Comparative Study and Optimization of Dry Sand Abrasive Wear Behavior of As-Cast and Retrogression and Re-Aging of 7075 Aluminum Alloy using Taguchi and ANOVA

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Abstract: ***For the past many years 7075 aluminum alloy widely used in aircraft structural parts where high wear resistance are required wear rate are reduced by the retrogression and re- aging heat treatment (RRA). Three body sand abrasive wear test is conducted on both as-cast and retrogression and re-aging specimens as per Taguchi's experimental design and L9 orthogonal array wear parameters like time, load, and speed are considered and track diameter kept constant it is found that when wear resistance of retrogression and re-aging heat treated (RRA) specimen is more as compared to the as-cast specimens. The design of experiments (DOE) approach using taguchi method was employed to analyze the abrasive wear behavior of material. Signal-to-noise ratio and analysis of variance (ANOVA) were used to investigate the influence of parameters on the wear rateand also determine the optimal parameters for minimizing the wear rate.***

Keywords: AL-7075 alloy, retrogression and re-aging, sand abrasive wear, Taguchi's orthogonal array, ANOVA

1. Introduction

7075 Aluminum alloys are classified as one of the high strength alloys which find extensive applications in aerospace, marine, automotive, aviation industries and automobile materials particularly for its low weight strength ratio result in lower fuel consumption. [8] It has a many good properties such as Heat treatable, Age hardness naturally, there for will recover properties in heat effected zone after welding and good ballistic deterrent properties. The properties of this alloy can be improved further by subjecting it to solutionsing and age hardening treatment. The 7000 series aluminum alloy is known as "heat treatable alloys. The mechanical properties of these alloys are strongly dependent on the thermo-mechanical process and it is therefore important to understand the relationship between the microstructure evolution during thermomechanical processing and the mechanical properties.[6]

Retrogression and Re-aging Heat Treatment: The concept of retrogression and re-aging (RRA) was first developed by Cina and his colleagues at the Israel Aircraft Industries in 1974 which consists of two steps: 1) retrogression of the 7xxx-T6 material at an intermediate temperature between the aging temperature and the solutioning temperature, and 2) re-aging of the retrogressed alloy. Re-aging is a process of repeated aging which significantly improves the strength of the alloy. [7]

Taguchi Method: Taguchi technique as valuable technique to deal with response influenced by multiple variables. It is formulated for process of optimization and detection of optimal combination of the parameters for a given response. This method significantly reduces the number of trials that are required to model the response function compared with the full factorial design of experiments. The most important benefit of this technique is to find out the possible interaction between the factors. Investigation of the experimental outcomes uses signal to noise ratio to supportthe determination of the finest process design.This method is effectively used to analysis of wear behavior of 7075 aluminum alloy [11]. Steps Involved in Taguchi Method: 1. Identify the main function and its side effects 2. Identify the noise factors, testing condition and quality characteristics 3. Identify the objective function to be optimized 4. Identify the control factors and their levels 5. Select a suitable Orthogonal Array and construct the Matrix 6. Conduct the Matrix experiment 7. Examine the data predict the optimum control factor levels and its performance 8.Conduct the verification experiment.

2. Methodology

Material selected: In the present study, 7075 aluminum alloy used were prepared by using the stir casting technique. The chemical composition of 7075 aluminum alloy is given in the Table 2

Table 2: Chemical Composition of Al7075 alloy

Content	Wt%
Al	REM
Si	0.346
Fe	0.216
Mn	0.046
Ni	0.152
Pb	0.029
Sn	0.021
Ti	0.013
Zn	5.483
Cr	0.287

B. Heat Treatment Procedure: heat treated is conducted for alloy step by step as shown the in table 2.2 followed by the water quenching after each step of the treatment the temperature of water maintain below 60°Cthe time delay between transferring the specimen to the water bath must not be less than 15 seconds.[2]

Table 2.1: Heat Treatment steps on Al-alloy

Step no	Type	Description of treatment
1	Solution heat treatment and age hardening.(T6 temper)	460°C (2 hours)+120°(24 hours)
2	Retrogression and Re-aging.(RRA)	200°C(50minutes)+ 120°(24 hours)

Figure 2: Heat Treatment Furnace

C. Plan of Experiments: Test samples of size 75 x 25 x 5 mm machined by HSS toll in HMT lathe. As per the G65-81 ASME standard. [5]

