Studies on Properties of Beryllium Particulate Reinforced Aluminium Alloy Composite

(Analaysing Mechanical and Wear Properties of Metal Matrix Composite)

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***Abstract*— Many research works carried out in the field of material science have found that composite materials are better than conventional materials due to their enhanced mechanical properties. In the recent trends, aluminium based composite materials are popular in most of the applications like automotive, aircraft, military and others. Among the various aluminium alloys, aluminium alloy 7075(AA7075) belonging to 7XXX series is the strongest alloy with the highest strength to weight ratio. The main concern of the study is to prepare aluminium metal matrix composite [AMMC] wherein aluminium 7075 is used as the metal matrix and beryllium particulates is added as the reinforcement. Beryllium is a rare element available with high melting point, stiffness and elastic modulus being 50% greater than that of steel. This combination of aluminium and beryllium is very popular in the field of aerospace due to their reduced weight, durability and high strength. Varying quantities of beryllium like 5%, 10% and 15% by weight are added and the specimens are prepared by stir casting process and machined as per ASTM standards. The samples are then subjected to tests like tensile, hardness, microstructure and wear. The obtained results are compared with as cast condition and conclusions are drawn. It is observed that tensile strength and hardness values increased and wear rate decreased with the increase in the beryllium content.**

***Keywords*— AMMC, AA7075, stir casting process**

I. Introduction

Undoubtedly AA7075 exhibits excellent mechanical properties compared to its other alloys. Beryllium also exhibits excellent mechanical properties compared to this alloy and thus in order to enhance the properties of AA7075 further, beryllium is added. By this combination, strength and hardness of the base material improves. Also, wear problem is reduced as this combination reduces the wear rate. William Speer et al [1] have studied the applications of aluminium and beryllium composite for structural aerospace components. In this study, 38% of AA6061 and 62% of beryllium were taken was observed that composite exhibited higher specific stiffness and higher strength to weight ratio and thereby improved performance compared to the aerospace components made of aluminium and titanium. Also, this combination showed better space savings and higher melting point, thermal conductivity and specific heat capacity that are favorable for aerospace applications. Thomas Parsonage [2] has studied the mechanical properties of beryllium based metal matrix composite for aerospace and commercial applications in two cases aluminium-beryllium and beryllium-beryllium oxide metal matrix composites. Combination of 20-62% of beryllium by volume and the remaining content of aluminium is taken by which density is reduced by 25% compared to aluminium and specific stiffness increases by four times compared to titanium, magnesium, steel and aluminium. Dampening capacity is improved better than aluminium and co efficient of thermal expansion is reduced by 50% compared to aluminium. In the second case of E-materials, 20-30% by volume in the matrix is Beryllium oxide and the remaining is beryllium. It is also seen that E materials / combination of beryllium and beryllium oxide have lesser density by 30% compared to aluminium and silicon carbide composite. D Hashiguchi et al [3] have studied the aerospace applications of aluminium based metal matrix composite. AA6061 is selected as the reinforcement and beryllium is added as the reinforcement in quantities of 20%, 40% and 62% by weight. It is observed that higher concentration of beryllium reduces density, increases strength and hardness and decreases ductility. Microstructure examination is carried out between ingot cast alloys and rolled cast alloys and comparisons were made. It is observed that ingot cast alloy affects the mechanical properties. K R Suresh et al [4] have studied the mechanical properties of AA6061 based metal matrix composite to which beryllium is added as the reinforcing material in quantities of 2%, 4%, 6%, 8%, 10% and 12% by weight in the form particles of grit size 53-75μm. It was observed that base alloy with 10% beryl particulates showed improvement of 15.38% in tensile strength and specific wear rate decreased by 8.9% at normal load of 9.81N as compared to the base alloy. Progressive improvements compared to the base alloy were seen in tensile strength and hardness with increase in beryllium content. However, tensile strength was found to have decreased at 12% addition of beryl particulates to the base alloy. Microstructure examination of the composites was made and was found that beryl particulates had dispersed uniformly in the matrix.

II. MATERIALS USED

A. Aluminium Alloy - AA7075

AA7075 with chemical composition as per ASTM B-209 is selected as the matrix material of overall weight about 6000g. This alloy is strongest alloy among the aluminium alloys.

