Study on UTS and microstructure of Al-Zn-Mg alloy by using Taguchi technique.

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Abstract: In this paper effort have been made to validate the UTS of Al-Zn-Mg alloy through Taguchi's Techniques. The Al-Zinc-Mg alloy by changing weight percentage of Zn (5.1, 5.6 and 6.1) and weight percentage of Mg (2.1, 2.5 and 2.9) through stir casting method. UTS of prepared Al-Zinc-Mg alloy increases with increase in wt.% of zinc and wt.% of Mg. In the present investigation, Taguchi's L_{27} Orthogonal array was used to know the percentage contribution of each factors on UTS by Analysis of Variance (ANOVA). Regression equation have been generated by using design of experiments through Minitab software.

Keywords – Al-Zn-Mg; ANOVA; UTS; Stir casting; Regression Equation.

I. INTRODUCTION

Aluminum is one of the furthermost abundant materials in the earth's crust any working ore deposit must be eagerly amenable to benefice, so that a pure aluminum oxide can be obtained. However, physical benefice of the oxides has to been very successful [1]. Al and their alloys show the additional consideration which is due to their wide use in the applications of engineering sector [2]. These alloys are extensively used due to their machinability, durability, high strength and low density. In addition, these materials are effective in terms of cost and the intermittent mixture of properties cannot be attained by traditional materials [3].

Aluminum AA7050 alloy subjected to heat treatment condition (T7451) finds in the manufacturing of aircraft components such as wing skins, bulkheads and fuselage. The choice is attributed to the combination of fracture toughness, fatigue initiation, high strength and propagation resistance with the essential corrosion crack resistance [4]. These alloys are generally aged to near maximum strength, which is designated as T6 heat treatment condition. However, the resistance to stress-corrosion cracking (SCC) at this condition is low. By over ageing to T73 temper condition the resistance to stress corrosion cracking can be improved with associated loss of about 10 to 15% in strength [5]. It is well known fact that mechanical properties of an aluminum alloy can be improved if alloy is aged after the quenching process, where the second phase particles would nucleate with the primary particles in the alloy [6]. Retrogression and reageing (RRA) treatment for Al-Zn based alloy series improve the stress corrosion cracking resistance while maintain their strength at the level of the peak aged temper. The key process for Al-Zn based alloy to achieve the required microstructure is ageing treatment. T6 heat treatment condition can obtain the maximum tensile strength and peak hardness with high SCC susceptivity [7]. RRA heat treatment exhibits higher yield strength and UTS when compared with T7451 overaged samples, while similar results to that of T6 peaked sample [8]. The literature work reveals that currently very few research studies are carried out on the mechanical properties of Al-Zn alloy matrix reinforced with different reinforcing material such as boron carbide, Al_2O_3, TiB_2, fly ash, e-glass fiber, SiC, graphite etc. Therefore, in the present investigation Al-Zn-Mg alloy were prepared by varying weight percentage of zinc and magnesium content to evaluate its UTS and microstructure. Further, Taguchi's Technique was been employed to validate the experimental UTS value.

II. EXPERIMENTAL DETAILS

In this chapter, selection of alloying elements and its weight percentage in preparation of modified Al-Zn-Mg alloy, machining of cast specimen for UTS and microstructural study and Taguchi's Technique have been discussed.

A. Preparation of modified Al-Zn-Mg alloy

Designed amount of aluminum, Zin, Magnesium and other elements were added into the pre-heated crucible (750℃) which is kept inside the casting furnace. The motel Al-Zn-Mg alloy is poured into the split die manually by using foundry tool and allowed to solidify for 15min as shown in Figure 1.

Figure 1: Formation of Al-Zn alloy

B. Machining and heat treatment

The cast component was machined with suitable machining parameter by using CNC lathe machine tool (LT 20C) with approximate weight of 3500Kg as shown in Figure 2. The motor capacity of 7.5KW power having cutting speed of 3500rpm. Prepared Al-Zn-Mg alloy is subjected to solutionzing treatment at 450°C for holding period of 3 hrs. followed by ageing at 180°C for 3 hrs. and then Retrogression Reageing (RRA) at 150°C for a holding period of 3, 5 and 7 hrs. by natural air cooling as quenching process.

