March - April 2020
ISSN: 0193-4120 Page No. 7181 - 7189

Effect of Cold Rolling Process on Properties of Aluminum-Magnesium Alloy (AA 5456)

Haider Tawfiq Naeem[1, 2*], Safaa A.S. Almtori[2]

[2] Materials Eng. Dep., College of Engineering, Basra University, Iraq
[1] Chemical Eng. Dep., College of Engineering, Al-Muthanna University, Iraq
[*]Corresponding Author: e-mail:dr.haider.naeem@gmail.com,ORICD ID-https://orcid.org/0000-0001-6519-0501

Article Info
Volume 83
Page Number: 7181 - 7189
Publication Issue:
March - April 2020

Article History
***Article Received**: 24 July 2019*
***Revised**: 12 September 2019*
***Accepted**: 15 February 2020*
***Publication**: 06 April 2020*

Abstract

In the present study, the effect of the cold rolling process unde the different reductions ratio (2.5, 5.0, and 7.5) were carried on AA 545 Al-Mg alloy. During study, at the beginning and before starting the rollin process, the cast aluminum (AA5456) have been subjected to the hea treatments of homogenization at 450 °C for 18 hours and then annealing a a temperature 360 °C for 30 minutes for stress release and removing th effects side of casting. The homogenized Al-Mg alloy samples wer undergone the plastic deformation process to assessments th microstructure and mechanical properties such Vickers hardness, Tensil strength as well erosion-corrosion property. The results showed that th homogenized rolled Al-Mg samples have the best value of both hardnes and tensile strength. However, the homogenized Al-Mg underwent 7.5 % cold rolling process showed that significant increasing for Vicker hardness, tensile strength and resistance of erosion/corrosion in the impac angle 90°and 30° respectively.

Keywords: Aluminum-Magnesium (5456), Plastic deformation, Physical Properties

1. Introduction

In recent years, weight reduction has become a key issue for automotive manufacturers. For this reason, Al-Mg alloys (5XXX series) have great attention and an important group of commercial Al alloys with good combination of strength and formability and therefore they have various applications in transport, marine, packaging and general engineering industries. They belong to the group of non-heat treatable Al alloys, which derive their strength mainly from solution strengthening and work hardening during deformation [1-2]. Cold deformation is particularly effective in strengthening since restoration processes thermally activated.The cold rolling is a metalworking process in which metal is deformation by passing it through rollers at the temperature below its recrystallization temperature [3-4]. Cold rolling increases the yield strength and hardness of a metal by introducing defects into the metal's crystalline structure. These defects prevent further slip and can reduce the grain size of the metal, microscopic defects nucleated throughout the deformed area these defects can be either point defects or a line defect, as defects accumulated through deformation, it becomes increasingly more difficult for slip, or the movement of defects to occur, this results in a hardening of the metal.

Due to the demanding nature of the service condition and environments in which

TEST Engineering & Management

March - April 2020
ISSN: 0193-4120 Page No. 7181 - 7189

marine vessels operate at using Al-Mg alloys (5XXX series), which cause microstructural degradation and may finally lead to failure. As the use of aluminium expands in the ship building sector, a great deal of research is been carried out mainly focusing on the fatigue properties and the long-term performance of the welded junctions. the purpose of this study, to find out the role of deformation plastic by rolling process on properties of AA 5456 Al-Mg alloys used in marinas sector. Many previously researches have investigated Al-Mg (5xxx) alloys under plastics deformation to evaluation their properties and efficiency for Al-Mg alloy under erosion-corrosion test. Jassim et al. [5] studied single roll melt spinning technique for modifying the microstructure and improved their properties of Al-Mg (5052, 5083) alloys. The result indicating that the hardness and the corrosion resistance were improved.

Ahmad et al [6] Single roll melt spinning made from brass with a diameter of 150 mm was used is a non-conventional forming process to produce rapidly solidified thin Al-Mg alloys ribbons. The result of hardness has improved to about twice the original hardness of alloy. Moreover, corrosion resistance of alloy was improved and their rate has reduced from 10.02 to 1.643 mpy for alloy type 5052 and from 6.91 to 1.943 mpy for 5083.

