International Journal on Applications in Mechanical and Production Engineering
Volume 1: Issue 3: March 2015, pp 8-11. www.aetsjournal.com

Review on Extrusion of Magnesium Matrix Nano Composites for Improved Strength and Corrosion properties

Indhu. R , Sooryaprakash.K

Abstract— This paper mainly outlines the importance of extrusion process of magnesium matrix nanocomposites and discuss the effect of various factors like temperature, grain size, extrusion speed, extrusion ratio etc on enhancing the microstructure and mechanical properties of the magnesium matrix composites. The extruded components have more excellent properties such as tensile strength, proof stress and elongation than the cast components. Addition of nano particles may lead to significant inhibition in grain boundaries resulting in refined grains after extrusion resulting in high strength of the composites. Nano particles can significantly increase the mechanical strength of magnesium matrix by effectively promoting particle hardening mechanism than micro size particles.

***Keywords* —** Magnesium matrix nanocomposites, nano particles, Extrusion process, Dynamically re-crystallized grains.

I. INTRODUCTION

Magnesium alloy with its low density and good strength to weight ratio is one of the candidate material for light weight construction [1] .With the increasing demand in light weight transport vehicles, there have been numerous studies in development of magnesium alloy by various methods. However magnesium alloys are not used for high performance applications like aerospace and automotive industries because of their low mechanical properties at room and elevated temperature and significant technical barriers like difficult formability at low temperatures, low creep resistance, high coefficient of thermal expansion and low ductility of finished components. Therefore In order to improve mechanical properties of magnesium , significant efforts have been taken to develop magnesium matrix composites with various reinforcements were produced by powder metallurgy and squeeze casting to obtain desired properties and achieve better performances.

There are some possibilities to overcome this issue in magnesium alloys. The Mechanical and microstructure properties can be developed either by process development or by alloying techniques. The various methods are described briefly.

II. PROCESS VARIATION IMPROVEMENTS :

In general squeeze castings are used for production of composites because of merits like cheap cost, produce goods in short time and reduce shrinkages. Stir Casting is also most commonly used for good distribution and dispersion of micro particles [4]. But nowadays metal matrix composites are widely formed by powder metallurgy techniques which offers improved mechanical properties to the composites compared to the casting techniques. But recent studies reveals that composites that are formed by extrusion have more excellent mechanical properties like tensile strength, proof stress and elongation than the cast composites. Moreover the extruded composites have less gas porosities than cast components [12]. Extrusion offers a relatively cheap method of producing complex shapes in long lengths with high geometric tolerances. But extruded magnesium alloys generally suffer from low strength, which mainly results from the coarse grain structure associated with high temperature processing [5].

The microstructural and mechanical properties of extruded materials are greatly affected by not only the alloy composition and initial billet condition, but also extrusion

conditions such as the temperature, speed, and ratio. The size of the dynamically recrystallized (DRXed) grains of an extruded material is strongly dependent upon the deformation temperature [4]. Extrusion under conditions of low temperature and slow speed. An extraordinarily high strength has been achieved in AZ80 alloy by use of extrusion under low temperature of 200□C and slow speed of 0.7mm/s [4]. Low temperature suppresses excessive grain growth thereby improving the strength and plasticity of extrusions [7]. This leads to the formation of finer grains, more precipitates and a stronger basal texture than conventional extrusion, which results in enhanced strength in extruded alloy.When the temperature is increased the tensile strength decreases. With the increase in temperature from 450□C to 525□C both tensile strength and plasticity of AZ31 alloy decreases gradually due to the growth of the grains and they sharply reduce at a temperature above 550□C resulting in abnormal coarsening of the grains [13]. Therefore with the enhancement of the temperature both thestrength and plasticity of AZ 31 alloys decreases and becomes zero .the variation of the grain size with the temperature is shown in the Figure.1 . The grains are fine and tend to increase gradually at the 450□C-525□C, then some bigger grains merge with the adjacent smaller grains, to coarsen at the temperature of 550-575□C. When the temperature is further increased at 600□C, the grain size is reduces to some degree, accompanying with some molten grain boundaries [13].

