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Single Roll Melt Spinning Technique Applied as a Sustainable Forming Process to Produce Very Thin Ribbons of 5052 and 5083 Al-Mg Alloys Directly from Liquid State

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Abstract

In this paper, single roll melt spinning technique is used as a sustainable manufacturing process to reduce waste, time, energy, and cost. The non-conventional forming machine is manufacturing to produce very thin ribbon of 5052 and 5083 Al-Mg alloys in the range of micrometer. It is a tool for modifying the microstructure of alloy and improved their properties. The process has a direct impact for saving materials, machine, method, men, and money (5M) compared with conventional forming technology due to their ability to produce very thin ribbons directly from liquid state. The properties of the produced ribbons were investigated and the result indicating that there is a possibility to produce ribbons with micro thickness of 20 to 330 µm and width of 0.97 to 7.4 mm. Moreover, the hardness was improved to be more than twice of the original hardness of alloy. The corrosion resistance of alloy was improved and their rate was reduced.

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*Keywords:*sustainability; manufacturing;.

1. Introduction

Metal fabrication techniques are normally proceeded by refining, alloying, and often heat-treating processes to produce alloys with desired characteristics [1]. These techniques include various metal forming methods, casting, powder metallurgy, welding, and machining. Forming technology can be classified into conventional and non-conventional forming technique [2].

Conventional forming process that used to produce the sheet metal is realized with die and mold as shown in figure 1. This technique lacks flexibility and used in the volume production, then rolling process to get the sheet. The ingot remained in the mold until to solidified then preheating in the furnace to deforming by tandem rolling mill to make a reduction in the thickness of slab or piece [3, 4, and5].

Non-conventional forming process is defined as a manufacturing process essential to know what is required for carrying out the manufacturing activity with reducing materials, methods, machining, men, and money. It is belong to sustainable manufacturing process.

Sustainable manufacturing process is defined by the US Department of commerce as the creation of manufacturing products that use processes to minimize the negative environmental impact, conserve energy and natural resources, which will save the employees, communities and consumers. This will have direct impact to minimize the diverse business risks inherent improving the process and products [6].

Since climate protection and reduction of carbon emissions have gained increasing significance in research, industry and legislation, it is not only important to reduce energy consumption and emissions of products during the use phase, but throughout the whole life cycle [7, 8, 9, and 10]. Therefore,the manufacturers and designers are focusing on sustainable manufacturing process to produce thin sheet metal with less steps of process and less environment pollution and waste. Melt spinning with rapid solidification is one of most popular non-conventional forming processes that used to produce advanced materials with unique properties. Melt spinning process was classified into three types according to the number and position of roll which are transvers, single roll, and twin roller melt spinning system that used for rapid

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solidification process [11, 12]. Rapid solidification is a processing technique in which the unusual properties and microstructures can be obtained in contrast to conventional methods. It can be produce materials with fine, uniform grain size and chemical homogeneity within the grains [13].

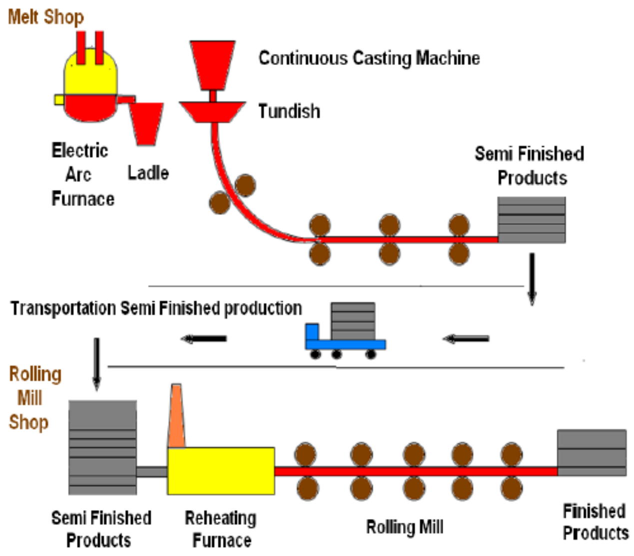


Fig. 1: Conventional forming process [14]

