

The role of microstructure on the super plastic behavior

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Abstract
In this work microstructure evolution and super plastic properties ofAZ31B Mg alloy processed by four routes in differential speed rolling with different speed ratio and reduction were studied in order to improve the poor plasticity of AZ31B alloy. In route UD, the sheet direction was kept constant and un changed between repeated rolling passes ;while the sheet was rotated 180^o about the rolling direction between repeated passes in route RD ;in ND route the sheet was rotated through 180^o about the normal direction to the repeated passes ; In HY route the sheet was rotated 180^o about the rolling direction first and then rotated 90^o about the normal direction between repeated rolling passes .The results of microstructure observation showed that the modification of the microstructure had been affected by applied rout, rolling speed ratio and reduction. At low speed heavily twin structure appeared, as reduction percentage increase dynamical re-crystallization on the twins and shear bands were encouraged. On the other hand increasing speed ratio caused an increase in the amount of dynamical re-crystallized grains and refined the microstructure. Ultrafine grains structure had been developed when the alloy was rolled by applying HY route at speed ratio of (1: 1.8) and 25% reduction, super plastic properties of rolled Samples were tested in tension at 673K and at initial strain rate ranging from1×10^{-3} $s^{-1}$to 2.2×10^{-3} s^{-1}.
Keyword: severe plastic deformation, Magnesium alloy, AZ31B, Super plasticity

1. Introduction

Super plasticity is the phenomenon of extraordinary ductility exhibited by some alloys with extremely fine grain size, when deformed at elevated temperatures and in certain ranges of strain rate. A finer grain size increases the strength and the fracture toughness of the material and provides the potential for super plastic deformation at moderate temperatures and high strain rates (W.Qudong et al. 2008). Therefore efforts have been made to improve poor ductility of magnesium alloys by refining the grain structure (Li et al.2012). Grain refinement in magnesium alloys by thermo-mechanical processing has been studied to enhance their mechanical properties. Conventional processes such as extrusion and rolling produced the grain sizes between 3 and 20 μm .To get finer microstructures, severe plastic deformation techniques such as equal channel angular pressing (ECAP) high pressure torsion accumulative roll bonding and asymmetric rolling have been used (W.J.Kim et al.2011).These techniques have to be effective for achieving significant grain refinement in metallic materials down to the sub-micrometer range, the grain structures are finer than those obtained in conventional thermo mechanical processing (Mosab et al.2015). Several studies have been conducted to undertake the microstructure, mechanical properties, of the various metallic materials fabricated via a differential speed rolling (DSR) technique in which different rotational speeds of upper and lower rolls are applied, so that the shear strain could be imposed along the samples due to the asymmetric deformation characteristics (Yao etal.2016). The results of these studies show that the grain refinement produced leads to important change in mechanical properties and avoid the deformation instability (H.G.Jeong et al. 2009). In 2010, a method for fabricating high-strain-rate super plastic Mg alloys by using high - speed ratio differential speed rolling was proposed. The ingot-metallurgy processed Mg alloy exhibited a super plastic performance comparable to that of powder metallurgy parts J.Sun et al.2016). By optimizing the controlling parameters in the rolling process , an ultra fine-grained microstructure with good thermal stability, which is the desired microstructure for achieving high -strain rate super plasticity, could be obtained.Recently in order to control the rolling process some researchers focus on the microstructure evolution and deformation mechanisms during high speed rolling of magnesium alloys(J.Su et al.2016). In this work, an asymmetric rolling process using different rolling speed ratio of upper and lower rolls and different processing schedule are suggested to reduce the grain size , and enhance superpasticity behaviour of the alloy by varying the applied routes during rolling .

2. The starting material

The starting material in the current study is AZ31B alloy sheet supplied by Magnesium Company (Mgf magnesium flach produkter, Germany). The chemical composition of the alloy sheet is shown in table (1). This material is wildly used in structure application, due to light weight and high durability.

Table (1) chemical composition of used alloy

AL%	Zn %	Cu%	Si%	Ni%	Mg%
2.67	0.679	<0.001	0.0233	<0.001	Rem

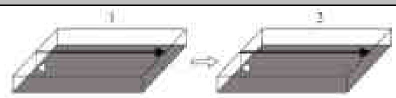
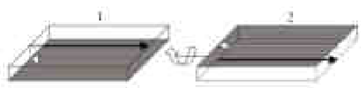
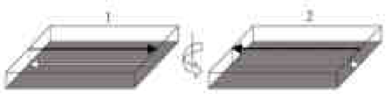
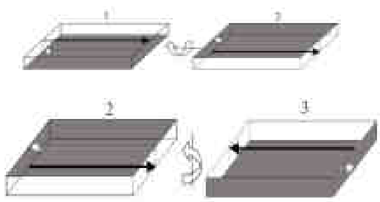
3. The rolling system

The rolling machine used in this work is design and manufacture by the researcher. The major component of machine consists of two rolling, supported on spring load bearing blocks mounted on frame. In order to facilitate the required rolling condition , the researcher was added four systems to the rolling machine which are :upper roll speed control system, lower roll speed control system ,control system for roller gap and roller heating control system

