HYPOEUTECTIC Al-Cu ALLOYS SUBJECTED TO SEVERE PLASTIC DEFORMATION

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Abstract

In this study, hypoeutectic AlCu5 alloy and AlCu25 alloy in the as-cast condition were severely plastically deformed by extrusion combined with reversible torsion (KoBo) method to produce ultrafine grained structure. Scanning transmission electron microscopy (STEM), scanning electron microscopy (SEM) were used for microstructure characterization. Tensile test for characterization of mechanical properties were also performed. Tensile test were carried at room temperature and at temperature of 100 °C and 200 °C, with a speed of $10^{-4}s^{-1}$. The results shows, that the KoBo deformation allows refinement of hypoeutectic structure. Tensile tests performed at room temperature revealed, that ultimate tensile strength (*UTS*) were 223 MPa and 366 MPa for AlCu5 alloy and AlCu25 alloy respectively. For AlCu5 alloy and AlCu25 alloy deformed at 200 °C, the *UTS* were 100 MPa and 182 MPa respectivelly. The elongation for failure (A_t) for AlCu5 alloy and AlCu25 alloy at room temperature were 18 % and 5 % respectively. For samples deformed at 200 °C, the A_t were 29 % and 40 % respectively.

Keywords: Al-Cu alloy, severe plastic deformation, KoBo, ultrafine-grains, STEM

1. INTRODUCTION

Severe plastic deformation SPD techniques are recognized as effective methods for improving mechanical properties of metals and alloys. However, by using the SPD techniques especially with cyclic mode of deformation it is possible to improve not only the tensile properties but also ductility [1-4]. KoBo methods has been widely used in many groups of metallic materials to obtain fine-grained structure [5]. This method has been applied to a wide range of alloys and composites [6-12]. Additionally, KoBo belong to methods with cyclic changes in the strain path [13-14].

As-casted Al-Cu alloys are commercially important and are difficult to shape by other methods than SPD technique. These alloys contain Al-based intermetallic precipitates and for this reason are candidates for structural applications at ambient and elevated temperatures. Thorough SPD processes, characteristic dimension and distribution of intermetallic precipitates may be changed into the matrix. In the result the ductility and strength of the Al-matrix alloy may be improved not only in elevated temperatures but also at room temperature. A literature review on Al-Cu alloys indicates that research work on the SPD deformed alloys with comparable chemical composition have not been attempted, except a few works [2,7-10]. The study of the plastic deformation of alloys with intermetallic phase is interesting not only for fundamental knowledge on the deformation mechanisms, but also gives more insight on the mechanical behavior of these materials.

The aim of this work is an analysis of the effect of the SPD technique, i.e. KoBo, on microstructure refinement of the hypoeutectic as-cast Al-Cu alloys.

2. EXPERIMENTAL PROCEDURE

The materials for KoBo extrusion were Al-Cu alloy with 5%wt. of Cu (CuAl5 alloy) and with 25%wt. of Cu (CuAl25 alloy). The materials were obtained by melting in the Leybold-Heraues furnace. The materials were melted in graphite crucible. The melted alloy were cast into a round cylindrical with a diameter of 50 mm and allowed to cool down. After cooling the ingots (see **Figure 1a**) were removed from the moulds. Obtained ingots were machined to 49.5 mm in diameter and were cut to the length of 100 mm (see **Figure 1b**). The severe plastic deformation tests were carried out with the modernized KoBo 2.5 MN horizontal hydraulic press. As-extruded KoBo was performed to manufacture of rods 9 mm in diameter (see **Figure 1c**). The recipient temperature was about 130 °C. All deformation tests were carried out at constant angle of die reverse-rotation +/- 8°. The die oscillation frequency was 5 Hz.

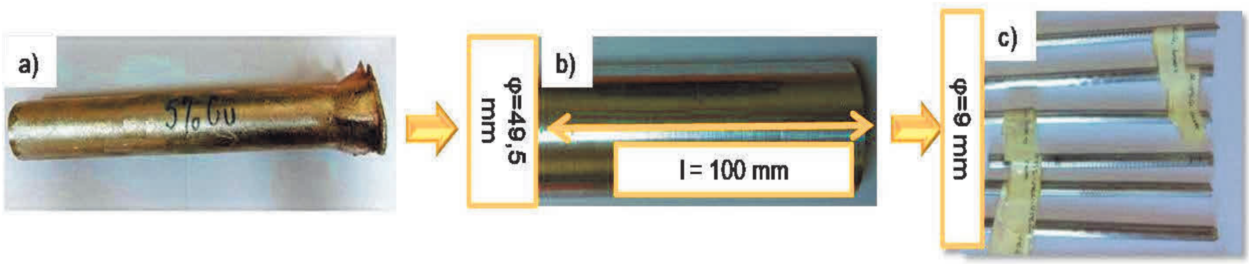


Figure 1 Example of experimental procedure: a) ingot, b) machined sample, c) rods after KoBo

