International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol. 3, Issue. 5, Sep - Oct. 2013 pp-2591-2599 ISSN: 2249-6645

Evaluation Of Factors Affecting Sliding Wear Behaviour Of Al-Flyash Metal Matrix Composites By Using Design Of Experiments

K.N.P. Prasad[1], M. Ramachandra[2]
[1] Associate Professor, Dept of Industrial Engineering & Management, BMSCE, Bangalore, India
[2] Professor, Dept of Mechanical Engineering, BMSCE, Bangalore, India

ABSTRACT: *The ability to produce near net shape components is made possible by means of squeeze casting process. Squeeze casting is a hybrid metal forming process which combines the features of both casting and forging in a single operation. The primary objective of this paper is to study the influence of the process parameters on wear resistance in squeeze casting of LM6 Al-flyash composite using Taguchi method. The parameters studied include percentage wt. of flyash, squeeze pressure, and squeeze time. In Taguchi method, a four level orthogonal array has been used to determine the S/N ratio. In this investigation, composites have been produced by incorporating flyash as a reinforcement material and eutectic Al–Si alloy as a matrix. Stir casting route has been adopted to disperse fly ash (from 5% to 12.5%wt.) in the Al–Si alloy matrix which is followed by applying the squeeze pressure of 30, 60, 90 and 120 bar for a varying squeeze time. The Pin-on-disc test was conducted on the specimen prepared out of these castings to determine the sliding wear behavior of the composite. The results of experimental investigation on wear resistance of flyash reinforced aluminium metal matrix composite shows that the inclusion of the flyash by weight percentage and the squeeze pressure are the recognized parameters to cause appreciable improvement in the wear resistance of the squeeze cast components.*

Keywords : *Al-flyash mmc, S/N ratio, wear.*

I. INTRODUCTION

Aluminium metal matrix composites are finding extensive applications in automobile and aerospace applications because of their superior mechanical and tribological properties. The increasing demand for lighter weight and fuel efficient materials is the major factor which is motivating the researchers for the development of more advanced metal matrix composite materials (1-5). Metal matrix composites containing hard or ceramic particulates offer superior operating performance. Aluminium based discontinuously reinforced metal matrix composites have attracted lot of the attention of the researchers because of their improved strength, high modulus and increased wear resistance when compared to conventional aluminium alloys (6,7,8).

The metal matrix composites are produced by several processes. The most economical one being the gravity die casting process. However, the main hindrance in the process is the presence of casting defects such as voids, cracks, shrinkage and porosity. It is reported that an improved method over the gravity die casting is squeeze casting process (**9**). It is a casting process in which metal is solidified under the direct action of external pressure. It is a combination of both gravity die casting and closed die forging. Squeeze casting process has several advantages such as, no feeder or risers are required. Therefore there is no wastage of the material. Parts are produced with no gas porosity or shrinkage porosity and castings produced by squeeze casting are found to have better mechanical properties and wear resistance (10,11,12).

Over the past two decades, squeeze casting process is found to be an important and proven process to produce near net shape high quality engineering products which are very much used in the automotive industry because of their superior quality and enhanced mechanical properties over those produced by conventional castings process (13,14).

One of the selection criteria for the discontinuously reinforced aluminium metal matrix composite is wear resistance. The wear resistance of the composite materials depends upon lot of factors apart from process parameters such as load, speed, temp., hardness and other conditions (15). The wear performance of the particulate reinforced aluminium metal matrix composites depends upon the type of reinforcement used, ranging from very hard ceramics particulates such as SiC, Al_2O_3, B_4C to soft materials such as graphite (16). Another important factor on which the wear of the composite material depends upon is the method of production of the composites.

Most of the available literature on the wear of the Aluminium metal matrix composites provide information about the different types of reinforcements used in different volume % and the production of the aluminium metal matrix composites by various methods (17,18). However limited information is available regarding the processing of the aluminium composite by squeeze casting with flyash as the reinforcement, and the analysis of their wear behavior using statistical method.

