 6 wt. % Al addition, it was stated that different phases will form with ranging aluminium addition. The α + β phases will form in 2 wt. %

aluminium addition, while single β-phase will result in addition of 4 and 6 wt. % aluminium, all occurring at temperatures below 950 ^{o}C. Martunis [6] attempted adding 6.4 wt. % Al to 79.8Cu-13.4Zn wt. % alloy of which final product revealed the presence of α-phase and eutectic α + γ microstructure with toughness and elongation of 0.355 J.mm^{-2} and 10.65%, respectively, in contrary to the thermodynamic system by Liang [5]. The research added that the presence of Al in brass will promote the formation of β-phase, whilst further addition will initiate the hard γ-phase to form. Suprihadi [7] then observed the effect of 6 wt. % Al addition to Cu-30Zn alloy. The Cu-30Zn-6Al alloy was found to have dominant β-phase content along with some γ-phase of with overall toughness and elongation of 0.202 J.mm^{-2} and 7.63%, respectively. In the present work, microstructural analysis and mechanical properties investigation were done on as-homogenized cast samples of Cu-28Zn alloy with 1.9, 5.7, and 6.2 wt. % Al addition. Effects of Al addition to the cartridge brass alloy was studied.

2. Experimental Method

Pure Cu, Zn, and Al ingots were used as starting materials. Cu and Al ingots were first melted in an electric furnace at 1150 °C. Zn ingots were added last to the molten metal. Borax was added to the molten metal as flux to reduce the formation of inclusions while no degassing process was conducted. Prepared molten alloys were casted into a metal mold preheated at 650 °C. The as-cast alloys were then homogenized in muffle furnace at 800 °C for 2 h followed by air-cooling. Nominal compositions of as-homogenized alloys were acquired by Optical Emission Spectroscopy (OES) as listed in Table 1.

Table 1. The chemical composition of the Cu-28Zn-Al (wt. %) alloy

Alloys	Zn	Al	Pb	Fe	P	Mg	S	Sn	Cr	Cu
A	29.516	1.934	0.009	0.015	<0.001	0.001	0.002	0.000	-	Bal.
B	28.369	5.744	0.006	0.015	<0.002	0.000	0.002	0.000	-	Bal.
C	25.1	6.24	<0.001	0.012	<0.003	<0.001	0.007	0.015	-	Bal.

Microstructures of the samples were observed by using optical microscope and Scanning Electron Microscope (SEM) EDX Oxford Quanta 650 instrument. Standard metallographic preparation was conducted based on ASM E3-11 using 10 gr $FeCl_3$ + 100 ml distilled water as etchant. *Image Pro Analysis* software was used to determine the actual volume fraction of each phase. Rockwell and Micro Vickers hardness testing were performed to each sample in accordance to ASTM E 18. Tensile testing was done on dog bone specimens according to ASTM E8 standard.

3. Results and Discussion

3.1. Microstructures

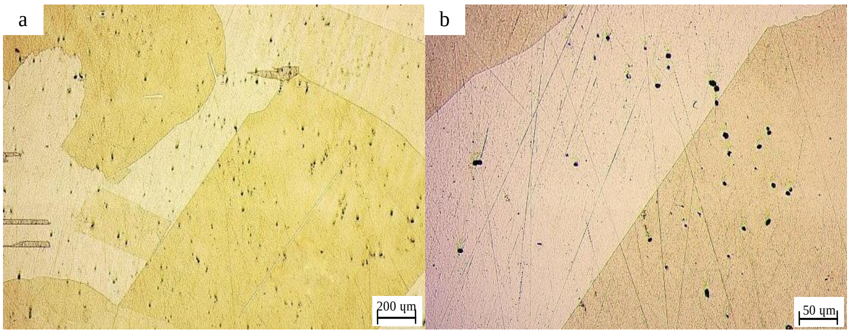

Figure 1. Microstructures of as-homogenized Cu-28Zn alloy of (a) 50 and (b) 200 x magnification

Figure 1 (a,b) shows large equiaxed grains of the Cu-28Zn alloy as a result of homogenization. However, such large and equiaxed grains were not found in alloys with 1.9 wt. % Al addition as seen in figure 2 (a.b). Microstructure of alloy A with Cu-29.5Zn-1.9Al alloy composition was consisted of irregular shapes in different colors that were identified as α + β phases [8]. According to Sampath [8], the more stable α-phase were formed from metastable β phase that transformed during homogenization and air cooling. Figure 2 (c,d) shows the microstructure of alloy B with Cu-28Zn-5.7Al wt. % composition, consisting of equiaxed grain identified as β phase [9,10]. This is supported with a research by Vilarinho [10], stating that the addition of Al in brass alloy will deplenish and further eliminate the existence of α phase, resulting in a single β phase morphology. In other words, Al was said to promote the formation of β phase in Cu-Zn alloy [10]. Subsequently, a second phase in four leaves clover shape was found in the microstructure of plate C with Cu-29.5Zn-6.2Al composition as shown in figure 2 (e,f). The corresponding shape was identified as γ phase [11].