The microstructure of samples was analyzed by means of scanning electron microscope LEO GEMINI 1525 and scanning transmission electron microscope (STEM) Hitachi HD-2300A equipped with FEG gun. The microstructure of the deformed samples were examined on their transverse sections.The qualitative investigations of microstructure were performed with using Metilo program [15].

The tensile tests were performed on a Zwick/Roell 100 machine at room temperature, 100 °C and 200 °C with a rate of 10^{-4} s^{-1}. Proposed tensile test rate is intentional, because it is assumed that the materials will have a superplastic properties. Appropriate tests will be carried in the future. Three tensile tests were performed on each sample and the average values were calculated. The dimensions of the samples were: diameter d = 4 mm, length l_0 = 50 mm.

3. RESULTS

In the microstructure of AlCu5 (see **Figure 2a**) and AlCu25 alloys (see **Figure 2b**) in initial state (as-cast state) the dendrites of α phase (dark field in SEM microstructure) were observed. Between the α phase dendrites is visible intermetallic θ-Al_2Cu phase (bright field in SEM microstructure). It is evident, that increase of Cu content leads to increase of interdentritic regions. The interdentritic regions of AlCu5 and AlCu25alloys consisted of massive eutectoid composition (α + Al_2Cu phase) and small particles of Al_2Cu phase (see **Figure 2a** and **Figure 2b**). After KoBo deformation fragmentation of the microstructure takes place (see **Figure 2c** and **Figure 2d**). The θ-Al2Cu phase are characterized by more globular shape compared with as-cast sample. This is well visible especially for AlCu25 alloy (compare **Figure 2b** and **Figure 2d**). The massive regions of eutectoid composition in AlCu5 alloy is near not deformed compared with initial state (see **Figure 2a** and **Figure 2c**). Although, the regions of α phase dendrites are refined especially in the areas where small particles of Al2Cu phase (net of Al2Cu phase) were observed (see **Figure 2c**).

Based on quantitative SEM investigations by using Metilo, the volume fraction of the intermetallic phase after KoBo deformation was estimated from the SEM images. Characteristic structural features were obtained for AlCu5 and AlCu25 alloys and assumed in **Table 1**. As expected, average area fraction of Al2Cu phase both massive and small phase of AlCu25 alloy is higher than for AlCu5 alloy. Average area of massive Al2Cu phase is about three times higher for AlCu25 alloy than for AlCu5 alloy. Although average area of small phase is quite comparable for discussed alloys. Based on microstructure investigations it is possible to assume, that small phases are not deformed. Dimensionless aspect is near this same for small Al2Cu phase in both deformed alloys but is higher for massive phase in CuAl5 alloy. Similar conclusions can be drawn based on the analysis of dimensionless coefficient of elongation for deformed alloys.