There has been increasing interest in developing composites containing low density and low cost reinforcements. In this regard flyash is one such least expensive, low density reinforcement which is available in huge quantities as a solid waste due to the combustion of coal in thermal power plants (19,20). Therefore by the incorporation of flyash as reinforcement in aluminium alloy many purposes can be achieved such as the cost of aluminium metal matrix composites and the weight of the products can be reduced, and by using the flyash as reinforcement to an extent, the environmental hazards can be prevented. Also some researchers have reported that the incorporation of flyash has resulted in enhanced mechanical properties and wear resistance in aluminium flyash metal matrix composites produced by liquid metallurgy routes (21-26). It is with this intent that the present investigation is carried out to study the wear behavior of the aluminium flyash composites produced by squeeze casting method using Taguchi method.

II. TAGUCHI TECHNIQUE

The design of experiments (DOE) approach using Taguchi technique has been used prominently by many researchers to study the effect of process parameters in different context. Taguchi technique is a powerful tool for the design of high quality systems (27,28). The Taguchi approach to experimentation provides an orderly way to acquire data and to analyze the effects of process and material parameters over some specific response. This method combines experimental and analytical concepts to determine the parameters with the strongest influence on the resulting response for a considerable improvement in the overall performance (29,30). The plan of experiments is generated in Taguchi method by the use of standard orthogonal arrays. DOE is not a single step process it is a series of steps which must be followed in a certain sequence for the experiment to yield an improved understanding of product or process performance. This design of experiments process is made up of three main phases, namely, the planning phase, the conducting phase and analysis or interpretation phase. The planning phase is the most important phase one must give a maximum importance to this phase. The data collected from all the experiments in the second phase are analyzed to determine the effect of various design parameters. This method makes use of fractional factorial approach and this may be accomplished with the aid of orthogonal arrays. The experimental results are then analyzed by using signal-to-noise ratio to determine the parameters that has the maximum influence on the sliding wear behavior of the composites produced.

III. EXPERIMENTAL PROCEDURE

3.1 Materials Used:

Aluminium casting alloy that conforms to British Standards 1490 LM6 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 5 wt%, 7.5 wt%, 10 wt%, and 12.5 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.

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

Table 1: Chemical composition of the LM6 aluminium alloy

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%

Table 2: Chemical composition of the flyash

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

3.2 Processing:

The composites were produced by liquid metallurgy route which was followed by squeeze casting. Firstly the matrix material was superheated to 800^oC in the Electric resistance furnace. It was the de-gassed by using Hexacholroethane tablets. By using a mechanical stirrer with a rotational speed of 600 rpm the vortex was created. At this stage the preheated flyash was slowly introduced into the slurry and 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 squeezed casting was allowed to cool down to the room temperature in the die itself and was later ejected out from the die. The test specimen for conducting hardness, wear testing and for microstructure were machined from as-cast samples.

3.3 Production of castings based on Orthogonal Array :

Dr. Taguchi has developed a method based on “Orthogonal array” of experiments which gives reduced number of experiments to be conducted without any significant loss of accuracy. Thus the Design of Experiments with Taguchi Method reduces time, cost, resources involved in the experiment.

Orthogonal Arrays (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for determining the significant effect on the performance characteristics (wear, hardness, productivity etc).

In this work the independent factors such as flyash % wt, Squeeze Pressure, and Squeeze time are considered at four levels of each and are shown in Table 3.

Factors	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Flyash (wt. %)	5	7.5	10	12.5
Squeeze Pressure (bar)	30	60	90	120
Squeeze time (min)	5	10	15	20

Table 3: The factors and the levels chosen for Squeeze casting of the composites

In this investigation three factors and four levels for each factor is used and the Orthogonal Array corresponding to L'16 is selected for the production of the castings.

3.4 Conduct of experiments according to the Orthogonal array table:

The casting of the composites based on the factors and their level selected were produced by squeeze casting method as per the Orthogonal Array table shown in the Table 4.