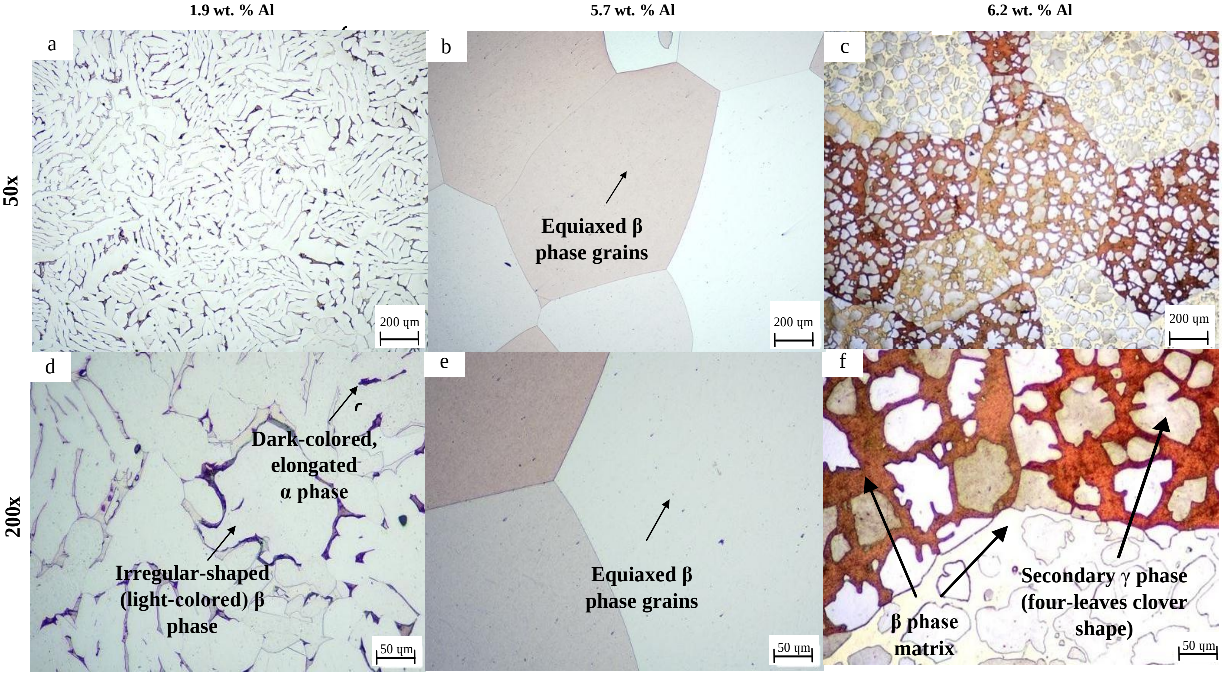

Figure 2. Microstructures of as-homogenized Cu-28Zn alloy with addition of: (a,b) 1.9, (c,d) 5.7, and (e,f) 6.2 wt. % Al

Microstructures of as-homogenized alloys A, B, and C were further inspected using SEM photography as presented in figure 3. Microstructure image of alloy A showed the presence of bright α phase and dark β phase. Equiaxed grain microstructures of β phase were also revealed from EDX testing of plate B, while plate C exhibited four leaves clover morphology of secondary γ phase with relatively uniform size. The EDX analysis also proved that the γ phase wielded greater Al content compared to those found in α and β phase as seen in table 2. From this result it can be reffered that the addition of aluminium in Cu-28Zn alloy could promote the formation of β phase and γ phase at further addition.

Volume fractions of each formed α, β, and γ- phase were calculated using Lever Rule principal on each sample compositions plotted on the vertical ternary diagram with constant 2, 4, and 6 wt. % aluminium content by Liang and Fetzer [5]. Both calculation and quantitative analysis using *Image Pro Analysis* results shows correspondence to each other. The Cu-30.36Zn-1.9Al wt. % sample was found to have more α phase to β phase as seen in figure 2 (a,b) where the light colored matrix was identified as α phase. Whereas the Cu-25.1-6.2Al wt. % sample was found to have greater amount of γ phase than β phase with volume fraction of 50.8 % and 49.15 %, respectively.