Royset *et al.* [7] studied the effect of Sc on the recrystallization resistance and hardness of a series of Al-Mn-Mg-Zr alloys.The Al-Mg alloys extrudedand followed by cold rolling. It concluded that the hardness of the alloys increases with increasing Sc content and with increasing degree of preceding cold rolling of the material.

Safaa Almtori et al. [8]they had investigated the effects of the impact angles (30°, 90°) on the Erosion-Corrosion Test of Al-Mg alloy**.** They had noticedthat the homogenized specimen’s erosion/corrosion resistance at impact angle 90° was higher than impact angle 30°.Haider T. Naeem [9] studied the effects of the cold rolling at different rates of reduction on the erosion / corrosion resistance of the 5xxx series Al-Mg alloys. The results showed that the Al-Mg alloys have a good resistance for erosion-corrosion at different rates reduction.Georgiou [10] he had investigated the effect of cold deformation on thecathode hydrogen charging of 5083 aluminum alloy. It indicated that the cold deformation process led to an increase of hydrogen embrittlement susceptibility of this aluminum alloy.

2. Materials and experimental procedures

The experimental works of alloys concerned with the homogenizing heat treatment, cold rolling and preparation of test specimens for (hardness test, tensile test and erosion/corrosion test) Table (1) shows the chemical compositions of Aluminum alloys (5456).

Table (1) Chemical Compositions of Al-Mg alloys[9].

Grade designation	Composition ,wt.%								
Aluminum Association	Elements%								
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
AA5456	0.25	0.4	0.1	0.7	4.9	0.25	0.25	0.25	rem

The heat treatment for this studyAl-Mg alloy has carried out by heating at 450 °C near the temperature of solution heat treatment, for 18 hours and then quenched in water to the room temperature. For stress-relief, the specimen annealed at a temperature of 360 °C for half an hour The Al-Mg alloy specimenscut into the dimensions (2 x 2 x 1) cm. After homogenizing and preparation the specimens for the rolling process which applied under reduction to (2.5, 5,

TEST Engineering & Management

March - April 2020
ISSN: 0193-4120 Page No. 7181 - 7189

7.5) percentage for improve the mechanical properties due to the decrease of the grain size. Table (2) shows the suggested designation for specimens which were subjected to cold rolling,followed by annealing at 360 °C for 30 minutes.

Table (2) showed the designation suggesting for the rolled specimens.

Alloy	Specimens	Suggested designation details
	A2	As cast
	B2	Heat treatment (homogenizing)
	C2a	Rolling 2.5%
	C2b	Rolling 5%
AA 5456	C2c	Rolling 7.5%

Vickers hardness was measured for each specimen before and after rolling process, using hardness tester [MIC-10 (Agfa NDT Gmb Hi)],with applied load 5kg. Tensile test (MIC-10) instrument was used for measuring Ultimate tensile strength for sample applied load is 10kg [11]. The erosion/corrosion test has carried out after specimen's preparation, washing with water.Then the specimen placed on the holder with a little clipper inside the basin provided with air compressor. At the same time, a mechanical nozzle jet was installed, according to Bernoulli basis.The liquid is pulled from mechanical nozzle jet on the surface specimen at an impact angles (30°,90°) for 1.5 hours then after each test the specimen was taken to with clean water then by acetone , dried and weighed to measure the weight loss per unit area by dividing the weight loss by the surface area of the specimen. However, the weight loss can be shown below, [9].The weight loss was measured and converted into erosion-corrosion rate expressed in millimetres per year (mm/y) as according to Eq.

$$\text{Corrosion rate (C.R)} = \frac{\text{K x W}}{\text{A x T x D}}$$

Where,

K = a constant (8.76×10^4)

W = weight loss in mg = $W_0 - W_f$

W_0 = original weight of the sample,

W_f = final weight of the sample after immersion

D = density of the sample in $\frac{g}{cm^3}$

A = total surface area of sample in cm^2

T = exposure time in hours

The Qarmat Ali river water analyzed at Oil southern company laboratory. The results listed in the Table (3) below.

