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Effect of Squeeze pressure on the hardness and wear resistance of Aluminium flyash composite manufactured by stir-squeeze casting

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ABSTRACT: *In the present investigation LM6 aluminium alloy was reinforced with 7.5% by weight flyash particles. The composite was prepared by stir-squeeze casting method. Different squeeze pressure was applied on the composite to study the effect of squeeze pressure on the hardness and abrasive wear behavior of the composite. It was observed that as the squeeze pressure was increased the hardness and the wear resistance also improved. The wear experiments were conducted at different speeds and loads using abrasive wear tester and the hardness test was performed using Brinell's hardness tester. The results of hardness and the wear resistance was compared with that of the monolithic alloy produced by gravity casting and also by squeeze casting. It was clearly evident from the results obtained that the composites produced by squeeze casting was superior in hardness and wear resistance than the monolithic alloy produced by gravity casting and squeeze casting. The increase in hardness and the wear resistance is attributed to the volume fraction of the reinforcement used and decrease in the porosity level due to the application of squeeze pressure.*

Keywords: *Al-flyash mmc, Abrasive wear, Hardness, Squeeze pressure*

I. INTRODUCTION

Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness and wear resistance. To overcome these shortcomings and to meet the increasing demand of modern day technology, composites have gained lot of attention because of the ability to tailor them to meet the required physical, mechanical, and tribological properties for a given application. There has been an increasing interest in the production of composites having low density and low cost reinforcements. Among various discontinuous dispersoids used, fly ash is found to be one of the most inexpensive and low density reinforcement available in large quantities as solid waste by-product during combustion of coal in thermal power plants. Flyash consists of, namely, precipitator (solid particle) and cenosphere (hollow particle) flyash. The major chemical constituents of fly ash are SiO_2, Al_2O_3, Fe_2O_3 and CaO. Mineralogically, the fly ash consists of aluminosilicate glasses containing quartz, mullite, hematite, magnetite, ferrite, spinel, anhydride and alumina (1). The particle size of the fly ash as received from the power plants generally lies in the range from 1 to 150 µm, while cenosphere fly ash particles have sizes ranging from 10 to 250 µm. It is reported that incorporation of fly ash particles improves the wear resistance, damping properties, hardness and stiffness and reduces the density of Al alloys (2 - 6). Therefore, composites with fly ash as reinforcement are likely to overcome the cost barrier for wide spread applications in automotive, small engine and the electromechanical industry sectors (7, 8). Hence it is expected that the incorporation of fly ash particles in aluminium alloy will promote the use of this low-cost waste by-product and, at the same time, has the potential for conserving energy intensive aluminium and thereby, reducing the cost of aluminium products (9).

Amongst the various processing methods practiced for the production of metallic components, casting is found to be more popular because of its simplicity and also being economical in nature. But due to certain drawbacks such as porosity, segregation, hot tears the castings produced will be having poor mechanical properties. In order to overcome these defects a recent technique called squeeze casting has been developed. The castings produced by this method have been known to show superior strength and other improved mechanical properties (10 - 13). It is also observed that composites produced by squeeze casting technique results in homogeneous distribution of reinforcement in metal matrix (14). There has been a continuous effort by the researchers in the pursuit of finding a material for the production of automobile components that shows improvement in mechanical properties and wear behavior with reduced weight (15). In the automobile and other allied industries there is a greater demand for the production of castings where strength and wear resistance is of paramount importance (16). It is reported by many researchers that the externally applied pressure on the melt reduces the porosity and voids and increases the densification of the material (17 - 21). Squeeze casting process is used for most of the low melting temperature non-ferrous alloys. Because of its wider application, abundancy in nature and due to some of its good properties, aluminium alloys find greater usage in the production of various components (22).

II. EXPERIMENTAL PROCEDURE

2.1 MATERIALS USED

Aluminium casting alloy of LM6 grade has been used as the matrix material in the present investigation. The chemical composition of the aluminium alloy is as shown in the Table.1. The aluminium alloy was reinforced with 7.5 wt% flyash to synthesize the composite through liquid metallurgy route followed by squeeze casting. The flyash which is used as a reinforcing material was tested in the laboratory and the test results are as given the Table.2.

Table 1: Chemical composition of the LM6 aluminium alloy.

Chemical Composition	Cu	Mg	Zn	Fe	Mn	Si	Al
Wt. %	0.002	0.065	0.021	0.32	0.62	12.2	Balance

Table 2: Chemical composition of the flyash.