4. Rolling operation

A sheet of (100x50 x5) mm^3 was cut from the as- received wrought alloy in the same rolling direction .Before rolling the samples were heated to 200˚C for 30 min in electric resistance furnace type (Carbolite1200˚C).Then the sheet was fed in to the gap between the two rolls without using lubricant. The differential speed rolling (DSR) process was carried out using different thickness reduction (20, 25, 30, 35)% at different roll rotation speed ratio between the upper and lower rolls varied from 1:1 to1:1.4,1:1.8 and1: 2.2 using same roll diameter (150mm). On the other hand the speed of the lower roller was fixed at (5) r.p.m, while the other was rotated at different speed, the rollers were preheated to 100˚C using special heating system connected with laser thermometer. Between each pass, the samples were pre-heated for five minutes and re-rolling. The DSR process was conducted using different route (UD, ND, RD, HY) as shown in table (2).

Table (2) the rolling routes

Route	Name	Deformation steps	Notes
UD	Unidirectional		the successive rolling direction of sheets are not changed
RD	Rolling direction		the successive rolling directions were rotated through 180^0 about the rolling direction
ND	Normal direction		the successive rolling directions were rotated through 180^0 about the normal direction.
HY	Hybrid		the successive rolling directions were rotated through 180^0about rolling direction and also at 90^0 about normal direction.

5. Design of experiment

In order to determine the optimum rolling conditions, design experiments by Taguchi method is used .The studied parameters are: rotation speed ratio, reduction, type of rolling routes and strain rate table (3) shows the process parameters and its values Minitab program is chosen to make the table of experiments designed by Taguchi as shown in table (4).

Table (3) process parameters of rolling process

Speed(r.p.m)	Speed ratio	Reduction %	Route	Strain rate S^{-1}
5	1:1	20	UD	$1x10^{-3}$
7	1:1.4	25	ND	$1.5x10^{-3}$
9	1:1.8	30	RD	$1.85x10^{-3}$
11	1:2.2	35	HY	$2.11x10^{-3}$

Table (4) design of rolling experiments by Taguchi

Specimen No	Speed r.p.m	Speed ratio	Red%	Strain rate$\times10^{-3}S^{-1}$	Route
1	5	1:1	20	2.11	UD
2	5	1:1	25	1.85	RD
3	5	1:1	30	1.50	HY
4	5	1:1	35	1.00	ND
5	7	1:1.4	20	1.85	HY
6	7	1:1.4	25	2.11	ND
7	7	1:1.4	30	1.00	UD
8	7	1:1.4	35	1.50	RD
9	9	1:1.8	20	1.50	ND
10	9	1:1.8	25	1.00	HY
11	9	1:1.8	30	2.11	RD
12	9	1:1.8	35	1.85	UD
13	11	1:2.2	20	1.00	RD
14	11	1:2.2	25	1.50	UD
15	11	1:2.2	30	1.85	ND
16	11	1:2.2	35	2.11	HY

6.Microstructure investigation

Microstructure examination was carried out using optical microscope type (Nikon Eclipse Me Goo) equipped with digital camera type (Dx M12 00F) and Scanning electron microscope (SEM) . The samples were etched in an acetic picric acid solution (4.2g picric acid, 10ml acetic acid, 70ml ethanol, and 10ml distilled water) for 5-7 seconds, and rinsed in ethanol and dried with hot air.

7. Tensile Test

The Super plastic behaviour of rolled samples was study by tensile test. Tensile test specimens were cut from as-received and rolled sheet a long plane coinciding with rolling direction according to (DIN 50125) standard .The tests were conducted at room temperature and at 400C°/673K, at different strain rate in the range of (1×10^{-3} to2.11×10^{-3}) by using universal testing machine type (WOW-200E III) equipped with Special heating system controlled with in ±10℃ which was manufactured for this purpose by the researcher. Specific gripper was manufactured in order to fixing the small tensile specimen into tensile test machine clamp to prevents slipping.

8. Results and discussion

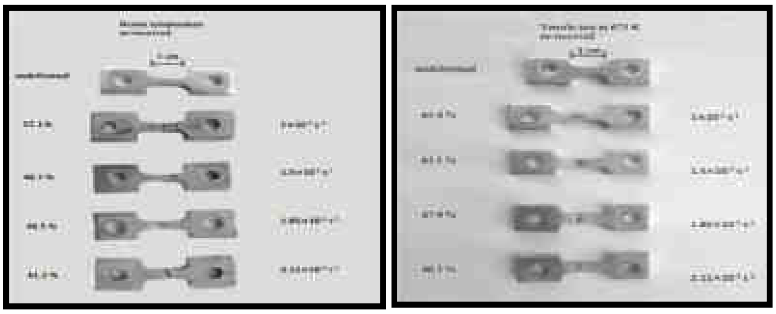
8.1. Tensile test results

Table (5) shows the maximum elongation to failure and maximum stress of as-receivedAZ31B alloy at room temperature and at 673K .The low elongation can be attributed to the limitation of slip systems at room temperature (M.Graf et al.2015) Figure (1) shows images of the samples from as-received alloy after pulled to failure at room temperature and at 673K.