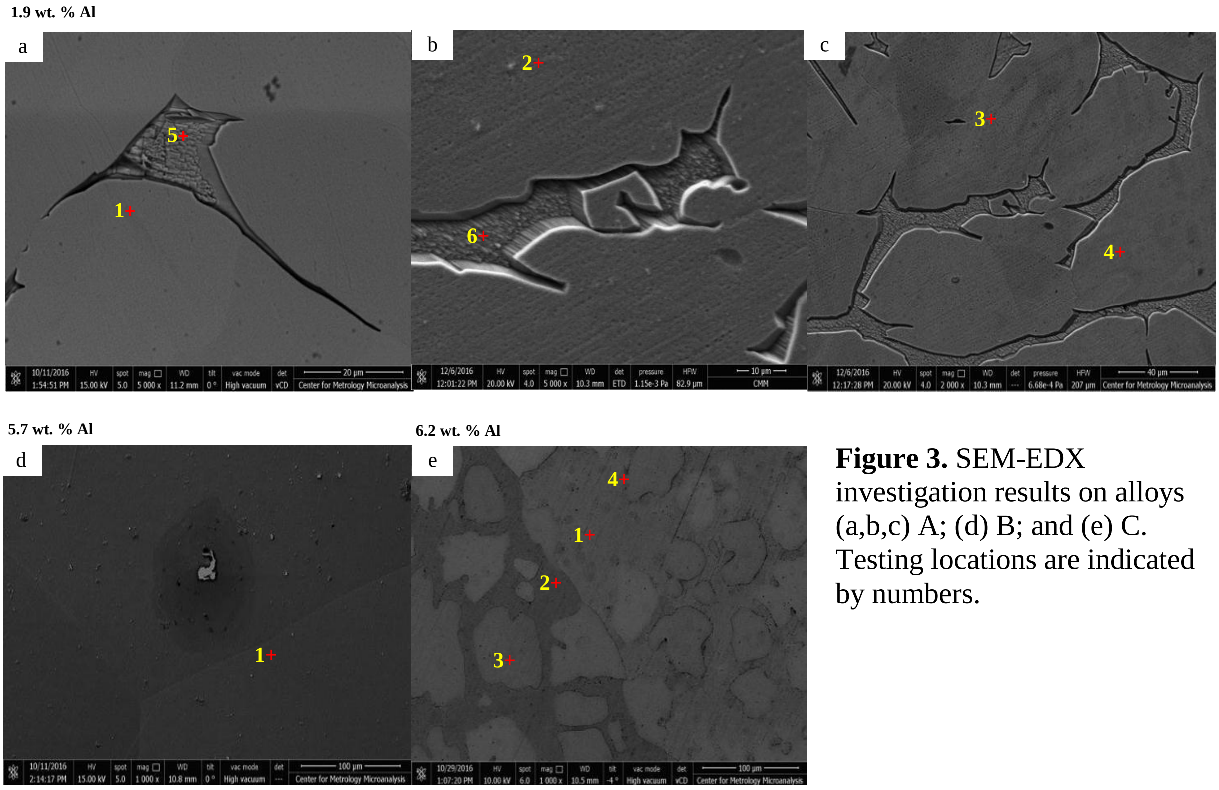

Figure 3. SEM-EDX investigation results on alloys (a,b,c) A; (d) B; and (e) C. Testing locations are indicated by numbers.

Table 2. Results of EDX analysis on alloys (a) A, (b) B, and (c) C

(a)

Loc. No.	Composition (at. %) Cu	Zn	Al	O	C	Possible Phase
1	63.64	30.25	5.59	1.12	2.65	α
2	69.70	25.60	4.80	-	-	α
3	70.00	25.80	4.30	-	-	α
4	69.80	25.60	4.60	-	-	α
5	60.49	28.41	11.11	3.56	2.12	β
6	60.00	31.90	8.10	-	-	β

(b)

Loc. No.	Composition (at. %) Cu	Zn	Al	O	C	Possible Phase
1	63.11	27.86	10.03	-	2.96	β

(c)

Loc. No.	Composition (at. %) Cu	Zn	Al	O	C	Possible Phase
1	63.15	25.40	11.45	0.21	2.96	β
2	61.05	24.15	10.82	-	-	β
3	60.67	23.59	15.74	0.76	3.02	γ
4	61.33	23.31	15.36	-	-	γ

3.2. Mechanical properties

Hardness of as-homogenized alloys A, B, and C with addition of 1.9, 5.7, and 6.2 wt. % Al were 40.3, 83.43, and 103.58 HRB, respectively, as seen in Figure 4. Increasing hardness was caused by the presence of aluminium, which significantly promoted the formation of β and γ phase at certain extent of addition. Figure 4 (a,b) shows the microhardness of plate A, B, and C. The number of microhardness of each plate A, B, and C were 77.64, 191.43, and 261.70 VHN, respectively. Both micro and macrohardness showed an increase along with more addition of aluminium to the alloy.

