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Experimental studies on magnesium metal matrix composites processed by Twist Extrusion

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Abstract. Recently magnesium alloys and magnesium composite were widely used due to their good strength to weight ratio. These materials find its applications in the bio-medical and in aviation industries. The aim of this study is to twist extrude the hybrid magnesium composite. The magnesium AZ91 alloy is used matrix medium and it was reinforced with 2%SiC and 1.5% B_4C. The twist extrusion was carried out in a split die with a slope angle of 54º. The composite is prepared by the bottom pouring method. The number of passes is limited to one, as adding the reinforcement increases the brittleness of the composites. The twist extrusion of the composite resulted in a porosity free sample. Hardness was measured by Macro-Vickers tester and ASTM A370 standard was used for the tensile test. Results indicate an increase 26.6% in strength and 38.5% hardness of the twist extruded composite.

1. Introduction

1.1. General

Metal matrix composites (MMC) are a group of engineering material that has superior mechanical properties over the pure metals and its alloys. The mechanical property of the metal matrix composites was improved by mixing a required amount of reinforcement material to the pure metal. In severe plastic deformation (SPD) process large amount of strain is induced which reduces the dislocations in the metal. By inducing large amount of strain, the sub-cell structure was formed due to the interaction of dislocation. Inside the sub-cell structure, small grains were developed. This improves the mechanical properties of the metal [1]. By extruding the MMC by the severe plastic deformation process will porosity can be reduced. It also aids the uniform distribution of particles in the magnesium matrix. The magnesium composite reinforced with Sic improves the wear resistance of the material and the interfacial strength of the composite is increased by adding B_4C. So the magnesium alloy reinforced with Sic and B_4C makes it an ideal material in the automobile, medical and aerospace industries [2].

1.2. Twist extrusion

Twist extrusion (TE) is a potent SPD method to develop ultra-fine grain metals. In the TE process the material pressed into a die cavity having a helical structure. While the material passes through the helical structure it is rotated parallel to the axis of the extrusion. The back pressure is provided at the exit channel of the die, to promote the material to completely fill the die cavity. The material experiences a severe strain, while it is processed by TE and the shape and size of the processed component is retained after the extrusion. Through multiple passes, large strain can be accumulated in metal and this result in ultra-fine grain refinement. Due to the rotation of the metal in the TE process result in a vortex flow in the structure and this vortex flow in the metal aids the formation of sub-cell structure inside the metals [3] . The important parameter in the twist extrusion process were twist and slope angle. Generally, to reduce the complexity the twist angle is kept as 90º. While the slope angle can be varied from 35º to 60º. The slope angle of the TE process determines the amount of strain induced. Smaller slope angle will intensify the shearing in the metal, so large amount of strain is induced. But smaller slope angle increase the load required to extrude the metal. The TE is performed in two routes. In first route-A, the metal is inserted into the entry channel without rotation after the first pass. In second route-B, after each extrusion the metal is rotated 180º and extruded subsequently. The route-B yield better mechanical properties in the metal, as vortex flow happen in both direction of rotation of the material during extrusion [4]