Single roll melt spinning process has one of the highest melt cooling rates among all continuous casting process because the solidification time and movement of the melt and substrate are very short. The major advantage of single roll melt spinning is the possibility of continuous production of rapidly solidified materials in the form of thin ribbons, even on a large industrial scale [15]. It can be classified into free jet melt spinning and planer flow melt spinning depending on the distance between ladle nozzle and substrate roll. For free jet melt spinning , the distance more than one millimeter and for planer flow melt spinning, the distance is less than one millimeter. Therefore, in the present research, single roll melt spinning machine with free jet is used to study the possibility to produce very thin ribbons from two types of Al-Mg alloys.

2. Experimental work

2.1. Manufacturing of machine

Single roll melt spinning machine was designed and manufacturing to use as rapid solidification with melt spinning technique which consist from two main units as shown in figure 2 to5. The first unit is melting unit and the second unit is rapid solidification unit. Rapid solidification unit consist from single roll that made from brass materials with outer diameter of 300 mm, inner diameter of 50 mm, and width of 80 mm.

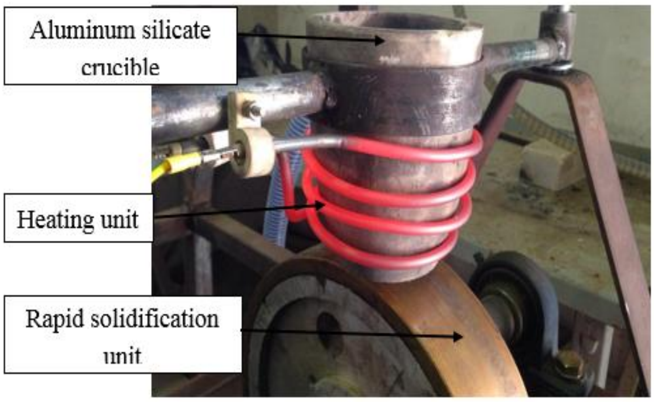


Fig.2: Single melt spining unit

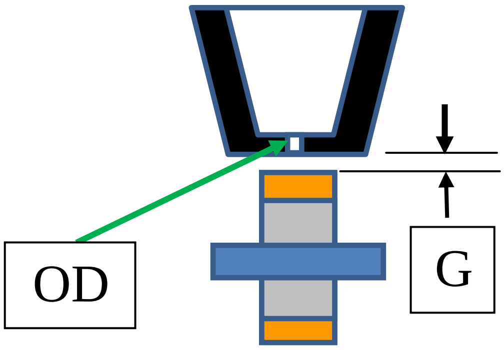


Fig.3: Position of orifice diameter OD and distance between ladle nozzle and substance single roll G

Fig.4: Single roll melting spinning Machine

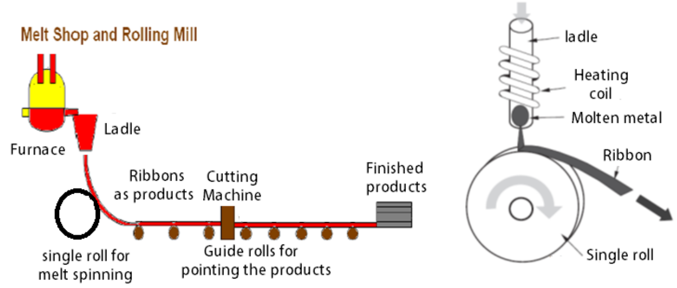


Fig. 5: Non-conventional forming process with single roll melt spinning

2.2. Materials

Al-Mg alloys is one of the most widely used structural materials owing to its appreciable properties such as low density, high specific strength, and so on. 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 [16, 17]. The principle alloys that are strengthened by alloying elements in solid solution are those in the aluminum – magnesium series, ranging from 0.5 to 6% Mg.

In the present work, two types of Al-Mg alloys are used which are 5052 and 5083 to study the effect of rapid solidification on their specification. These alloys were produced in the conventional forming methods, which included melting and rolling by multi pass and multi rolls (tandem). The specification of these alloys are shown in Table 1.

