Production of Al-Mg alloy Ribbons by Using Single Roller Wheel Melt Spinning as a Non-Conventional Forming Technology.

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***Abstract*- Single roll melt spinning is a non-conventional forming process used to produce rapidly solidified thin ribbons as a near net shaper by direct casting from liquid state. In this paper, single roll made from brass with a diameter of 150 mm was used to produce rapidly solidified Al-Mg alloys ribbons. The ribbons are produced with thickness in the range of 20 to 330 µm. The results exhibited unique advantages in refining the microstructure, and modifying the mechanical properties of these ribbons. The hardness was improved to about twice the original hardness of alloy. Moreover, corrosion resistance of alloy was improved and their rate was redcued from 10.02 to 1.643 mpy for alloy type 5052 and from 6.91 to 1.943 mpy for 5083.**

Key wards: non-conventional forming, melt spinning, rapid solidification, ribbons.

1. Introduction

Forming operations are those in which the shape of a metal piece is changed byplastic deformation. An external force must induce the deformation or stress with magnitude value must be exceeding the yield strength of thematerial. Rolling isthe most widely used deformation process which is done by passing a piece ofmetal between two rolls. A reduction in thickness results from compressive stressesexerted by the rolls [1]. The forming technology can be classified into two types of techniques ;conventional and non-conventional forming technique.
A traditional forming process that is used to produce the sheet metal is realized with die and mould. This technique lacks flexibility and it is used in the volume production, then rolling processes to get the sheet. To achived higher throughput time rates, the ingot remains in the mold until the solidification is about complete. They placed in the gas fired reheating furnaces unitl they have attained uniform working temperature. Then the ingots are moved directly to the tandem rolling mill which consist from series rolling stands up to ten stands to make the reduction in the thickness and refining their structure [2, and 3]. The result of that, high friction was generated during rolling process and that could damage the surface of the rolled product, therefore, lubrication materials should be used to reduce the friction [4].
Today manufacturing are fouced on the non-conventional forming process to reduce Materials, Methods, Machining, Men and Money, which are called 5Ms. Among the methods of production, scientists are focusing on rapid solidification by melt spinning. Single roll strip casting is a similar technology used to produce near-net shaper thin strip. The process is first formed and then impinges against a rapidly moving substrate surface, which acts both to chill continuously and to transport the material away from the melt impingement area, resulting in the fabrication of a continuous rapidly quenched ribbons [5-8].
Rapid cooling and solidification during melt spinning and strip casting result from highly effective heat transfer at the interface between the ribbon and the spinning wheel. Using this method will reduce the equipment and the effort that is required for conventional forming methods. For example, one or two rolls can be used to produce ribbons directly from liquid state to solid state without using mould and additional rolling [9, and 10].
Rapid solidification process has been successfully applied to many different alloys for structural application, magnetic and electronic application [11-13]. This technique canbe produced materials with fine or powder ; uniform grain size, flakes, ribbons, wires and foils containing chemical homogeneity grains [14, and 15].
Melt spinning is one of the most commonly used processes for the production of rapidly solidified thin metal foils or ribbons with amorphous, microcrystalline or even combined microstructures. Melt spinning can be classified into single rolling melt spinning, twin melt spinning and transverse melt spinning. Single rolling melt spinning can be divided into free jet melt spinning and planar flows melt spinning [11, 16– 20].
The major advantage of single roll melt spinning is the possibility of continuous production of rapidly solidified material in the form of thin ribbons, even on a large industrial scale [21].