Specimen	**Flyash**		**Squeeze pressure (bar)**		**Squeeze time (min)**	
	Levels	**% wt. Flyash**	**Levels**	**Sq. Pr.(bar)**	**Levels**	**Sq. time (min)**
C1	1	5	1	30	1	5
C2	1	5	2	60	2	10
C3	1	5	3	90	3	15
C4	1	5	4	120	4	20
C5	2	7.5	1	30	2	10
C6	2	7.5	2	60	1	5
C7	2	7.5	3	90	4	20
C8	2	7.5	4	120	3	15
C9	3	10	1	30	3	15
C10	3	10	2	60	4	20
C11	3	10	3	90	1	5
C12	3	10	4	120	2	10
C13	4	12.5	1	30	4	20
C14	4	12.5	2	60	3	15
C15	4	12.5	3	90	2	10
C16	4	12.5	4	120	1	5

Table 4: Orthogonal Array table for the three factor and four levels

3.5 Macro and Microstructural Analysis

Macrostructural study was conducted on the as processed and machined composite castings in order to investigate distribution of flyash particles retained in the MMC. Castings were plain turned on lathe to remove 5mm of material to reveal the particle distribution on macroscopic scale.

Microstructural characterization studies were conducted on reinforced samples. This is accomplished by using Nikon metallurgical microscope. The composite samples were metallographically polished prior to examination.

3.6 Hardness Test

One of the important properties which effects wear resistance of any metal or alloy is hardness. The hardness measurements were carried out on Al-flyash particulate composite specimens by using Brinell hardness tester in order to investigate the influence of flyash particles on the matrix alloy hardness. The applied load was 500 Kgs and an indenter of 10 mm diameter steel ball was used. The specimens were prepared and polished on different grits of emery paper. 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.

3.7 Sliding Wear Test

The wear test was performed using computerized pin-on-disc wear testing machine to evaluate the dry sliding wear behavior of the composite specimen. The computerized pin-on-disc wear tester, shown in Figure 1 & 2, with data acquisition system is used for recording the wear rate. The specimen of Φ6 mm and 30 mm long prepared with different percentage of flyash, Squeeze Pressure and Squeeze time was subjected to the wear test.

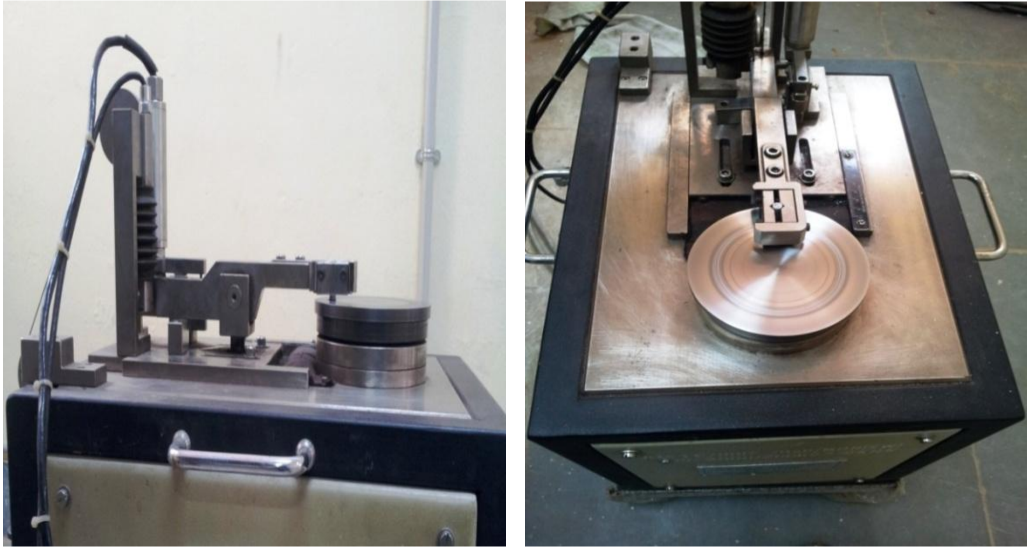


Fig 1 & 2: Computerized Pin-on-disc Wear tester

The load, speed and the track radius was set before the experiment was started. All the specimens were tested under a particular load of 9.81N, speed 500 rpm and track radius of 40mm. The experiment was carried-out for one hour on each specimen. The machine was started and the corresponding wear was recorded by the system. The experimental results were transformed into signal-to-noise (S/N) ratios. S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. The S/N ratio for wear rate using 'smaller the better' characteristic, which can be calculated as logarithmic transformation of the loss function, is given as: $S/N = -10 \log [1/n (\Sigma y^2)]$ where y is the observed data (wear rate) and n is the number of trials. The above S/N ratio transformation is suitable for minimization of wear rate.