Sio_2	Tio_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I	SO_3
63.96%	0.5%	25.5%	6.07%	1.97%	0.81%	0.54%	0.45%	0.15%	<0.1%

Density of Fly ash = 1.31 g/cc.   Type of Flyash: F Class (CaO < 20%)   Source: RTPS Raichur (India)

2.2 Processing

The composites were produced by liquid metallurgy route which was followed by squeeze casting. Firstly the matrix material was superheated to 800°C in the Electric resistance furnace. It was then de-gassed by using Hexa-chloroethane tablets. By using a mechanical stirrer with a rotational speed of 600 rpm the vortex was created. At this stage the flyash which was preheated at 150°C to remove any moisture content was slowly introduced into the molten slurry. A small quantity of magnesium was also added into the molten metal to enhance the wettability of the reinforcements with molten metal. The stirring of the slurry was carried out for nearly five minutes to promote wetting and uniform dispersion of the reinforcement. After that a metered quantity of mixture was poured into the preheated steel die of D4 grade mounted on the 20 tonne Hydraulic press and was squeezed through the punch by the application of pressure. The pressure applied was 30, 60, 90, and 120 bar. The formulation of different MMCs used in the study is shown in Table 3. The squeezed castings were allowed to cool down in the die itself to the room temperature and were later ejected out from the die. Apart from composites, casting of base aluminium alloy was also cast by gravity method and by squeeze casting method for the comparison purpose. All the castings were later machined to prepare the test specimen for conducting hardness and abrasive wear tests. The photographs of the sample specimen are shown in Fig.1

Table 3: Formulations of different MMCs used in the study

Specimen	Matrix material used (Al)	Flyash wt. (%)	Pressure applied (bar)
C1	LM6	7.5	30
C2	LM6	7.5	60
C3	LM6	7.5	90
C4	LM6	7.5	120
Sq. cast (SC)	LM6	---	90
Gr. cast (GC)	LM6	---	---

Fig 1: Photographs of the sample specimen

Al-Flyash 7.5wt% Composite

Squeeze Cast Al. alloy

Gravity Cast Al. alloy

2.3 Microstructure

Microstructural characterization studies were conducted on reinforced, squeeze cast and gravity cast samples. This is accomplished by using Nikon metallurgical microscope. The composite and base alloy samples were metallographically polished prior to examination.

2.4 Hardness Test

Hardness is one of the important properties which affects wear resistance of any metal or alloy. The hardness measurements were carried out on Al-flyash particulate composite specimens and also on the monolithic alloy specimen by using Brinell hardness tester in order to investigate the influence of the squeeze pressure on hardness. The specimens were prepared and polished on different grits of emery paper. An indenter steel ball of 10mm diameter and load of 500 kg was applied. The test was carried out at four different locations to controvert the possible effect of indenter resting on the harder particles and the average of all the four readings was taken.

2.5 Abrasive Wear test

A three body dry sand abrasive wear test was performed as per ASTM G65 standards on the specimen to determine the wear rate. The test specimen of size 75mm x 25mm x 8mm were metallographically prepared and polished. The experiment was conducted at three different loads of 47N, 71N and 95N and speeds of 250, 300 and 350 rpm of the rubber wheel. The silica sand of 50 µm grain size was made to flow at a constant rate of 350 gm/min. The experiment was conducted for five minutes for all the specimens and the weight loss method was used to determine the wear rate. An electronic weighing balance of 0.1mg accuracy was used for determining the weight loss.

III. RESULTS AND DISCUSSIONS

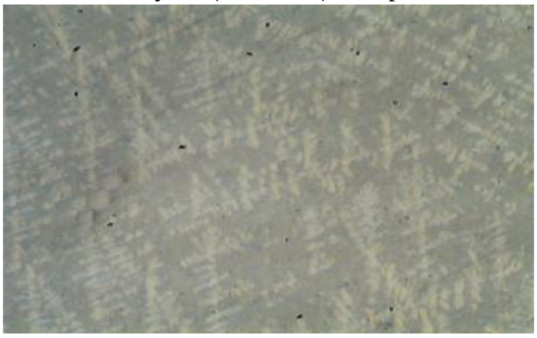
3.1 Optical Micrographs

The optical micrographs of the composite and base alloy are shown in Fig.2. The microstructure of MMCs clearly shows a good retention and almost uniform distribution of flyash in the matrix without any voids and discontinuities. However there is some amount of small agglomeration of flyash particles at some areas in the composite samples. The micrograph shows good interfacial bonding between the flyash particles and matrix material. The micrograph of the aluminium alloy squeeze cast sample indicates sound casting with no porosity or voids present in the sample investigated. It also shows smaller silicon dendritic structure in the matrix due to the application of the external pressure. The micrograph of the aluminium alloy gravity cast sample shows the presence of voids and also large needle like silicon structure in the aluminium matrix material.