2. Al-base Alloy

Nowadays, the manufacturers and designers are focused on the sustainable manufacturing processes to reduce the weight, time, energy, and cost. Therefore, there is a growing need to reduce the weight of structure. One way to achieve this goal is to make use of lightweight alloys as a replacement for conventional iron-based alloys [22].
Amorphous and nanostructured Al-based alloys have seen an increased potential for technological application during recent years.
Al-Mg alloy is one of the most widely used structural material owing to its appreciable properties such as low density, high specific strength and so on [23]. Aluminum corrodes over 100 times slower than the carbon steels. The most popular aluminum alloys for use in corrosive environments are non-heat treatable 5xxx [24]. The major

alloying element in these alloys is magnesium that is used with or without manganese to produce a modern alloy with high strength work-hardenable. Magnesium is considerably more effective than manganese as a hardener because 0.8% Mg is equal to 1.25% Mn that can be added in considerably higher quantities. Al-alloys are used in boats, ships, cryogenic tanks, crane parts and automotive structures etc., [25]. Therefore, two types of Al-Mg alloys will be used in this research work, which are 5052 and 5083 to study the posibility of production ribbons and study the effect of rapid solidofication process (RSP) on the quality of ribbons.

3. Experimental Work

Single roller wheel melt spinning machine that used in this work was manufactured from materials that were available in the local market. It consisted from two main units ; melting unit and rapid solidification unit. These two units have been fixed on the carbon steel frame with dimensions (150 x 80 x 100) cm as shown in Fig. (1).

Fig. 1 Single roll melt spinning machine

3.1 Melting Unit

The furnace was made from carbon steel plate and lined by high alumina castable as refractory material. The temperature inside the furnace can be reach up to 1200 ºC which was controlled througha digital thermocouple with an adjustment device. Two alloys were melted by using the furnace after preparing them to the suitable size for charging in the furnace.

3.2 Rapid Solidification Unit

A rapid solidification unit wasmanufactured to allow the liquid metal to cool as fast as possible. This unit was designed as a free jet melt spinning system, which consists from single roll wheel for rapid cooling, tundish, heating unit, speed control, leaving guide and temperature measurement unit as shown in Fig. (2).

Fig. 2 Rapid solidification unit

A. Single Roll Wheel

The roll used in this work was manufactured from two parts, an inner ring made from aluminum-zinc and the outer ring made from brass as shown in Fig. (2). The outer diameter of the ring is 150 mm, the width of ring is 80 mm and the thickness of brass ring is 16 mm. It was designed to reduce the number of rolls and increase the efficency of heat transfer.

B. Tundish

Alloys are melted with different temperatures to become liquid then poured through the tundish made from aluminum silicate refractory materials. Different orifice diameters are made in the bottom side of the tundish to use as a nozzle. This orifice is used to control the flow of liquid metals by dropping the liquid on the surface of rotating roll wheel to get the best rapid solidification process. The orifice diameters of tundish used in this work were designed as 2.5, 3, 3.5 and 5 mm to investigate the effect of orifice diameters on the quality of products.

C. Tundish Heating Unit

A tungsten coil with diameter of 10 mm and length equals to 1000 mm that consumes 1000 watts was used as heating unit to generate the heat temperature up to 800 ºC approximately. This coil has been turned around the tundish as spiral coil to heat the tundish before and within the casting time. It was used to reduce the loss of heat and to ensure the metal flow uniformally without any freezing at the end of casting and increasing the life of tundish.

D. Temperature Measurement

An infrared temperature measurement device was used as a portable device to measure the temperature of liquid metals inside the ladle before pouring in the tundish. In addition, measuring the temperature of tundish before pouring the liquid metals inside it and the temperature of ribbon that was produced through rapid solidification unit was measured too.

4. Production of Ribbons

A number of experiments were performed in this work usingthe constructed machine as shown in Tables 1 and 2. In these experiments, the speed of rotation was constant which was equal to 2840 rpm, and the roughness of contact brass surface was 400P. The tundish was preheated to temperature up to 600 ºC.Different orifice diameter (OD), nozzle- roll gap (G), and melting temperature (MT) was used to study their effects on the quality of ribbons.

