

Effect of Ti-B Grain Refiner on Microstructure and Mechanical Properties of a New Super High Strength Aluminum Al-Cu-Mg-Zn Cast Alloy

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Abstract: This work has been investigated on the effect of Ti-B grain refiner on a new super high strength aluminum Al-Cu-Mg-Zn cast alloy with high amounts of Zn (15%). To find the optimum, deferent amounts of Ti-B were added. 0.05% Ti-B was found the optimum amount and enhanced tensile strength, yield strength and elongation values about 20%, 23% and 100% respectively. Microstructural investigations showed that grain and cellular size decreased (approximately 30%). It means Ti-B could act as a heterogenic nucleation substrate and reduced the grain size of alloy. It also optimizes the morphology and size distribution of dendrites and results in homogenous distribution of eutectic structure between dendrite arms. Fractographic examinations of fractured surfaces of specimens illustrated that Ti-B reduced the eliminated contraction porosities and it also reduced the size of features on the fracture surface. Also, a dimple-like fracture mechanism appeared, however, the fracture still had a cleavage surface.

Keywords: Super High Strength, Ti-B, Grain Refiner, Al-Cu-Mg-Zn, Mechanical Properties.

1. Introduction

Al-Cu-Mg-Zn alloys are called aluminum super high strength aluminum alloys and are widely used in aerospace industry, but their high cost limits their application. These alloys are stronger than 6xx and 2xx alloys and even they exceeding normal structural steels [1].

Zinc is only effective in 7xx.x aluminum cast alloys and in other grades it neither increase nor decrease an alloy properties [2]. In order to achieve super high strength and toughness new Al-Cu-Mg-Zn alloys were designed [3-7]. As-cast structure of the alloys have a significant effect on their mechanical properties and the quality of the products, especially when the amount of alloying elements increases. In Al-Cu-Mg-Zn alloy a lot of compounds and eutectics of Al-Cu-Mg-Zn in non-equilibrium solidification lead to mainly grain boundary segregation which reduce the Mechanical properties of the alloy. The structure of such materials can be controlled by adding grain refiners, minimizing inclusions and applying thermo-mechanical treatments [8].

Grain refinement is widely used in aluminum foundries to promote a fine equiaxed grain structure which improved mechanical properties, reduced segregation and hot crack propensity, and improved fluidity. The majority of grain refining agent is Al-Ti-B, in particular Al-5Ti-1B, which is widely used as aluminum grain refiner over past decades and typically consist of the soluble Al₃Ti and the insoluble TiB₂ particles are often credited for grain refining effect [7, 9, 10]. Addition of Al-Ti-B in compare with salt tablets provides many benefits, including emissions reduction and better composition controlling. However, controlling the contact time is important. If the contact time is lower or longer than optimized time, the effectiveness of grain refiner decreases [10].

The aim of this investigation is to observe the effect of Ti-B grain refiner on the mechanical properties of Al-Cu-Mg-Zn super high strength aluminum alloy and those related micro- and macro-structure.

2. Experimental

The composition of the parent alloy used in this work was Al-2.5%Cu-2.5%Mg-15%Zn. The parent ingot was remelted within a small SiC crucible (with-1 Kg capacity) in a resistance furnace in order to prepare alloys with 0, 0.01, 0.03, 0.05, 0.08, 0.1, 0.3, 0.5 and 1 wt. % Ti. After 3 min holding time to make certain dissolution, the molten alloy was stirred manually with graphite rod for about 1 min to ensure complete mixing. After stirring and cleaning off the dross, molten alloy was poured into a cast iron mold. The mold was prepared according to B108-03a ASTM standard (Fig. 1) [11]. The main merit of this mold is few sound casting because of adequate uphill filling system and feeding design.

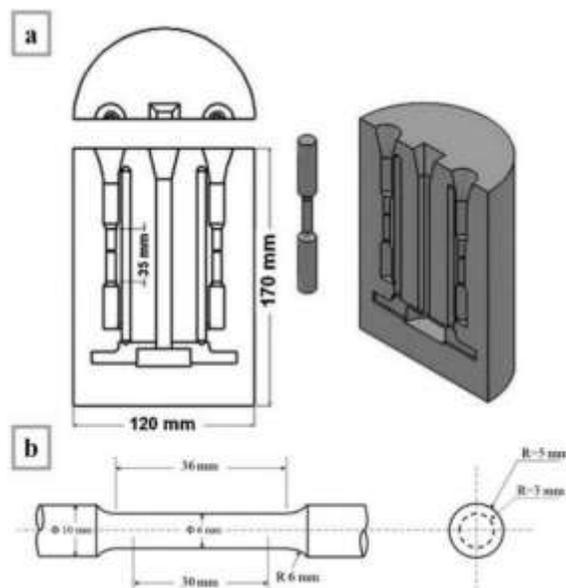


Fig. 1: Schematic drawing of (a) casting mould and (b) tensile test specimen.

