A review on Heating and Rolling Effect of AZ31 Magnesium Alloy

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Abstract - *The AZ31 Mg alloy is one of the most popular magnesium alloys with aluminum. Due to its low mass density and good mechanical properties, this structural material offers considerable potential for the aircraft manufacturing industry. The AZ31 alloy is used in the aircraft industry to produce flat parts with ribs, such as brackets. As an extremely light metal, magnesium alloy is of excellent specific strength, excellent damping capability, good castability, hot formability and have excellent machinability. Heat treatment is one of the easiest methods of improving the mechanical and physical properties of MgAZ31 alloy. During heat treatment the grain size will change and thus improve its physical and mechanical property. Solutionizing followed by ageing has been also used for the mechanical property improvement. And rolling is yet another important method used for the physical and mechanical property change in MgAZ31 alloy. During rolling the coarser grain become finer which increase its mechanical property by hindering its dislocation.*

Key Words: **Bio implant, Specific strength, damping capability, Solutionizing.**

1. INTRODUCTION

Development of technique, especially in the Bio medical designing branch, caused the increase in demand of designing materials with small specific gravity. Magnesium alloys seem to fulfill these requirements (specific gravity 1.7 g/cm3). In aircraft industry, AZ31 magnesium alloy from group Mg-Al-Zn, characterized by good plasticity, has been widely applied [1]. At present, for manufacturing of such type of parts, casting and machining are applied. Lowered resistance properties of casts and large material loss during machining (about 70% constitutes waste) lead to development of other manufacturing methods of these parts based on metal forming processes, for example: forging [1]. Here are some commonly used techniques for material property improvement in AZ31 Mg alloy.

1.1 Heat treatment

The mechanical properties of this magnesium alloy at room temperature were improved significantly after extrusion and heat treatment compared to an as-cast alloy. The results of mechanical properties show that the yield strength (YS) decreases with increasing extrusion temperature. Heat treatment temperature plays a more important role than heat treatment time at the same rolling reduction. In the view that both cast and wrought magnesium –alloy are heat treated and here we are studying different heat treatment temperature that makes considerable change in both physical and mechanical properties of material[3,4]. Some of the practically possible heat treatments are solution heat treatment, ageing treatment and annealing these three heat treatments can really modify the microstructural and material property of magnesium alloys. In addition to the above heat treatments stabilizing and stress relieving are used in practice [3]. The former is a type of 3 precipitation process and the latter is a type of annealing operation [4]. More over in any heat treatment processes solutionizing temperature is very important.

1.2 Rolling

Rolling is a good method of forming magnesium alloy sheets; however, some challenges arise as rolling passes are added, smaller single pass reduction, low production efficiency and obvious mechanical anisotropy [4]. These challenges greatly limit the development of magnesium alloys. The mechanical properties of Mg alloys are violently influenced by their deformation texture[4]. Wrought Mg alloys exhibit much higher mechanical properties than their cast Counterparts because metal forming processes such as rolling, extrusion, and forging lead to the elimination of casting defects, grain refinement via dynamic recrystallization, formation of fine precipitates via dynamic precipitation, and/or work hardening via accumulation of dislocations[4,5]. Therefore, weight reduction can be achieved to a greater extent through the application of wrought Mg alloys[6]. Mg alloys are known for their very high specific strength and light weight applications. However, their formability at room temperature because of the inherent hexagonal close packed structure limits their widespread commercial usability and it leads to plastic behavior[6]. The number of rolling passes was an influential factor for the microstructure. The mechanical properties of strength and hardness also depended on the number of rolling passes. These properties were improved with increased number of rolling passes [7]. At room temperature the basal slip is the predominant contributor to plastic deformation while at elevated temperature the critical resolved shear stress for prismatic and pyramidal slip systems get reduced, thereby improving the workability. Tensile strength and plasticity of the alloy depend mainly on rolling reduction. With the increase of rolling reduction, the plasticity becomes more sensitive than strength on heat treatment [8].