Table 1 : Experiments performed to produce ribbons type 5052

Exp. No.	Al-Mg type 5052		
	OD (mm)	G (mm)	MT (ºC)
1	2.5	2	700, 800, 850, 900, 1000
2	2.5	3	700, 850, 950, 1000
3	3.5	2	700, 750, 800, 950, 1000
4	3.5	3	750, 850, 900, 950, 1000
5	5	2	700, 750, 800
6	5	3	

Table 2 : Experiments performed to produce ribbons type 5083

Exp. No.	Al-Mg type 5083		
	OD (mm)	G (mm)	MT (ºC)
1	2.5	2	750, 800, 850 900, 1000
2	2.5	3	750
3	2.5	5	850
4	3	2	750
5	3.5	2	800
6	5	2	750

5. Results and Discussions

Samples ofalloy type 5052 and 5083 were prepeared in order to investigate the effect of RSP on their microstructure and mechanical properties.

5.1 Chemical Analysis

Chemical composition of Al-Mg alloys as recived, and as rapid solidified ribbons was examined using SPECTRO device and the results are shown in Table 3.

From the above table, it can be found that the percentage of aluminum and magnisuim (alloyingelement) are close for alloy as recieved and as rapid solidified ribbons.Therefore, there is no significant change in the chemical composition of alloy after rapid solidification process.

Table 3 : Chemical analysis of Al-Mg alloy

Element	5052		5083	
	As recieved %	As ribbon %	As recieved %	As ribbon %
Si	0.16	0.41	0.14	0.085
Fe	0.42	0.50	0.27	0.26
Cu	0.092	0.15	0.042	0.028
Mn	0.062	0.049	0.52	0.46
Mg	2.55	2.58	4.06	4.23
Zn	0.054	0.0092	0.008	0.008
Ni	0.005	0.005	0.005	0.005
Cr	0.25	0.26	0.23	0.25
Al	96.3	95.8	94.7	94.6

5.2 Dimensions Test

Ribbons of Al-Mg alloys were produced with different thicknesses, widths and lengths as shown in Fig. 3 and Table 4. The vairation in ribbons dimensions occurs due to the variation of volumetric flow rate of molten metals which leading to instable melt pudle. Therefore, ribbons thickness and width are variable along the length of ribbons.

Fig. 3 Ribbons produced in this work

5.3 Metallography Test

Metallography is the scientific discipline of examining and determining the constitution and the underlying structure in metals, alloys and materials. In this work, SEM was used to examine the microstructure of rapid solidified ribbons and the result shown in Fig. s (4) to (10).

Rapid solidification process was modifying the microstructure of ribbons. The results showed different structure which include flower like grains, cluster and verys small grains in the range of nano scale, and dendritic growth. Additionally, cubic body of SEM showed three sides of ribbon (roll wheel side, transverse side, and airside surface). The results showed that the refined microstructure is not uniform in the ribbon sides due to the effect of rapid solidification and heat transfer. Wheel side ribbon was exhabited uniform distribution crystalline with with nano scale and the roughness side was shown in the air side with high crystalline structure. However, transverse side of ribbon was showed small recrystallized nucless as a deformation bands with grains size less than wheel and airside. Moreover, the direction of rolling is very clear.

