Comparison of wear behaviour and mechanical properties of as-cast Al6082 and Al6082-T6 using statistical analysis

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Abstract. In the present work the wear behavior and mechanical properties of as cast Al6082 and Al6086-T6 were compared and analyzed using statistical analysis. The as cast Al6082 alloy was solutionized at 550°C, quenched and artificially aged at 170°C for 8hrs. Metallographic examination and XRD analysis revealed the presence of intermetallic compounds Al₆Mn. Hardness of heat treated Al6082 was found to be more than as cast sample. Wear tests were carried out using Pin on Disc wear testing machine according to Taguchi L9 orthogonal array. Experiments were conducted under normal load 10-30N, sliding speed 1-3m/s, sliding distance 400,800,1200m respectively. Sliding speed was found to be the dominant factor for wear in both as cast and aged Al 6082 alloy. Sliding distance increases the wear rate up to 800m and then after it decreases.

Keywords: Metallographic examination, Pin-on-disc wear test, Taguchi, L9 orthogonal array, sliding speed

1. Introduction

Recent applications require materials of high strength, light weight, and less expensive. With increased demand of fuel economy and improved engine performance in automobiles it is necessary to develop materials with high strength to weight ratio [1].

The 6xxx aluminium alloys possess high specific strength and good corrosion resistance which makes them worthy to replace steels for automotive applications. These alloys are heat treatable which again enhances the mechanical properties [2]. G. Mrówka-Nowotnik et.al [3] studied the intermetallic phase particles in 6082 aluminium alloy and found seven phases in between the aluminium dendrites of as-cast Al6082. G.Mrowka-Nowotnik et.al [4] during their investigation on 6005 and 6082 aluminium alloys studied the influence of solution heat treatment on kinetics of ageing. They observed that during cooling after homogenization, β-Mg₂Si phase readily precipitates. The generally accepted precipitation sequence in 6xxx alloys [5-7] is.

Super saturated solid solution → Mg₂Si clusters → Guiner Preston Zones → β[I] → β

Jadhav et.al [8] investigated the effect of heat treatment on mechanical properties and microstructure of Al6082 and observed that the type and distribution of the phases significantly affect the mechanical properties. Recently industries are using statistical analysis to find out the parameter having significant influence on the response. Number of statistical analysis techniques (Response surface methodology, Factorial design, random design etc) can be applied to determine
the significant controlling parameter during wear test, design of experiment approach using Taguchi method not only decreases the number of experiments and time but also doesn’t affect the accuracy and quality of results [9].

2. Materials and Methods

2.1. Alloy preparation and heat treatment

In the present investigation, Al6082 alloy was used which contains 1% Si, 0.8%Mn, 1%Mg and balance aluminium was prepared by stir casting process. The process involves (i) melting of pure aluminium in a graphite crucible in an electrical resistance furnace (ii) continuous addition of manganese and Al-Si master alloy followed by mechanical stirring (iii) addition of magnesium turnings (iv) casting and solidification of the melt in cast iron mould. The alloy Al6082 was solutionized at 550°C for 2hrs in an electric resistance furnace and then subjected to water quenching to room temperature. Then the homogenised alloy was aged for 8hrs at 170°C in the furnace.

2.2. Microstructure

The microstructural characterization was done using CARL ZEISS optical microscope. The Al-6082 and Al-6082-T6 samples were polished using emery paper and diamond paste and etched using Keller’s reagent.

2.3. Hardness

Hardness of both Al-6082 and Al-6082-T6 samples was measured using a micro Vickers’s hardness testing machine Modd FMV-1, FSA.

2.4. X-Ray diffraction studies

The X-Ray diffraction studies were performed on both as-cast and heat treated samples to identify the phases present. The X-Ray diffraction plot with various phases present is shown in Fig.1.

![XRD plot of as-cast and heat treated (T6) Al6082 alloy](image)

Figure1. XRD plot of as-cast and heat treated (T6) Al6082 alloy
2.5. Wear test

Wear test of both as-cast and heat treated samples were carried out using a Pin-on-disk wear testing machine as per ASTM G99. The specimens were prepared of dimensions 10mm diameter and 30mm height. The weights of the samples were measured using an electronic balance.

2.6. Statistical analysis using Taguchi method

Taguchi method is an important tool for determining the effect of design parameters on the response (output). The statistical analysis using Taguchi method is carried out in various stages (i) identification of response or output, (ii) determination of design parameters influencing the output, (iii) selection of orthogonal array according to the design parameters, (iv) conducting experiments in accordance with the orthogonal array, (v) calculation and tabulation of signal to noise ratios and (vi) the range is determined from the S/N ratios and higher rank is assigned to higher range. In this work, the influence of three factors, i.e. load, sliding speed, sliding distance on wear response were studied. The factors and levels used in the experiment are shown in Table 1.

| Control Factors | Levels | Units |
|-----------------|--------|-------|
| Load (A)        | 10, 20, 30 | N     |
| Sliding speed (B) | 1, 2, 3 | m/sec |
| Sliding distance (C) | 400, 800, 1200 | m     |