1.3 A review on heating and rolling effect of AZ31 Magnesium alloy

P. Moldoven et al. [1]: In this P. Moldovan and his colleagues presents the results obtained in T6 heat treatment of Aluminium-7Si-0.3 Mg alloy carried in liquid state with a new alloy AlTiBSr for modification and simultaneous grain refining. They also studied about the possibility to reduce the cost of the operation and the energy consumption through strontium modification and also studied about the influence of strontium in mechanical properties. They had presented a new master alloy (Strobloy) for grain refining and modification of hypoeutectic aluminum silicon foundry alloys and they have carried out investigation to produce new master alloys (AlTiBSr) to reduce the number of additions from 2 to 1. It was the most commonly used heat treatment for Al -Si & amp; -Mg alloys in T6 which involves solution heat treatment, natural and artificial ageing.

Lei Guan et al. [2]: In this Lei Guan studied the microstructure evolution in cold rolled AZ31 magnesium alloy during electro pulsing treatment and which was analyzed by texture analysis. The process of cold rolling during electro pulsing treatment was adapted because of the poor formability of magnesium sheet alloy at ambient temperature. This problem is mainly due to jcp structure that consequently limits slipping at a temperature below 495K. But in order to avoid cracking and obtain desirable mechanical properties. Conventional heat treatment in a furnace requires a long time resulting in coarse graining as well as reduction in strength and ductility if the wrought magnesium products. Electropulsing treatment is an effective method for grain refinement through recrystallization.

A.Styczynski et al.[3]: The main aim of this paper is to investigate about all the possible combination of slip and twinning modes in HCP providing a basis for model calculations of texture evolution. The samples of the magnesium alloy AZ31 with two microstructures, recrystallized and squeeze cast, were rolled at room temperature. Then the initial texture and the final cold rolling texture were investigated by using X-ray diffraction. Two samples of the AZ31 magnesium alloy (3 wt% Al, 1 wt% Zn, balance Mg) were investigated corresponding to different microstructure conditions: a commercial recrystallized sheet (RXS) and a squeeze cast bar. From these sheets and casting materials the specimens were prepared for cold rolling experiments. The rolling was carried out at room temperature on a too-high mill with a roll diameter of 200 mm and a roll velocity of 3 m/min. Texture samples were cut after rolling from the middle part of the rolled sheet. The textures were measured on a D8 DISCOVER X-ray Diffractometer. The orientation distribution function (ODF) and complete pole figures were calculated using the harmonic method of Bunge.

W.J.Kim et al.[4]: The paper included asymmetrical rolling methods for severely deformed MgAZ31 alloy. It's a very simple but worthy experiment setup by passing the metal sheet into a asymmetric roller and a very fine grain size of 1.4 micrometer could be achieved after a single pass of 70% thickness reduction. And the experiment shows that the rolled sheet exhibit high yield stresses over300Mpa and a maximum elongation of 35%. They have studied its microstructure and mechanical properties in detail.

Zuzana et al. [5]: The paper deals with the cyclic loading condition on AZ31 Mg alloy and also, they deal with internal damping condition. This internal damping condition was measured by using ultra sonic resonance method for the specimen before and after heat treatment. This paper deals mainly with mechanical properties of AZ31 Mg alloy.

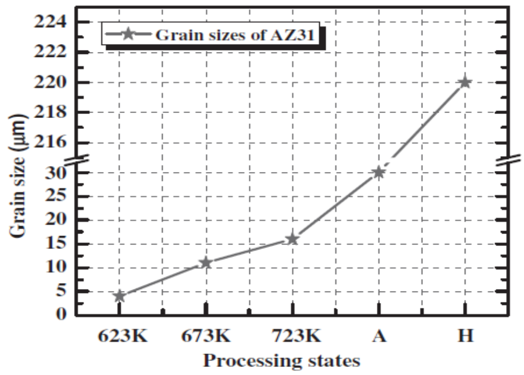


Fig -1 Average grain sizes of Mg alloy AZ31 at different processing states. (A-annealed at 623K for 2 h, H-homogenized at 673K for 14 h and as extruded at 623 K, 673 K, 723 K).(Xiaofei Lei et al.[2011])

Xiaofei Lei et al. [6]: The work of Xiaofei Lei use compound channel extrusion process for the study of properties of MgAZ31 alloy. They use equal channel angular extrusion (ECAE) and change channel angular extrusion (CCAE) and they fix the temperature range in between 623K to 723k and after the process they find out that the sample was remarkably refined, which is attributed to the grain subdivision and dynamic recrystallization during the drastic deformation. And at the conclusion they have said that single pass compound channel extrusion can acquire better mechanical property and continuous production compare to that from multi pass compound channel extrusion. While considering the shape of material, the production efficiency and the cost this process is good.