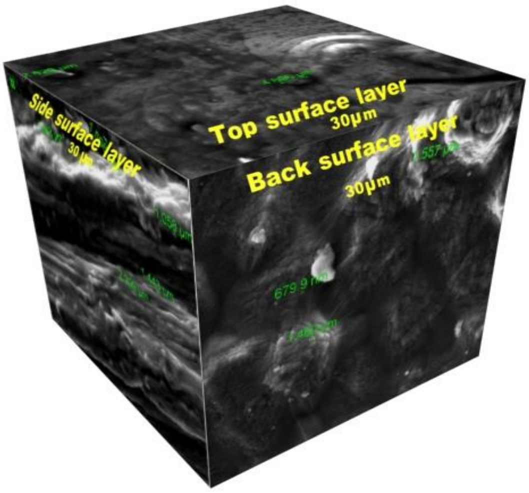
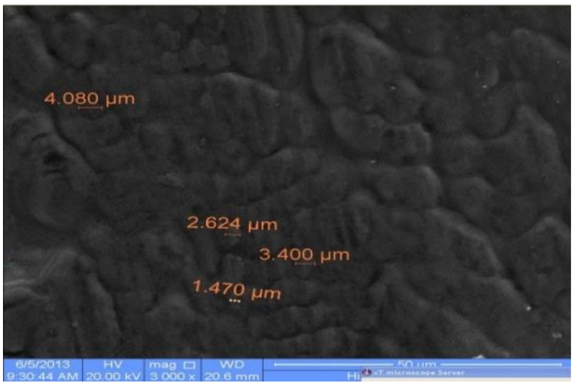
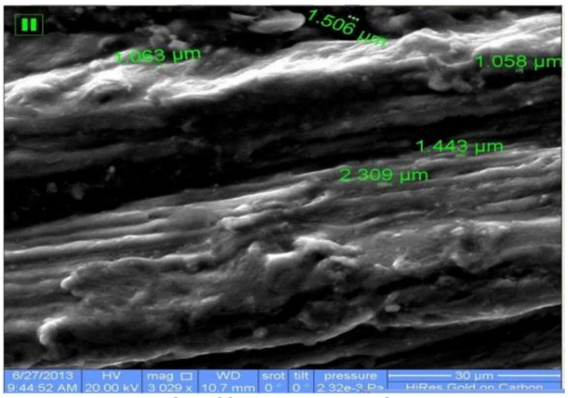


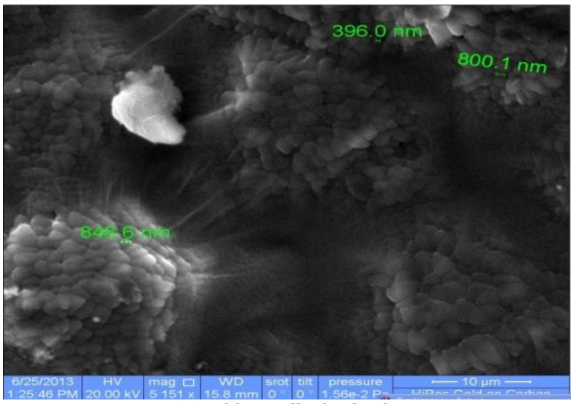
Fig. 4 Cubic body of SEM for 5052 roll wheel side ribbon, transverse side, and airside ribbon produced by RSP with OD of 2.5 mm and G of 2.5 mm at MT of 1000 ºC.



(a) Ribbon air side



(b) Ribbon Transverse side



(c) Ribbon roll wheel side

Fig. 5 SEM for (a) air side, (b) transverse side, and (c) roll wheel side of 5052 produced by RSP with OD of 2.5 mm and G of 2.5 mm at MT of 1000 ºC.

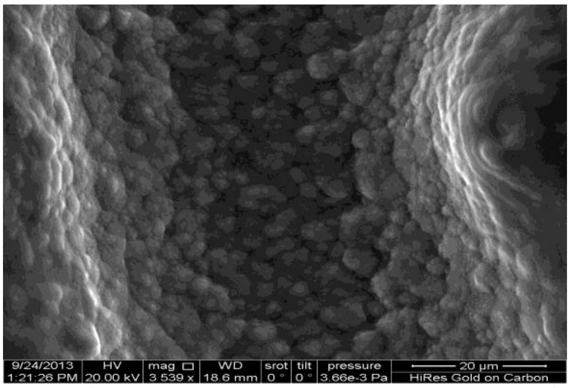


Fig. 6 SEM for ribbons type 5083 produced by RSP through OD of 2.5 mm, G of 2 mm and MT of 850 ºC.

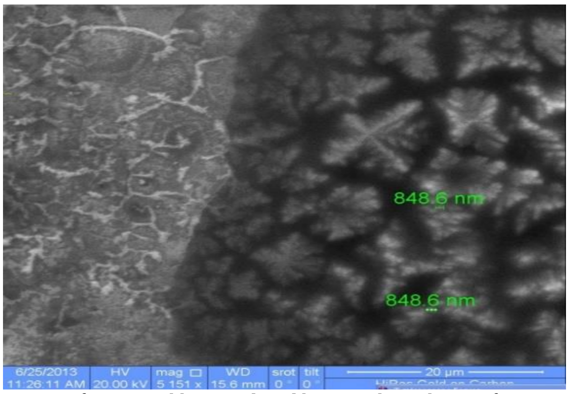


Fig. 7 SEM for 5083 ribbon produced by RSP through OD of 2.5 mm, G of 5 mm and MT of 850 ºC.