IV. RESULTS AND DISCUSSION

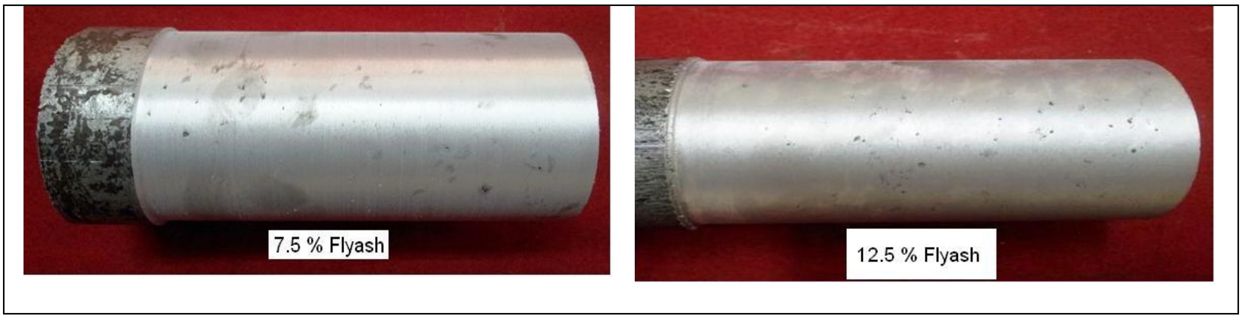


Figure 3 & 4: Marcograph of the squeeze cast specimen.

4.1 Macro and microstructural characterization

Macrostructural studies revealed reasonably uniform distribution of flyash particles with small percentages of segregation of particles. The distribution of flyash particles is influenced by the tendency of particles to float due to density differences and interactions with the solidifying metal. Photo macrograph, fig.3 & 4, shows the distribution of flyash particles (7.5% and 12.5% wt percentage) in squeeze cast ingot. The concentration of flyash particles was found to be more at the top than at the bottom of the castings which is due to the lesser density of the flyash particles.

The optical micrograph of 5%, 7.5%, 10% and 12.5% wt. Al-flyash composites is shown in Fig. 5. The micrographs show that there is a good interfacial bonding between flyash particles and Al matrix. Good interfacial bonding is attributed to heating of flyash particulates prior to dispersion and addition of magnesium in small quantities during stirring which improved wettability of flyash particles.