Hiroyuki et al. [7]: Here in this paper differential rolling technique was used for modifying the texture of the material and to enhance room temperature ductility. After that they studied and find out that. The grain sizes after rolling were refined for all materials. The grain size decreasing rolling temperature. And one of the important conclusions that they have find out that the the yield strength of the material has been increased in the process.

Dan Luo, et al [8]: In this work the rolling of Mg AZ31 alloy sheets at four speed ratios is analyzed and the microstructure and tensile properties of this AZ31 material is studied. Also, the effects of basal texture on the difference of elongation-to-failure of AZ31 alloy sheets processed between DSR and ESR at room temperature to elevated temperature is determined. From the results we can say that the DSR methods weaken the basal texture of the AZ31 alloy sheets. And the difference of the elongation-to-failure of the AZ31 alloy sheets processed by the Equal Speed Rolling (ESR) and DSR decreases at elevated temperatures, which can be attributed to the weakening of the influence of the basal texture on elongations at elevated temperatures

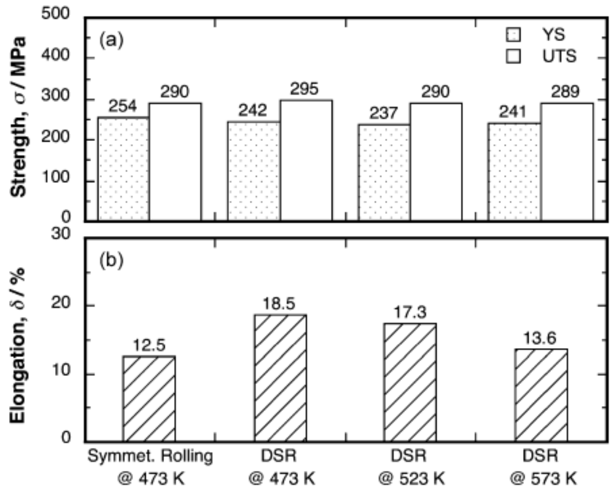


Fig -2 Room temperature tensile properties of AZ31 sheets processed by symmetric and asymmetric rolling. (Hiroyuki Watanabe et al. [2007])

Sensen Chai et al. [9]: In this work, the microstructure, tensile properties and micro hardness of the TIG welded Mg AZ31 alloy which was subjected to annealing and hot rolling at 350°C with various passes were examined. Results shows that as the hot rolling reduction increased the microstructure of the weld fusion zone and heat affected zone (HAZ) became more and more consistent with that of the base metal. And by hot rolling the ultimate tensile strength of the material can be improved. The micro hardness results show that the hardness of the Fusion zone, HAZ and base metal increases with the rolling reduction. Before rolling and annealing the FZ is as-cast and soft, while the BM is as-rolled with fine grain size. According to the Hall-Petch relationship, finer grain size provides higher strength and hardness for the alloy at room temperature. So, the BM exhibits the higher hardness. After hot rolling the residual stress condition and many other factors, which were different in various regions, also influenced the hardness.

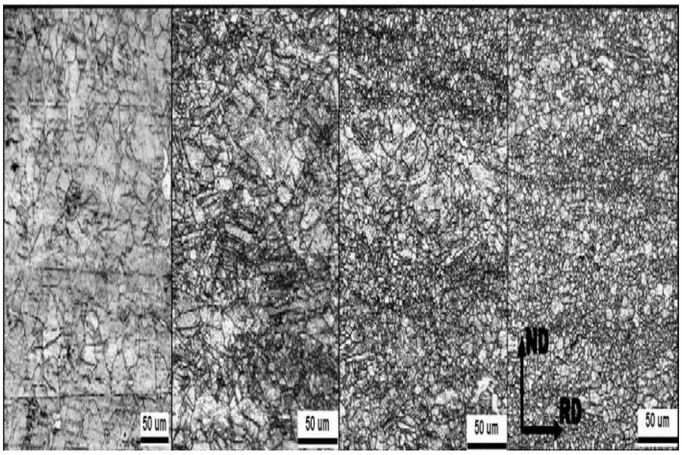
Ru Ma, et al. [10]: In this work the Mg AZ31 alloy sheet is initially deformed at 773K with the large reduction by single pass. Then on the next stage the material is deformed at 573K by a multi-pass warm rolling method. Dynamic recrystallization was taken place in all rolled sheets resulting in the grain refinement after the first stage rolling. About 65% of reduction is carried out by this first stage rolling and a homogeneous microstructure is obtained after this first stage rolling.