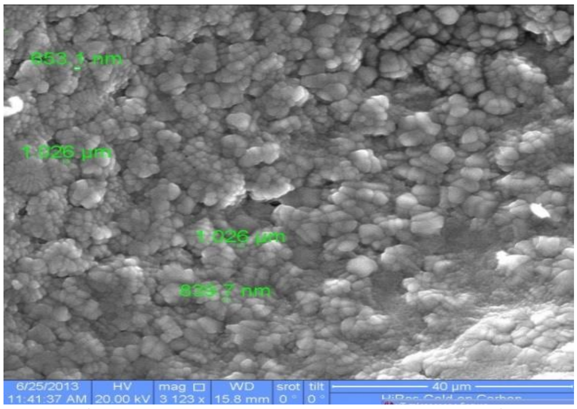


Fig. 8 SEM for 5083 ribbon produced by RSP through OD of 2.5 mm, G of 2 mm and MT of 850 ºC.

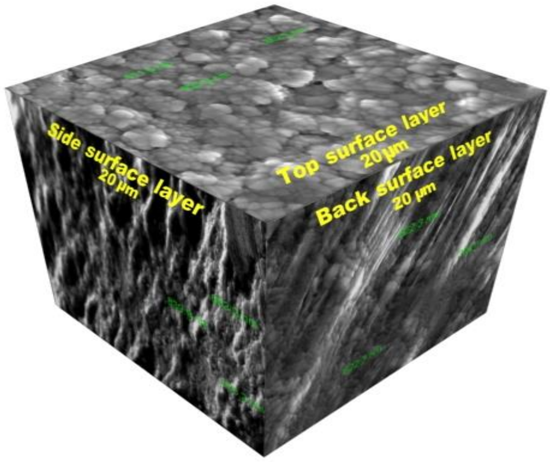


Fig. 9 Cubic body of SEM for 5083 roll wheel side ribbon, transverse side, and airside ribbon produced by RSP through OD of 2.5 mm, G of 2 mm and MT of 850 ºC.

5.4 Hardness Test

The hardness test is a means of determining the resistance of materials to penetration and it is a function for wear resistance. In this work, a microhardness tester device was used to determine the microhardness of specimens. Vickers microhardness test HV was applied with a load equals to 2.942 Kgf and apyramid shape pointer. The result values and shapes of Vickers hardness HV for Al- Mg alloys type 5052 and 5083 as recieved and asribbons are shown in Table 5 and Fig. 11. From this table found that the hardness of rapid solidified ribbons was increased twice of the original hardness (for alloy as recived). The reason for that because RSP was modifying their microstrcuter and made it in the nano scales.

Table 5 : Micro-hardness values

Micro-hardness value (HV)			
Alloy type	As recieved	As cast	As rapid solidified ribbons
5083	73-100	94-101	279-283
5052	67-78	73-79	138-153

Fig. 10 Shape of Pyramid Micro-hardness printed on the specimen

5.5 Grain Size Dimension

The dimensions of grains are very important factors that can be used to calculate the theoretical yield strength of thin film materials. By using SEM, the dimensions of grain sizes of rapid solidified ribbons are determined with magnification up to 5000X. The results showed that there are different dimensions appearing in the specimens equal to micro and Nano scale crystalline sizes as shown in Table 6.

Table 6 : Grain size of ribbon

Types of alloys	Ribbons grain size dimensions	
	nm	µm
5083	396-996	1.068-17.89
5052	396-907	1.058-14.37

5.6 Corrosion Test

In this work, corrosion test was performed for different samples of ribbons types 5052 and 5083 before and after rapid solidification using an electrochemical corrosion method.This method was applied using Tafel device witha corrosive solution containing 3.5% NaCl, which was approximately equal to the salt concentration of seawater.