Fig 2 : Micrographs of composite specimen and base alloy

Al-Flyash (7.5 % wt.) Composite

Al-Flyash (7.5 % wt.) Composite



Squeeze Cast base Al alloy

Gravity Cast base Al alloy

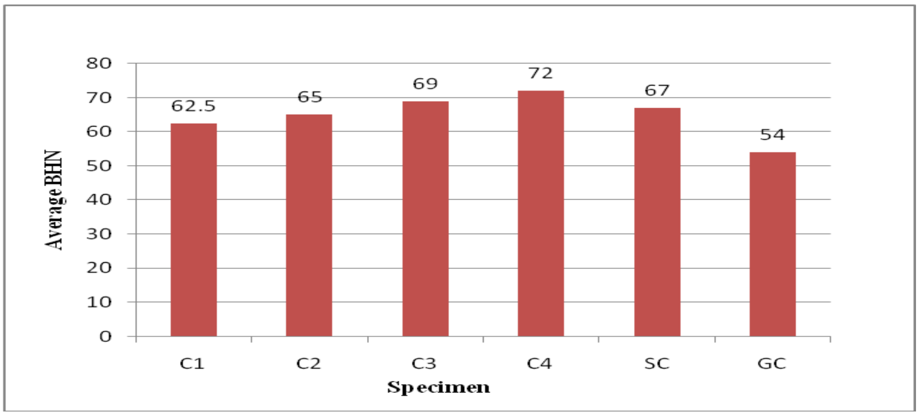
3.2 Hardness Test Results

The results of the hardness test performed on the 7.5 wt.% Aluminium- flyash composite and the monolithic aluminium alloy produced by squeeze casting and by gravity casting is shown in the Table 4. It is observed from the Graph 1 that hardness of the gravity cast aluminium alloy is the lowest. The hardness of the squeeze cast alloy, when compared with the gravity cast alloy has increased by 24%. The increase in hardness value in the squeeze cast alloy is attributed to the densification of the material due to the externally applied pressure. It is also observed that the hardness value of the aluminium-flyash composite with 7.5 wt % reinforcement increases with the increase in the squeeze pressure and the hardness is maximum at 120 bar pressure. This is attributed to the fact that (i) the harder flyash particle reinforced in the softer aluminium matrix enhances the hardness of the composite and, (ii) the externally applied pressure increases the densification of the composite thereby increasing its hardness.

Table 4: Experimental results of Hardness test.

Specimen	%Fly ash	Squeeze pr. in kg/cm^2	Trials				Avg BHN
			T1	T2	T3	T4	
C1	7.5	30	62	62	63	63	62.5
C2	7.5	60	64	65	65	66	65
C3	7.5	90	69	69	68	69	69
C4	7.5	120	73	73	77	65	72
SC	-	90	67	69	67	65	67
GC	-	-	53	52	57	55	54

Graph 1: Average BHN Vs Specimen



3.3 Dry sand Abrasive wear test Results

The wear rate results obtained for the Al-flyash composite, monolithic aluminium alloy casting produced by gravity casting and squeeze casting at different combinations of loads and speeds are shown in Table 5, 6 and 7. It is observed from Graphs 2, 3 and 4 that the loads and speeds at which the experiment was conducted, the wear rate of the aluminium alloy produced by gravity casting is more. The wear rate of the aluminium alloy produced by squeeze casting method is comparatively lesser than the one produced by the gravity casting method. This is due to the fact that because of the application of the external pressure there is a densification of the material which has increased the hardness of the casting and that has resulted in the improvement of the wear resistance. Compared to the wear rate of the aluminium alloy produced by the gravity casting and squeeze casting the wear rate of the Al-flyash 7.5 wt% composite produced by squeeze casting is very much less. This is due to the fact that because of the reinforcement of harder flyash particles in the aluminium matrix and due to the application of the external pressure the hardness of the composite has increased, which has resisted the abrasion wear substantially.