Tensile test specimens were prepared as per ASTM E8-16a standard size to evaluate the experimental UTS of the specimen.

Figure 2: CNC machine (LT 20C)

C. Process parameter and its levels

In the present research work, L_{27} orthogonal array with three parameters (wt.% of Zn, wt.% of Mg and reageing duration) at three level each are selected as tabulated in the Table 1.

Table 1: Process parameter and its level

Sl. No.	Factors	Levels
A	Wt.% of Zinc	5.1, 5.6 and 6.1
B	Wt.% of Magnesium	2.1, 2.5 and 2.9
C	Ageing duration	3, 5 and 7 (hrs.)

III. Results and Discussion

A. Effect of Zinc addition on Al-2.9Mg alloy

Source	wt.% of Zn	wt.% of Mg	Reageing Duration	Error	Total
DF	2	2	2	20	26
Seq SS	487.14	294.42	0.33	253.27	1035.16
Adj SS	487.14	294.42	0.33	253.27	
Adj MS	243.57	147.21	0.17	12.66	
F	19.23	11.62	0.01		
P	0	0	0.987		
% Contribution	47.05	28.44	0.031		
Rank	1	2	3		

at 7 hours of reageing temperature.

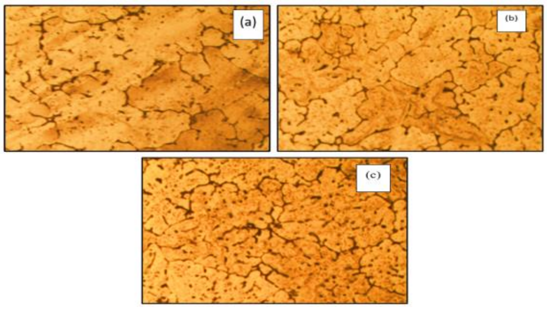

Figure 3: Optical images of Al-Zn-Mg alloy reageing at 150°C for 7 hrs. after solution heat treatment and ageing process (a) Al-5.1Zn-2.9Mg; (b) Al-5.6Zn-2.9Mg; (c) Al-6.1Zn-2.9Mg.

The modified Al-Zn-Mg alloy were observed under optical microscope at 250x magnification factor. It is seen from figure 5.3 (a) that the structure look like reddish colour with large number of coarse grain structure. The grains exhibit irregular and differ in grain size and shape representing a smaller number of grain boundaries. Figure (b-c) shows the formation of new grain boundary separating each grain thereby increasing the strength if the modified alloy. The average grain size is increased noticeably however, non homogeneous distribution of grains is still observed. The acceptable precipitation is observed during re ageing heat treatment process which results in increase in hardness of the modified Al-Zn-Mg alloy. The formation of new grains boundaries and precipitation results in restriction in dislocation of grains from one region to another region resulting less ductility of the alloy.

B. Effect of Zn content on Ultimate tensile strength on modified Al-Zn-Mg alloy reageing at 7 hrs.

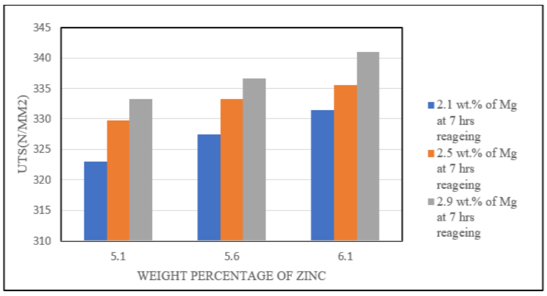

Figure 4: Variation of UTS on modified Al-Zn-Mg alloy for varying weight percentage of Zn and Mg reageing at 7 hrs.

It is clear from figure 4 that UTS of modified Al-Zn-Mg alloy increases with increase in Zn and Mg content for constant 7 hrs. of reageing duration. It is observed that the UTS of modified Al-Zn-Mg alloy increased for all the combination when compared with 3 hrs. of reageing duration which is attributed to refinement of grain structure, and quality bounding between the newly formed grains.