Table (3) The results of river water analysis

Seawater	Measuring limit	Type of analysis
7.8	-----	pH
6620	mus/cm	X
4634	mg/l	T.D.S
2000	mg/l	T.H
1200	mg/l	CL $^{-1}$
900	mg/l	Ca $^{+2}$
1000	mg/l	Ca as caco3
1100	mg/l	Mg as caco

1284	mg/l	So4
0	mg/l	P
235	mg/l	M
1.5	mg/l	Fe^{+2}

3. Result and discussion

The results of the present experimental work with its discussion showed the effect of percentage reduction by cold rolling on the mechanical properties (hardness & ultimate tensile strength), and erosion/corrosion rate at the different impact angles in the river water .The effect of reduction ratio by cold rolling on the mechanical properties of the alloys. Table (4) shows the values of Vickers Hardness for specimens before and after rolling.

Table (4) showed the values of the Vickers hardness for alloys (5456) before rolling and after rolling.

Nominal of AA5456 Alloy	Details	Values of Vickers hardness	
		Before rolling	After rolling
A2	AS Casting	88	96
B2	homogenize	89	98
C2a	Rolling 2.5%	95	105
C2b	Rolling 5%	104	116
C2c	Rolling 7.5%	115	124

Before the rolling process

It was noticed that the hardness values (table 4) of specimens [A2(96) ,B2(98)] has a good value due to the presence of Mg in the alloy, the element Mg is a highly soluble in solid solution than other elements due to its ability to reduce the grain growth rate and the precipitation of the phases.

After the rolling process

The specimen C2a after 2.5% reduction showed high hardness than the specimens A, B. That is indicates to the hardness increased due to the change in the structure of the Al-Mg alloy. This changes led to high density of defects (which is hindered the sliding of dislocations inside the structure of matrix). As well as hindered the establishment of new dislocation and their sliding ,these defects can be either point defects (a vacancy on the crystal lattice) or a line defect (an extra half of atoms jammed in a crystal) as defects accumulated thought deformation, it becomes increasingly more difficult for slip,or the movement of defects, to occur.

In addition, the hardness of C2b alloy specimens increased due to increasing the reduction of rolling to 5 %. The hardness of the specimens C2c increased due to increasing reduction that led to an increase in density of dislocation the alloy structure and increased hardness. The previous work of some authors [12].

The effect of cold rolling on the ultimate tensile strength of Al-Mg alloys

Measurements of the ultimate tensile strength of the specimens shown in table (5).Table

March - April 2020
ISSN: 0193-4120 Page No. 7181 - 7189

(5) showed of values the Ultimate tensile strength for specimens'alloys (5456) before rolling and after rolling.

Table (5): The ultimate tensile strength for the specimens before and after rolling.

Nominal of AA5456 Alloy	Details	Values of Ultimate tensile strength	
		Before rolling	After rolling
A2	AS Casting	348	364
B2	Homogenize	350	366
C2a	Rolling 2.5%	356	370
C2b	Rolling 5%	360	376
C2c	Rolling 7.5%	367	380

It was noticed that there is no remarkable change difference in the average of the ultimate tensile strength of the cast specimens (A2) table (5) by comparison to the specimens of homogenizing (B2). Apparently, thealloys are not affected by heat treatment process, because there is no change in their mechanical properties andthe precipitation phases did not change for (A2) alloy.It was noticed that the average of the values of the ultimate tensile strength of the rolled specimens C2b, C2cincreased because of increasing ofthe % cold rolling, moreover the yield strength and hardness also increased due to introducing defects into the metal's crystalline structure [16].

The Effect of Erosion-Corrosion Rate for Different Impact Angles

Erosion/corrosion is the most processes that affected on materials andthe quantity of damage depends on many factors such as temperature, metalcomposition, collision angles, the chemical structure for the materials (metal or alloys) and the constituents of water. The experimental work involves study the effect of the erosion/corrosion on rolled specimens shown in the table (4) by exposing the specimens to river water at different periods and a maximum time of 15 hours [see the analysis of water in Table (3)] and exposing it at collision angles (30°, 90°).