And after the second stage rolling the material is reduced up to 89%. The analysis of the results says that after the second stage rolling and annealing, the tensile strength of all the sheets was increased significantly, especially the yield strength. And also, with the increase in the rolling passes during second stage deformation, the YS and failure elongation of the sheet slightly changed, while the ultimate tensile strength (UTS) increased progressively with a larger value. As a conclusion it says that this type of two stage rolling is a simple and effective method for fabricating high strength AZ31 Mg alloy sheets.

L L Chang et al. [11]: This paper deals with microstructure and texture evolution of AZ31 Mg alloy during cold roll was investigated. The material was solution hardened alloy with minimum precipitation. The thickness of sheets was produced by casting and subsequent hot extrusion at 673 K was 14mm. Cold rolling was performed at room temperature under various reductions of 9, 16, 22, and 25 %.The diameter of the rod was 150 mm and roll speed is 165mm/s. Microstructure of rolled specimen was observed by optical microscopy. From this it was concluded that texture of hot extruded AZ31 Mg alloy was expressed by texture, when goes of cold rolled sheet was characterized by texture with a double peak distribution, showing the basal texture tilted about a particular distance away from the normal direction towards a rolling direction.

Hyo Tae et al. [12]: These papers deals with the effect of warm rolling of AZ31 magnesium alloy in texture development. Experimental setup is that the thickness of initial sheet produced by ingot casting and subsequent bill rolling. Warm rolling was carried at a preheating temperature of 200°C and roll surface temperature of 110°C at a speed of 200 m/min. Specimens were soaked for 1 hr. The microstructures were observed by optical microscopy. From this it was concluded that major texture of all specimens was expressed by fiber texture. The intensity of fiber components however decreased as the reduction in single pass rolling increased.

Lili Guo et al. [13] In this work, the effect of rolling temperature, equivalent strain and rolling time on DRX microstructures in AZ31 alloy at certain ranges of rolling speed, strain and temperature is studied. Also, the dynamic recovery effect on high angle grain boundary and low angle grain boundary formation and related mechanisms are analyzed. High angle grain boundary percentage increases with average rolling temperature. The largest percentage of 65% is obtained when the average rolling temperature is 430°C and the equivalent strain is 0.38-0.42. High angle grain boundary length per unit area is not at all affected by the rolling time whereas strongly affected on the low angle grain boundary. As the rolling time increases, the recrystallized grain size and average sub grain size decreases.



(a) (b) (c) (d)

Fig -3: Optical microstructures of AZ31 Mg alloy sheets produced by (a) hot rolling and (b) 18%, (c) 30%, (d) 50% warm rolling**.** (Hyo Tae et al. [2007])

Su,Hyeon et al.[14]: This paper deals with the texture and microstructural change in an asymmetrically hot rolled AZ31 Mg alloy sheets. In this, a rectangular AZ31 cast product of 20mm thickness was used. Before rolling, the material was annealed at 400°C for 24 hrs to get homogenized. Three different samples were prepared on symmetrical rolling mill and asymmetrical rolling mill. It undergoes different kinds of rolling at different rolling mills. They got 6 pole figures for each samples which when measured by means of X Ray diffraction goniometer in the back reflection mode with Cu-K alpha radiation and it was predicted that asymmetrically hot rolled AZ31 Mg alloys sheet exhibit a texture gradient where the intensity of basal textures decreased from the upper surface through the Centre to the lower surface. After subsequent annealing. The intensity of components was reduced significantly throughout the thickness and the grains were refined possibly by discontinuous recrystallization.

Ju-Won et al.[15]:The journal mainly focused on electric current on recrystallization kinetics on MgAZ31 alloy by using electropulsing treatment and furnace heat treatment and investigate hardness by using Vickers and they have concluded that electropulsing treated AZ31 alloy have low Vickers hardness value than furnace heat treated AZ31 alloy both of them are in the same annealed condition and also it is noted that by using EPT and it is possible to reduce the annealing and the time for recrystallization compare to conventional heat treatment.

