PRODUCTION METHOD AND MICROSTRUCTURE INVESTIGATIONS OF FUNCTIONALLY GRADED SIC REINFORCED LAYERED METAL MATRIX COMPOSITE

[1]UĞUR AVCI, [2]ŞEMSETTIN TEMIZ

[1]Technical Sciences Vocational High School, Department of Machine, Kahramanmaras Sütçü İmam University, Kahramanmaraş, Turkey
[2]Mechanical Engineering Department, İnönü University, Malatya, Turkey
Email: [1]ogrtmugav@gmail.com, [2]semsettin.temiz@inonu.edu.tr,

Abstract - In this study, the production steps determined to make the production of functional graded metal matrix composite (FGMLC) more economical and practical are listed. Firstly, by mixing casting method, molten Al 7039 matrix material was reinforced with 3%, 5%, 7% by weight of SiC particles and then 7 MPa pressure was applied to specially prepared die cast material. The surface of the obtained 6 mm thick aluminum metal matrix composite (AMMC) was cleaned and placed in another mold by placing side by side without using any adhesive. In the mold placed in the annealing furnace, the three plates were joined by applying pressure at the time of beginning of liquefaction of MMCs. Firstly, about 60% of the thickness of the produced material was subjected to hot forging and subsequent homogenization heat treatment. Finally, FGMLC production is completed by the aging heat treatment applied. The application is presented with microstructure studies.

Key words - AMMC, FGMLC production

I. INTRODUCTION

For the last thirty years, aluminum based metal matrix composites (AMMK) have received great interest. The use of lightweight aluminum alloys as matrices is required for many applications of highly feature-resistant materials. Reinforcing ceramic materials such as Al2O3 and SiC into an aluminum based composite provides a remarkable advantage in meeting the manufacturing requirements of different engineering materials where strength, hardness, abrasion, fatigue and creep properties are very important [1]. However, it has also been found that the ductility of the produced material is reduced during the studies [2,3].

Stir casting (vortex technique) is generally accepted commercially as a low-cost method for fabricating AMMCs [4,5]. Its advantages lie in its simplicity, flexibility, and applicability to large volume production. This process is the most economical of all the available routes for AMMCs production, and it allows very large-sized components to be fabricated[6]. Although this method is considered to have problems with particle distribution, many researchers have found that homogeneity of AMMC's particle distribution is achieved by applying stir casting technique [7,8].
Along with the development of technology, composite materials have been developed and started to be produced in different structures. These developments have led to the formation of a composite product, which changes its structure from one material to another and for which the resulting material has properties different from those of the original material [9]. These composites, referred to as functional graded materials (FGM), are high-performance microscopically homogeneous grades of the composition in terms of their specific properties [10]. Continuous changes in microstructures distinguish FDM from other commercial composite materials. This high-tech material has high heat and corrosion resistance and has the ability to resist ultra-heat ratings [11].
Nowadays, FGMs are produced using methods such as powder metallurgy [12], centrifugal casting [13], remelting and sedimentation process [14], and friction stir welding [15]. However, recently layered composite production methods have also contributed to FGM production. Composite sheets can be combined with three methods as solid-solid phase, liquid-solid phase and liquid-liquid phase composite methods [16]. Monazzah et al. produced three layered composite by hot rolling method by placing Al-Mg-Si / SiC composite layer on two outer surfaces and the Al 1050 ductile layer on the interface [17]. At the same time, Avci and Temiz have combined the AMMCs, they have produced at different rates in their work, inspired by the semi-solid method and have taken a new approach to FGM production [18].

II. MATERIAL AND METHOD

In this work, Al 7039 material, which is distinguished by its high power and energy absorption capacities, preferred as an armor material in the defense industry and can be heat treated, is used as a matrix material [19]. In Table 1, the content of 7039 aluminum alloy is given [20]. SiC, which is one of the most commonly used materials and has the most suitable properties in the engineering ceramics family, is preferred as a reinforcing material.

Table 1. The content of 7039 aluminum alloy.

Mg	Zn	Mn	Cr	Si	Fe	Cu	Ti	Al
2.3 -3.3	3.5-4.5	0.10-0.40	0.15-0.25	0.30 max	0.40 max	0.10 max	0.10 max	Balance

During the production of the composite, care should be taken to apply the general production steps of the matrix material. Therefore, considering the production method of Al 7039 alloy, the steps to be used in the production of FGMLC are given in Fig. 1. In the first step, the Al 7039 matrix material placed in the pot was fluidized at approximately 730°C in a specially manufactured melting furnace. The SiC reinforcing material with an average size of 15 µm was gradually added to the matrix material after preheating to ensure wettability. After sufficient stirring by means of a graphite stirrer, casting was carried out in the mold which had previously been preheated to 650°C. After the mold lid was closed, the material was compressed by applying a pressure of approximately 7 MPa and the air was cooled in the mold. With this method, three separate MMC plates with a 3%, 5% and 7% reinforcement ratio of finished weight were subjected to surface cleaning.