B. Beryllium

Beryllium particulates of grit size 60μm are selected as the reinforcement material of overall weight about 512g. Beryllium is rare element available in the earth's crust and has superior properties compared to AA7075.

III. EXPERIMENTAL PROCEDURE

Two sets of samples were prepared. First set of sample was prepared without reinforcement and 1200g of the alloy was casted. Initially melting furnace with empty graphite crucible is preheated at 700˚C for an hour. On the other side, inner surface of the mold is coated with mixture of graphite particles and ethyl alcohol and heated in a muffle for an hour at 250˚C. Finger type mold is used so as to get enough samples to conduct various tests. Once the alloy melts, hydrochloroethane tablet is added as a degassing agent and the molten metal is poured to preheated mold and allowed to cool. In the second set, three composite samples were prepared with beryllium particulate reinforcement by stir casting process. 1300g of alloy is kept in the furnace containing the crucible, and is heated for 3hours at 740˚C. On the other side along with the coated mold, beryllium particulates of 5% weight i.e., 62g is also heated for hour at 250˚C. After the melting of the alloy, degassing agent is added and stirrer is introduced to the furnace and immediately preheated beryllium is added. Ceramic coated stirrer is used. Stirring action is done for two minutes at speed of 200rpm. After stirring is completed, stirrer is removed and the molten composite is poured to the mold and allowed to cool. Similarly other two composite samples are prepared with 10% and 15% beryllium reinforcement.

A. Abbreviations and Acronyms

AA 7075 = Aluminium Association 7075 – aluminium alloy with high content of zinc.

AMMC = Aluminium Metal Matrix Composite

ASTM = American Society for Testing and Materials

AA6061 = Aluminium Association 7075 – aluminium alloy with high content of magnesium and silicon

B. Units

- g = gram
- W/mK = Watts per meter Kelvin
- MPa = mega Pascal
- GPa = giga Pascal
- N = Newton
- rpm = revolutions per minute

IV. METHODOLOGY

1. TENSION TEST:

Samples were machined and tested as per ASTM E8 standard. Bench tensometer was the device used to test the tensile strength. The electronic Tensometer is a compact and bench model horizontal Tensile Testing Machine of capacity 20 KN. It is a small version of UTM- Universal Testing Machine and is used for testing tension and also compression, shear and flexural properties of different materials. PC 2000 model tops in the series of Tensometer and was used to test the tension.

- Suitable pair of shackles was selected to fix the shoulder. Specifications of the specimen mainly gauge length and its outer diameter was entered and accordingly percentage elongation was set.
- The sample was laid in the cradle before stretching it and the pivoted arm was moved to the right slide before the arm reading is zero.
- The right slide is locked and test was conducted.
- The test graph is displayed online and thus instantaneous results are obtained.

2. WEAR TEST:

Samples were machined and tested as per ASTM G99 standard. Pin-on-disc wear testing machine was used to determine the wear rate.

The apparatus has finely polished steel disc of grade EN 25 with l50mm diameter and surface being hardened to about 80 RHN. The disc is connected to an AC monitor. The speed of the motor can be varied and a radial arm is hung over the disc in a way to remove the side play. The specimen is carried by the arm and is made to load the specimen when the disc is rotating. The metallic sample whose wear rate had to be determined was fixed to the arm.

- The specimen was initially weighed and was placed in the radial arm and loaded accordingly.
- The motor was set to the fixed time and was started.
- After the fixed time completes, machine stops automatically and then specimen is weighed again to determine the wear rate.

Wear rate is determined by:
(Initial Weight-Final Weight) / Sliding Distance (g / m)
Sliding distance = ΠDNT / 1000 (m)
Where,
D = track diameter in m
N = speed in rpm
T = time in min

3. HARDNESS TEST:

Samples were machined and test is carried out as per ASTM E18 standard. Rockwell hardness tester was used to test the hardness.

- Surface of the specimen whose hardness is to be tested, is cleaned and kept on the anvil.
- The location on the specimen where indentation is to be made is selected so as to indicate the properties of the material.
- The specimen was placed on the anvil such that its surface is normal to the direction of applied load.
- Anvil is raised by means of elevating screw till the pointer reaches red dot on the dial. This indicates that minor load of 10kg is applied on the indenter and is done to ensure the perfect seating and loading of the specimen.
- Later, major load of 100 kg was applied as per B scale for duration of 30 seconds, to ensure complete acting of the load on the specimen by the indenter.
- After 30 seconds load was removed and the final position on B scale was noted down which directly indicates the Rockwell Hardness number.
- The indentations were taken at five different points on each specimen and the average was considered as the hardness value.