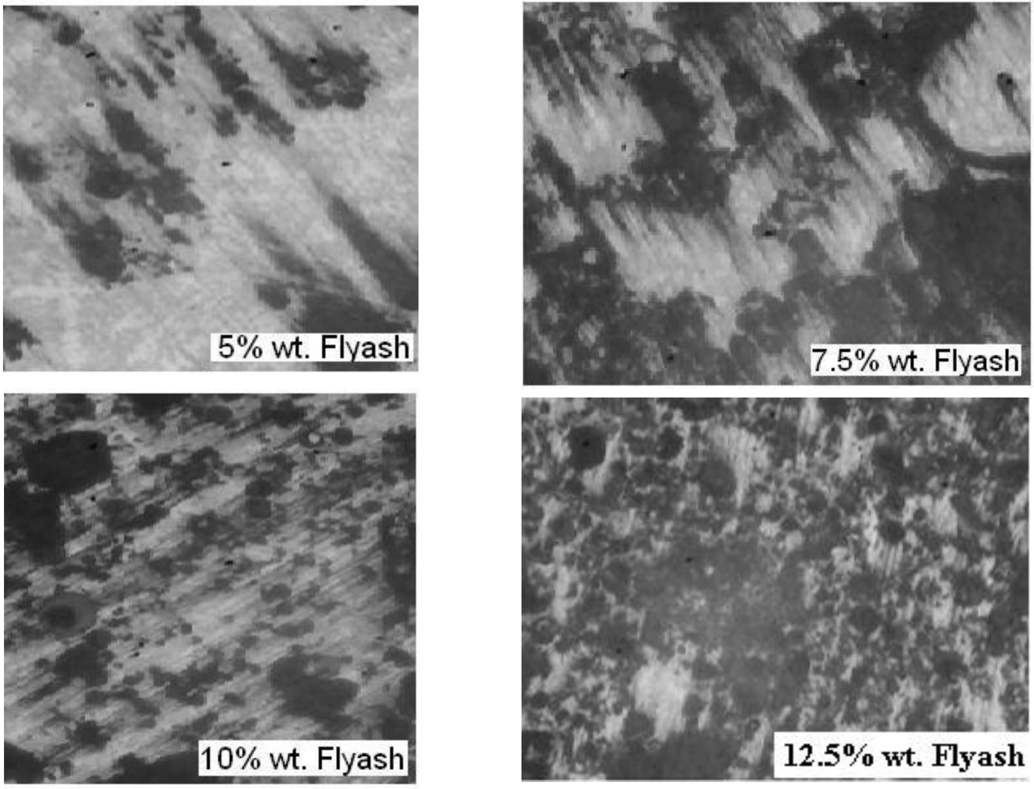


Figure 5: Optical micrograph of Al-flyash composites.

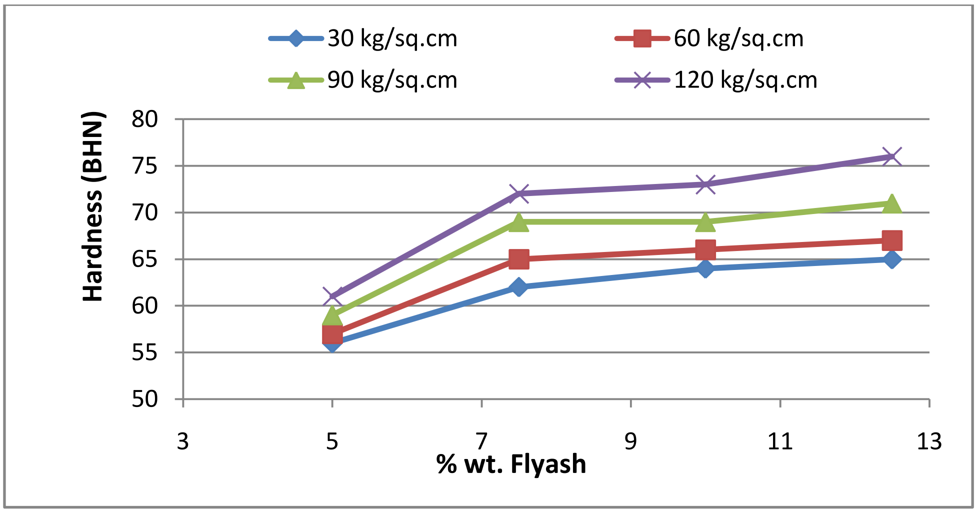
4.2 Hardness

The results of the hardness test for the various combinations of flyash wt.%, squeeze pressure and squeeze time are shown in the Table 5. It is observed from the graph 1 & 2 that hardness increases with increase in weight percentage of Flyash particles and the squeeze pressure on the matrix alloy of the squeeze cast composites. Increased hardness with increased weight percentage of flyash particles and the squeeze pressure can be attributed to the following reasons:

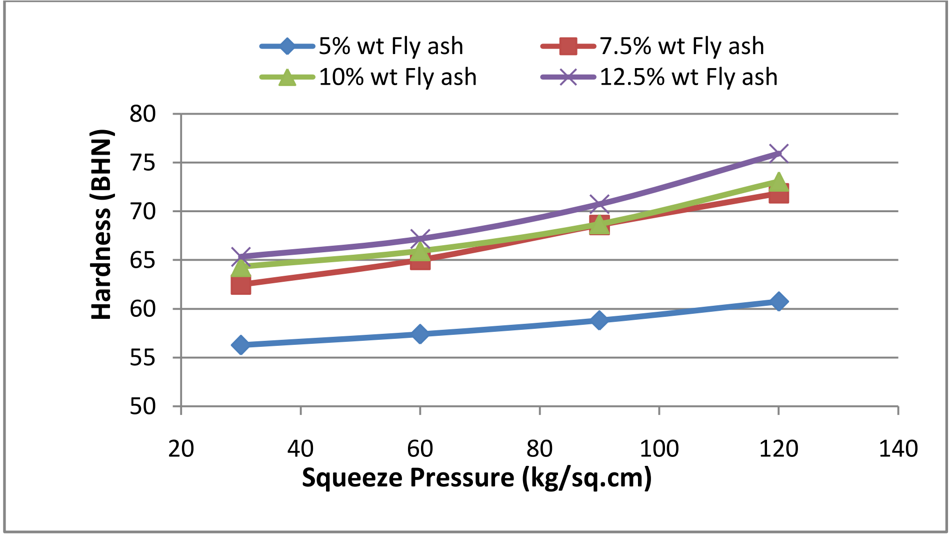
i) The flyash particles whose hardness is higher than the aluminium matrix material generally enhances the hardness of the composite material.
ii) Good interfacial bonding between matrix alloy and particle reinforcement.
iii) Increase in squeeze pressure increases the compaction of the matrix alloy.