Table (6) shows the Taguchi analysis results for mean elongation and ranking of rolled samples pulled at 673K. From the results it appeared that the symmetric rolled and differential speed rolled samples have higher elongation to failure percentage than that of un deformed one.

Table (5) Elongation to failure, maximum stress for as-received AZ31B alloy .

Strain rate$\times 10^{-3}$ S^{-1}	Elongation to failure %		Stress MPa	
	at room Temp	at 673K	at room Temp	at 673K
2.11	41.1	46.1	356.68	73.66
1.85	46.5	47.9	307.23	69.33
1.50	48.7	63.1	242.95	63.74
1.00	57.1	65.4	210.23	50.10



a **b**

Fig (1) As-received samples and elongation after pulling for possessed different strain rates, a) at room temperature, b) at 673K.

From the Taguchi analysis results table(6) , it had been shown that the most important parameter for the samples pulled at 673K (ranking of rolling parameter) is strain rate (rank 1)followed by speed ratio(rank 2), then rolling route(rank 3), and finally the rolling reduction(rank 4). On the other hand, it appeared that the elongation to failure of rolled samples was increased with the increase of speed ratio and/or with percentage reduction, at the same initial strain rate and the same rolling route. In addition, the samples elongation decreased with the increase of strain rate at the same rolling conditions. The previous results analysis show that the strain rate was the most important parameter in these experiments .Therefore to compare the elongation values of deformed samples after applying various rolling conditions and rolling route, tensile tests were carried out for all samples at the same initial strain rate 1×10^{-3} S^{-1} , and constant temperature 673K, and the results are put in the table (7).Figure (3)demonstrates image of the samples before and after rolling and pulled at 673 K with constant initial strain rate $1x10^{-3}$ s^{-1}. It appears that the deformation is comparatively uniform and no noticeable necking took place around the fracture and necking is restrained through the test. From Table (6,7) and Figure (2,3) it is reviled that the maximum super plastic tensile elongation of(430.5-387.6) % had been obtained for the samples rolled by applying repetitive differential speed rolling using HY route at 25% reduction and (1:1.8) speed ratio. The maximum elongation (401.1-351.3) % was achieved when applying repetitive UD rolling route at 30 % reduction and (1:1.4) speed ratio. By using repetitive RD route the elongation exhibit (324.2-311.6) % for the samples processed at 20% reduction and (1:2.2) speed ratio. Finally a maximum elongation to failure of (268.6-244.1) % was demonstrated when applying DSR and repetitive ND route at 20% reduction and (1:1.8) speed ratio. The minimum elongation values had been obtained at initial strain rate $1x10^{-3}$ s^{-1} in the samples rolled at low speed and symmetric rolling (speed ratio1:1).The HY route possessed samples exhibited (214.1-210)% at 30% reduction ,while RD route samples obtained (202.3-200.4)% at 25 % reduction . When ND was applied an elongation of (203.5- 201.0) % was observed at 35% thickness reduction. Finally a minimum elongation to failure of (186.4-179.5) % had been obtained when applying repetitive UD route at 20% reduction. The minimum elongation to failure values show that the most important factor in the ductility of samples rolled at similar speed and similar rolling speed ratio, pulled at the same strain rate $1\times 10^{-3}s^{-1}$, are the rolling route and reduction. On the other hand, the results show that the elongation to failure of rolled samples increased with the increase of speed ratio and/or with percentage reduction at the same initial strain rate and the same rolling route. In addition the samples elongations increased with the decrease of strain rate at the same rolling conditions.

Table (6) Taguchi analysis for mean elongation and ranking of samples pulled at 673K

Specimen No	Speed r.p.m	Speed ratio	Red%	Strain rate×10^{-3} S^{-1}	Route	δ_1	δ_2	SNRA	MEAN
1	5	1:1	20	2.11	UD	164.5	163.0	44.2834	163.75
2	5	1:1	25	1.85	RD	200.9	190.2	45.8154	195.55
3	5	1:1	30	1.50	HY	201.4	196.8	45.9797	199.10
4	5	1:1	35	1.00	ND	203.5	201.0	46.1173	202.25
5	7	1:1.4	20	1.85	HY	219.3	210.6	46.6414	214.95
6	7	1:1.4	25	2.11	ND	201.3	198.3	46.0112	199.80
7	7	1:1.4	30	1.00	UD	401.1	351.3	51.4513	376.20
8	7	1:1.4	35	1.50	RD	273.7	262.5	48.5603	268.10
9	9	1:1.8	20	1.50	ND	255.4	238.8	47.8428	247.10
10	9	1:1.8	25	1.00	HY	430.5	387.6	52.1997	409.05
11	9	1:1.8	30	2.11	RD	225.6	220.6	46.9684	223.10
12	9	1:1.8	35	1.85	UD	224.6	216.8	46.8720	220.70
13	11	1:2.2	20	1.00	RD	324.2	311.6	50.0407	317.90
14	11	1:2.2	25	1.50	UD	291.0	247.2	48.5119	269.10
15	11	1:2.2	30	1.85	ND	237.8	233.6	47.4462	235.70
16	11	1:2.2	35	2.11	HY	242.5	236.7	47.5878	239.60
Ranking	-	**2**	**4**	**1**	**3**				