The L9 orthogonal array design with S/N ratio for both as-cast and heat treated conditions are given in Table 2 and 3 respectively. The experimental observation was converted into a logarithmic function called signal-to-noise ratio(S/N). This can be determined as logarithmic transformation of a loss function as: The smaller is the better characteristics: 

\[ \frac{S}{N} = -10 \log_{10} \left( \frac{1}{n} \sum y^2 \right) \]  

Where y is the observed data and n is the number of observations.
Table 3—L9 orthogonal array with response and S/N ratio for Al 6082-T6 alloy

| SL No | Load (A), N | Sliding speed (B), m/sec | Sliding distance (C), m | Mass Loss (gm) | S/N Ratio, (dB) |
|-------|-------------|--------------------------|-------------------------|-----------------|-----------------|
| 1     | 10          | 1                        | 400                     | 0.0840          | 21.5144         |
| 2     | 10          | 2                        | 800                     | 0.0062          | 44.1522         |
| 3     | 10          | 3                        | 1200                    | 0.0150          | 36.4782         |
| 4     | 20          | 1                        | 800                     | 0.0068          | 43.3498         |
| 5     | 20          | 2                        | 1200                    | 0.0978          | 20.1932         |
| 6     | 20          | 3                        | 400                     | 0.0071          | 42.9748         |
| 7     | 30          | 1                        | 1200                    | 0.0115          | 38.7860         |
| 8     | 30          | 2                        | 400                     | 0.0377          | 28.4732         |
| 9     | 30          | 3                        | 800                     | 0.4383          | 7.1646          |

3. Results and Discussion

3.1. Microstructural characterization

Figures 2(a) and 2(b) shows the optical micrographs of Al 6082 and Al 6082T6 alloy. The microstructural analysis reveals the presence of intermetallic compounds such as Al$_6$Mn that is confirmed by X-ray diffraction analysis shown in Fig.1. It can also be seen in the micrograph that grain growth has taken place in the heat treated sample.

Figure 2. Optical micrographs of (a) as-cast Al6082 (b) Al6082-T6

3.2. Hardness

Hardness of both Al-6082 and Al-6082- T6 samples were measured using a micro hardness tester and are reported in Table 4. It was found that the Al6082-T6 alloy was having higher hardness than the as-cast alloy that is Al6082-T6 alloy had 88.28 VHN and as-cast Al6082 it was 55.67 VHN. The increase in hardness can be due to the precipitation strengthening after ageing.

Table 4. Hardness values of as-cast Al6082 and Al6082-T6 alloy

| Microstructural condition | Hardness values (VHN) |
|---------------------------|-----------------------|
| As-cast Al6082            | 55.67                 |
| Al6082-T6                | 88.28                 |
3.3. Analysis of wear behaviour using Taguchi Methodology

The Taguchi orthogonal arrays design of Al-6082 and Al6082-T6 alloys with all experimental data’s and S/N ratios are shown in Table 2 and 3 respectively. MINITAB 16 software was used to determine the values of S/N ratios for each experiment. The response table of the S/N ratios for both Al6082 and Al6082-T6 are shown in Tables 5 and 6 respectively [9].

| Table 5—Response table of S/N ratio for as-cast Al6082 (smaller is the better characteristics) |
|---------------------------------|--------|------|------|
| Level                          | A      | B    | C    |
| 1                              | 43.25  | 40.19| 36.13|
| 2                              | 23.92  | 32.11| 31.10|
| 3                              | 30.14  | 25.01| 30.17|
| Delta(A)                       | 19.33  | 15.18| 5.96 |
| Rank                           | 1      | 2    | 3    |

| Table 6—Response table of S/N ratio for Al6082-T6 (smaller is the better characteristics) |
|---------------------------------|--------|------|------|
| Level                          | A      | B    | C    |
| 1                              | 34.05  | 34.55| 30.99|
| 2                              | 35.51  | 30.94| 31.56|
| 3                              | 24.81  | 28.87| 31.82|
| Delta(A)                       | 10.70  | 5.68 | 0.83 |
| Rank                           | 1      | 2    | 3    |

The rank and the delta values in the response table were generated basing on S/N ratios. From Table 5 it is clearly observed that, load is the prominent design parameter influencing the wear behaviour followed by sliding speed and sliding distance. In case of Al6082-T6 alloy, again load was found to be the major contributor to wear loss as can be seen from Table 6. This is mainly attributed to the soft nature of aluminium alloy. This also shows that there is no change in the significant controlling factor affecting wear behaviour with change in microstructure due to heat treatment. The main effect plot for S/N ratios of as-cast Al6082 alloy is shown in Figure 3.

The above plot shows that the combination of A2, B3, C3 factors would result in less wear in as-cast Al6082 alloy. The main effect plot of S/N ratios of Al6082-T6 is shown in Figure 4. The plot shows that lesser wear will result with the combination of A3, B3, and C1 factors.
4. Conclusions

The conclusions are as follows.

I. The comparison of wear behaviour of as-cast Al6082 and Al6082-T6 was studied using Taguchi experimental design approach.

II. Microstructural characterization and XRD results showed the presence of intermetallic compounds.

III. The hardness of the Al6086-T6 was found to be 88.28VHN and that of Al6082 as-cast was found to be 55.67VHN.

IV. From the response table of Taguchi orthogonal array, load was found to be the prominent factor affecting wear loss in both as-cast Al6082 and Al6082-T6 samples.

5. References

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