Table 1: chemical analysis for Al-Mg alloys types 5052 & 5083

Element	**5052**	**5083**
Si	0.16	0.14
Fe	0.42	0.27
Cu	0.092	0.042
Mn	0.062	0.52
Mg	2.55	4.06
Zn	0.054	0.008
Ni	0.005	0.005
Cr	0.25	0.23
Al	96.3	94.7

2.3. Work Principle

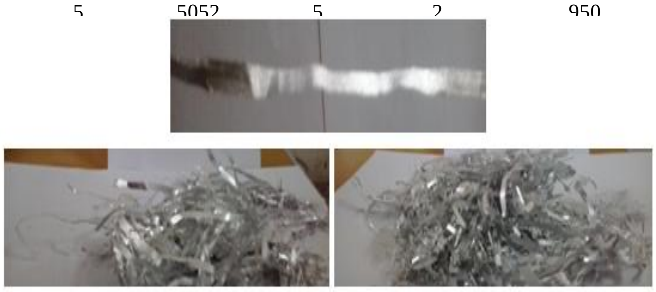
Al-Mg Alloys are melted with different temperatures to be a liquid, and then poured to the crucible made from aluminum silicate. The molten metal is driven from nozzle in the form of a jet, which on impingement with rotating disc form a melt puddle. The shape of this puddle is form under the continuous forces of tangential flow of the material and the surface tension. The melt beneath the puddle solidifies into a ribbon. The ribbon leave the disc under the action of the centrifugal force.

2.4. Processing

Different conditions have been applied to produce ribbons from Al-Mg alloys (5052 and 5083) which include melting temperature (MT) from 700 to 1000 ^{o}C, orifice diameter (OD) of 2, 3 and 5 mm, and distance between nozzle and roll wheel(G) are 2 and 3 mm as shown in Table 2.

Table 2: Experimental work condition

Experiment No.	Metal type	OD (mm)	G (mm)	MT (ºC)
1	5052	2.5	2	750
2	5052	2.5	3	800
3	5052	3.5	2	850
4	5052	3.5	3	900
5	5052	5	2	950



3. Results

3.1. Shape and dimension of products

Figures 6 shows the shape of ribbons that produced in this work by using single roll melt spinning machine.The dimension of rapid solidified ribbonswas obtained with thickness of 20 to 330 µm and width of 0.97 to 7.4 mm.

Fig. 6: Shape of rapid solidified ribbons

3.2. Hardness

In the present work, the microhardness device was used to determine the hardness of rapid solidified ribbons and alloys as received. Vickers microhardness test HV was applied with load of 2.942 Kgf. The hardness of rapid solidified ribbons increase with decreasing thickness of ribbons as shown in figure 7.

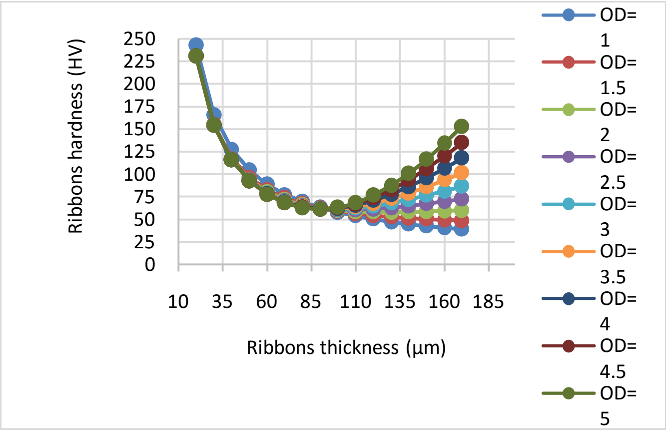


Fig. 7: relationship between ribbon thickness and hardness

The result shows that the hardness of rapid solidified ribbon is more than twice of the original hardness of alloys before rapid solidification process as shown in Table 3. This is due to modify the microstructure of alloys, which produce homogenous structure with massive Nano grain size.