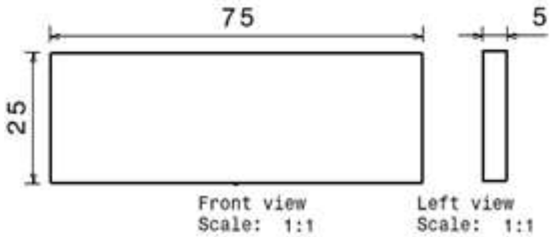

Figure 2.1: Dimension of Specimens

Figure 2.2: Dry Sand Abrasion Tester

Specifications of Dry sand abrasion tester

1. Supplied by Magnum Engineers
2. Motor speed range 0 to 210 RPM
3. Sand grade 550 to 600 Microns

Procedure:

1) specimens was polished and cleaned using acetone to eliminate the dirt and dust present on its surface [4]
2) The samples are weighed using a six digit electronic balance.
3) Samples are attached tightly using hand and the load is applied on the hanger.
4) The test is conducted as per the Taguchi's experimental design and L9 orthogonal array.[10]
5) Wear parameters like time, load, and speed are considered and track diameter (10.5 cm) kept constant.
6) Weight loss method (i.e. difference between initial weight and final weight) used for the analysis.

Table 2.2: Parameters and Their Levels

Symbol	wear parameter	Level 1	Level 2	Level 3
A	Time (minute)	5	10	15
B	Load (kg)	1	2	3
C	Speed (rpm)	100	150	200

3. Results and Discussion

The experiments were conducted as per orthogonal array and the wear rate results obtained for various combinations of parameters are shown in Table 3 and 3.4. The experimental values were transformed into S/N ratios for measuring the quality characteristics using MINITAB 18. The S/N ratio obtained for all the experiments are shown in Table.

Case 1: Influence of Dry Sand Abrasion Wear Parameters on As-cast sample

Table 3: Response Table for S/N ratio For Abrasion Wear Rate of RRA sample

SL N0	Time (min)	Load (kg)	Speed (rpm)	Initial weight (gms)	Final weight (gms)	Weight loss (gms)	S/N ratio wear rate
S1	5	1	100	25.4683	25.4679	0.0004	67.9588
S2	5	2	150	25.6333	25.6324	0.0009	60.9151
S3	5	3	200	25.7413	25.7378	0.0035	49.1186
S4	10	1	150	24.9982	24.989	0.0092	40.7242
S5	10	2	200	25.7184	25.6991	0.0193	34.2889
S6	10	3	100	25.6177	25.5997	0.0180	34.8945
S7	15	1	200	25.6611	25.6392	0.0219	33.1911
S8	15	2	100	25.4041	25.3742	0.0299	30.4866
S9	15	3	150	25.6448	25.6621	0.0230	32.7654

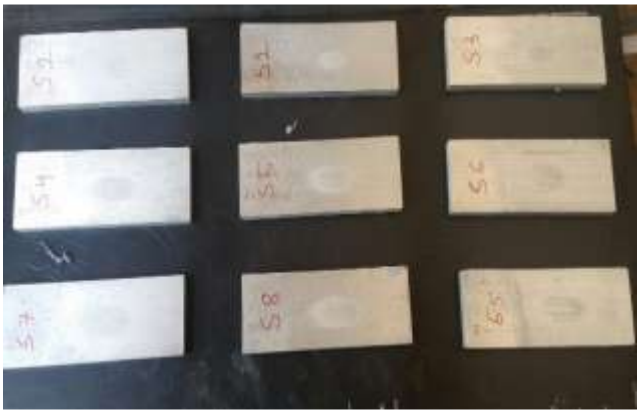

Figure 3: As-cast Specimens after Dry Sand Abrasion Wear

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Table 3.1: Main Effects Plot for S/N Ratio Table for Abrasive Wear Rate of As-cast sample

Level	Time (min)	Load (kg)	Speed (rpm)
1	59.33	47.29	44.45
2	36.64	41.90	44.80
3	32.15	38.93	38.87
Delta	27.18	8.37	5.94
Rank	1	2	3

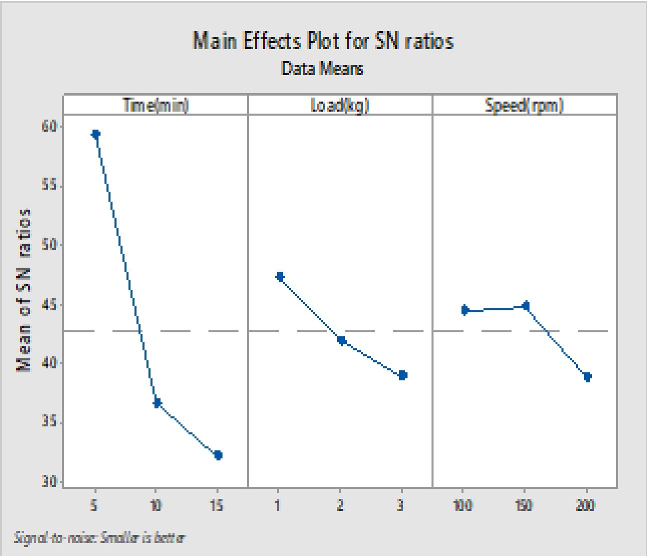

Figure 3.1: Graph representing the influence of abrasion wear parameters on As-cast sample

Table 3.2: Optimum abrasion wear parameters for As-cast sample

Parameter	Optimum value
Time (min)	15
Load(kg)	3
Speed (rpm)	200

ANOVA analysis considering wear parameters as input and wear rate as output for As-cast samples reveals the influence of wear parameter on wear rate.

