Analysis of Wear Behavior of Aluminium-7075 and Beryllium Composite

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Abstract- *Aluminum alloys are widely used in aerospace and automobile industries due to their low density and good mechanical properties, better corrosion resistance, wear resistance and low thermal coefficient of expansion compared to conventional metals and alloys. These materials exhibit good mechanical properties and production cost is comparatively low. Hence they form a very strong contender in variety of applications. In this work, attempts were made to produce the Aluminum-7075 alloy composite by adding different amounts of Beryllium to the melt(5%,10%,15%). Wear studies in dry sliding condition for three different speeds and loads were studied. Comparison between the base aluminium-7075 alloy and the composite alloy were carried out. Simulation studies for wear has also been carried out. Temperature profile along the whole length of the specimen is generated; these are compared with the simulated ones, (ANSYSY workbench software has been used for this study).*

Keywords- Aluminium-7075, Wear study, Temperature profile.

I. INTRODUCTION

Aluminum is a durable metal with light weight and exhibits silver like appearance when cut. It is easily machinable and is good conductor of heat and electricity. It is extracted from bauxite ore and purified by several processes. It is also found in several mineral rocks combined with compounds namely silicon (Si) and oxygen (O_2) and is after refered to as alumino silicates. [1]. Among the various alloys available, aluminium alloy Al-7075 (belonging to 7XXX series) is the strongest alloy. The strength of this alloy is comparable to steel and is found to exhibit high strength to weight ratio. Due to this reason it is mainly used in the field of aerospace applications and in industries like military, marine and structural equipments where high strength and low weight is required.[2]. In recent trends aluminum based composites are used for their enhanced properties and found to have replaced the use of conventional materials in most of the industries. Considering this major application, aluminum is alloyed with beryllium. This combination is used to make structural aerospace components as they exhibit high strength. Beryllium is a rare earth element and not that easily available in the earth's crust. It is expensive and not used much for usual commercial purposes. Its toxic nature makes its use limited as more exposure to its fumes results in fatal problems and is hazardous to health. However, it exhibits superior properties compared to aluminium; main properties attractive are, high strength, high melting point, stiffness and elastic modulus (which is 50% greater than that of steel) thus enhances basic qualities of aluminium when combined. In this investigation successful attempts have been made to fabricate aluminium metal matrix composite; Al-7075 reinforced with three different percentage additions (5%, 10% and 15%) of beryllium. Wear studies in dry sliding condition (for three different speeds, three different loads) have been studied in detail. Comparison of the wear properties with respect to the base alloy has been made. Further simulation studies for wear test has also been carried out keeping in mind the temperature generated or the heat developed which is attributed to the friction between the mating surfaces.

II. MATERIALS USED

2.1. Matrix material

The alloy used for the present investigation is AA7075. This alloy was procured and processed. Table 1 gives the detail of the AA7075 alloy.[3]

Table 1 Properties of matrix material(AA-7075)

PROPERTIES	UNITS	
Density	g/cc	2.81
Melting point	^{0}C	477-635
Poisson's ratio	-	0.33
Brinell hardness	-	60
UTS	Mpa	228
Elastic modulus	Gpa	71.7
Thermal conductivity	W/mK	173
Thermal expansion	$10^{-6}/^0$C	23.2

2.2. Reinforcement material

The reinforcement material used for this alloy is Beryllium a rare earth material which was alloyed in different quantities by weight basis (5%, 10% and 15%) of the matrix material. Table 2 summarizes the properties of the reinforcement alloy.[2]

Table 2 Properties of Reinforcement material(Beryllium)

PROPERTIES	UNITS	
Density	g/cc	1.85
Melting point	^{0}C	1287
Poisson's ratio		0.032
Brinell hardness		180-395
UTS	Mpa	370
Elastic modulus	Gpa	287
Thermal conductivity	W/Mk	200
Thermal expansion	10^{-6}/K	11.3

III. EXPERIMENTAL PROCEDURE

Two sets of samples were prepared. First set of sample was prepared without reinforcement and in the second set three composite samples were prepared with beryllium particulate reinforcement by stir casting process. Melting of the alloy were carried out using resistance type furnace. Matrix material AA7075 (known quantity) was taken in a crucible and melted in the furnace. When the metal attained the molten condition slag and other impurities were removed. To this clean metal Beryllium in known quantity is added and stirred well using mechanical stirrer. After mixing for 3-4 minutes duration the molten metal was transferred into precoated, preheated finger type metallic moulds.