Plate B with single β phase was found to have higher strength compared to α + β phase in plate A due to the lattice strain caused by solute Al in the matrix, which prevented dislocation movement and initiated a solid solution strengthening mechanism. While further strength increase in plate C is assumed to happen due to the presence of γ phase which exhibited greater strength than β phase. Furthermore, it was supposed that the well-distributed γ phase contributed in the dispersion strengthening mechanism to occur.

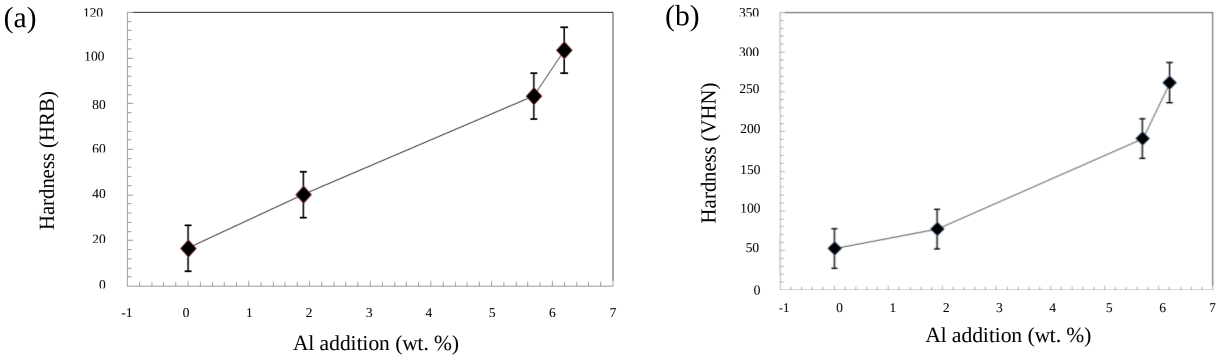

Figure 4. Increasing hardness properties of as-homogenized Cu-28Zn alloy with adddition of 1.9, 5.7, and 6.2 wt. % Al: (a) macrohardness and (b) microhardness

Figure 5 shows the mechanical properties of alloys A, B, and C with addition of 1.9, 5.7, and 6.2 wt. % Al, respectively. The tensile strength of alloys A, B, and C were 415.7, 545.25, and 412.65 MPa, while the yield strength were 21.39, 465.66, and 381.38 MPa, both respectively. From this data, it is known that both tensile and yield strength increased linearly with the hardness increase until the addition of 5.7 wt. % Al. However, contradicting result was found in plate C, where increasing hardness was followed by decreasing tensile and yield strength. This phenomenon was assumed to happen due to the presence of porosity that initiated microcracking before the specimen reached its actual yield strength and UTS. Elongation of plate A, B, and C were 43.32, 9.5, and 1%, respectively, while reference Cu-28Zn alloy showed elongation of 58% as shown in figure 5. It can be inferred that more Al content in the cartridge brass matrix could decrease the elongation of the alloy due to the presence of lattice strain caused by the addition of aluminum which further inhibited the dislocation movement through solid strengthening mechanism.

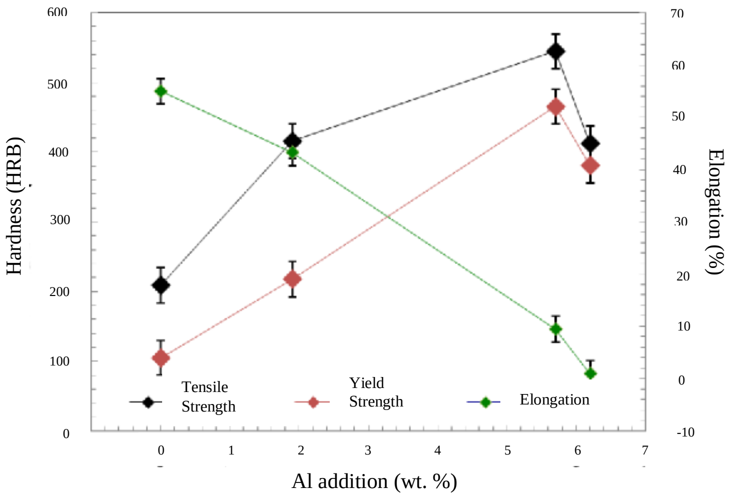

Figure 5. Effect of 1.9, 5.7, and 6.2 wt. % Al addition to several mechanical properties of as-homogenized Cu-28Zn brass alloy