The weight loss of alloys at two impact angles (30°, 90°)

Figure (3) represents the relationship between the weight loss in riverwater and the exposure time for the specimens (A2, B2, C2a, C2b &C2c) at an impact angle 90°. It was noticed that the weight loss in (C2c) specimen was less than for (A2) by about (81.8 %) and (C2b) by about (56.8 %) and (C2a) by about (45.45 %) and (B2) by about (1%). The weight loss for (C2c, C2b, C2a) specimens was less than for B2 by about, (81.8 %, 56.8 % & 45.45 %) respectively. The weight loss for (C2c & C2b) specimens was less than for (C2a) by about (66.66 % & 20.8 %) respectively.

March - April 2020
ISSN: 0193-4120 Page No. 7181 - 7189

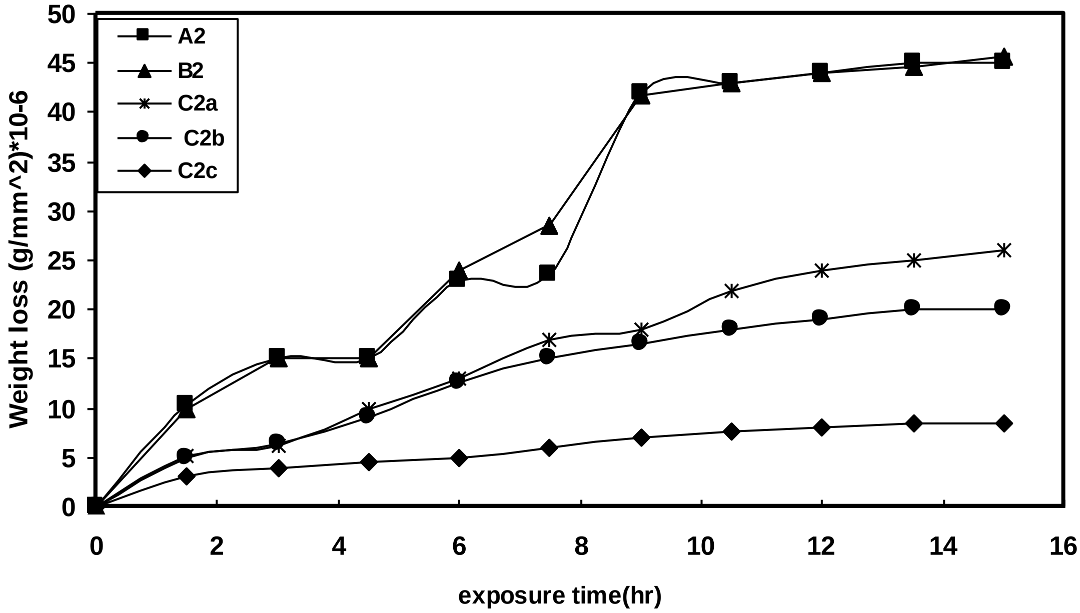

Figure (1) represents the relationship between the weight loss in the riverwater and the exposure time for AA 5456 Alloy specimens (A2, B2, C2a, C2b, C2c) at an impact angle90°.

It was noticed that the weight loss in (C2c) specimen was less than for (A2) by about (71.3 %) and (C2b) by about (66 %) and (C2a) by about (53.4 %) and (B2) by about (8.9 %).The weight loss for (C2c, C2b, C2a) specimens was less than for B2 by about (68.52 %, 62.62 % & 48.85 %) respectively. The weight loss for (C2c & C2b) specimens was less than for (C2a) by about (38.46 % & 26.92 %) respectively.