In the second stage, MMC plates prepared at different ratios were placed side by side and placed in the combination mold. The prepared mold was placed in the annealing furnace and kept at 630°C for 30 minutes. When the materials in the mold come to a solid density liquid consistency, the mold lid is closed and compressed with a pressure of 6 MPa. After compaction, the mold was cooled in air and the combined plates were removed from the mold.

In the third stage, hot forging is usually applied to remove faults that occur during the assembly. The composite, heated at approximately 450°C, was reduced from 18 mm thickness to approximately 10.8 mm thickness as a result of the forging process.

In the fourth stage, homogenization annealing was applied to reduce the microsegregation in which the forging process was completed with the layered composite. In our preliminary studies, the values we determined for post-cast homogenization of Al 7039 matrix material were 24 hours at 480oC. In this case, the homogenization process was carried out for these composites using these values.

In the fifth step, the composite was suddenly cooled in water after 8 hours at 475oC and 4 hours at 485oC + 2 hours at 495oC. At the last stage, the material was left to stand at 121oC for 24 hours and the artificial aging process was completed.

The samples taken during FGMLC production were sanded and polished in Keller (1 ml HF, 1.5 ml HCl, 2.5 ml HNO3, 95 ml H2O). Microstructure studies were performed on a LEICA DM4000M optical microscope.

III. RESULTS AND DISCUSSION

3.1. MICROSTRUCTURE STUDIES IN MMC PRODUCTION

Before passing through the microstructure formed in the production steps, the matrix structure of Al 7039 given in figure 2a was investigated. It has been observed that the grain structure of the hot rolled material during the production is oriented in a fine and long way, and random distributions of intermetallic particles varying in average size between 10 and 25 microns have also been determined. Microformations of MMC layers with 2%, 5% and 7% SiC reinforced, respectively, produced by the mixing and post-compression process are given in Figures 2b-c-d. When post-production MgZn2 dispersions were detected, it was observed that voids were formed around the reinforcement particles by increasing the SiC reinforcement ratio. Besides, it can be said that there is a homogeneous reinforcement distribution.

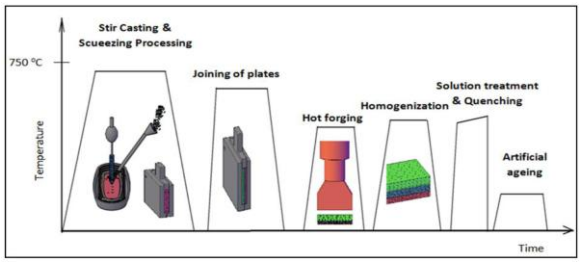


Fig.1. The production steps of FGMLC

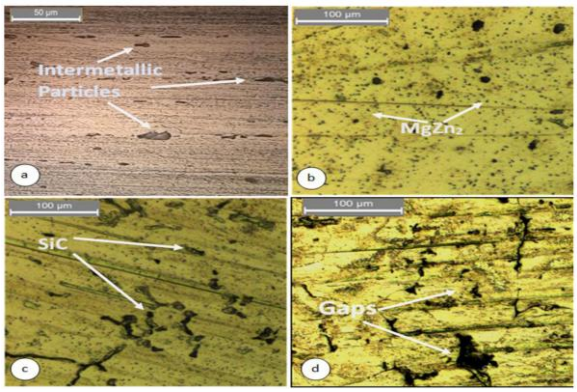


Fig.2. Microstructure images a) Al 7039 matrix, b) 2% SiC reinforced MMC, c) 5% SiC reinforced MMC, d) 7% SiC reinforced MMC





Fig.3. Microstructure of join boundary a) full boundary, b) intermittent boundary