Metallurgical specimens were prepared through standard routines by polishing and etching in hydrofluoric acid (HF) solution (1%) for about 6 sec at room temperature. The microstructures of the composite were assessed by using both an optical microscope equipped with an image analysis system (Clemex Vision Pro. Ver. 3.5.025) and Vega©Tescan SEM equipped with an energy dispersive X-ray (EDX) analyzer.

Tensile test were carried out on computer controlled MTS tension machine at a constant cross-head speed of 1mm/min. The fracture surface of tensile test specimens were also examined with SEM.

3. Results and Discussion

3.1. Microstructural Study

A typical microstructure of Al-Cu-Mg-Zn as-cast alloy is shown (Fig. 2) [12]. As it is illustrated the alloy microstructure contains of a continuous eutectic which is between dendrite arms. It is due to rejection of alloying elements to the last steps of solidification. The predominant structure of the alloy is understood to be consisting of a quasi-binary reaction products, evolving from parallel solidification of three quasi-binary eutectic reactions viz. α -Al/ η [MgZn₂], α -Al/T[Al₂Mg₃Zn₃] and α -Al/S[Al₂CuMg]. However apart from this eutectic T-base and S-base phases are also present as divorced phases [13]. The electron back scatter image of Al-2.5Cu-2.5Mg-15Zn alloy is shown in (Fig. 3). The microstructure is similar to typical ones. The continuous eutectic and divorced S phase are presented in the microstructure.

The microstructure which is shown in (Fig. 4) demonstrates the dendrite structure of as-cast alloy before (Fig. 4-(a)) and after (Fig. 4-(b)) addition of 0.05% Ti grain refiner. Grain refiner changed the shape of dendrites from a rough to a smooth shape. Also, it resulted in more uniform size. On the other hand, more homogenous distribution of eutectic structure between dendrite arms was obtained in the alloy consisting Ti-B.

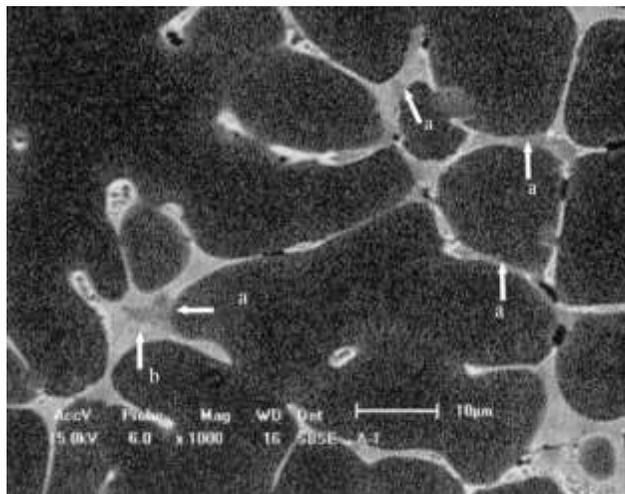


Fig. 2: Back scattered electron image of Al-Cu-Mg-Zn alloy [12].

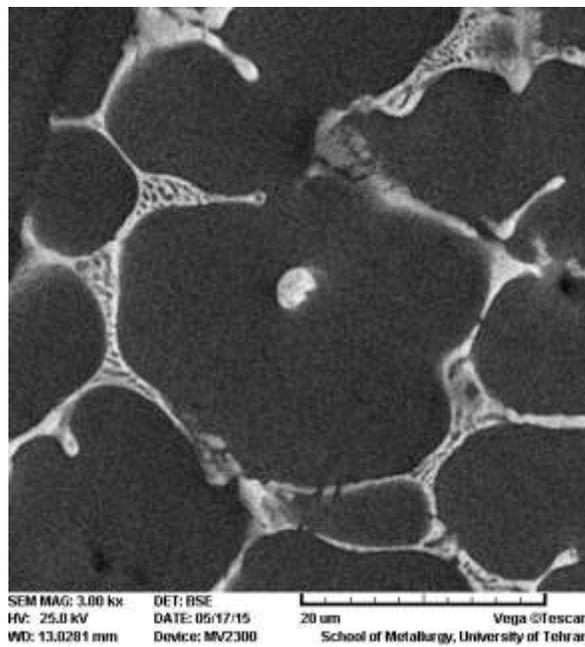


Fig. 3: The electron back scatter image of Al-2.5Cu-2.5Mg-15Zn alloy.