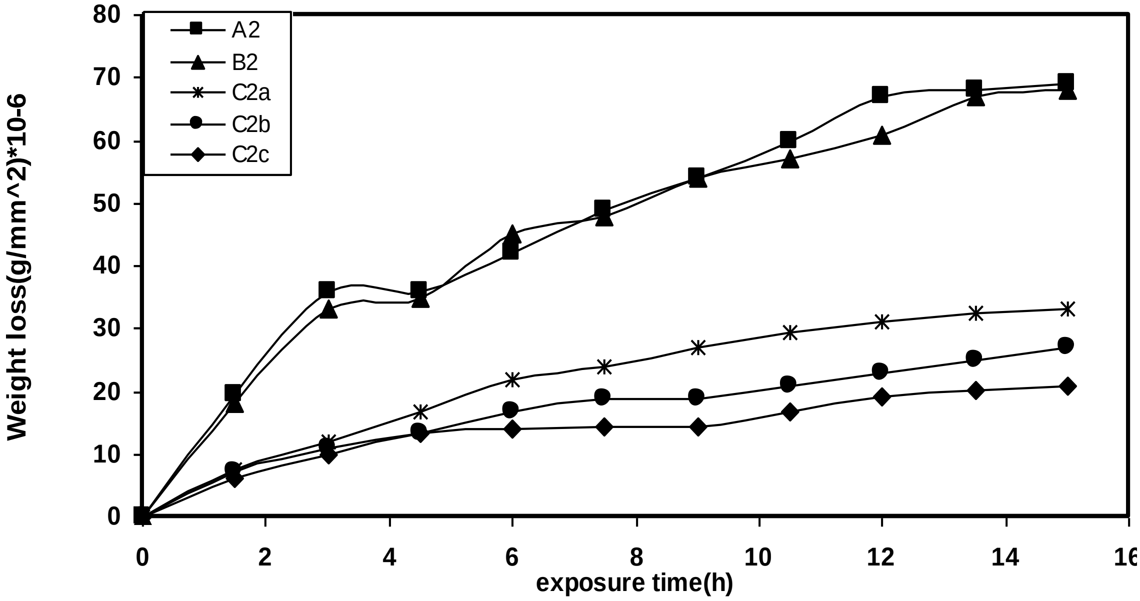

Figure (2) represents the relationship between the weight loss in the river water and the exposure time for AA 5456 Alloy specimens (A2, B2, C2a, C2b, C2c) at an impact angle 30°.

The Erosion/Corrosion Rate of the Alloys at Impact Angle 30°

The relationship between the erosion/corrosion rates against the exposure time at an impact angle 30°, represented in figures (3). It was found that the erosion /corrosion rate of the specimens (C2a,C2b,C2c) is higher than(A2, B2) because the hardness of rolled specimens (C2a,C2b,C2c) in the reduction (2.5, 5, 7.5)% increased when the rolling% reductions increased. were at an impact angle 30° which cause a decrease of the erosion/corrosion rate for the cold rolled specimens C2a, C2b and C2c compared with unrolled specimens A2,B2 .This can be related to the increase of the hardness which lead to a decrease of the erosion/corrosion rate for the rolled specimens.

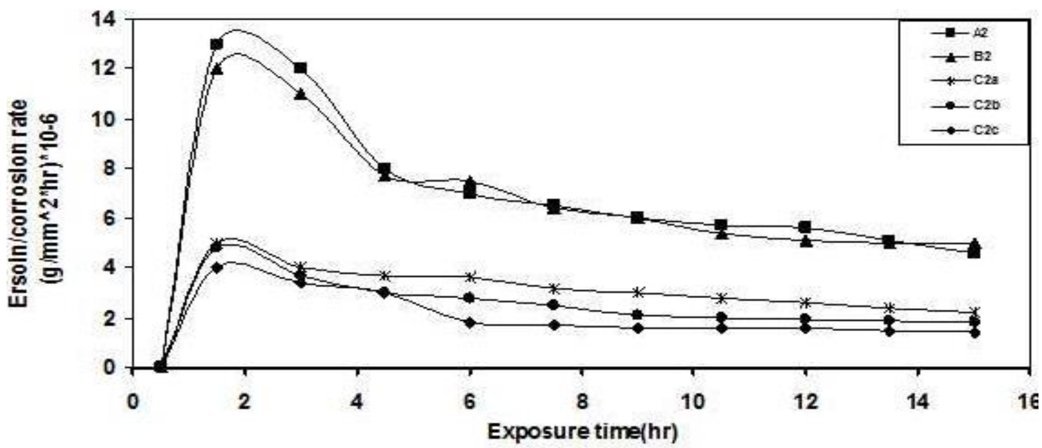

Figure (3) represents the relationship between the erosion-corrosion rate in the river water and the exposure time for AA 5456 Al-Mg specimens (A2, B2, C2a, C2b, C2c) at an impact angle 30°.