Table 5: Readings of the Hardness test conducted on the composites

Specimen	**L**	**Fly ash (Wt.%)**	**L**	**Squeeze pr. in (kg/cm^2)**	**L**	**Squeeze time (min)**	**T1**	**T2**	**T3**	**T4**	**Avg BHN**
C1	1	5	1	30	1	5	55	60	53	56	56
C2	1	5	2	60	2	10	59	59	56	56	57
C3	1	5	3	90	3	15	58	59	60	59	59
C4	1	5	4	120	4	20	60	61	59	62	61
C5	2	7.5	1	30	2	10	62	62	63	63	62
C6	2	7.5	2	60	1	5	64	65	65	66	65
C7	2	7.5	3	90	4	20	69	69	68	69	69
C8	2	7.5	4	120	3	15	73	73	77	65	72
C9	3	10	1	30	3	15	64	64	63	66	64
C10	3	10	2	60	4	20	65	67	64	67	66
C11	3	10	3	90	1	5	68	69	69	69	69
C12	3	10	4	120	2	10	73	73	72	73	73
C13	4	12.5	1	30	4	20	65	65	65	66	65
C14	4	12.5	2	60	3	15	67	67	68	67	67
C15	4	12.5	3	90	2	10	69	71	73	70	71
C16	4	12.5	4	120	1	5	79	77	75	73	76



Graph 1: Graph of Hardness Vs %wt. Flyash



Graph 2: Graph of Hardness Vs Squeeze Pressure

4.3 Sliding Wear Test

The composites produced as per orthogonal array and their wear rate results obtained for various combinations of factors are shown in Table 6. The experimental values were transformed into S/N ratios and the calculated S/N ratio for each experiment is shown in Table 7.

Specimen	**% wt. Flyash**	**Sq. Pr. (bar)**	**Sq. time (min)**	**T1 in µm**	**T2 in µm**	**T3 in µm**	**T4 in µm**	**Ave. Wear (µm)**
C1	5	30	5	632	705	318	230	471
C2	5	60	10	640	636	434	400	528
C3	5	90	15	276	410	262	276	306
C4	5	120	20	409	437	380	524	438
C5	7.5	30	10	565	435	330	262	398
C6	7.5	60	5	402	507	385	333	407
C7	7.5	90	20	821	403	464	364	513
C8	7.5	120	15	517	560	483	440	500
C9	10	30	15	330	704	213	413	415
C10	10	60	20	425	387	330	291	358
C11	10	90	5	605	477	219	421	431
C12	10	120	10	495	709	580	372	539
C13	12.5	30	20	813	709	604	565	673
C14	12.5	60	15	821	609	528	388	587
C15	12.5	90	10	705	282	610	389	497
C16	12.5	120	5	490	508	463	554	504

Table 6: Pin on disc wear test results

Specimen	**SN Ratio**	**Spe. No**	**Ave. of SN Ratio for fly ash**	**Spe. No**	**Ave. of SN Ratio for Sq. Pr**	**Spe. No**	**Ave. of SN Ratio for Sq. time**
C1	-54.19	C1	-52.8978	C1	-54.0754	C1	-53.4144
C2	-54.63	C2		C5		C6	
C3	-49.88	C3		C9		C11	
C4	-52.88	C4		C13		C16	
C5	-52.34	C5	-53.3399	C2	-53.4402	C2	-54.0552
C6	-52.29	C6		C6		C5	
C7	-54.71	C7		C10		C12	
C8	-54.01	C8		C14		C15	
C9	-53.12	C9	-53.0638	C3	-53.0245	C3	-53.1695
C10	-51.17	C10		C7		C8	
C11	-53.11	C11		C11		C9	
C12	-54.85	C12		C15		C14	
C13	-56.65	C13	-55.1918	C4	-53.9532	C4	-53.8542
C14	-55.67	C14		C8		C7	
C15	-54.39	C15		C12		C10	
C16	-54.06	C16		C16		C13	
	MAX-MIN		2.2940		1.0509		0.8857
	RANK		I		II		III

Table 7: SN ratio values for flyash, squeeze pressure and squeeze time

The average wear of each trials are taken and SN ratios for all the experiments are calculated by using the SN ratio formula.