Indhu. R, Sooryaprakash.K, Department of Manufacturing Engineering,Anna University Regional Centre, Coimbatore- 641047. (Email : indhume91@gmail.com)

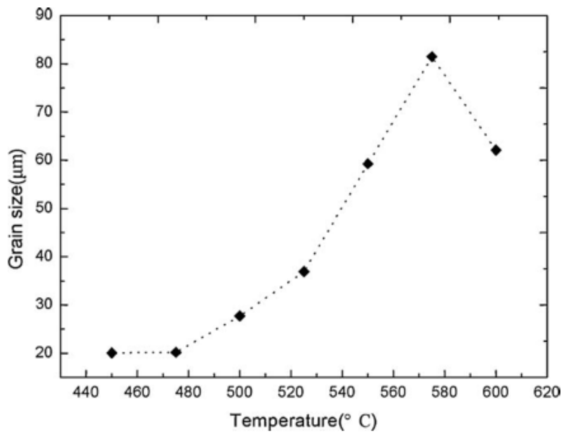

Fig.1 Variation of grain size of AZ31 alloy at different temperatures [13].

Another method to develop high strength magnesium alloy is use of low-temperature indirect extrusion process capable of extruding magnesium alloy at a temperature below 200□C by means of artificial cooling [1]. Indirect extrusion was carried out with an initial billet temperature of 250 □C, a ram speed of 1.3 mm /s and an extrusion ratio of 25. Cold water was used as cooling medium and air was passed through inlets of stem surface as shown in figure.2 .The cooling media were transferred through holes inside the stem and were then directly sprayed onto the extruded rod at the die exit. The water feeding rate and air pressure were 1.71/ min and 0.8 MPa, respectively. The die exit temperatures of the alloys subjected to extrusion with and without artificial cooling were 180□C and 292 □C, respectively. The artificial cooling has significant effect on grain refinement of magnesium. The grain size can be considerably reduced from 5.5 to 1.8 μm by application of artificial cooling. These grain refinements lead to increase in yield strength to as high as 50 MPa at room temperature as well as enhanced plasticity with tensile elongation.

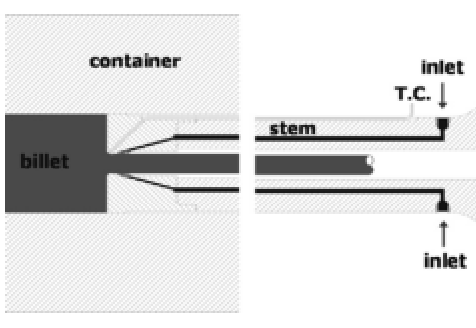

Fig.2 Schematic diagram of an indirect extrusion process capable of artificial cooling [1].

Many methods are employed to improve ductility of magnesium alloys. The mostly used one is the refining of the grains to enable magnesium alloys to contain more slips [25]. Another method to achieve high plasticity in magnesium alloy is by introducing a new plastic phase to magnesium alloy. It is reported that magnesium alloy with lithium content of 5.3–10.7 wt.% possess a ductile β-Li phase [26]. The β-Li phase enables Mg-Li dual phase alloys to be much ductile even superplastic [27-29]. Mg-Li dual phase alloys are the only magnesium alloy system lighter than Mg itself , Li is the lightest metal and they offer potential to develop alloys with specific properties higher than magnesium.Generally, the β-Li phase is soft and it decreases the strength ofMg alloys. Furthermore, the work-hardening of β-Li phase are also low [30].Therefore β-Li phase cannot improve the strength of the magnesium, Until recently researches are focused on mechanical properties of duplex Mg-Li alloy with lithium contents among 7-9wt% [26-30].