Table: 5. Experimental Results of Dry sand Abrasive Wear test
Load Applied: 47N

Specimen	Time (min)	Speed (rpm)	Total weight loss (mg)	Wear rate(mg/min)
C1	5	250	179.9	35.98
C2	5	250	187.4	37.48
C3	5	250	165.5	33.1
C4	5	250	175.3	35.06
SC	5	250	217.7	43.54
GC	5	250	296.2	59.24
C1	5	300	223.7	44.74
C2	5	300	229.4	45.88
C3	5	300	229	45.8
C4	5	300	215.3	43.06
SC	5	300	255	51
GC	5	300	285.8	57.16
C1	5	350	211	42.2
C2	5	350	210.6	42.12
C3	5	350	224.1	44.82
C4	5	350	214.5	42.9
SC	5	350	293	58.6
GC	5	350	314.2	62.84

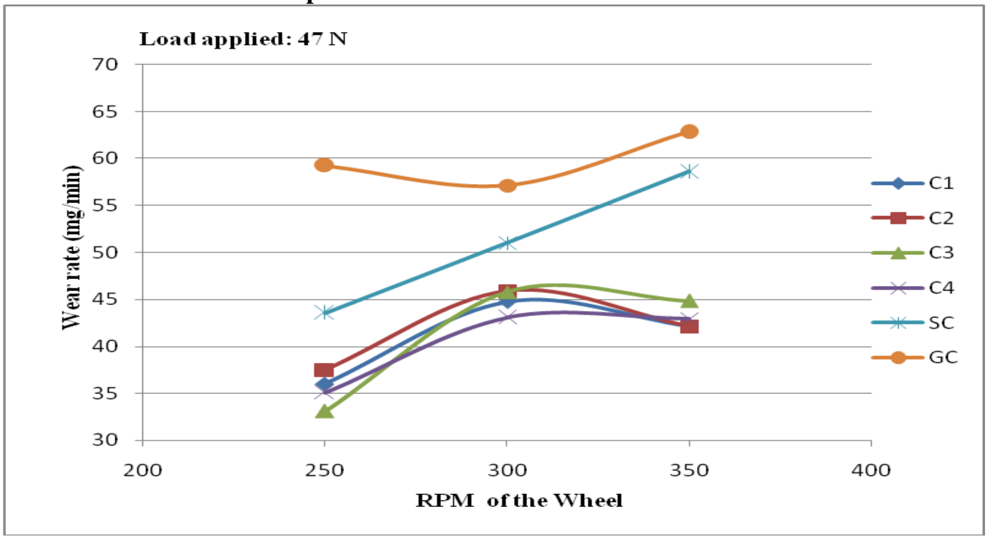
Table: 6. Experimental Results of Dry sand Abrasive Wear test
Load Applied: 71N

Specimen	Time (min)	Speed (rpm)	Total weight loss (mg)	Wear rate(mg/min)
C1	5	250	271.6	54.32
C2	5	250	200.1	40.02
C3	5	250	257.3	51.46
C4	5	250	209.9	41.98
SC	5	250	298.2	59.64
GC	5	250	378.6	75.72
C1	5	300	221	44.2
C2	5	300	181.9	36.38
C3	5	300	204.5	40.9
C4	5	300	229.5	45.9
SC	5	300	275.9	55.18
GC	5	300	374.9	74.98
C1	5	350	276.8	55.36
C2	5	350	209.8	41.96
C3	5	350	283.7	56.74
C4	5	350	228.9	45.78
SC	5	350	351.4	70.28
GC	5	350	401.8	80.36

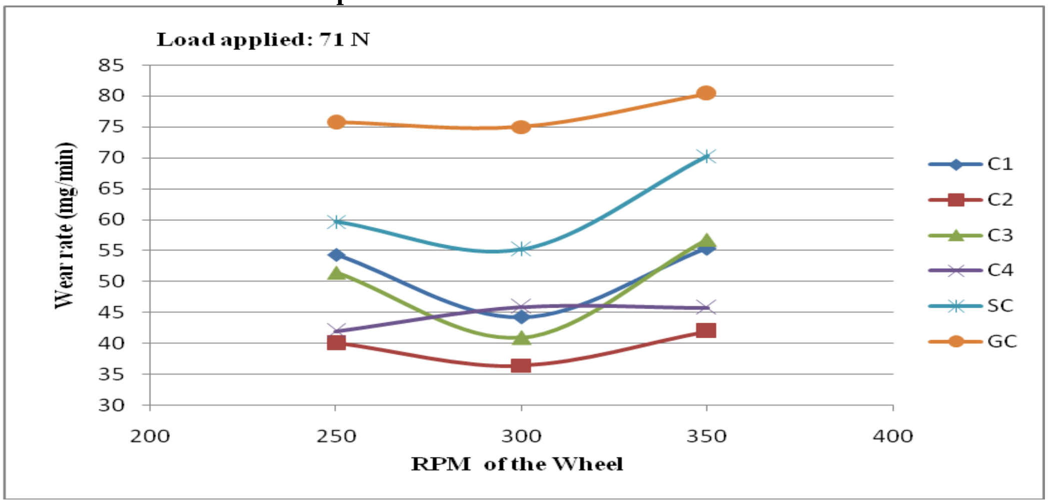
Table: 7. Experimental Results of Dry sand Abrasive Wear test
Load Applied: 95N