Figure 1 Melting furnace and graphite crucible

Figure 2 Finger type mold

Figure 3 Stir casting unit.

After solidification and cooling to room temperature the casting is ejected out and are used for the assessment of different properties.

1. **Hardness test** – specimen was subjected to hardness testing using Rockwell hardness testing machine (as per ASTM E-18 standard).
2. **Wear test** – specimen were subjected wear tests (as per ASTM G-99) for determining wear rate and temperature at the contact surface using pin on disc wear testing machine under the following conditions.
   - Varying load of 10N, 15N and 20N with constant time of 5 minutes and constant speed of 500rpm.
   - Varying time of 5min, 10min and 15min with constant load of 20N and constant speed of 500rpm.
   - Varying speed of 500rpm, 580rpm and 700rpm with constant load of 20N and constant time of 5min.
3. **Temperature measurement -** The temperature of the fixed pin was measured by using two K type thermocouple. These two thermocouple were fixed on the pin at a distance of 6mm and 16mm from the contact surface of the pin. These two thermocouple gives two temperature readings T1 and T_2 at a distance of 6mm and 16mm respectively. The temperature at any point on the pin can be calculated by using the following analytical equation. [5]

   $T = T_a + C_1 \exp(mx) + C_2 \exp(-mx)$

   where

   $m = (C_0 h / KA)^{1/2}$

   K = The thermal conductivity of the pin material,

   h = The convection heat-transfer coefficient, can be calculated by $h = 1.42 (T_1 - T_2) / L$

   C_0 = The circumference of the pin, and

   T_a = Room temperature.

   L= Length of the pin.

   The temperature at the apparent contact area, T_0 is found to be

$T_0 = T_a + C_1 + C_2$.

4. **Thermal analysis -** The following are the basic steps employed to perform the thermal analysis:[6]
   a. Set the analysis preference.
   b. Create or import solid model.
   c. Define element attributes (element types, real constants, and material properties)
   d. Mesh the solid model.
   e. Specify the analysis type, analysis options and the loads to be applied.
   f. Solve the analysis problem.
   g. Post-Process results.

IV. RESULTS AND DISCUSSIONS

1. Hardness Measurements

Hardness measurements were carried out using Rockwell hardness tester. Three hardness measurements were carried out at different locations across the cross section of the specimen and the average hardness has been considered for the analysis.

Table 3 summarizes the hardness value of the specimen for different conditions.

Table 3 Rockwell hardness value.

Sl. No	Condition	Hardness value
1	As cast	39
2	AA7075+5% Be	43
3	AA7075+10% Be	45
4	AA7075+15% Be	50

It can be seen from the above table the as cast alloy exhibits the least hardness value. Upon the beryllium additions to the alloy the hardness value has increased. Alloy with 15% beryllium addition shows the maximum hardness value. From the study it is clear that beryllium addition has an effect in improving the hardness of the specimen. A 22% increase in hardness value is notice with 15% addition of beryllium.

2. Wear Test

Dry sliding wear tests were carried out on the as cast alloy and the alloy treated with different percentage addition of beryllium. The tests were carried out for varying load, varying time and varying speed condition. Following table summarizes the parameters selected for wear studies in the present investigation.[4]

Table 4; Parameters for wear test

Sl. No	Speeds investigated (rpm)	Load (N)	Time (minutes)
1	500	10	5
2	580	15	10
3	700	20	15

1. Wear Rate

Wear rate was determined using the formula

Wear rate(g/m)= $(W_1-W_2) / d$

Where

W_1= Initial weight (g)

W_2= Final weight (g)

d= Sliding distance (m)

d= πDNT/1000 (m)

Where

D=Track diameter in m, N= Speed in rpm, T= Time in minute.