1.3. Literature review

In the past decade the metal matrix composites were gaining lot of interest in the fields like automotive, structural and biomedical applications as they have good wear and corrosion resistant properties [5]. Magnesium and its alloys are identified as a suitable alternative for the aluminium because of their low density and high specific strength but magnesium is more brittle compared to aluminium, This problem associated with the brittleness of magnesium can overcome by the magnesium metal matrix composites [6]. The major drawback in using two reinforcement in MMC is porosity and uniform distribution of secondary particles in the prepared composite. Porosity in the as-cast MMC is a detrimental factor that prevents the usage of these composites in the structural and biomedical applications [7]. Severe plastic deformation (SPD) of the as-cast MMC can reduce the porosity of the material, as high amount of strain is induced on the material. As the composite material undergoes SPD, uniform distribution of the reinforcement particles can also be achieved and thereby improved mechanical properties can be attained [8-9]. Twist extrusion is one of the SPD process, results in fine grain refinement on the metal. Huang et al [10] has extruded the Mg-SiC composite by the equal channel angular extrusion (ECAP) process and found that ECAP improve the distribution of extruded Mg-composites. Khani et al [11] analysed the impact of two-step ECAP process on the Mg alloy and concluded that fine grains were evolved due to the dynamic recrystallization. Mani and paydar et al [12] have successfully consolidated the Al- SiC particle by forward extrusion-equal channel angular pressing (FE-ECAP) and they experimentally confirmed an increase in ductility and strength of the composite. She et al [13] has worked on a novel on-line twist extrusion of Mg alloy and concluded that grains in the periphery of the alloy are refined more than the grain at the centre. Chandiran Sakthivel et al [14] performed experiments to study the effects of prior annealing on the mechanical properties of a Twist-Extruded AA 7075 Aluminum Alloy. It was concluded that the two major factors that influence the material tensile strength and micro-hardness are the prior-annealing temperature and the increased number of TE passes. Iqbal et al [15] optimized the TCAP die parameters and stated that channel of 110º and twist angle of 45ºyields better load to strain ratio. Based on the literatures, it is understood that SPD of composite results in improved mechanical properties and also helps in uniform distribution of the reinforcement. Twist extrusion is a potent method that can induce high strain on the material and thereby porosity in the composite can be reduced. So, in this work, an attempt has been made to twist extrude the prepared hybrid Mg-composite to improve its mechanical properties.

2. Experimental studies

In this particular study, Magnesium-AZ91D is reinforced with 2% silicon carbide(SiC) and 1.5% of Boron carbide (B_4C). The casting is done by stir casting method andduring the casting process magnesium is melted to 750ºC. Then the calculated amount of silicon carbide and boron carbide is poured into the stir casting furnace.According to the calculated value, 22.2 gms of silicon carbide (2% wt) and 16.5 gms (1.5% wt)of boron carbide is added to magnesium in the furnace. The stir casting setup has a motorized lift type stirrer which will operate in rotary motion so as to mix the SiC and B_4C as reinforcement for magnesium. The complete setup is fully guided by a computerized system, and a depositor is fixed nearer to the furnace, so as to deposit the reinforcements.After the reinforcement deposition, the stirrer which is placed in the top of the furnace is used for mixing the reinforcement with the magnesium AZ91D. The melt from the furnance is poured into a cylindrical moulding die of length 150 mm and 30mm diameter. Three cylindrical samples were casted using stir casting method. The hardness and the tesile strength value of the prepared composite before and after the twist extrusion was measured by Macro-vicker's tester and UTM machine respectively. Akash VKM Vickers hardness tester was used to determine the hardness of the samples. In hardness test the load is set at 5 kg and dwell time of 5 sec. With equal distances five indendation weremade and its average value is taken as exact hardness of the specimen. ASTM A370 standard was used to prepare the tensile test specimen. The tensile strength was measured using GR-3 micro-tensometer (Kyowa instruments Pvt. Ltd,India).

Figure 1 shows the twist extrusion die used for the experimentation. The slope and twist angle of the die used were 54º and 90º. The die is of split type with height of 230mm and twist length of 40mm.Each halves of the die are kept inside the container and clamped together with help of side plates. The die is made up of oil hardened H13 die steel material.MoS_2spray was used as the lubricant which gives the co-efficient of friction between 0.2 to 0.3.Both the sample was extruded at room temperature using a 100 tons hydraulic press (Henrison make, US).

Figure 1. Twist extrusion die.

Fig 2(a) shows the experimental setups during the extrusion in the die. The sample is pressed into the die with help of the plunger, kept on the top of the die. The assembled die and container setup is shown in the fig 2(b).

Figure 2. Experimental setup (a) During extrusion (b) Die and container assembly.

Figure 3 show the Mg composite sample before and after the extrusion process. According to the cross section of the twist die,three sample of 28x18mm were cut for the extrusion process. During the extrusion process,the load obtained to extrude the Mg-composite was 45 tonnes.

a b

Figure 3. Composite samples(a) Before extrusion; 6(b).After extrusion.

3. Results and discussion

The hardness test results areshown in table.1. The hardness of the prepared composite is 83 Hv and the hardness of the Mg-composite after the twist extrusion is increased on average to 115Hv.