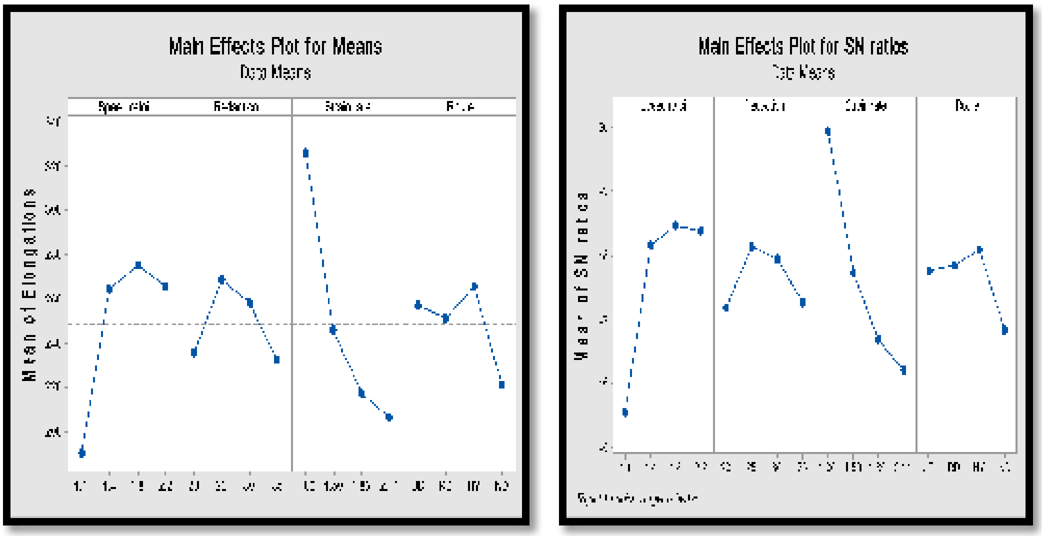


Figure (2) the effect of rolling parameters on Maximum elongation and SN ratio for rolling parameters

Table (7) Elongation to failure, Maximum stress of samples rolled by applying different condition pulled at673K and different strain rates.

SpecimenNo.	Speed r.p.m	Speed ratio	Red%	Strain rates×10^{-3} S^{-1}	Route	Elongation% at 673 K		MaxStress Mpa
						δmax	δmin	
1	5	1:1	20	2.11	UD	164.5	163.0	52.18
1	5	1:1	20	1.00	UD	186.4	179.5	37.58
2	5	1:1	25	1.85	RD	200.9	190.2	49.5
2	5	1:1	25	1.00	RD	202.3	200.4	52.54
3	5	1:1	30	1.50	HY	201.4	196.8	60.89
3	5	1:1	30	1.00	HY	214.1	210	55.57
4	5	1:1	35	1.00	ND	203.5	201.0	67.65
5	7	1:1.4	20	1.85	HY	219.3	210.6	38.41
5	7	1:1.4	20	1.00	HY	224.5	224.3	61.11
6	7	1:1.4	25	2.11	ND	201.3	198.3	69.52
6	7	1:1.4	25	1.00	ND	216.3	211	44.38
7	7	1:1.4	30	1.00	UD	401.1	351.3	71,67
8	7	1:1.4	35	1.50	RD	273.7	262.5	55.33
8	7	1:1.4	35	1.00	RD	281.5	277.8	70.52
9	9	1:1.8	20	1.50	ND	255.4	238.8	51,22
9	9	1:1.8	20	1.00	ND	268.6	244.1	60.44
10	9	1:1.8	25	1.00	HY	430.5	387.6	67.22
11	9	1:1.8	30	2.11	RD	225.6	220.6	59.18
11	9	1:1.8	30	1.00	RD	234.4	233,6	76.59
12	9	1:1.8	35	1.85	UD	224.6	216.8	49.50
12	9	1:1.8	35	1.00	UD	248.6	237	55.56
13	11	1:2.2	20	1.00	RD	324.2	311.6	57.11
14	11	1:2.2	25	1.50	UD	291.0	247.2	55.33
14	11	1:2.2	25	1.00	UD	302.3	280.2	49.56
15	11	1:2.2	30	1.85	ND	237.8	233.6	47.41
15	11	1:2.2	30	1.00	ND	245.1	240.5	38.99
16	11	1:2.2	35	2.11	HY	242.5	236.7	64.45
16	11	1:2.2	35	1.00	HY	244.3	240.8	58.67

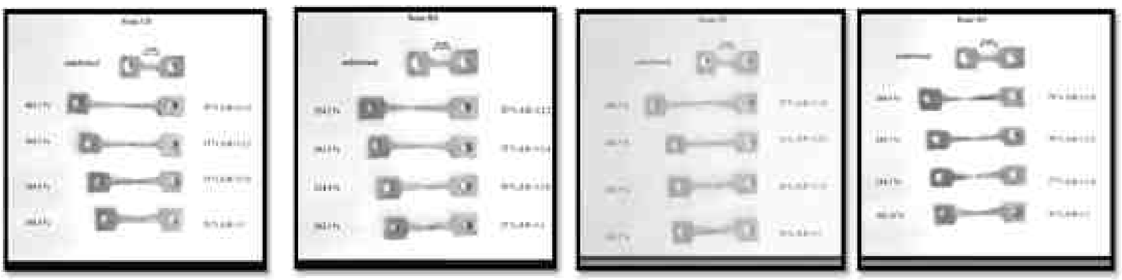


Figure (3) tensile specimens and elongation after rolling at 473K and pulling and constant initial strain rate 1×10^{-3} S^{-1}

8.2. Microstructure evolution

Figure (4) shows the optical microstructure of as-received AZ31B magnesium alloy. The microstructure shows coarse grains with average size of 78µm. Some thin twins were found inside the grains.