LZ52 alloys extrudedwith extrusion ratios of 10, 25 and 79 [3]. There are two phases, i.e.graya-Mg phase (bcc) and dark b-Li phase (hcp).The b-Li phase is in lower amount than the a-Mg phase and isalso separated by thea-Mg phase. When increasing the extrusion ratio, the widths of b-Li phases, which are the distances betweena-Mg phases, are decreased as well as the widths of a-Mg phases,i.e. the distances between b-Li phases as shown in figure.3. The table.1 shows the width of α-Mg phase and β-Li phase in microns and the grain size of α-Mg phase [3].

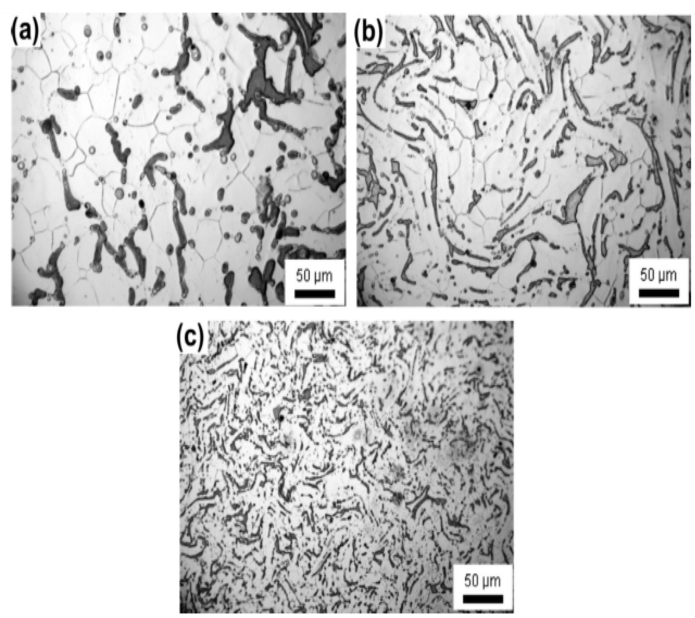

Fig.3 optical microstructures of the extruded Mg-5Li-2Zn alloys with extrusion ratio of (a) 10μm (b) 25μm (c) 75μm [3].

Table 1 Parameters of microstructures of the extruded Mg-5Li-2Zn alloys [3].

Alloy	EX10	EX25	EX79
Width of α-Mg phase (μm)	135	61	33
Width of β-Li phase (μm)	8–20	~5	2–3
Grain size of α-Mg phase (μm)	29	21	8

It is believed that the deformation of the duplex Mg-Li alloy is mainly due to the β-Li phase during the deformation. The strength is improved only when there is sufficient growth of β-Li phase .The α-Mg phase in EX 10 and EX 25 alloys are only slightly deformed after extrusion ,which brings only little strength enhancement to α-Mg phase in these alloys. The grain boundaries in these two extruded alloys are almost similar. The α-Mg phase in EX 10 alloys are straight lines whereas in α-Mg phase in EX 25 alloys are slightly curved as shown in figure.3. Only when the extrusion ratio is increased to 79, there is much deformation of a-Mg phases and there is significant improvement in the strength of the alloy. When increasing the extrusion ratio, the strength increased while the ductility demonstrated a tendency of decreasing. The alloy extruded with the ratio of 79 possessed a higher strength than the other two extruded alloys, which showed strengths near to each other [3].

Other studies [20-23] have succeeded in producing high-strength Mg alloys (347-480 MPa TYS, 405-525 MPa UTS, and 2-12% EL) by refining the grain size of commercial Mg-Al-Zn alloys through SPD processes such as equal channel angular extrusion (ECAE) [20], high ratio differential speed rolling (HRDSR) [21], accumulative roll bonding (ARB) [22], or multi-directional forging (MDF)

[23]. However, these SPD processes have also proven difficult to commercialize due to the difficulties in making them a continuous process, as well as the inherent constraints on the size of the material.