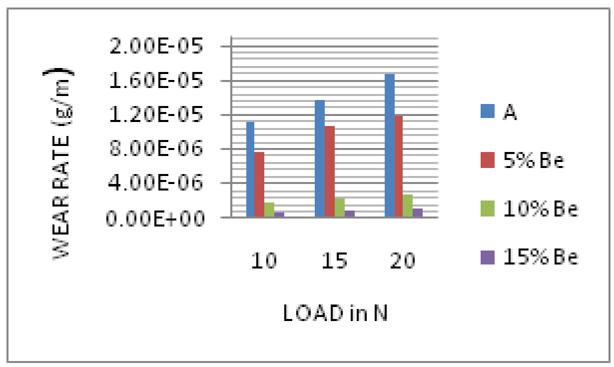

Figure 4: Variation of wear rate for varying loads

Figure 4 shows the variation of wear rate for varying load conditions. It can be seen from the figure that the wear rate is more in case of the as cast alloy; less is seen in the alloy subjected to the Beryllium additions. Least wear is seen in this specimen subjected to higher percentage of Beryllium addition. Table 5 summarizes the detail of the same.

Table 5: Wear rate values for varying load

VARYING LOAD (N)	As cast (A) ($x10^{-5}$)	AA7075 + 5% Be ($x10^{-6}$)	AA7075 + 10% Be ($x10^{-6}$)	AA7075 +15% Be ($x10^{-6}$)
10	1.10	7.56	1.72	0.545
15	1.38	10.6	2.091	0.818
20	1.664	11.82	2.63	1.00

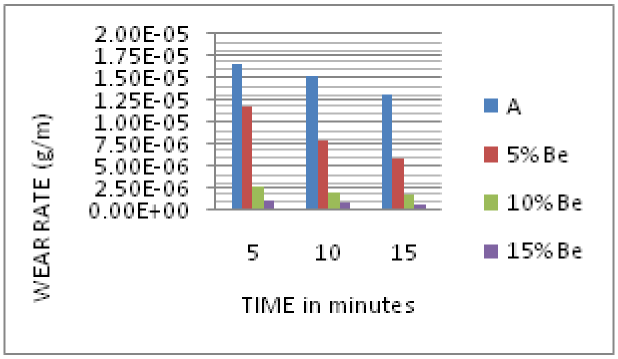

Figure 5: Variation of wear rate values for varying time

Figure 5 shows the variation of wear rate for varying time duration. It can be seen from the figure that the wear rate is more in case of the as cast alloy, less is seen in the alloy subjected to the Beryllium addition. Least wear is seen in this specimen subjected to higher percentage of Beryllium addition. Table 6 summarizes the detail of the same.

Table 6: Wear rate values for varying time duration

VARYING TIME (minutes)	As cast (A) ($x10^{-5}$)	AA7075 + 5% Be ($x10^{-6}$)	AA7075 + 10% Be ($x10^{-6}$)	AA7075 +15% Be ($x10^{-6}$)
5	1.664	11.82	2.63	1.00
10	1.51	7.866	1.86	0.773
15	1.32	5.82	1.606	0.606