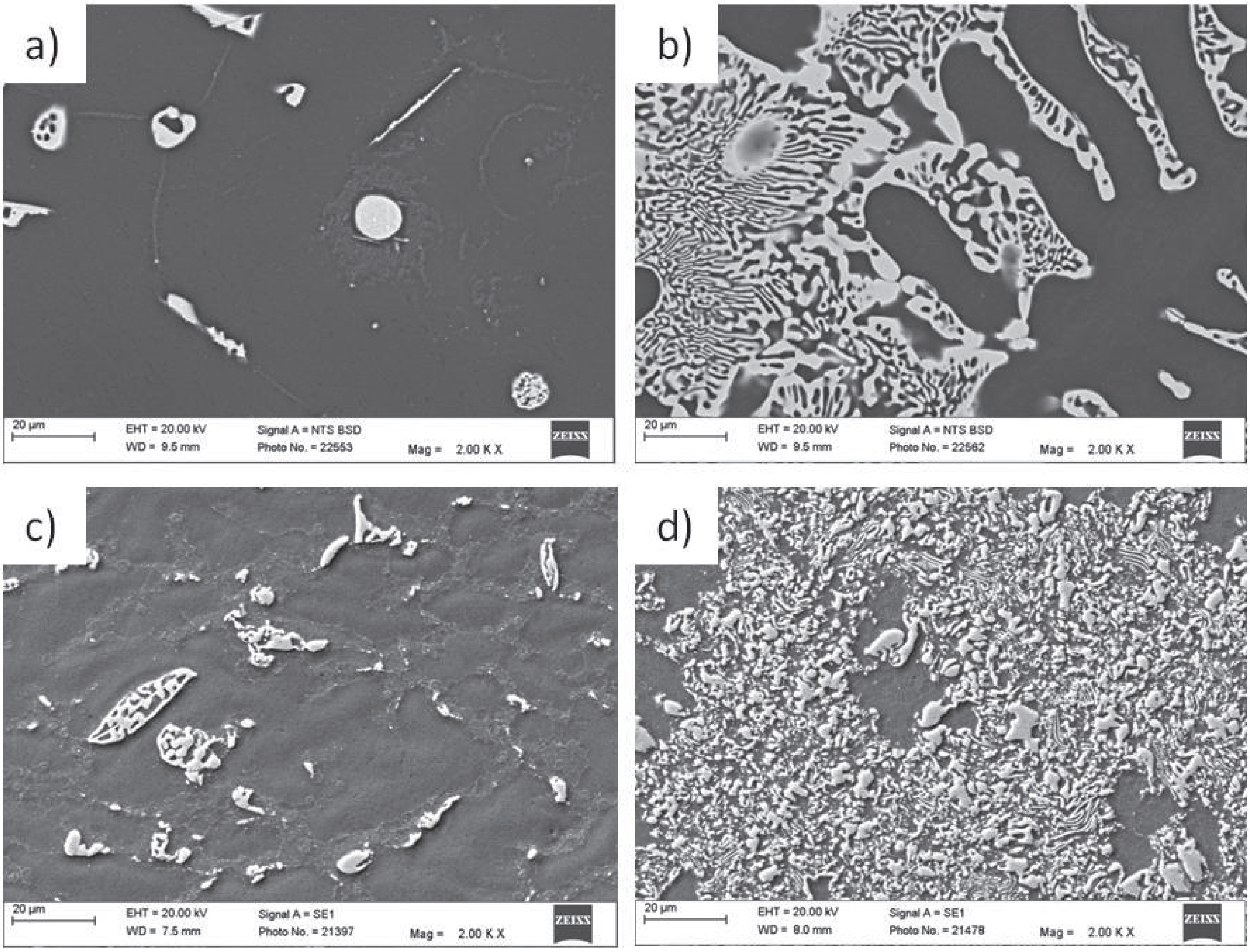


Figure 2 Microstructure of investigated alloys: a) AlCu5 alloy at as-cast; b) AlCu25 alloy at as-cast; c) AlCu5 alloy after KoBo deformation; d) AlCu25 alloy after KoBo deformation

Table 1 The results of quantitative SEM investigation of Al_2Cu phase after KoBo deformation

	AlCu5		AlCu25	
	Massive phase of Al_2Cu	Small phase Al_2Cu	Massive phase of Al_2Cu	Small phase Al_2Cu
Fraction of average area(%)	3.51±1.27	2.27±1.61	19.03±2.16	4.95±1.61
Average area, (µm^2)	8.15±6.84	0.12±0.05	27.33±9.99	0.15±0.07
Dimensionlessaspect ratio ξ	0.48±0.26	0.71±0.18	0.32±0.19	0.64±0.19
Dimensionless coefficient of elongation δ	2.03±0.75	1.82±0.50	1.84±0.54	1.76±0.55

Based on STEM investigations (see **Figure 3a** and **Figure 3b**) it is visible that AlCu5 alloy after KoBo deformation contains intermetallic particles distributed randomly in the α-Al matrix. The results of the STEM analysis showed two visible types of particles of Al_2Cu phase: small spherical particles and higher irregularly shaped particles. The α-Al matrix broke up as a result of the KoBo deformation. The diameter of refined grains is about 1 µm. The microstructure of AlCu5 alloy after deformation revealed that most of the dislocations are presented near the particles (see **Figure 3a**). In AlCu25 alloy, deformation process is connected with redistribution of Al_2Cu phase, which assured a more homogeneous microstructure (see **Figure 3c** and **Figure 3d**). The new grains of are α-Al matrix and Al2Cu phase are near equiaxial. In the result of AlCu25 alloy deformation the fine grains with dislocation and without dislocation are created (see **Figure 3c**).