<u>The Erosion/Corrosion Rate of the Alloys at Impact Angle 90°</u>

The relationship between the erosion/corrosion rate and exposure time at an impact angle 90° is represented in figure (4).

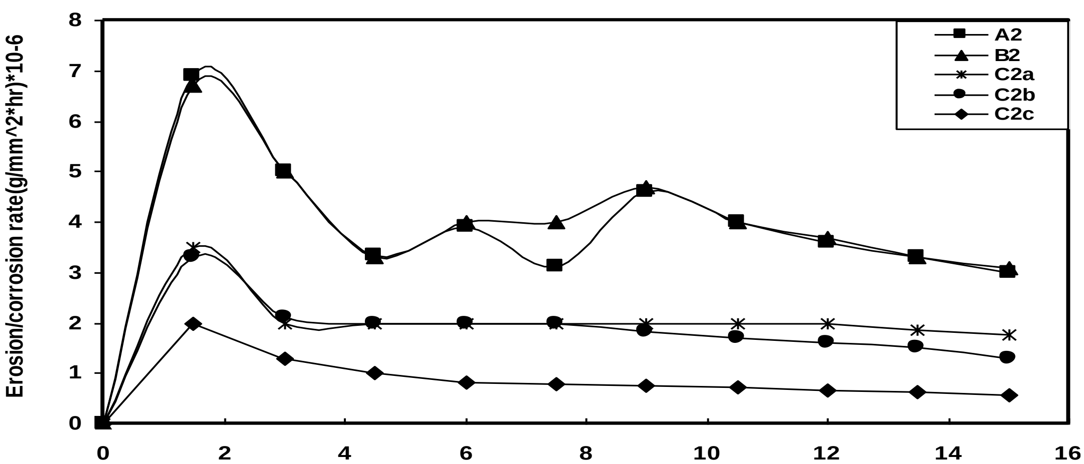

Figure (3) represents the relationship between the erosion-corrosion rate in the river water and the exposure time for AA 5456 Al-Mg specimens (A2, B2, C2a, C2b, C2c) at an impact angle 90°.

It found that the erosion /corrosion rate of the specimens (C2a, C2b, and C2c) was smaller than (A2, B2). It is so the hardness of rolled specimens (C2a, C2b, C2c) with% reduction of (2.5, 5, 7.5) % was found when the rolling reductions increased .The low values of the erosion/corrosion rate for the cold rolled specimens [C2a, C2b and C2c about (3.5, 3.3, 2) g/mm2 . hr *10 -6 respectively] and for the specimen A2,B2 were (6.9, 6.7) g/mm2 hr *10-6 respectively.

All the measurements were performed at an impact angle 90° which lead to the decrease of the erosion/corrosion rate for the cold rolled specimens C2a, C2b and C2c compared to un-rolled specimens A2,B2 ,that might be due to the increase of hardness and erosion/corrosion rate for rolled specimens respectively [29] .It was noticed that the period of the incubation is short during the early hours in which the alloy resist the collision water current impact due to presence of the oxide film .After that ,it was noticed that the increase of weight loss as a result of the breakage of the oxide film because of the repeated impacts of the water current , this stage is called (acceleration period), which is resulting from repeated impact to water current, after this stage ,there is a period of (deceleration) in the rate of weight loss when it decreased become rate less than as was in the early hours where the oxide film begins to build ,the steady stage weight loss and the increase of the time period did not affect the rate of weight loss, that was called (steady period) depending on the nature of the oxide film (Al_2O_3) and the power of adhesive oxide with the surface.The mechanism of erosion at impact angle 90⁰ is the plastic deformation due to the strain hardening which occurs by rolling after that the steady stage begins. So the cold rolling deformations on the specimen surface lead to high roughness .It was noticed that in figures (3),(4) showed the same behavior the erosion/corrosion rate that appears at impact angle 90° which involves the incubation period, acceleration period ,deceleration period and steady period, but in the present study the mechanism of erosion at impact angle 30° is the processes of cutting that occur to the specimen's surface and it is removed by the cutting in the form of the micro chips and the deformation is little, the specimen surface will be relatively smooth and have a little roughness.So erosion/corrosion rate in the impact angle 30° is higher than in impact angle 90°.