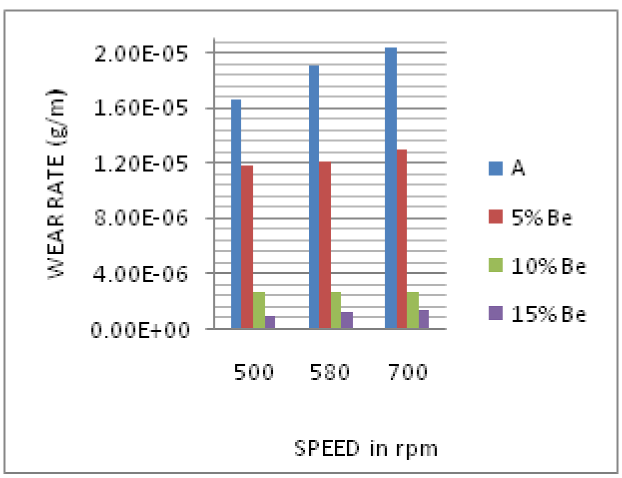

Figure 6: Variation of wear rate values for varying speed

Figure 6 shows the variation of wear rate for varying time duration. It can be seen from the figure that the wear rate is more in case of the as cast alloy, less is seen in the alloy subjected to the Beryllium addition. Least wear is seen in this specimen subjected to higher percentage of Beryllium addition. Table 7 summarizes the detail of the same.

Table 7: Wear rate values for varying speed

VARYING SPEED (rpm)	As cast (A) ($x10^{-5}$)	AA7075 + 5% Be ($x10^{-6}$)	AA7075 + 10% Be ($x10^{-6}$)	AA7075 +15% Be ($x10^{-6}$)
500	1.32	5.82	1.606	0.606
580	1.905	12.06	2.66	1.176
700	2.04	13.03	2.663	1.364

2. Temperature Measurement

Temperature developed at the interface of the specimen and the wear disc and at different location on the specimen(pin) was measured and recorded using thermocouple mounted at different location as explained in section 3.3. The variation of temperature with varying load is shown in figure 5.4.

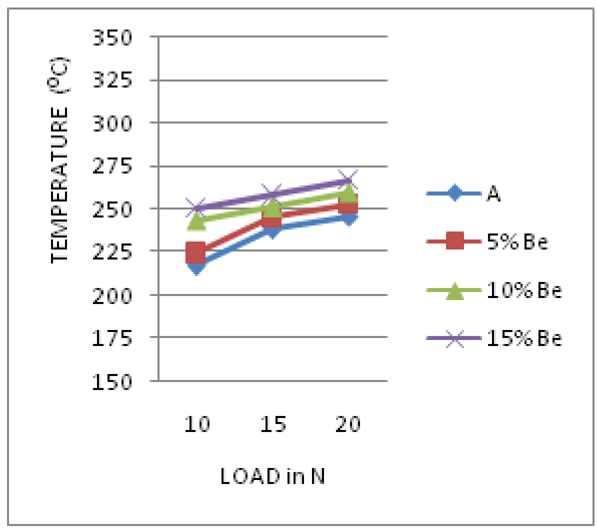

Figure 7: Variation of Temperature values for varying load

It can be seen from the figure 7 that the temperature developed for low load application is less compared with the higher temperature developed with the application of higher loads. Similar trend of increasing temperature with increasing load is observed for the composite reinforced with different percentage of Beryllium additions. This indicates the load has an influence with respect to temperature. Marginal increase in temperature is observed for 15N and 20N load applied. Table 8 summarizes the temperature developed for varying load conditions for different composition of the composite.

Table 8: Temperature values for varying load

VARYIN G LOAD(N)	As cast(A)	AA707 5+ 5% Be	AA707 +10%B e	AA707 5 +15%B e
10	217	224	243	250
15	238	245	251	258
20	246	253	260	267

Figure 8 shows the variation of temperature with time of testing for the specimen loaded with constant weight of 20N.