C. Signal to noise ratio and optimization on UTS for modified Al-Zn-Mg alloy

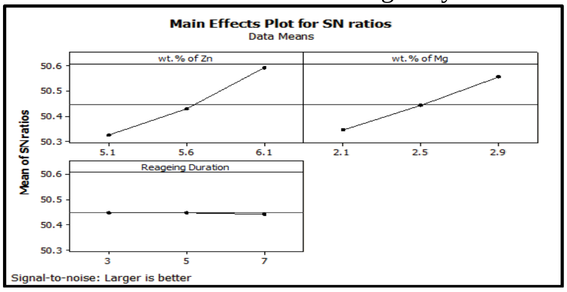

Figure 5: signal to noise ratio on UTS for modified Al-Zn-Mg alloy

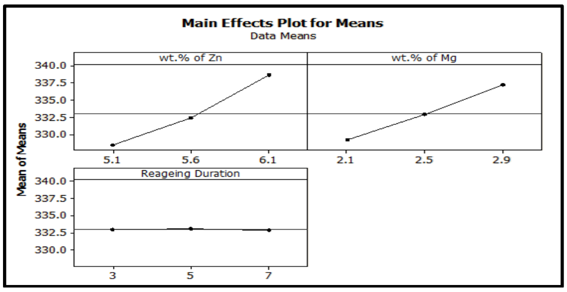

Figure 6. Means on UTS for modified Al-Zn-Mg alloy

Figure 5 represent the signal to noise ratio on UTS for modified Al-Zn-Mg alloy with three factors (wt.% of Zn, wt.% of Mg and Reageing duration) with three levels each. It is observed from the figure that better signal to noise ratio for 6.1 wt.% of Zn, 2.9 wt.% of Mg and 5hrs of reageing duration. i.e A3B3C2

Figure 6 shows the optimization on UTS for modified Al-Zn-Mg alloy. It is clear that the optimum levels for hardness for modified Al-Zn-Mg alloy is 6.1 wt.% of Zn, 2.9 wt.% of Mg and 5hrs. of reageing duration i.e A3B3C2.

Table 2: Response Table for Signal to noise ratio (Larger the better) for UTS for modified Al-Zn-Mg alloy

Level	wt.% of Zn	wt.% of Mg	Reageing Duration
1	50.32	50.34	50.45
2	50.43	50.44	50.45
3	50.59	50.56	50.45
Delta	0.27	0.21	0.01
Rank	1	2	3

Table 3: Response Table for means (Larger the better) for UTS for modified Al-Zn-Mg alloy

Level	wt.% of Zn	wt.% of Mg	Reageing Duration
1	328.3	329.1	333.1
2	332.3	332.9	333.2
3	338.6	337.2	332.9
Delta	10.3	8.1	0.3
Rank	1	2	3

D. Analysis of Variance (ANOVA) for modified Al-Zn-Mg alloy - UTS

Table 4: ANOVA for UTS for modified Al-Zn-Mg alloy.

Source	wt.% of Zn	wt.% of Mg	Reageing Duration	Error	Total
DF	2	2	2	20	26
Seq SS	487.14	294.42	0.33	253.27	1035.16
Adj SS	487.14	294.42	0.33	253.27	
Adj MS	243.57	147.21	0.17	12.66	
F	19.23	11.62	0.01		
P	0	0	0.987		
% Contribution	47.05	28.44	0.031		
Rank	1	2	3		

The table 4 represent the ANOVA for UTS for modified Al-Zn-Mg alloy. It is evident that out of three factors (wt.% of Zn, Wt.% of Mg and reageing duration) wt.% of Zn contribute highest percentage (47.05%) followed by wt.% of Mg (28.44%) and reageing duration (0.031%). Hence, wt.% of Zn has to be the controlled properly in achieving the UTS.

E. Regression analysis for UTS for modified Al-Zn-Mg alloy

F.

Table 5: Comparison result of experimental and regression analysis values for UTS for modified Al-Zn-Mg alloy.