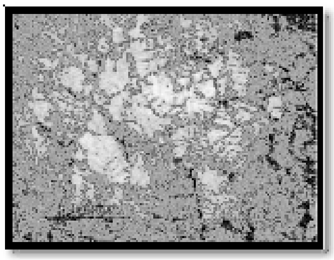
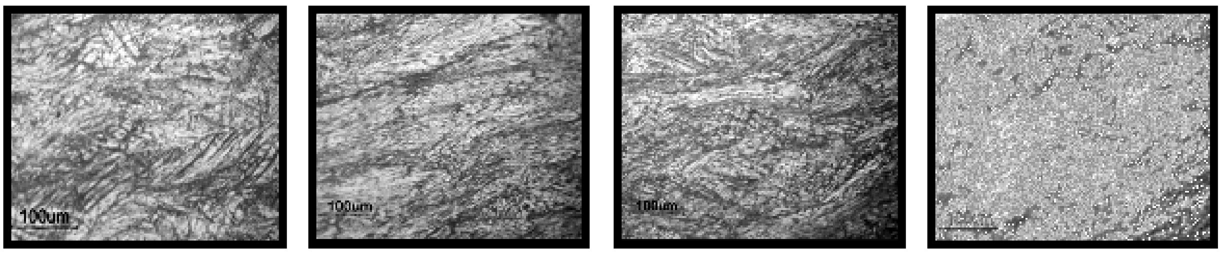


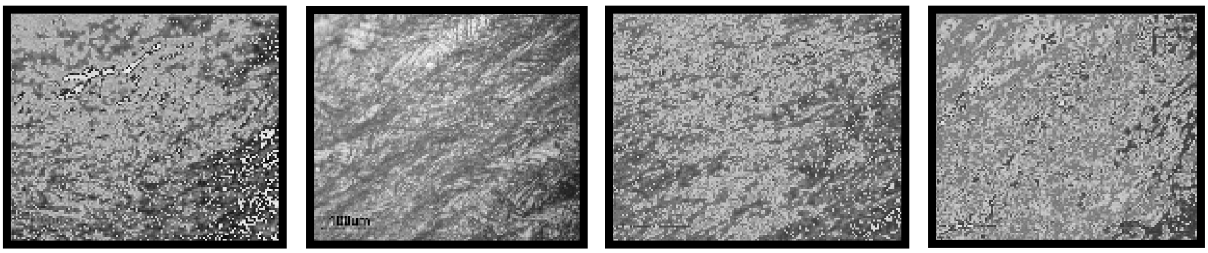
Figure (4) optical image of as-received AZ31B magnesium alloy

Figure (5) shows the microstructure of the samples rolled by applying UD route at different rolling speed ratio and reduction. At a low reduction20% and1:1 speed ratio i.e. (ESR) .It can be seen that a large number of twins was formed .In addition a coarse elongated grains were observed as shown in Fig.(5-a) .The microstructures of samples deformed by UD route and applying differential speed rolling are shown in Fig (5-b, c, d). When the sample was rolled at 30% reduction and (1:1.4) speed ratio, see Fig (5-b), shear bands were formed; dynamic recrystallizatin can be seen near the shear bands. Increasing rolling speed ratio and reduction to(1:1.8)and 35% respectively ,the density of shear bands increased and the amount of recryestallized grains at the twins and shear bands were increased ,the microstructure were nearly fully recrestalized as shown in Fig.(5-c). It had been reported by (M.Sanjari et al.2015). That the “twinning bands tended to be localized highly strained regions. The most favorable sites for dynamically recryestallization and played an important role in refining the microstructure because they have higher stored energy” (Kai et al.2016).When the rolling speed ratio was increased to (1: 2.2) and reduction decreased to 25%, the density of shear bands was decreased and thick shear band with coarse elongated grains had been formed, see Fig .(5-d).