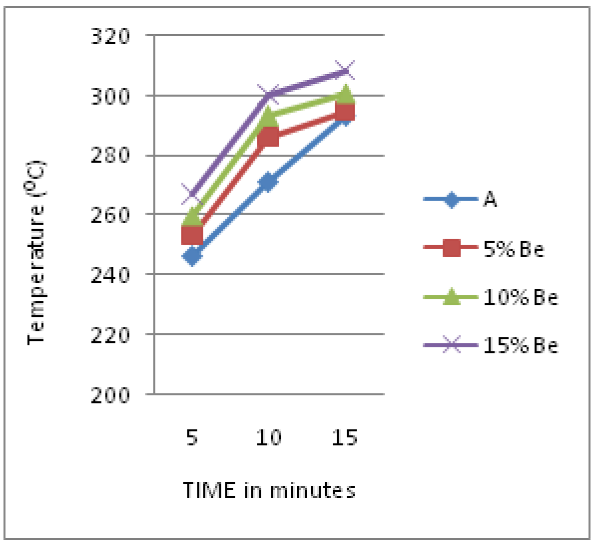

Figure 8 Variation of Temperature values for varying time

It can be observed from the figure that the temperature developed at the interface is less for 5 minutes duration. With increasing the duration of the testing the temperature developed also increases. Table 9 shows the detail of the same.

Table 9: Temperature values for varying time

VARYIN G TIME(min)	As cast(A)	AA707 5+5% Be	AA707 5+10% Be	AA707 5+15% Be
5	246	253	260	267
10	271	286	293	300
15	293	295	301	308

Temperature measurement studies were carried out for three different speeds, namely 500rpm, 580rpm and 700rpm.figure 9 shows the variation of temperature with speed for a constant load of 20N.

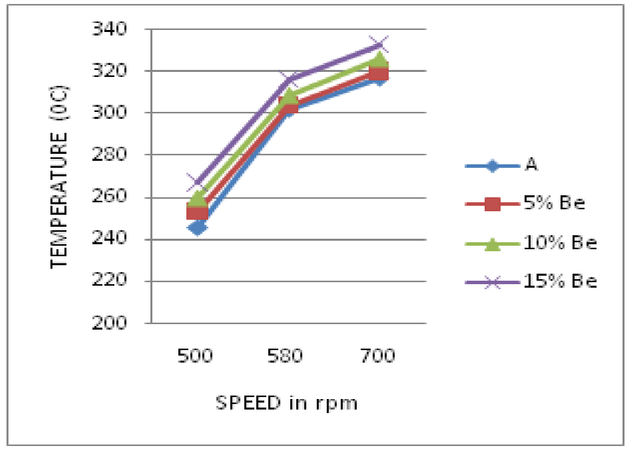

Figure 9: Variation of Temperature values for varying speed

It can be observed from the figure 9 that the temperature developed for a low speed is less. However with increasing the speed of testing the temperature developed also increases. This increasing the temperature is observed for the other speed studied also i.e. 700rpm. Similar increasing trend in the temperature values is observed for the higher speed studied with increasing beryllium additions. Table 10 summarizes the details of the same.

Table 10: Temperature values for varying speed

VARYING SPEED (rpm)	As cast (A)	AA7075 +5% Be	AA7075 +10%Be	AA7075 +15%Be
500	246	253	260	267
580	302	304	309	316
700	317	320	326	333

3. Thermal Analysis

The temperature profile generated along the whole length of the specimen for the given thermal load for a speed of 700rpm are shown in the following figures.