The Tafel plots were obtained as a result of the electrochemical corrosion test shown in Fig. s13 to 17. From these plots, current (I_{corr}) in µA/cm^{2}wasfound by Tafel plot as a result of electrochemical corrosion test which was used to calculate the corrosion rate. Tafel equation that is shown in Equation (1) was used to calculate the corrosion rate (CR) in (mpy)of these alloys, taking into account the main alloying elements present in these alloys.Al-Mg alloys that were used in this work consist from 3 to 4 alloy elements. For instance, 5052 alloy has Al, Mg, and Cr, but 5083 alloy has Al, Mg, Mn, and Cr. The values of these alloy elements were obtained from the standards table.

$$CR = 0.128\, I_{corr} \left(\frac{\text{atomic weight of the element}}{\text{valence} * \text{density}} \right) * \text{percentage of element} \,\% \qquad (1)$$

Equation 1, can be simplified to be as present in Equations 2 and 3 to calculate the corrosion rate for 5052 and 5083 Al-Mg alloys,respectively. The results corrosion rate values of these alloys present in Table 7.

$$CR_{5052}=0.4369\, I_{corr} \qquad (2)$$

$$CR_{5083}=0.4482\, I_{corr} \qquad (3)$$

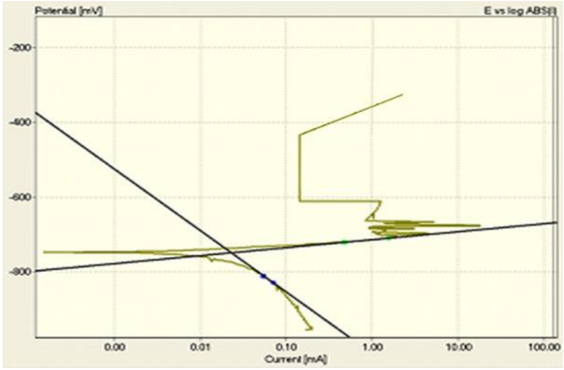


Fig. 11 CorrosionTafel plot for alloy type 5052 as received

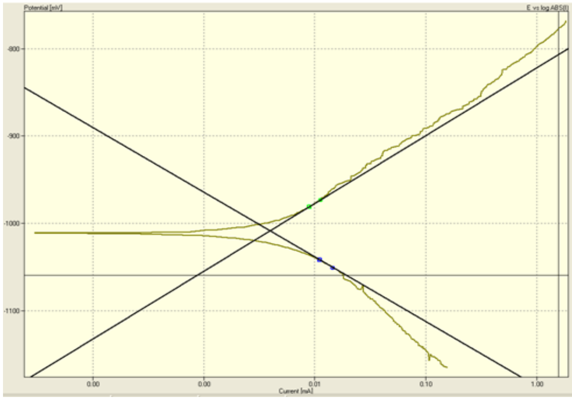


Fig. 12 CorrosionTafel plot for rapid solidified ribbons type 5052 produced by RSP through OD of 3.5 mm, G of 2 mm and MT of 750 ºC.