4.4 S/N Ratio Analysis

The influence of parameters such as % wt. fly ash content, squeeze pressure and squeeze time on wear rate has been evaluated using S/N ratio response analysis. The SN ratio for fly ash, squeeze pressure and squeeze time was calculated using $SN_i = -10 \log\left(\sum_{u=1}^{N_i} \frac{y_u^2}{N_i}\right)$ where, i=experiment number, u=trial number and N_i=number of trials for experiment number i. The control parameter with the strongest influence was determined by taking the difference between the maximum and minimum values of mean SN ratio of a particular parameter, SN max-min $_F$ = maximum-minimum. Higher the difference between the mean of S/N ratios, the more influential is the control parameter. The S/N ratio response analysis, presented in Table 7 shows that among all the factors, % wt. fly ash content was found to have highest difference than the other two parameters. Therefore, it can be construed that % wt. fly ash is the most influential and significant parameter followed by squeeze pressure and squeeze time respectively in controlling the wear rate of the composite material.

V. CONCLUSIONS

From the present investigation the following conclusions are drawn.

1. The squeeze casting process was successfully carried out in producing Al-flyash composites containing upto 12.5 wt. % flyash as reinforcement.
2. From the macrostructure analysis it was evident that presence of porosity in the composites produced by squeeze casting method was almost eliminated.
3. The S/N ratio analysis results show that the % wt of flyash has the strongest effect among the other parameters on the sliding wear resistance of the Al-flyash composite.
4. The order of influence of the controllable factors on the wear resistance of the composite is as follows: % wt. fly ash content, squeeze pressure and squeeze time respectively.