Tien-Chan et al. [16]: The paper tells us a detail overview of grain refinement of magnesium alloy AZ31 by rolling method. By the HCP structure of magnesium, it is less formable at room temperature for achieving good formability it should be grain refined so that that they will get excellent formability and superplastic behavior. Hot rolling was used for grain refining and the outcome that was expected to increase its machinability and ductility but multiple passes by heating the material did not full fill the requirements but high temperature tensile test indicate that this rolled structure of MgAZ31 alloy exhibited some superplastic behavior.

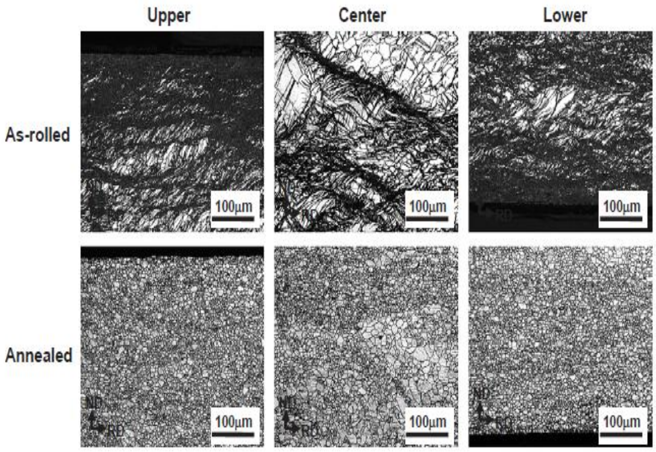


Fig -4 Longitudinal section optical micrographs of single pass asymmetrically hot rolled AZ31 sheets. (Su, Hyeon et al.[2017])

Xiangchen Meng et al. [17]: Paper mainly focused on surface mechanical attrition treatment (SMAT) of Mg AZ31 alloy. They found that a simple and gradient nanostructure can be formed in the sample. And the yield strength and ultimate tensile strength also increased for SMAT treatment on Mg AZ31.

Wei Guobin et al. [18]: Mg-10Y master alloys are added to AZ31 mg alloy they are added for as modifier and can observe a grain refinement, there after the addition of as-extruded modifiers if has been found out that, the mechanical properties of AZ31 alloy reach the maximum at room temperature and have high ultimate tensile strength upto 199.3Mpa and elongation is up to 9,2%.

Liming et al. [19]: The paper has studied the impact of Gas tungsten filler arc welding on AZ31 mg alloy. They have found out a series of conclusions that the grain size of the heat effected zone (HAZ) weld joint holds a verity compare to that of GTAW joint (without adding filler wire). The modified microstructure of HAZ has change the fracture location and has changed tensile strength. Filler rode can make very good impact on the mechanical property of the material during GTAW process.

Thickness (rolling reduction)	Tensile strength at room tempera ture (Mpa)	Yield strength (0.2% offset) at room temperat ure (Mpa)	Elongati on (%)
2.0 mm (as extruded) Longitudinal Transverse	254 257	161 159	14.2 10.8
1.3 mm (35%) Longitudinal Transverse	260 268	212 220	12.5 13.9
1.00(50%) Longitudinal Transverse	286 317	242 276	3.8 12.2
0.5mm (75%) Longitudinal Transverse	301 325	253 273	6.0 12.1
AZ31B Sheet	255	150	21
AZ31B Sheet-hard rolled	290	220	15

Table-1: Room temperature mechanical properties Of Mg alloy AZ31 after rolling. (Tien et al,[2003])

Yasumasa et al.[20]:In this paper most of the tests were conducted in room temperature such as tensile test.They have found that AZ31 metal sheet which having large grain size will have high stretched forming rate. In the tensile tests, the elongation to failure at room temperature increased with decreasing grain size. Twin formation was enhanced by grain coarsening.

2. CONCLUSIONS

From the above-mentioned studies, it is clearly understood that heat treatment and rolling have a significant effect on the microstructure of the material, and they have good ability to control the mechanical property of the material especially the tensile strength and ductility. In the majority of the cases the mechanical property has been improved through heat treatment method and found out that they are more economical and mostly controllable and for finding solutionizing temperature is a difficult task in heat treatment. Rolling and extrusions can also improve the grain Structure and increase the yield to a large extent. In some cases the material gets over deformed and has seen cracks in them. And also we have investigated various other methods such as electropulsing technique (EPT) and compound channel extrusion methods to see the effect on MgAZ31 alloy. And also for hardness measurement Vickers hardness is taken in most of the journal papers.

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