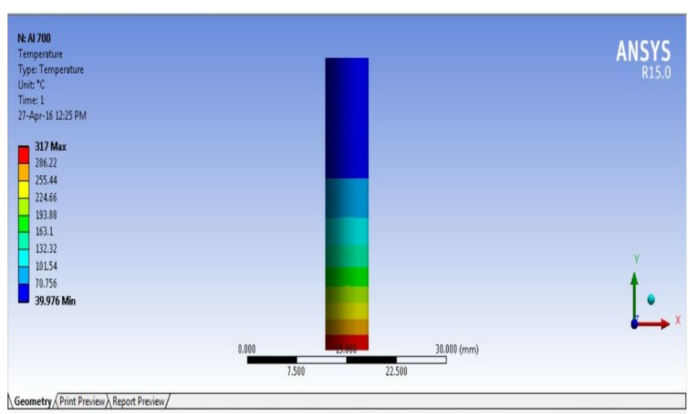

Figure 10: Temperature profile generated along the As cast specimen

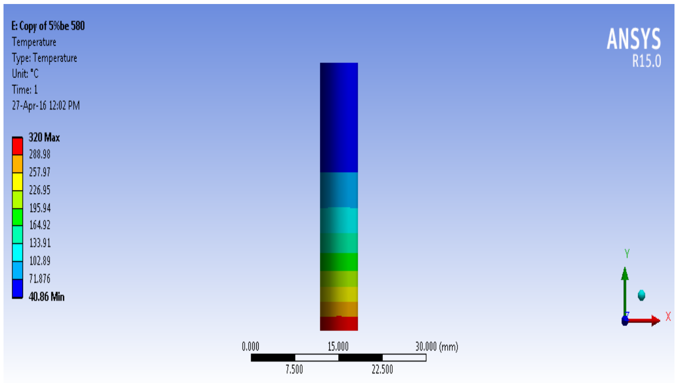

Figure 11: Temperature profile generated along the specimen for 5% Beryllium addition

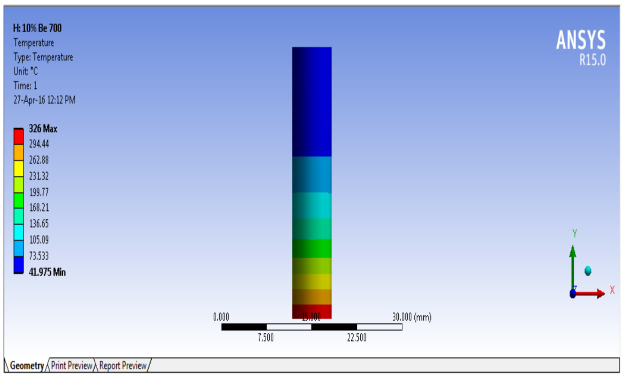

Figure 12: Temperature profile generated along the specimen for 10% Beryllium addition

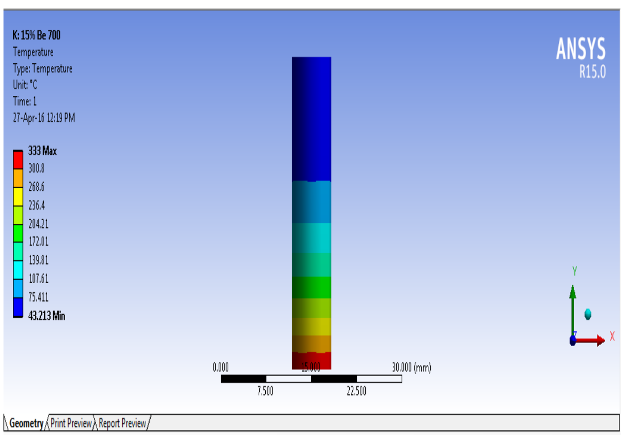

Figure 13: Temperature profile generated along the specimen for 15% Beryllium addition

Figures (fig 10 to fig 15) show the temperature profile generated along the specimen for different condition. It can be seen from the figure that the temperature generated for the as cast condition is least compared with the alloy reinforced with beryllium additions. This study also indicates that the higher percentage of beryllium addition exhibits higher temperature value compared to other condition studies namely 5% and 10% beryllium additions.

IV. CONCLUSIONS

The studies carried out on the aluminum-7075 beryllium composite indicate the following,

1. Beryllium reinforced composite with beryllium addition of 5%, 10% and 15% was successfully fabricated with liquid metallurgy route.
2. Hardness studies indicate that lower hardness values are seen for the as-cast alloy whereas improved hardness value for the alloy reinforced with beryllium addition. Alloy reinforced with 15% beryllium addition exhibits the highest hardness value.
3. From the wear studies carried out, it is observed that the as-cast alloy exhibits the least resistance to wear. Beryllium reinforced composite exhibits improved resistance to wear indicating that the beryllium addition has an influence on improving the wear resistance property.
4. Temperature measurement studies carried out for the specimen indicate that the temperature increases with increase in wear rate and the temperature is also increases with increase with Beryllium additions.

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