REFERENCES

1. M K Surappa, Aluminium matrix composites: Challenges and Opportunities, *Sadhana* Vol. 28, Parts 1&2, February / April 2003, pp. 319–334
2. S. Anoop, S. Natarajan, S.P. Kumaresh Babu, Analysis of factors influencing dry sliding wear behavior of Al/SiCp–
3. brake pad tribosystem, *Materials and Design* 30 (2009) 3831–3838
4. D. Milosavljević, G. Jovičić, Properties of Metal Matrix Composites for Automotive Applications , *Tribology in industry*, Volume 24, No. 3&4, 2002.
5. Ray Erikson, Syntactic Metals: A Survey of Current Technology, *5th Aerospace Materials, Processes and Environmental Technology Conference*, Von Braun Center, Huntsville, Alabama, September 16—18, 2002.
6. M.R.Ghomashchi, A.Vikhrov, Squeeze casting: an overview, *Journal of Materials Processing Technology 101*(2000) 1-9
7. A. Daoud, M.T. Abou El-Khair, and A.N. Abdel-Azim, Effect of Al_2O_3 Particles on the Microstructure and Sliding Wear of 7075 Al Alloy Manufactured by Squeeze Casting Method, *Journal of Materials Engineering and Performance* (2004) 13:135-143
8. Bekir Sadık Unlu, Investigation of tribological and mechanical properties Al2O3–SiC reinforced Al composites manufactured by casting or P/M method, *Materials and Design 29* (2008) 2002–2008.
9. Varuzan Kevorkijan, Development of Al MMC composites for automotive Industry , *Yugoslav Association of Metallurgical Engineers*, June 26-27 2002
10. J. Bienia, M. Walczak, B. Surowska, J. Sobczaka, Microstructure And Corrosion Behaviour Of Aluminum Fly Ash Composites, *Journal of Optoelectronics and Advanced Materials*, Vol. 5, No. 2, June 2003, p. 493 - 502
11. L.J. Yang, The effect of casting temperature on the properties of squeeze cast aluminium and zinc alloys, *Journal of Materials Processing Technology 140* (2003) 391–396
12. T.M. Yue, Squeeze casting of high-strength aluminium wrought alloy AA7010, *Journal of Materials Processing Technology 6* & (1997) 179-185
13. D.J. Britnell, K. Neailey, Macrosegregation in thin walled castings produced via the direct squeeze casting process, *Journal of Materials Processing Technology 138* (2003) 306–310
14. T.M. Yue, G.A. Chadwick , Squeeze Casting of Light alloys and their Composites, *Journal of Material Processing Technology 58* (1996) 302-307
15. C.S. Goh, K.S. Soh , P.H. Oon , B.W. Chua, Effect of squeeze casting parameters on the mechanical properties of AZ91–Ca Mg alloys, *Materials and Design 31* (2010) S50–S53
16. S. Venkat Prasad, R. Subramanian, N. Radhika, L. Arun, N. Praveen, Influence of Parameters on the Dry Sliding Wear Behaviour of Aluminium/Fly ash/Graphite Hybrid Metal Matrix Composites, *European Journal of Scientific Research* Vol.53 No.2 (2011), pp.280-290
17. S.V. Prasad, and R. Asthana, Aluminum metal–matrix composites for automotive applications: tribological considerations, *Tribology Letters*, Vol. 17, No. 3, October 2004
18. D.B. Miracle, Metal matrix composites – From science to technological significance, *Composites Science and Technology 65* (2005) 2526–2540
19. Pradeep K. Rohatgi, Metal-matrix Composites, *Defence Science Journal*, Vol 43, No 4, October 1993, pp 323-349
20. T.P.D. Rajan, R.M. Pillai, B.C. Pai, K.G. Satyanarayana, P.K. Rohatgi, Fabrication and characterisation of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes, *Composites Science and Technology 67* (2007) 3369–3377.
21. P.K. Rohatgi, D. Weiss, and Nikhil Gupta, Applications of Fly Ash in Synthesizing Low-Cost MMCs for Automotive and Other applications , *Low-Cost Composites in Vehicle Manufacture* an Overview.
22. Sudarshan, M.K. Surappa, Dry sliding wear of fly ash particle reinforced A356 Al composites, *Wear 265* (2008) 349–360
23. K.V. Mahendra, K. Radhakrishna, Fabrication of Al–4.5% Cu alloy with fly ash metal matrix composites and its characterization 23), *Materials Science-Poland*, Vol. 25, No. 1, 2007,
24. M. Ramachandra, K. Radhakrishna, Effect of reinforcement of flyash on sliding wear, slurry erosive wear and corrosive behavior of aluminium matrix composite, *Wear 262* (2007) 1450–1462
25. Pradeep. K. Rohatgi, Pressure infiltration technique for the synthesis of A356 Al/Fly ash composites: Microstructure and Tribological performance Grigorious Itskos, *World of Coal ash (WOCA) Conference*: May 9-12, 2011
26. J. Babu Rao, D. Venkata Rao and N.R.M.R. Bhargava, Development of light weight ALFA composites, *International Journal of Engineering, Science and Technology* Vol. 2, No. 11, 2010, pp. 50-59 www.ijest-ng.com

27. T.P.D. Rajan, R.M. Pillai, B.C. Pai, K.G. Satyanarayana, P.K. Rohatgi, Fabrication and characterisation of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes, *Composites Science and Technology 67* (2007) 3369–3377
28. S. Basavarajappa and G. Chandramohan, Dry Sliding Wear Behavior of Metal Matrix Composites: A Statistical Approach, *JMEPEG (2006)* 15:656-660
29. S. Basavarajappa, G. Chandramohan, J . Paulo Davim, Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites, Materials and Design 28 (2007) 1393–1398
30. H. Siddhi Jailani & A. Rajadurai & B. Mohan & A. Senthil Kumar & T. Sornakumar, Multi-response optimisation of sintering parameters of Al–Si alloy/fly ash composite using Taguchi method and grey relational analysis, *Int J Adv Manuf Technol (2009)* 45:362–369.
31. P. Vijian, V.P. Arunachalam, Optimization of squeeze cast parameters of LM6 aluminium alloy for surface roughness using Taguchi method, *Journal of Materials Processing Technology 180* (2006) 161–166