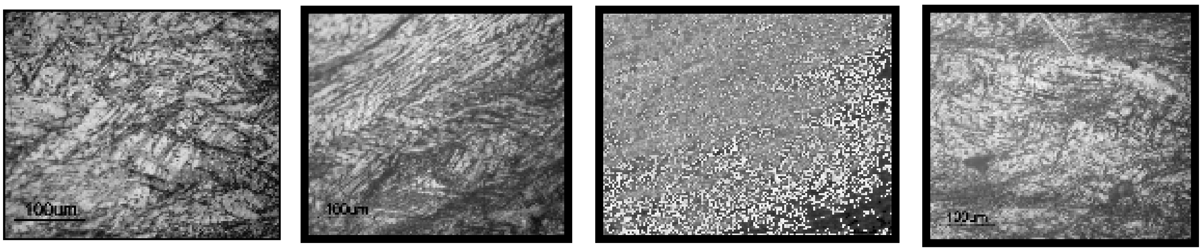
a.ratio1:1, red 20 % b. ratio 1:1.4, red 30% c. ratio1:1.8, red35 % d. ratio 1:2.2, red25%

Figure (5) Microstructures of samples rolled by (UD) route



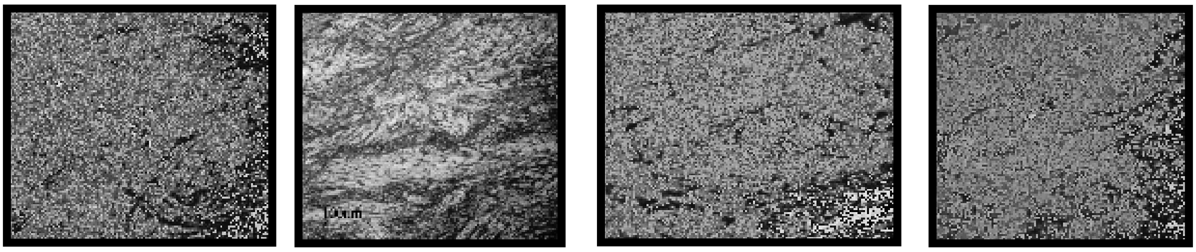
a.ratio1:1 ,red25 % b. ratio 1:1.4,red35% c. ratio1:1.8 ,red 30% d.ratio1;2.2,red20%

Figure (6) Microstructures of samples rolled by (RD)route.



a.ratio1:1 ,red 30%   b. ratio 1:1.4,red20%   c. ratio1:1.8 ,red 25%   d.ratio 1;2.2,red35%

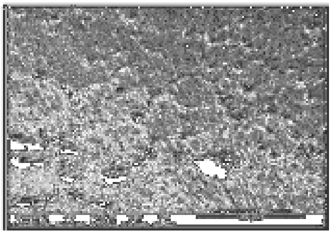
Figure (7) Microstructures of samples rolled by (HY)route.



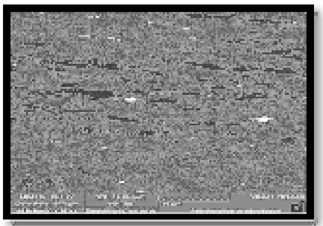
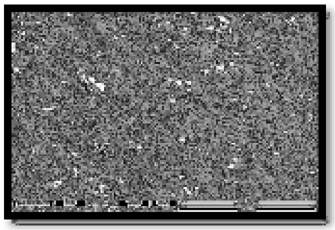
a.ratio1:1 ,red 35%   b. ratio 1:1.4,red25%   c. ratio1:1.8 ,red 20%   d .ratio 1;2.2,red30%