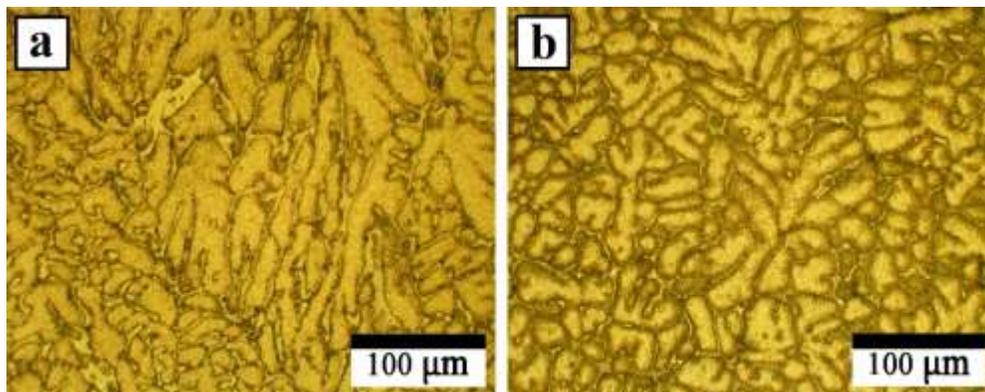


Fig. 4: Microstructure of Al-2.5Cu-2.5Mg-15Zn as-cast alloy with (a) no addition (b) 0.05% Ti.

3.2. Mechanical Properties

The elongation values of the specimens are demonstrated in (Fig. 5) as a function of Ti content. It shows that elongation values increases from 3.1% in 0 wt. %Ti to 6% in 0.05 wt. %Ti. It means 100% increase in elongation. The improvement of elongation properties with the addition of Ti, may be a result of easier slip of grains while grain boundary angle increases by grain refinement. On the other hand, the improvement in shape of dendrites and more homogenous distribution of eutectic structure, which was discussed earlier in this paper, could be another reason.

(Fig. 6) shows the results of UTS values after adding Ti to the Al-2.5Cu-2.5Mg-15Zn alloy in as-cast condition. It shows that UTS values raise up remarkably, by adding Ti to the alloy in as cast condition. The highest UTS value is obtained in the 0.05%Ti, which improves from 301.3 MPa to 362.7 MPa, showing approximately 20% improvement. It could be due to grain refining effect of Al-5Ti-1B addition. Smaller grain size could result in more uniform distribution of stress and strain and it prevents local stress and strain concentration.

(Fig. 7) illustrates the results of Yield stress (YS) values after adding Ti to the Al-2.5Cu-2.5Mg-15Zn alloy in as-cast condition. It shows that YS values raise up remarkably, by adding Ti to the alloy in as cast condition. The highest YS value is obtained in the 0.05%Ti, which improves from 184.4 MPa to 226 MPa, showing approximately 23% improvement. It may be due to grain refining effect of Al-5Ti-1B addition, which increases the UTS according to Hall-Petch mechanism [14].

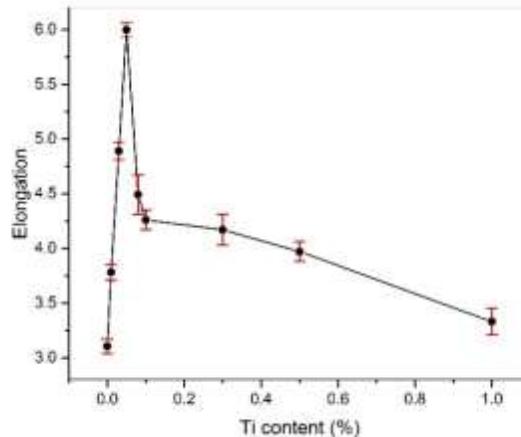


Fig. 5: Elongation values of alloy as a function of Ti content.

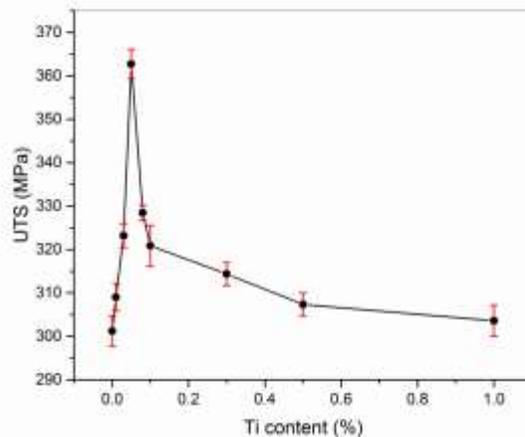


Fig. 6: UTS values of alloy as a function of Ti content.