Table 3.3: ANOVA table for abrasion wear rate of As-cast sample

Source	Degrees of freedom	Sum Of squares	Mean square	F value	P value	% C
Time (minute)	2	0.000827	0.000413	1084.52	0.001	88.92
Load (kg)	2	0.000061	0.000030	79.64	0.012	6.55
Speed (rpm)	2	0.000042	0.00002	55.18	0.018	4.51
Error	2	0.000001	0.00000			0.10
Total	8	0.000930				100

The analysis carried out by using MINITAB software indicates the influence of wear parameters on wear rate. From the above ANOVA table we can see that for As-cast sample time influencing the wear rate than other parameters This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of Table 3.3 shows the percentage of contribution (c %) of each parameter.

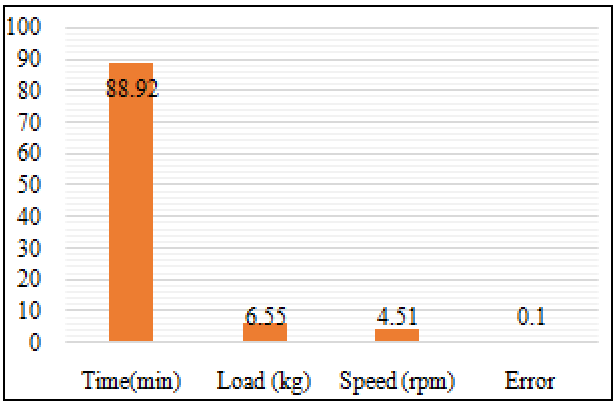

Figure 3.2: Effect of each parameter on wear rate of As-cast sample (%)

Fig shows the percentage effect of each parameter on the wear rate of as-cast sample. It is illustrated that time has the most significant effect on the output response (wear rate). Other significant parameters are in turn load and speed. These results can be used to optimally determine the best set of wear parameters.

Case 2: Influence of Dry Abrasion Wear Parameters on RRA sample

Table 3.4: Response table for S/N ratio for sliding wear rate of RRA sample

SL N0	Time (min)	Load (kg)	Speed (rpm)	Initial Weight (gms)	Final Weight (gms)	Weight Loss (gms)
S1	5	1	100	24.7706	24.770	0.0002
S2	5	2	150	25.8047	25.8044	0.0003
S3	5	3	200	26.1117	26.1094	0.0023
S4	10	1	150	25.6699	25.6625	0.0074
S5	10	2	200	25.7759	25.7602	0.0157
S6	10	3	100	25.4536	25.4413	0.0123
S7	15	1	200	26.0331	26.0231	0.01
S8	15	2	100	26.0820	26.0605	0.0125
S9	15	3	150	25.4058	25.3925	0.0133

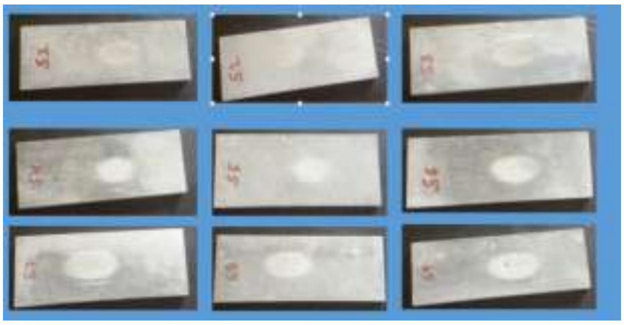

Figure 3.3: RRA heat treated specimens after dry sand Abrasion wear

Table 3.5: Main effects plot for S/N ratio table for abrasion wear rate of RRAsample

Level	Time (min)	Load (kg)	Speed (rpm)
1	65.73	52.20	50.08
2	38.97	48.20	50.20
3	38.53	42.83	42.95
Delta	27.21	9.37	7.25
Rank	1	2	3