Figure (8) Microstructures of samples rolled by (ND)route

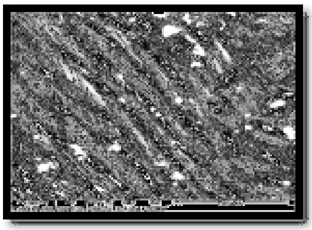
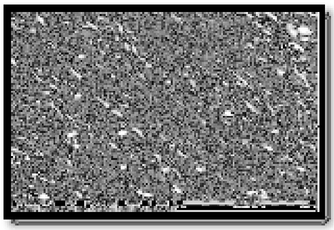
Figure (6) shows the microstructure of the samples deformed by RD route at various rolling speed ratios and thickness reductions. After symmetry deformation by RD route using low speed ratio(1:1) and reduction 25%, the microstructure shows thick shear band filler with recryestallizated grains as shown in Fig(6-a). There are small amounts of fine grains near the shear bands boundaries. In the asymmetry deformation by RD route, the density of shear bands increased with increasing rolling speed ratio to (1:1.4) and reduction to 35%, see Fig (6-b).On the other hand, high amounts of grains were formed in the twins and shear bands regions. When increasing the rolling speed ratio to (1:1.8) and decreasing the reduction to 30%, a mixture of elongated and coarse grains had been formed after rolling, see Fig (6-c) .The size of the recryestallized grains was larger than that of sample in Fig.(6- b) .This agrees with(J. Su et.al 2016).Observation that “at high speeds the dynamic recrystal grain sizes increases as the reduction increases”. At higher speeds and higher speed ratios, except low reduction 20% as in Fig (6-d), the thickness of shear bands increased, elongated grains had been seen in the same direction and perpendicular to the shear bands, with amounts of coarse grains had been seen between the shear bands. Fig (7) shows the microstructure of the symmetry and asymmetry deformed samples by HY route using differential speed rolling and reductions. The microstructure of symmetric rolling at low speed rolling , rolled at 30% reduction , shows heavily twin structures and fraction of recrystallized grains spread at the whole area of shear band and twins boundaries as shown in Fig(7-a).When the speed ratio in differential speed rolling increased to(1: 1.4) and reduced reduction to 20% , the microstructure consisted of elongated grains of different orientations aligned along the shear band direction, in addition to amounts of grains with different sizes created near the long grains boundaries. Increasing the rolling speed, speed ratio and reduction to (1:1.8) and 25% respectively, a high density shear bands were formed and the microstructure seem to be nearly filled with dynamic recrystallized grains in the whole area, as Shown in Fig(7-c). The further increase in rolling speed to(11 r.p.m) and reduction to 35% and speed ratio to (1:2.2),a higher non homogenous structure or mushy microstructure had appeared .The microstructure contain different types of grains in different directions. The first is small recrystallized grains localized at the twins and between the shear bands boundaries. The second is coarse grains formed on the shear bands aligned in different directions. The microstructures of samples produced by ND route are illustrated in Figure (8). It is obvious that cross shear bands and twins had be seen at low speeds, when symmetric velocity rolling and high reduction of 35% were applied as shown in Fig (8-a) .In addition, a small amount of recrystsllization can be seen between the shear bands and twins. This may be due to the high rolling reduction in thickness and repetitive deformation by ND route. Some researchers report that “the high rolling reduction cause a higher amount of deformation, which enhances the formation of new grains at the grain boundaries and deformation bands” (Mosab et al.2015). Rolling ratio was increased to (1:1.4) and reduced reduction to 25%, the deformed sample shows coarse grains along the shear bands as shown in Fig (8-b). Increasing the speed ratio to (1:1.8) and applied 20% reduction, the microstructure become nearly full with coarse nearly equal size grains as shown in Fig (8-c). When applying 30% reduction and (1: 2.2) speed ratio as shown in Fig (8-d) .It is obvious that the structure is non homogenous and a coarse grains evolution in different directions and formed at the matrix of shear bands. From microstructure observation it is concluded that the reduction and rolling speed ratio are the important factors in the modification of the deformed samples microstructure. At low speeds, firstly the increase in the reduction percentage will increase the local amount of deformation and appearance of heavily twin structure. A higher increase in the reduction percentage, the nucleation of new grains in the twins and shear bands will be courage. On the other hand, the microstructure observation shows that the increase in the speed ratio will increase the amount of dynamically re crystallized grains .The variation in elongation values can be correlated to the modification in the microstructure of samples after rolling, which related to the applied rolling route and variation in rolling conditions. Therefore, a scanning electron microscopy was employed to investigate the correlation between the super plastic behavior and internal microstructure of rolled samples. The maximum elongation of differential speed rolling sample by using HY route (at 25 % reduction and (1: 1.8) speed ratio) can be attributed to the band like microstructures that consist of ultra fine and very fine grains, see Fig (9).Which was provided by increasing the amount of dynamic recrystallization."The occurrence of dynamic recrystallization at high speed ratio was attributed to high-dislocation density accumulation and high temperature rise of a deforming sample due to large plastic deformation of which amount increased with speed ratio"(W.J.Kim et al 2011). Therefore the ductility of the deformed sample increases with increasing the amount of dynamically recryestallized grains, some researcher reported that "The DRX would absorb the deformation energy and eliminate lattice defects and dislocations, resulting in remarkable softness in the materials" (F.Z.Hassani et al 2011). In addition the repetitive differential speed rolling will change the strain path due to the rotation of sample between each pass according to HY route (180^o about the rolling direction and then rotated 90^o about the normal direction), and weakening the basal texture at high speed ratio due to twinning, Some researchers deduced that when speed ratio increased, the amount of shear deformation increased. On the other hand, the increase in speed ratio can weaken the basal texture intensity and inclining the basal plane and hence improve the formability of magnesium alloy (H.Zhang et al. 2013). Therefore the optimum combinations of reduction and speed ratio can enhance the ductility by dynamic recrystallization and inclining the shear planes and weakening the basal texture. The minimum elongation of sample by using HY route (at30%reducrtion and 1:1speed ratio) can be attributed to the high reduction and activation of multi shear plane. The high reduction led to cumulated strain regions that provide twins and creation of new grains near the twin boundaries as deduced by (Zhen et.al 2012) "twinning bands tended to be localized highly strained regions, which usually provided Preferential sites for DRX nucleation". As shown in Figs. (7) and (9f)." *twin boundaries act as barriers to dislocation motion leading to an increase in dislocation density in the materials" (*Seld et al. 2014).Therefore, they impeded the dislocation movements during deformation and affected the elongation values of samples .The ductility of samples were lower than that of sample rolled at25% reduction and (1:1.8) speed ratio ,at the same time was higher than the as-receivedAZ31B alloy sample. The minimum elongation had been achieved at samples rolled by applying UD route at low speed ratio 1:1 and 20% reduction may be due to accumulated strain induced by thickness reduction during multi pass rolling. The imposing deformation at the same direction (in UD the orientation of sample is not change between each pass) and rolling at low speed will provide accumulation strain, as was discussed before. Therefore, the symmetric rolling by applying UD route at these rolling conditions achieved minimum values of elongation and led to the formation of elongated grains aliened in the same direction of rolling, with same amount of recryestallized grains located at the grain boundaries of elongated grains as shown in Fig,(5).The elongation of samples rolled by applying ND route differential speed rolling (at 20%reduction and speed ratio1:1.8) ,was attributed to weakened basal texture at high speed ratio ,resulted from altering the deformed shear planes by rotation of sample by 180^o normal to the rolling direction between each pass . However, the enhancement in ductility was less the super plastic behavior and high elongation values of samples rolled by applying UD route(at 30% reduction and(1:1.4) speed ratio) , can be attributed to optimum combination of high reduction and inter medium speed ratio . The high reduction created highly distorted areas and activated the dynamic recrystallization. The dynamic recrystallization behavior increases with the increase speed,(Jing et al. 2012) has been reported that "Increasing the rolling speed will increase the temperature of sheet near the higher speed roll and may reach the recrystallization temperature of magnesium alloy, therefore increased the amount of dynamically recryestallized grains" (H.G.Jeong et al. 2009).Therefore the elongation will increase and reveal a mixed microstructure of coarse and fine grains as shown in Fig.(5-b).