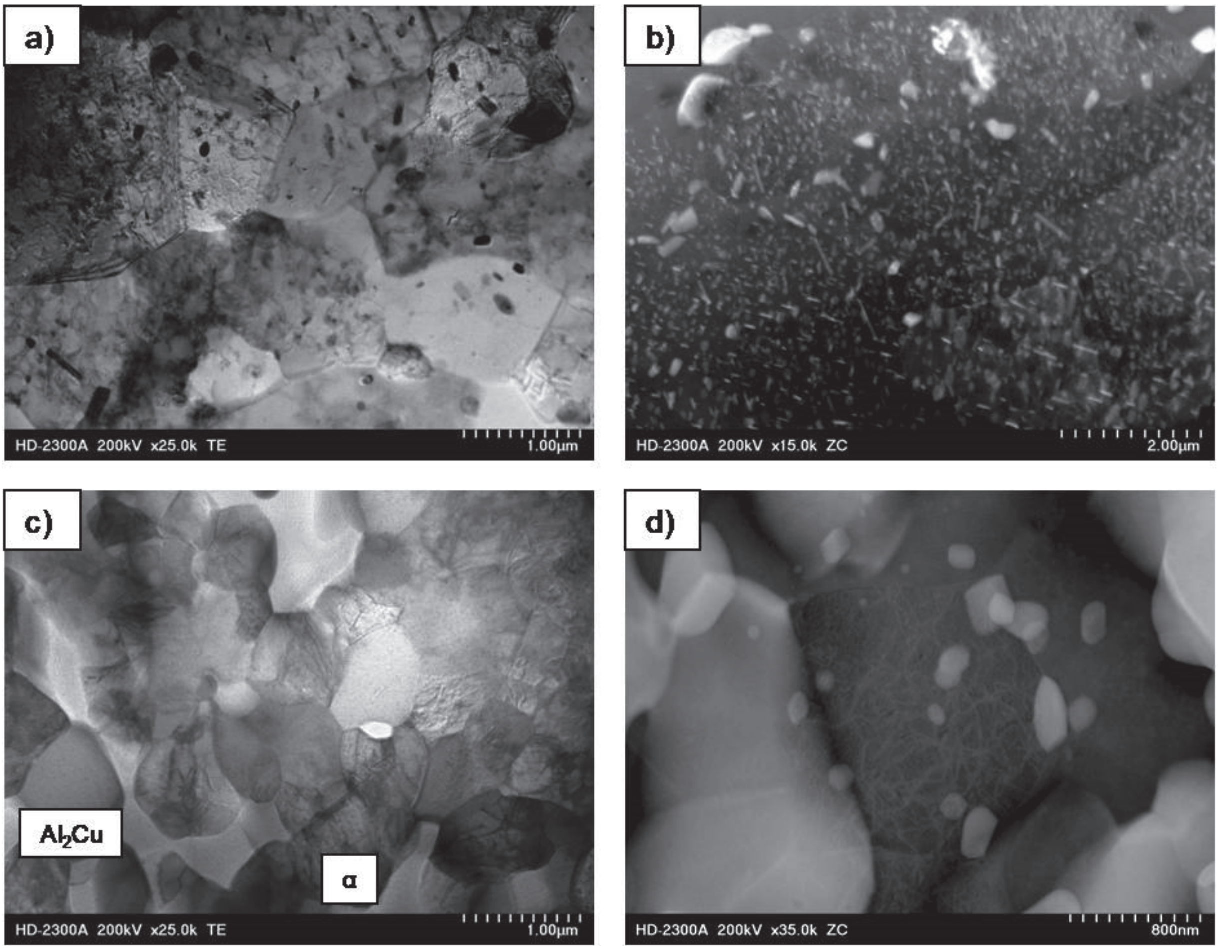


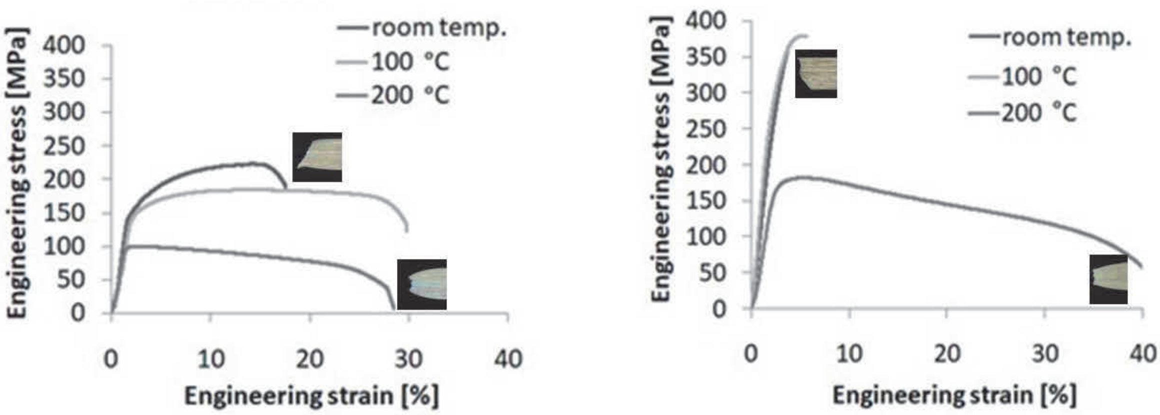
Figure 3 Microstructure of alloys after KoBo deformation: a, b) AlCu5 alloy; c,d) AlCu25 alloy

Detailed investigations using scanning transmission electron microscopy showed that, grains of the α-Al phase have a higher density of dislocations (see **Figure 3d**), than Al_2Cu phase. This situation is connected with the fact that for AlCu25 alloy, the processes of recovery proceed easier than in matrix. The obtained results are in accordance with the literature [16]. During deformation in Al_2Cu phase is observed mechanism connected with non-conservative motion of glide dislocation. This mechanism provides rapid diffusion channels during plastic deformation and indicates structural instability of intermetallic phase.

Should be noted, that the increase of the Cu content in 25%Cu alloy compared with 5%Cu result in a change in the dendrite composition and of their volume fraction (see **Table 1**) as well as shape of intermetallic phases. Additionally, the obtained results indicate, that the KoBo method is most effective in reducing the grain size and rebuilding of initial structure. These microstructural changes significantly influence on the mechanical behavior (see **Figure 4** and **Table 2**).

The *UTS* of AlCu5 alloy are noticeably lower compared to the AlCu25 alloy independently of temperature testify. The higher strength of AlCu25 alloy compared with AlCu5 alloy is caused by the intermetallic phase strengthening. The AlCu25 alloy has significantly improved *UTS* whereas the ductility (A_{gt}) remains at low level (about 5 %) compared with AlCu5 alloy.