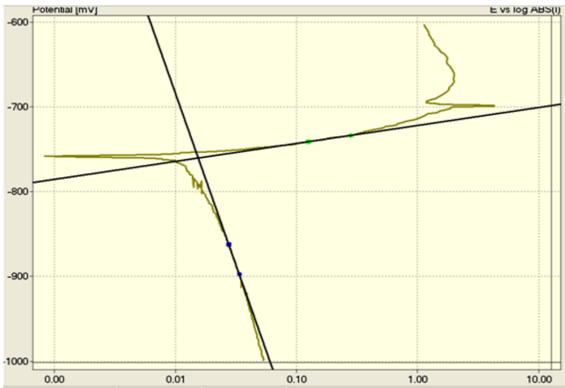


Fig. 13 CorrosionTafel plot for 5083 as received

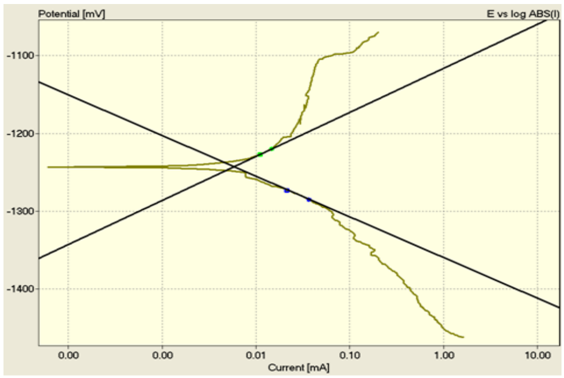


Fig. 14 CorrosionTafel plot for rapid solidified ribbons type 5083 produced by RSP through OD of 2.5 mm, G of 2 mm and MT of 850 ºC.

A comparsion between two sets of curves showed that rapid solidified ribbons have higher corrosion resistance than alloy as recieved. Their corrosion current was decreased by more than an order of magnitude and the corrosion rate was decreased from 10.02 to 1.643 mpy for alloy type 5052 and from 6.911 to 1.954 mpy for 5083. Although, 5083 has lower corrosion rate for alloy as recived compared with 5052, their rates after rapid solidification process are closed.This is due to the effect of rapid solidification process wich refining the microstructure of alloy and increased the homogenity of alloy. The results microstructures exhibited finger microstructure with small grain size in the range of nano scale without segrigation and consequently better mechanical properties in the RSP.

6. Conclusion

1. RSP with single roller wheel melt spinning is one of the non-conventional forming technology that help to reduce waste, process steps, labours, money, energy, and pollution. It is belong to sustainable manufacturing process.
2. Orifice diameter, nozzle-roll wheel gap, and melting temperature are the major parameters that influence the quality of rapidly solidified ribbons.
3. There is a few change in the chemical composition of alloys after melt spinning and RSP.
4. Ribbons was produced with thickness in the range of 20 to 330 µm and width of 0.61 to 7.40 mm depending on the orifice diameter and nozzle-roll wheel gap, and melting temperature.
5. Rapid solidification with single roll melt spinning produced ribbons with high percentage of nano scale grain size less than 396 nm.
6. The hardness of rapid solidified ribbons are greater than the hardness of alloys before rapid solidification. It increases to about 283 HV instead of 100 HV for 5083 and 153 HV instead of 78 HV for 5052 alloy. It is improved to about twice the original hardness due to the rapid solidification.
7. Corrosion rate of rapidly solidified ribbons is lower than the rate of alloys as recieved. It is reduced from 10.02 to 1.643 mpy for alloy type 5052 and from 6.911 to 1.954 mpy for alloy type 5083.

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Table 4: Dimensions of ribbons

Type of alloys	**Orifice Dia. Mm**	**Gapmm**	**MeltingTemp. ºC**	**Dimension of ribbons**	
				Thickness (μm)	**Width (mm)**
5052	2.5	2-3	700-1000	60-200	0.97-4.88
	3.5			100-230	1.16-7.40
	5			80-290	0.97-6.92
5083	2.5			20-220	0.61-5.04
	3.5			100-230	4-6.34
	5			150-330	2.05-4.14

Table 7: Corrosion rate values for CR of Al-Mg alloy

Types of process	**5052**			**5083**		
	Potential (mV)	**I_{corr} (μA)**	**CR (mpy)**	**Potential (mV)**	**I_{corr} (μA)**	**CR (mpy)**
As Recieved	-749.7	22.94	10.02	-760.2	15.42	6.911
As cast	-679.6	19	8.301	-765.9	2.42	1.084
As rapid Solidified ribbons	-1008.5 -1010.2	3.95 3.76	1.686 1.643	-1242.7 -1092.2	5.83 4.36	2.613 1.954