Specimen	Time (min)	Speed (rpm)	Total weight loss (mg)	Wear rate(mg/min)
C1	5	250	196.8	39.36
C2	5	250	173.3	34.66
C3	5	250	270.4	54.08
C4	5	250	148.9	29.78
SC	5	250	320.1	64.02
GC	5	250	399.3	79.86
C1	5	300	285.1	57.02
C2	5	300	229.3	45.86
C3	5	300	220.5	44.1
C4	5	300	303.7	60.74
SC	5	300	365.3	73.06
GC	5	300	381.2	76.24
C1	5	350	322.9	64.58
C2	5	350	309.6	61.92
C3	5	350	322.4	64.48
C4	5	350	286.5	57.3
SC	5	350	471.4	94.28
GC	5	350	490.3	98.06

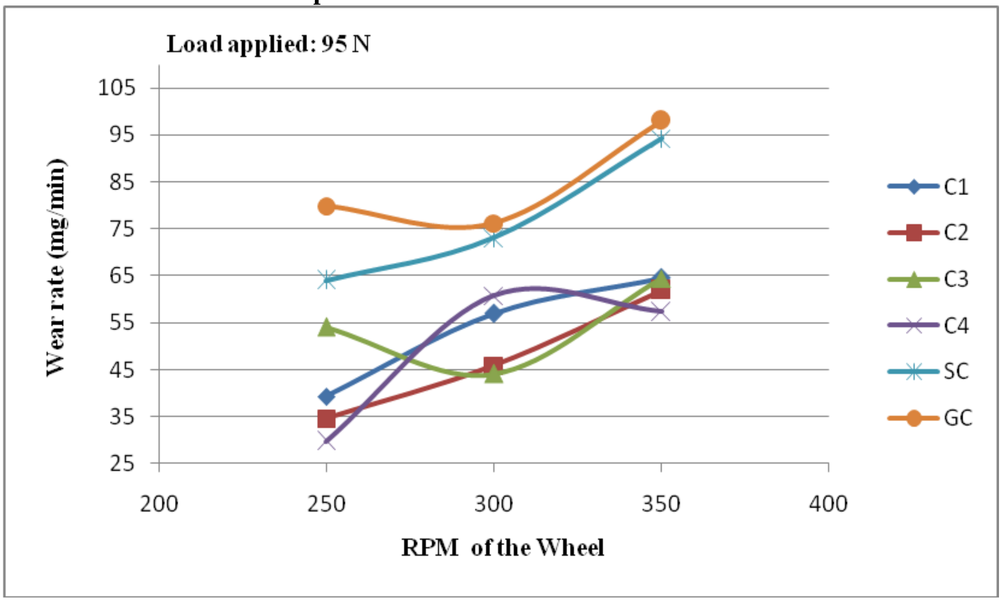
Graph: 2. Wear rate Vs RPM of the Wheel



Graph: 3. Wear rate Vs RPM of the Wheel



Graph: 4. Wear rate Vs RPM of the Wheel



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IV. CONCLUSIONS

From the present investigation the following conclusions are drawn.

1. The abrasive wear rate of LM6 aluminium alloy produced by gravity casting is maximum when compared to LM6 aluminium alloy produced by squeeze casting and Al-flyash composite.
2. The LM6 aluminium alloy produced by squeeze casting method shows improved resistance to abrasive wear due to the increased hardness and densification of the material when compared to the base alloy produced by gravity casting method.
3. The Al-flyash 7.5wt% composite has revealed superior resistance to abrasive wear because of the harder constituents of flysh reinforcement and increased hardness due to squeeze casting.

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