4. MICROSTRUCTURE TEST:

Samples were machined and tested as per ASTM E-3 and E-340 standard. The metallurgical microscope was used to observe the microstructure.

- The specimens were polished by using emery papers with grades such as P 80, P 120, P 220, P 400, P 800, P 1200, P 1500, P 2000, P 2500 and P 3000 for duration of 5min on each paper at a speed of 500-600rpm and alumina liquid is added in between to give a fine and even finish at the surface.
- This was followed by polishing on a mescaline cloth by using diamond paste.
- Once the polishing is done, surface is etched for 10 seconds to clean the surface to be observed by the use of etchant called Keller's reagent which has:
- HCl = 2.5 ml
- HF = 1 ml
- HNO_3 = 1.5 ml
- H_2O = 95 ml
- After etching, specimen is washed by ethyl alcohol and dried for few minutes and later observed for microstructure

A. Authors and Affiliations

1) Deepika M.S: currently pursuing Masters in Manufacturing Science at MS Ramaiah Institute of Technology, Bengaluru, Karnataka. I am working my thesis under the guidance of Mr. C.M.Ramesha. I am interested in the field of Materials Science and keen on the development of new materials.

2) C.M.Ramesha: currently working as Associate Professor in Department of Mechanical Engineering at MS Ramaiah Institute of Technology, Bengaluru, Karnataka. I have open mind towards new ideas and like to enhance my knowledge by learning something new pertaining to Materials Science. I love my work and I like to guide the budding students.

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4) S.K. Rajendra: presently working as Associate Professor at Dr. Ambedkar Institute of Technology, Bengaluru, Karnataka in the Department of Industrial Engineering and Management. I am a keen learner and creative person. I am interested in development of new materials and thus like to commit myself to my work and learn something new.

B. Figures and Tables

TABLE I. PROPERTIES OF MATRIX AND REINFORCEMENT MATERIALS

PROPERTIES	units	AA7075	Beryllium
Density	g/cc	2.81	1.85
Melting point	˚C	477-635	1287
Thermal conductivity	W/mK	173	216
Rockwell hardness B	-	17	75-85
UTS	MPa	228	370
Elastic modulus	GPa	71.7	287

TABLE II. TENSOMETER TEST VALUES OF UNREINFORCED AND REINFORCED ALLOYS

Engg UTS (Mpa)	As cast (A)	AA7075 +5% Be	AA7075 +10% Be	AA7075 +15% Be
	108.3	112.7	135.6	156.9
True UTS (Mpa)	114.8	118	142.2	165.5
Peak load (N)	3432.5	3569.7	4295.5	4972.1
Break load (N)	3432.5	3569.7	4295.5	4972.1

It is observed that by increase in beryllium content, tensile strength is also improved. Alloy with 15% beryllium showed 31% increase with respect to the unreinforced alloy

TABLE III. HARDNESS VALUES OF UNREINFORCED AND REINFORCED ALLOYS

Hardness (HRB)	As cast (A)	AA7075-5% Be	AA7075-10% Be	AA7075-15% Be
	39	43	45	50

Hardness improved with increase in the beryllium content and was seen that alloy with 15% beryllium had improved by 22% as compared with unreinforced alloy

TABLE IV. WEAR RATE VALUES OF UNREINFORCED AND REINFORCED ALLOYS UNDER VARYING TIME

Varying Time	As cast (A)	AA7075-5% Be	AA7075-10% Be	AA7075-15% Be
5 min	.0015	.0014	.0012	.0011
10 min	.0018	.0015	.0013	.0012
15 min	.0125	.0048	.0037	.0016
20 min	.0156	.0080	.0054	.0027
25 min	.0172	.0015	.0062	.005

TABLE V. WEAR RATE VALUES OF COMPOSITE SAMPLES AS COMPARED WITH UNREINFORCED ALLOY UNDER VARYING LOAD.