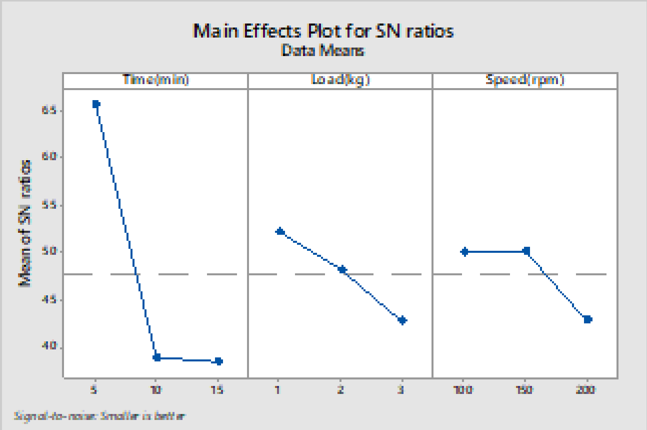

Figure 3.4: Graph representing the influence of abrasion wear parameters on RRA sample

Table 3.6: Optimum abrasion wear parameters for RRA sample

Parameter	Optimum value
Time (min)	15
Load(kg)	3
Speed (rpm)	200

ANOVA analysis considering wear parameters as input and wear rate as output for T6 tamper samples reveals the influence of wear parameter on wear rate.

Table 3.7: ANOVA table for abrasion wear rate of As-cast sample

Source	Degrees of freedom	Sum of squares	Mean square	F value	P value	% C
Time (minute)	2	0.000728	0.000364	11.27	0.082	74.13
Load (kg)	2	0.000170	0.000008	2.64	0.275	17.31
Speed (rpm)	2	0.000019	0.000010	0.30	0.769	1.93
Error	2	0.0000065	0.000032			6.61
Total	8	0.000982				100

The analysis carried out by using MINITAB software indicates the influence of wear parameters on wear rate. From the above ANOVA table we can see that for RRA sample time influencing the wear rate than other parameters.This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of Table 3.6 shows the percentage of contribution (c %) of each parameter.

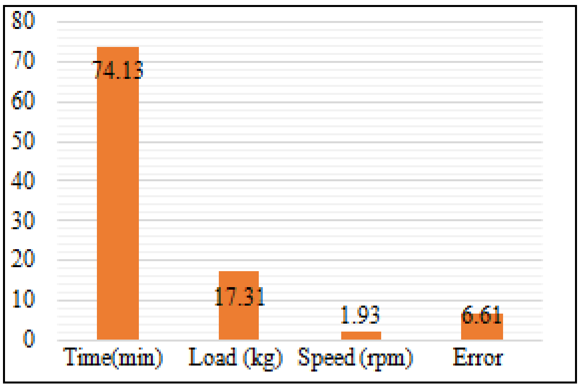

Figure 3.5: Effect of each parameter on wear rate of RRA traded sample (%)

Fig. 3.8 shows the percentage effect of each parameter on the wear rate of T6 temper sample. It is illustrated that time has the most significant effect on the output response (wear rate). Other significant parameters are in turn load and speed. These results can be used to optimally determine the best set of wear parameters

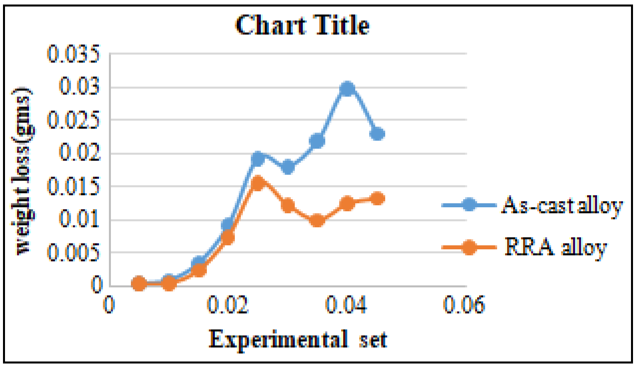

Figure 3.6: Weight loss vs. experimental sets

The slope for as-cast specimen is greater when compared to the RRA, which implies that the weight loss of as-cast is more. Retrogression and re-aging heat treatment strengthens the metal by creating solid impurities or precipitates because of this property wear resistance of RRA is more as compared to as-cast

4. Conclusion

1) Weight loss is more in as-cast specimens due to wear it clearly indicates that Retrogression re-aging heat treatment increases the wear resistance as compared to the As-cast material.
2) The analytical results of taguchi shows the time, speed and load influences the wear rate.
3) time has the most significant effect on the output response (wear) as compared to other parameters in both as-cast and RRA materials shown in the table 3.3 and 3.7
4) The optimal parameters for minimum wear rate of as-cast and RRA heat treated material are time 15 minute, load 3kg and speed 200 rpm.

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