Table 3: Hardness of alloys before and after rapid solidification process

Metal type	As received (HV)	As cast (HV)	As Rapid solidified (HV)
5052	67-78	73-79	138-153
5083	73-100	94-101	279-283

3.3. Microstructure

The microstructure of alloys as received and as rapid solidifiedwas examined by scanning electron microscopy as shown in figure 8 and 9. The microstructure of rapid solidified ribbons show that the majority of structure is Nanograin, which lead to improve the mechanical properties and corrosion resistance.

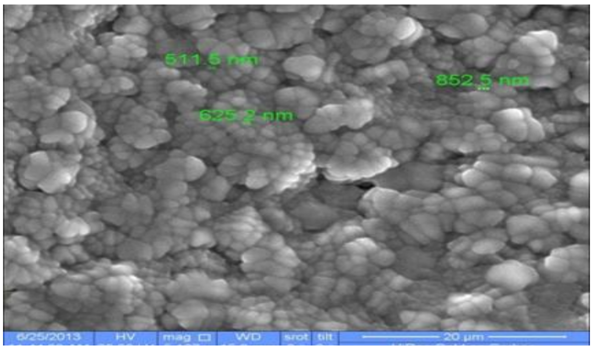


Fig.8: Microstructure of rapid solidified ribbons

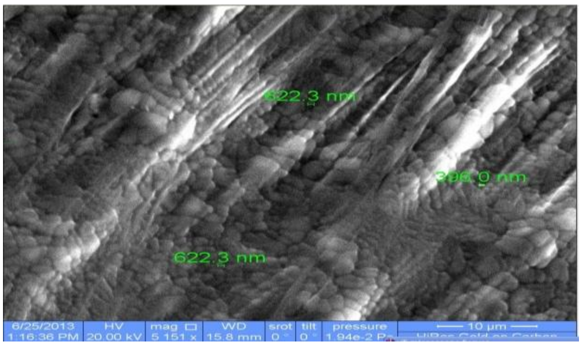


Fig.9: Microstructure of rapid solidified ribbons

3.4. Corrosion resistance

Corrosion test was performed for different samples of ribbons before and after rapid solidification using an electrochemical corrosion method. It was applied using Tafel device with corrosive solution of 3.5% NaCl. The result shows that the corrosion resistance was improved and the corrosion rates were reduced to be 16% and 28% of the original rate for alloys type 5052 and 5083 as received, respectively as shown in Table4. From this table, it can be found that the two alloys have closed corrosion rates after rapid solidification process although they have different percentage of magnesium element. Moreover, corrosion rate of 5052 is lower than 5083 after rapid solidification, although 5052 has lower percentage of magnesium element than 5083. This is due to the effect of rapid solidification process on the microstructure of alloys.

Table 4: corrosion test and rate for rapid solidified ribbons

Metal type		Potential E_{coor}(mV)	Current I_{coor}(µA)	Corrosion Rate(mpy)
5052	As received	-749.7	22.94	10.02
	As cast	-679.6	19	8.301
	As rapid solidified	-1010.2	3.76	1.643
5083	As received	-760.2	15.42	6.911
	As cast	-765.9	2.42	1.084
	As rapid solidified	-1092.2	4.36	1.954

4. Conclusions

The results shows that there is a possibility to produce ribbons with very thin thickness of 20 µm using single roll melt spinning process as a sustainable manufacturing process. The process was reduced the steps of producing thin sheet to be one pass and one roll instead of multi pass and multi roll as in traditional rolling process (tandem roll). On the other hand, there is no need to use reheating furnace, which led to reduce the energy and pollution. Moreover, the properties of rapid solidification alloys were improved.The hardness and tensile strengthwere improved to be more than twice of the original values before rapid solidification process and the microstructure was modified too. Corrosion rate of rapid solidified ribbons was improvedto be lower than the rate of original alloys before rapid solidification. They were become

1.643 instead of 10.02 mpy for 5052 and 1.954 instead of 6.911 mpy for 5083 alloys.

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