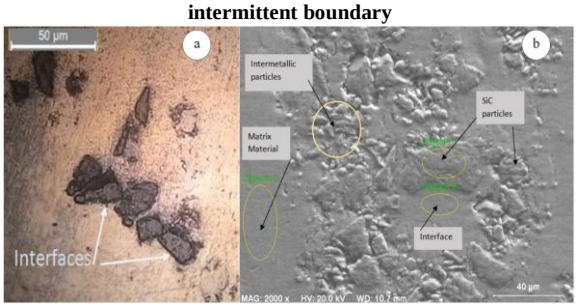


Fig.4. Post-joining microstructure studies a) optical microscope, b) SEM

3.2. MICROSTRUCTURE STUDIES OF MMCS AFTER JOINING

As a result of the joining, the boundaries between the MMCs were determined in the vicinity of the die edge of the composite sheet. In figure 3a, the wave-formed boundary of 3% and 5% reinforced plates is shown. As as it is approached to the center of the composite, these boundary lines disappear completely after taking the intermittent shape. In the optical microscope image shown in Figure 3b, the boundary is cut off and shaped. In Fig. 4a, the interfaces formed around the SiC particles were clearly detected after joining the plates. In addition, the strain that occurs in the particles after compression is determined in the microstructure image. In Fig. 4b, matrix material, SiC reinforcing particles, interfacial interstitial particles and intermetallic particles are marked. In this image, one of the important factors that intermetallic particles with an average size of 5 µm are condensed around the SiC particles.

The results of the post-joining EDX analyzes show that formation of the $Al_{13}Zn_{30}Mg_{12}$ in the matrix region preserves the integrity of Al7039 and the $Al_{13}Si_{14}C_6Zn_{30}Mg_{12}$ was obtained at the interface. The results taken from intermetallic particles showed the formation of $Al_{13}Si_{14}C_6Zn_{30}Mg_{12}O_8$.

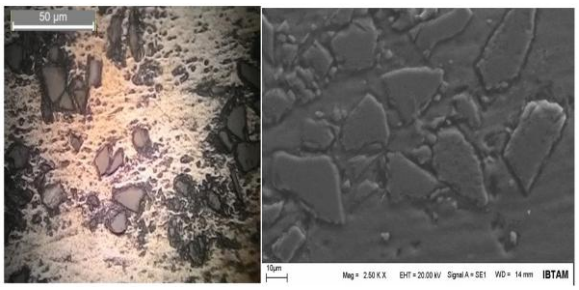


Fig.5. Microstructure image after hot forging

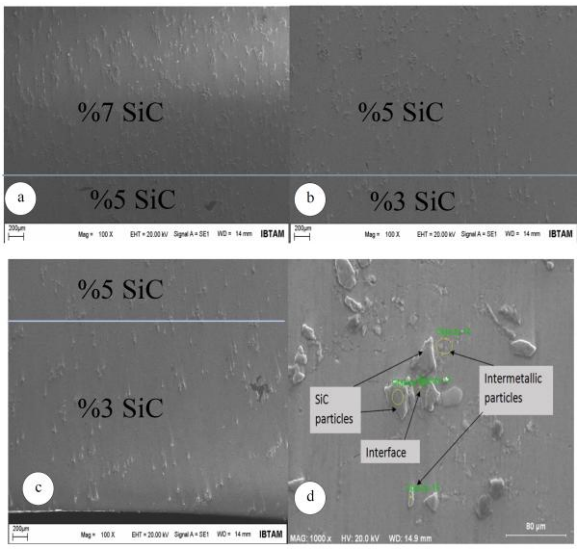


Fig. 6. The SEM images of the FGMLC material with transition areas, a) SiC reinforcing zones with density of 3%, b) SiC reinforcing zones with density 5% c) SiC reinforcing zones with density 7%

3.3. MICROSTRUCTURAL INVESTIGATIONS OF CONVERSION OF LAYERED COMPOSITE TO FGMLC AFTER HOT FORGING AND HEAT TREATMENT

It is planned to increase the strength of the MMCs by means of the hot forging method applied to the layered composite after joining and to remove the joining defects. As shown in Fig. 5, the interface areas of reinforcing materials after hot forging become more clear, and many voids and joint boundary lines in the material interior have disappeared.

As a result of the homogenization and aging heat treatment applied, the SEM images of the FGMLC material with transition areas are given in Figures 6a-b-c with density of 3%, 5% and 7% SiC reinforcing zones, respectively. In Figure 6d, it is clear that the density of intermetallic particles decreases after heat treatment.

CONCLUSIONS

1. In the study, firstly, SiC-reinforced MMCs were obtained at different weight ratios. As a result of microstructural investigations of MMCs produced by stir casting and compressing method, it was determined that the homogeneous distribution of reinforcing materials is realized but the void ratios in the material are increased by increasing the reinforcing ratio. In addition, $MgZn_2$ distributions and intermetallic formations were determined.

2. When the microstructure of the layered composite produced by the joining of MMCs is examined, it has been found that the inter-plate joint boundaries are formed at the edges of the material but are intermittently discontinuous near the canter. The EDX analysis showed that the intermetallic particles were concentrated around the SiC reinforcement, and

the matrix, reinforcement and interface areas formed in the composite were clearly marked.

3. At the end of the hot forging, including the last stages of FGMLC formation, the boundaries of the joints are lost and the material is brought together. As a result of the heat treatments, it was determined that the density of intermetallic particles decreased.

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