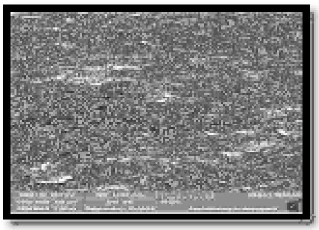
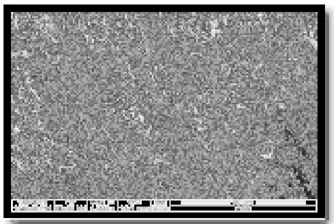
As-received AZ31B alloy

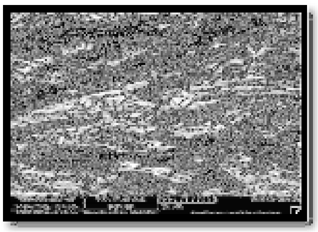
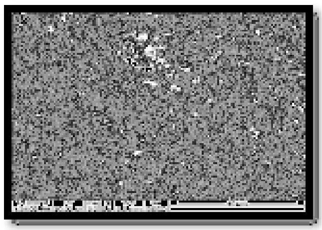
a. 1:1, UD, 20% b. 1:1.4, UD

c. 1:1, RD, 25% d. 1:2.2, RD, 20%.

e .1:1, HY, 30% f. 1:1.8,HY, 25%

g. 1:1 ND, 35% - h. 1:1.8, ND, 20%

Figure (9) SEM micrographs of samples after rolling .Left:-symmetric rolling, speed ratio (1:1), Right: differential speed rolling at optimum conditions.

The minimum elongation of samples rolled by applying ND route (35% reduction and low speed ratio 1:1) was attributed to the high reduction that increases the strain accumulated, and increases the amount of twins during multi pass rolling. Increasing the twins will prevent the dislocation motion. On the other hand recryestallized grains were initiated at twins boundaries and softening the alloy. Therefore, the elongation value is a result of opposite action of twins and dynamic recryastallization .The microstructure of sample at this condition shows a large number of twins and small amounts of recryzstallized grains. The minimum elongation at samples deformed by applying RD route (at 25%reduction and1:1 speed ratio), can be attributed to formation of twins and shear bands. By applying RD route, the shear bands formed by one pass crossed those by two-pass due to the "rotation of sample by 180^{o} along the rolling axis between each pass" , and allowing the elongated grains formed in the first pass return to original equal axed shape after the second pass in order to hold the intense plastic strain. So, different planes will deform and during multi pass rolling producing small grains. Increasing the speed ratio in RD route differential speed rolling to (1:2.2) will enhance the elongation and produce band likes microstructures consist of fine elongated grains and equiaxed grains.

9. Conclusions

The commercial wrought AZ31B magnesium alloy was deformed at a temperature of 473K, by applying different rolling routes, different thickness reduction and speed ratios .The microstructure, and tensile properties of rolled alloy were examined. The conclusions drawn are as follows.

1- The microstructure of the samples after rolling had been affected by applied rout, rolling speed ratio and reduction. Shear bands and twins were observed at low rolling speed and low speed ratio, while dynamic re-crystallization was produced at high speed ratio and high reduction.

2-The maximum elongation to failure of (430.5-387.6)% had been obtained for the samples rolled by applying repetitive differential speed rolling using HY(180^o about the rolling direction and then rotated 90^o about the normal direction), route at 25% thickness reduction and(1:1.8) speed ratio at initial strain $1\times 10^{-3}S^{-1}$.

3-The minimum elongation values had been obtained in the samples rolled at low speed and symmetric rolling (speed ratio1:1) .Applying UD route shows minimum elongation of (186.4-179.5) % at 20% reduction and speed ratio1:1

4-It appeared that the maximum elongation to failure of rolled samples increased with the increase of speed ratio and/or reduction at the same initial strain rate and the same rolling route.

5-The maximum elongation to failure of rolled samples decreased with the increase of strain rate at the same rolling conditions.

6-The elongation of the deformed sample increases with increasing the amount of dynamically recryestallized grains (due to softening of alloy). While decreases with twins (due to impede the dislocation movements).

7-The samples rolled at low rolling speed ratio and high reduction obtained high flow stress due to strain hardening. At high speed ratio, the flow stress will be reducing by softening effect due to dynamic recrystallization.

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