Although at temperature of 200 °C the AlCu25 alloy exhibit high strength and high tensile ductility (A_t) compared with AlCu5 alloy. AlCu25 alloy shows the significant plastic deformation of 40 % after the onset of plastic instabilities whereas AlCu5 alloy exhibits about 30 %. From the obtained results, should be noted that the effect of the intermetallic strengthening and plastic deformability in AlCu25 alloy seems to be considerable in temperature about 200 °C.



a)AlCu5 alloy b)AlCu25 alloy

Figure 4 Characteristics engineering stress - engineering strain curve of the investigated alloys

Table 2 Mechanical properties of AlCu5 alloy and AlCu25 alloy obtained in static tensile test

	AlCu5			AlCu25		
	UTS(MPa)	A_{gt}(%)	A_t (%)	*UTS*(MPa)	A_{gt}(%)	A_t(%)
room temp.	223	14	18	366	4	5
100 °C	184	14	30	379	5	8
200 °C	100	3	29	182	5	40

4. CONCLUSIONS

The obtained results lead to the following conclusions:

- In the microstructure of AlCu5 and AlCu25 alloys, the dendrites of α phase were observed. The interdentritic regions consisted of eutectoid composition (α + Al_2Cu phase). The content of composition (α + Al_2Cu phase) increase with Cu increase.
- The obtained results showed possibility of KoBo deformation of as-cast alloys. KoBo processing contributed to the refinement of grains. The grain size is above 1 µm, regardless of alloy composition.
- KoBo processing is required to improve mechanical properties of alloy. The higher ultimate tensile strength *UTS* of AlCu25 alloy compared with AlCu5 alloy is caused by the intermetallic phase strengthening.
- Eutectoid composition of (α + Al_2Cu phase) control ductility properties as A_{gt} and A_t. The characteristic feature of AlCu25 alloy compared with AlCu5 alloy is higher plastic deformability in temperature 200 °C.

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