Table 1. Hardness test results**.**

Samples	Before extrusion (Hv)	After extrusion (Hv)	Increase in %
Specimen-1	83.4	113.66	36.2
Specimen-2	82	117	42.6

After the twist extrusion process, the hardness of the Mg-composite is increased on average by 39.5%. Due to the twist extrusion process, finer grain formation results in a greater number of grain boundaries. This offers resistant for slipping. So, the hardness is increased [4]. The tensile strength results were tabulated in the table.2. The strength of the prepared Mg-composite on average was 165Mpa. After the twist extrusion it is increased to 209 Mpa.

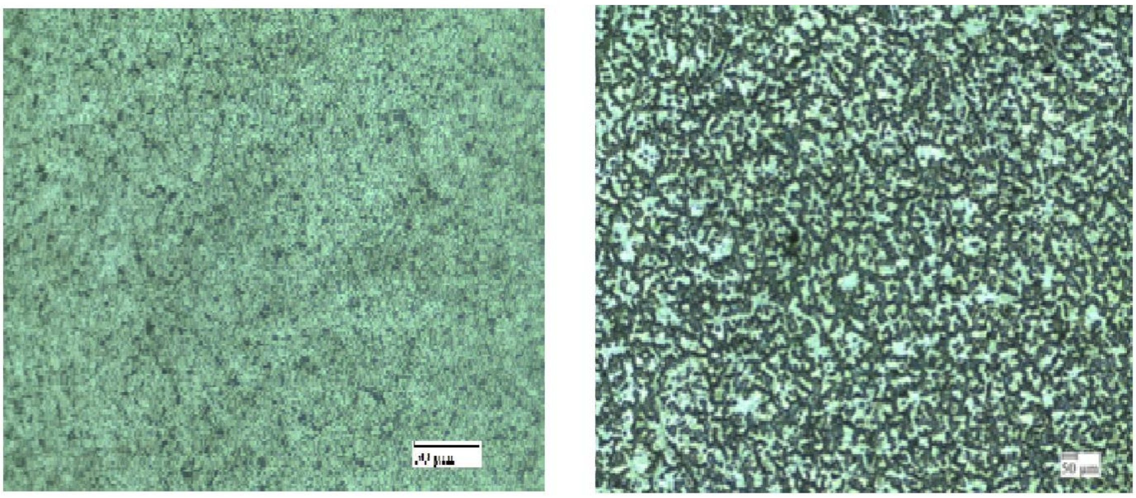
Table 2. Tensile test results.

Samples	Before extrusion (Mpa)	After extrusion (Mpa)	Increase in %
Specimen-1	162	208	28.4
Specimen-2	167	210	25.7

It is observed that an average increase of 27.1% in tensile strength of the samples after the twist extrusion. According to the hall-patch equation, grain size is inversely proportional to the strength of the component. So the strength of the extruded sample is increased, as result of grain refinement during twist extrusion [16].

3.1. Micro-Structural Studies

The fig 4 shows the OLM image of the before and after extrusion Mg-Composite. In fig 9(b) the grain refinement was observed and the grain boundary is distributed uniformly. It is also observed that the grains are having dendrite region and a tree type structure. By analysing the captured image using image analyser software, the minimum grain size was 8µm and the maximum grain size was14.5µm. According to Beygelzimer Y.et.al, the twinning and slipping phenomenon happen at the edge of the twisted sample, whereas only slipping happens at the centre of the sample. For lower slope angle between 35º to 45º, twinnings intensify at the edge of sample. So it results in more grain refinement at the edges than at the centre [4]. The slope angle of the twist die used for this study was 54º. At this higher slope angle, both twinning and slipping phenomenon happens at same rate [14]. Hence a homogenous grain refinement was obtained in the twist extruded sample.



a b

Figure 4. OLM image of Mg-Composite (a) Before extrusion; (b) After extrusion.

4. Conclusion

The following conclusion was drawn from this study.

- The prepared hybrid Mg-composite was successfully extruded by twist extrusion.
- The tensile strength of the Mg-composite is increased by 26.6% after the twist extrusion.
- An increase of 35.5% in hardness of the hybrid Mg-composite was observed, due to the twist extrusion process.
- From the OLM image, dendrite region was observed and the minimum grain size of 8µm is achieved after the twist extrusion process.

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