Fracture surfaces of tensile samples of alloys A, B, and C are shown in figure 6. Figure 6 (a) shows the fracture surface of alloy A which appeared to have concave fracture surface (blue area), fibrous fracture surface (white area), and area of plastic deformation. Similarly, fracture surface of plate B in figure 6 (b) were having conformable fracture characteristics of plate A, with greater area of plastic deformation observed. Both plate A and B possessed area of plastic deformation or necking area due to tensile testing, which indicated that the two plates had a ductile fracture characteristic. On the other hand, fracture surface of plate C shown in figure 6 (c) was flat with a very small amount of plastic deformation which indicated a brittle fracture characteristic. This brittle characteristic is caused by the inhibition of dislocation movement when tensile force was applied. It is commonly found that materials with brittle fracture characteristics have a high tensile and yield strength, but on the contrary, plate C showed a decrease in both tensile and yield strength due to the presence of porosities in the specimen that allow cracks to propagate more swiftly.

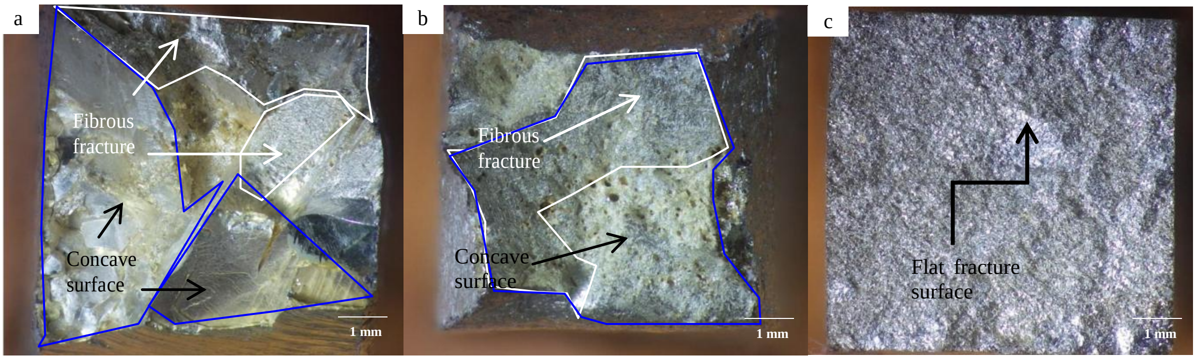

Figure 6. Fracture surfaces of as-homogenized Cu-28Zn tensile testing specimen with addition of (a) 1.9, (b) 5.7, and (c) 6.2 wt. % Al

4. Conclusions

Microstructure and mechanical properties of Cu-28Zn alloys with various wt. % Al addition were investigated. The following conclusions are drawn:

1) As homogenized Cu-28Zn alloy with 1.9 wt. % Al addition showed elongated α phase grain and β phase matrix morphology. The corresponding alloy with 5.7 wt. % Al content exhibited equiaxed grain morphology consisting of β phase while microstructure of Cu-28Zn-6.2Al wt. % alloy indicated the presence of γ phase in four leaves clover shapes dispersed on β matrix.
2) Addition of 1.9 and 5.7 wt. % Al increased the tensile strength of Cu-28Zn alloy from 209 MPa to 415.7 and 545.25 MPa and the yield strength from 105 MPa to 218.39 and 456.66 MPa. However a decrease in both tensile and yield strength of the alloy to 412.65 and 381.38 MPa were found in addition of 6.2 wt. % Al due to the existence of porosity.
3) Hardness of Cu-28Zn alloy increased along with more Al content from 53 VHN to 77.46, 191.43, and 356.23 VHN on the addition of 1.9, 5.7, and 6.2 wt. % Al, respectively. Strenghtening in alloys with 1.9 and 5.7 wt. % Al addition were due to the formation of β-phase and solid solution strengthening mechanism, while dispersion strengthening mechanism by the presence of well dispersed γ-phase was responsible for the improved hardness of alloy with 6.2 wt. % Al addition.
4) Elongation of Cu-28Zn alloy decreased from 58% to 43.32, 9, and 1% with the addition of 1.9, 5.7, and 6.2 wt. % Al, respectively. This result was confirmed by observing the fracture behaviors of each sample, where samples of 1.9 and 5.7 wt. % Al addition showed characteristics of ductile fracture while on the contrary, sample with 6.2 wt. % Al exhibited brittle fracture surfaces.

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