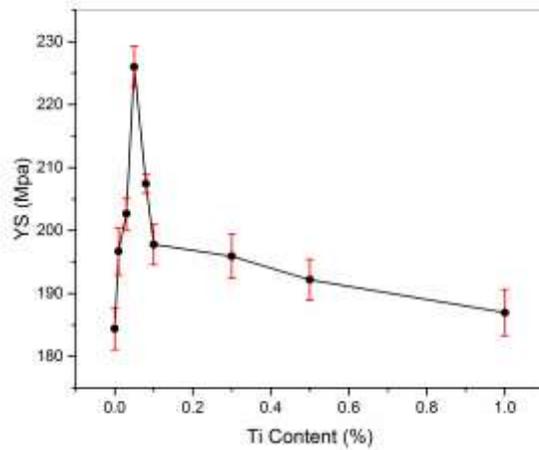


Fig. 7: Yield Strength values of alloy as a function of Ti content.

Fracture surface of Al-2.5Cu-2.5-Mg-15Zn alloy before and after addition of 0.05%Ti, is shown in (Fig. 8). Ductile fracture is introduced by the size of features in the fracture surface, it means more homogenous and smaller features result in higher ductility. (Fig. 8-(a)) illustrates that in the alloy without grain refiner there are lots of contraction porosities in the fracture surface. The dendrite structure in the surface these porosities proves that they are contraction porosities. This kind of porosity has a remarkable destructive effect on mechanical properties of the material due to stress concentration on its sharp corners.

However, addition of Ti-B reduced the size of features on fracture surface (Fig. 8-(b)). The dimple shape features also appeared, in other words, the addition of Ti-B resulted in a more ductile fracture. Furthermore, it is shown that there are no contraction porosities in the fracture surface. It may be interpreted that the omission of the porosities is a reason for improvement in ductility and UTS of the alloy.

However, cleavage fracture surface shown in (Fig. 8-(b)) and results of (Fig. 4), both demonstrated a non-uniform distribution of second phases, especially in the grain boundaries and dendrite arms which results in low ductility of as-cast alloy even when Ti-B grain refiner has been added.

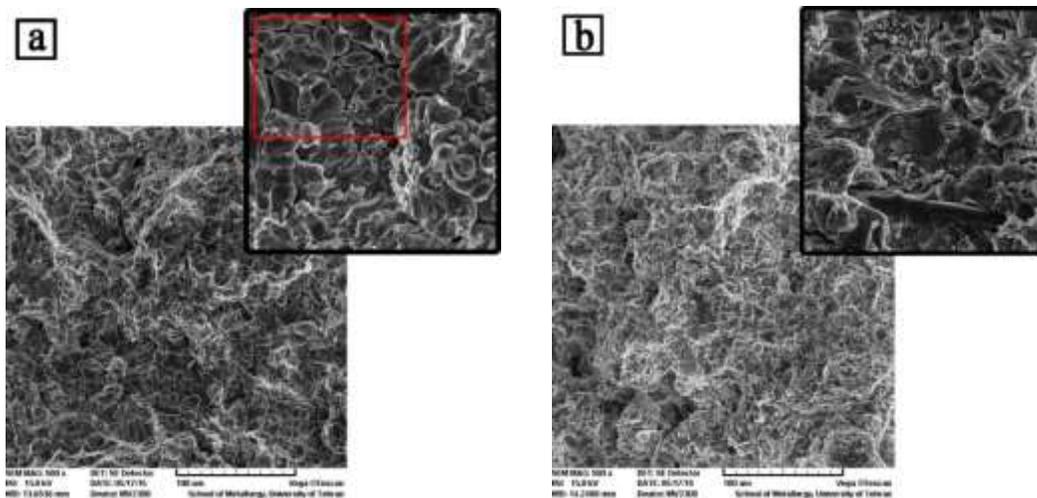


Fig. 8: Fracture surface of Al-2.5Cu-2.5-Mg-15Zn alloy (a) before and (b) after addition of 0.05%Ti.

4. Conclusion

In this study, the effect of Ti-B grain refiner on the microstructure and tensile properties of super high strength Al-2.5-Cu-2.5-Mg-15Zn alloy have been investigated. The following conclusions are drawn:

1- With the addition of Ti-B, the morphology and size of dendrite arms improves and eutectic structure has a more uniform distribution between grain boundaries and dendrite arms.

2- By adding Ti up to 0.05wt. %, yield and ultimate tensile strength values increase from 301.3 and 184.4 MPa to 362.7 MPa and 226 MPa respectively. Also, elongation values increase from 3% to 6.1%. It shows 20, 23 and 100 percent increase respectively.

3- Fracture surfaces show that Ti-B omitted contraction porosities which increases UTS and elongation of the alloy.

4- Fracture surface of alloy containing 0.05wt. % Ti demonstrates finer features and more dimples on the fracture surface.

5- However, fracture surfaces of specimens with Ti-B grain refiner show that cleavage planes are still dominant features.

5. Acknowledgements

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