Run	Wt.% of Zn	Wt.% of Mg	Re-Ageing duration (hrs.)	Experimental UTS (N/mm^2)	Predicted UTS (N/mm^2) from Eq. 1	E[illegible]
1	5.1	2.1	3	323	322.91	0[illegible]
2	5.1	2.1	5	326.4	323.85	0[illegible]
3	5.1	2.1	7	323	324.79	0[illegible]
4	5.1	2.5	3	326.4	326.95	0[illegible]
5	5.1	2.5	5	329.8	327.89	0[illegible]
6	5.1	2.5	7	329.8	328.84	0.29
7	5.1	2.9	3	329.8	330.99	0.36
8	5.1	2.9	5	333.2	331.93	0.38
9	5.1	2.9	7	333.2	332.88	0.10
10	5.6	2.1	3	326.4	328.06	0.51
11	5.6	2.1	5	330.82	329.01	0.55
12	5.6	2.1	7	327.42	329.95	0.77
13	5.6	2.5	3	327.42	332.10	1.43
14	5.6	2.5	5	334.56	333.05	0.45
15	5.6	2.5	7	333.2	333.99	0.24
16	5.6	2.9	3	336.6	336.15	0.13
17	5.6	2.9	5	337.28	337.09	0.06
18	5.6	2.9	7	336.6	338.04	0.43
19	6.1	2.1	3	332.52	333.22	0.21
20	6.1	2.1	5	340.68	334.16	1.91
21	6.1	2.1	7	331.5	335.11	1.09
22	6.1	2.5	3	333.2	337.26	1.22
23	6.1	2.5	5	346.12	338.21	2.29
24	6.1	2.5	7	335.58	339.15	1.06
25	6.1	2.9	3	338.98	341.30	0.69
26	6.1	2.9	5	347.82	342.25	1.60
27	6.1	2.9	7	341.02	343.19	0.64

The regression equation for UTS of modified Al-Zn-Mg alloy is shown below:

UTS (N/mm2) =247.669 + 10.3133*wt.% of Zn + 10.1056*wt.% of Mg + 0.472222* Re-Ageing hours (Eq. 1)

The table 5 shows the comparison result between experimental and predicted values for UTS of modified Al-Zn-Mg alloy through regression analysis. It is evident that the percentage of error is well within the satisfactory limit. The average percentage error is 0.686% which indicates that the experimental results are very close to the predicted values and hence the experimental hardness values are validated.

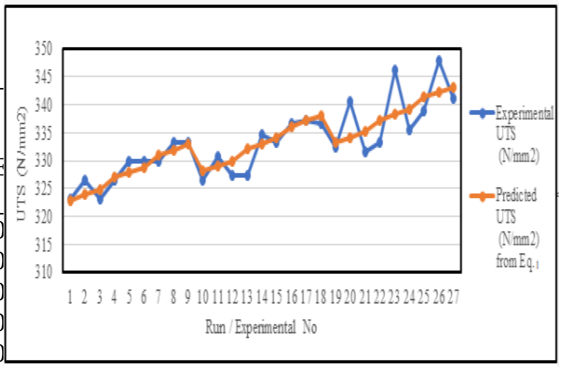

Figure 7: Comparison plot of experimental and predicted UTS values for modified Al-Zn-Mg alloy through regression analysis.

Figure 7 shows the comparison result between experimental and predicted values for UTS of modified Al-Zn-Mg alloy through regression analysis. It is evident that the experimental values are very close to the predicted values and there is no much variation therefore, the experimental values are validated.

III. CONCLUSION

Based on the study, the modified Al-Zinc-Magnesium alloy are fabricated by routing through stir casting method. The UTS has been evaluated experimentally by standard test process. L_{27} orthogonal array was used through design of experiments and found out that 6.1 wt.% of Zn, 2.9 wt.% of Mg and 7 hrs. of reageing duration are the optimum process parameter on UTS. The major percentage contribution on hardness is wt.% of Zn (47.05%) followed by wt.% of Mg (28.44%) and reageing duration (0.031%). Regression model developed shows that the experimental results are very adjacent to that of regression model values and hence the experimental results are validated. The average percentage error is found to be 0.68%.

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