Conclusions

In this research, AA 5456 aluminum alloy has cold rolled at different percentage reduction for evaluating itshardness and tensile strength properties. The results showed that the values of hardness and tensile strength of the specimens of alloy have increased by a linear increase with the reduction of plastic deformation during cold rolling process. The erosion/corrosion property was performed at certain conditions of the specimens of alloy and found that the erosion/ corrosion resistance also increased by increasing the mechanical properties values. Therefore, erosion/corrosion reduce with increasinghardness and tensile strength of the rolled Al-alloy AA 5456

Reference

1. Frank king, “Aluminum and its alloys”, first published by Ellis Harwood Limited, (1987).
2. Singh R.V., “Aluminum- rolling”, a publication of TMS, U.S.A, www.tms.org, (2000).
3. Ghosh, S., M. Li, and D. Gardiner. "A computational and experimental study of cold rolling of aluminum alloys with edge cracking." *Journal of manufacturing science and engineering*126.1 (2004): 74-82.
4. Alil, Ana, et al. "Influence of an accumulative roll bonding (ARB) process on the properties of AA5083 Al-Mg alloy sheets." *Metallurgical and Materials Engineering* 20.4 (2014): 285-295.
5. Ahmad K Jassim, Single Roll Melt Spinning Technique Applied as a Sustainable Forming Process to Produce Very Thin Ribbons of 5052 and 5083 Al-

March - April 2020
ISSN: 0193-4120 Page No. 7181 - 7189

Mg Alloys Directly from Liquid State" Journal Procedia CIRP, Vol. 40, P.133-13,(2016)

6. Ahmad K Jassim, Ali S Hammood "Single Roll Melt Spinning Technique Applied to Produce Micro Thickness Rapid Solidified Ribbons Type 5083 (Al-Mg) alloy"J. of International Parallel Conference on Researches in Industrial and Applied Science,p.1-7.(2014) .
7. RYSET J., Riddle Y.W., “The effect of Sc on the recrystallization and subsequently cold rolled Al-Mn-Mg-Zr alloy”, U.S.A, Proceedings of the 9International conference on Aluminum Alloys, (2004).
8. Safaa A.S. Almtori ,Haider T. N. , T. A. Selman" Studythe Effect of Cold Rolling of Aluminum-Magnesium (5083) Alloys on the Erosion-Corrosion Test at the Impact Angles (30°, 90°) in River water" JKAU: Eng. Sci.,Vol. 27 ,No.1, pp: 45 -62
9. Haider T. Naeem Al-Khozaeey “Construction of Erosion-Corrosion System for Cold Rolled Aluminum-Magnesium Alloys" , M.Scs., Thesis, University of Basra, (2009).
10. E.P. Georgiou, J.-P. Celis, and C.N. Panagopoulos"The Effect of Cold Rolling on the Hydrogen Susceptibility of 5083 Aluminum Alloy" J. Metals 2017,7, 451
11. A.N. Taher,safaa A.S.Almtori, Wathiq A .Taha " Effect of Cd Additive on the Hardness and Tensile Properties of Al-Mg-Si Alloy " J.of Chemistry and Materials Research, Vol.8 No.2, 2016.
12. Callister W. D., “Materials science and Engineering An Introduction”, Department of metallurgical Engineering, The university of Utah, sixth edition ,copyright John Wiley &Sons, Inc., (2003).
13. Muna Khethier Abbass" Study of Erosion-Corrosion Behavior of Aluminum Metal Matrix Composite" , Eng. &Tech.Journal, Vol. 32, Part (B), No. 3,2014.
14. HUSSEN A., “effects of graphite addition on the mechanical properties of(Aluminum-silicon) Alloys”, M.sc., Thesis, Department of mechanical, university of Basrah, (2005).