Varying load	As cast (A)	AA7075-5% Be	AA7075-10% Be	AA7075-15% Be
5N	.0036	.00008	.00007	.00003
10N	.0048	.0008	.0005	.0002
15N	.0065	.0036	.0006	.0005
20N	.0085	.0076	.0008	.0007
25N	.0316	.0130	.0015	.0012

TABLE VI. WEAR RATE VALUES OF COMPOSITE SAMPLES AS COMPARED WITH UNREINFORCED ALLOY UNDER VARYING SPEED.

Varying speed	As cast (A)	AA7075-5% Be	AA7075-10% Be	AA7075-15% Be
350 rpm	0.00016	0.00013	0.00012	0.00011
450 rpm	0.0002	0.00017	0.00015	0.00014
550 rpm	0.00023	0.00021	0.00018	0.00017
650 rpm	0.0003	0.00028	0.00024	0.00021
750 rpm	0.00037	0.00035	0.00028	0.00025

WEAR RATE DRASTICALLY REDUCED AS THE BERYLLIUM CONTENT WAS INCREASED IN ALL THREE CONDITIONS

Fig. 1. Stir casting unit

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Fig. 2. Casting furnace

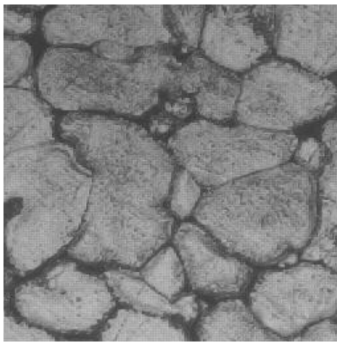
Fig. 3. Bench Tensometer

Fig. 4. Tensile specimens

Fig. 5. Pin-on-disc wear testing machine

Fig. 6. Wear test samples

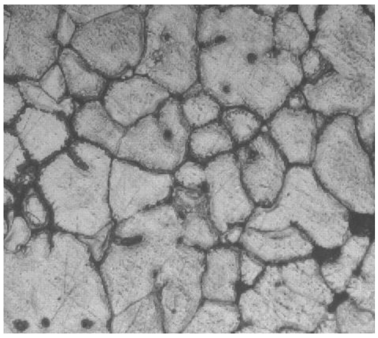
Fig. 7. Microstructure of the unreinforced alloy AA7075



It is observed that:

- Microstructure contains fine inter metallic particles in the matrix observed as dark lines in between the boundaries.
- No segregation or porosity is seen.
- Grain boundaries are observed clearly

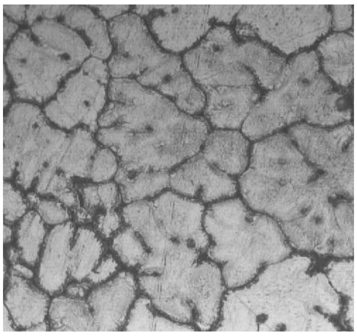
Fig. 8. Microstructure of alloy AA7075 with 5% Be



It is observed that:

- Microstructure contains fine inter metallic particles in the matrix
- No segregation or porosity is seen.
- Beryllium particles added are seen in the form of black dots on the matrix.
- Grain boundaries are visible.

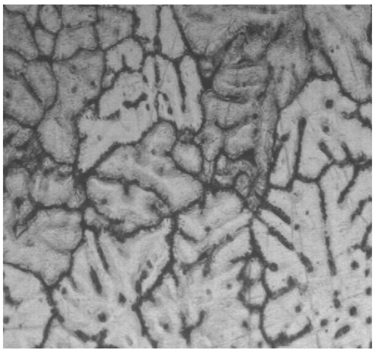
Fig. 9. Microstructure of alloy AA7075 with 10% Be



It is observed that:

- Microstructure contains fine inter metallic particles in the matrix.
- No segregation or porosity is seen.
- Beryllium particles added are seen in the form of black dots and are distributed over the matrix
- Grain boundaries are visible

Fig. 10. Microstructure of alloy AA7075 with 15% Be



It is observed that:

- Microstructure contains fine inter metallic particles in the matrix.
- No segregation or porosity is seen.
- Beryllium particles added are seen in the form of black dots and are distributed over the matrix and appears much denser compared to other samples
- Grain boundaries are visible.

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