III. MICROSTRUCTURE VARIATION BY NANO REINFORCEMENT:

In the above portion the strength and microstructural properties of the extruded magnesium alloy is achieved by varying the process parameters like extrusion speed , extrusion temperature or by alloying elements like Li. In this portion the mechanical and microstructural properties are improved by developing magnesium matrix composites(MMC's). Compared with the unreinforced magnesium alloys, the micro particles reinforced MMCs usually have a considerably improved strength [21]. But the disadvantage is that their ductility is reduced,which limits their widespread application. Recent research [6,19,21] shows that the mechanical properties of the metals would be further enhanced while ductility is maintained by decreasing the size of the reinforcement particles from micrometer to nanometer level [21]. Nano particles can significantly increase mechanical strength of the alloy matrix by more effectively promoting particle hardening mechanisms than micro size particles. Thus use of nanoparticles to reinforce metallic materials has inspired considerable research interest in recent years because of the potential development of novel composites with unique mechanical and physical properties [11,31].Processing technique is the key to obtain magnesium matrix nanocomposites with optimized properties. Generally the metal matrix nano composites are produced by powder metallurgy process, ball milling, infiltration techniques, deposition and ultrasonic vibration [33-38].

Recently a novel technique that combined stir casting and ultrasonic vibration has been used to achieve uniform dispersion and distribution of nanoparticles in magnesium melt [6]. AZ 91 alloy was taken as the matrix and SiC nanoparticles with an average size of 60nm and 1%volume were selected as reinforcements. The SiCp/AZ91 nanocomposites were fabricated by semisolid stirring with ultrasonic vibration and then followed by extrusion process at 350□ and extrusion ratio 0f 12:1. The grains of matrix in SiCp/AZ91 nanocomposites are significantly reduced after the extrusion process. The OM micrograph of the SiCp/AZ91 nanocomposites before and after extrusion are shown in figure.4 [6]

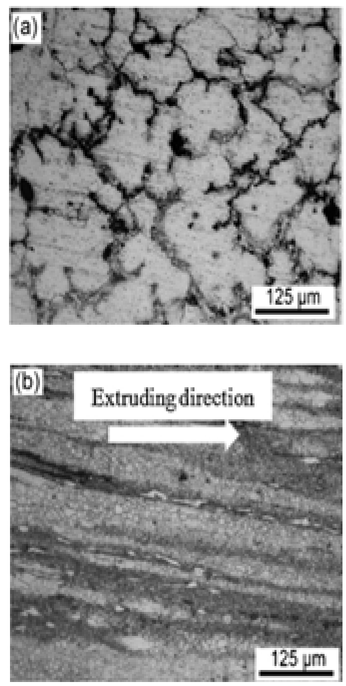

Fig.4 OM micrographs of the SiCp/AZ91 nanocomposite:

(a) as-cast and (b) as-extruded [6].

The grain refinement is mainly due to the addition of SiC nanoparticles, which introduces larger strain resulting in severe dynamic recrystallization and restricts the grain growth effectively during the extrusion process. There is an increase in yield strength, ultimate tensile strength and elongation to fracture of SiCp/AZ91 nanocomposite after extrusion.

Magnesium matrix nanocomposites were also formed by reinforcing nanosized Al2O3 particulates by using an innovative disintergerated melt deposition technique followed by hot extrusion.

IV. Conclusion

Compared with the unreinforced magnesium alloys, the micro particles reinforced MMCs usually have a considerably improved strength. But the disadvantage is that their ductility is reduced, which limits their widespread application. Recent research shows that the mechanical properties of the metals would be further enhanced while ductility is maintained by decreasing the size of the reinforcement particles from micrometer to nanometer level. Nano particles can significantly increase mechanical strength of the alloy matrix by more effectively promoting particle hardening mechanisms than micro size particles. Thus use of nanoparticles to reinforce metallic materials has inspired considerable research interest in recent years.

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