INVESTIGATION ON THE BEHAVIOUR OF ALFA COMPOSITE IN PRE AND POST HEAT TREATED CONDITIONS

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Abstract

Of the many types of particulate reinforcements fly ash is one type that is being used from the recent past to develop the composites. In the current research fly ash is reinforced in the aluminium alloy AA2024 to develop ALFA (ALuminium Fly Ash) composites. The stir casting technique is employed in the development of the said composite as this technique is economical and would produce a composite with fairly uniform distribution of the fly ash reinforcement in the alloy matrix. The fly ash was added in 2.5 and 5% by weight to the molten metal. Increase in the percentage weight of fly ash reinforcement resulted improvement in the mechanical properties. The composite is tested for hardness, tensile strength and wear performance under pre-heat treatment, as quenched and in peak hardened conditions. The peak hardened composite showed a superior hardness, tensile strength and wear resistance than the others.

Keywords: *stir casting, fly ash composites, heat treatment, and characterization*

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1. INTRODUCTION

MMCs are tailor made materials, resulting when two or more non similar materials (of which one is a metal) are mixed to improve the properties. Conventional materials may not always give the desired properties in all service environments. MMCs exhibit highly enhanced properties like higher specific strength, modulus, damping ability and good resistance to wear in comparison to plain alloys. From the recent past researchers interest has been in composites processing lower density and lower cost dispersions. Of the many particulate dispersions employed, fly ash is one of the low cost and low density material hugely existing as waste material in coal fired plants. Thus, composite having fly ash as reinforcing material will reduce the cost of automobile and small engine components.

In the on hand research, 2024 aluminium alloy is considered as the base matrix and fly ash as the reinforcement. Motorized stir casting is adapted for fabricating composite specimens. The fly ash was mixed in 2.5 and 5% by weight to the alloy melt. The composite is tested for hardness, tensile strength wear characteristics.

Previously there were many attempts by the investigators to fabricate ALFA composites especially with wide variety of aluminium grades. The summary of their findings has been presented here in the chronological order of the work progress.

T.P.D Rajan *et al* [1] analyzed the influence of different stir casting methods on the structure and properties of fine fly ash particulates (13 μm) reinforced Al–7Si–0.35Mg alloy composite. The liquid metal stir casting, compo casting (semi solid processing), and modified compo casting followed by squeeze casting methods were analyzed and found that the latter has been effective method to fairly disperse , give relatively low agglomeration and pore free fly ash particle reinforced composites.

Al (12 wt. % Si) matrix was introduced with 15 wt. % of fly ash particles by liquid state processing in the investigation by M. Ramachandra *et al*, [2]. The wear and friction properties of the as cast composite is examined by sliding wear test, slurry erosive wear test and fog corrosion test. The findings of this group is that the resistance to wear increased with increase in fly ash quantity, but decreased with rise in normal load, and sliding velocity. In the study reported by K.V. Mahendra and K. Radhakrishna [3] corrosion rate enhanced with rise in fly ash content in Al–4.5% Cu alloy matrix. The composite here is fabricated by regular foundry technique. Fly ash was included in 5, 10, and 15 wt. % in the melt. The test results indicated an improvement in hardness, tensile strength, compression strength, and impact strength with rise in the fly ash quantity. On the other hand the density was found to reduce with rise in fly ash quantity. Resistance to the dry wear and slurry erosive wear enhanced with rise in fly ash quantity.

A356 Al based fly ash composite was processed by stir cast method followed by hot extrusion. Composites with 6 and 12 vol. % of fly ash dispersions were produced in the investigation by Sudarshan and M.K.Surappa [4]. Fly ash with narrow size (53–106 µm) and wide size (0.5-400 µm) was employed for producing composites. Hardness, tensile and compressive strength, damping properties of the plain alloy and composites were tested. The findings of the present work are that the composites reinforced with former size range fly ash particle exhibited better mechanical properties in comparison with the composites having later size range particles. Keeping in mind the previous reference A356 based composites containing 6 and 12 vol. % of fly ash particles were further tested for sliding wear in dry conditions by the same team [5]. The dry sliding wear characteristics of plain alloy and composites was investigated using Pin-On-Disc machine by loading at 10, 20, 50, 65 and 80 N at a constant sliding velocity of 1 m/s. The test outcomes showed that resistance to wear of ALFA composite is almost similar to that of aluminium oxide and silicon carbide dispersed aluminium alloy. Size and volume fraction of fly ash particles were found to be mainly affecting the wear and friction characteristics of composites. In the latest work by S. Sarkar *et al* [6] composites are fabricated by varying quantity of fly ash dispersion phase. Also, the composites were analyzed through XRD, wet chemical analysis, and image analysis. Mechanical and wear characteristics of the composites are also evaluated. The results showed that, fly ash can be added to maximum of 17 wt. % to Al-Mg alloy by vortex method to fabricate composites. Introduction of Mg is found to enhance the wettability of fly ash with Al melt and hence leads to an increase in the retention of the fly ash in the composites. The strength and hardness could be enhanced significantly with the inclusion of fly ash. The ductility was also appreciable as compared to the composites analyzed previously. The resistance to wear was also increased with the increase in quantity of fly ash and Mg.

Significant work is done by the researchers like A. Daouda *et al* [7] on nickel coated fly ash micro balloon composites. This group demonstrated that stir casting technique could be effective to fabricate Pb–Ca–Sn alloy based composites having high quantity (45 vol. %) of Ni- coated fly ash micro balloons. The thermal cycling characteristics of A535 based composites having varying amount of fly ash produced through stir casting are investigated by W.A.Uju *et al* [8]. The test samples were applied with ten thermal cycles in the range 40-300^{o}C in a Seteram Setsys Evolution Thermo mechanical analyzer. The test outcome indicated that strain hysteresis loops evolved during thermal cycling. The hysteresis and residual plastic strains introduced in the alloy while thermal cycling reduced with the increase of fly ash. Also, the addition of fly ash in A535 enhanced its dimensional stability.

The possibility of using the aluminium syntactic foam to develop fly ash composite by making use of stir casting technique is explored in the study indicated by D.P. Mondal, S. Das [9].The produced syntactic foam was analyzed through microstructure, hardness and compressive deformation characteristics. It was observed that the syntactic foam behaves like high strength Al foam under compressive deformation showing flat plateau area in the stress-strain plot.

In the research work by N.Suresh *et al* [10], composites were synthesized with cenospheres type fly ash as dispersion phase and eutectic Al-Si alloy as a matrix. Stir casting approach was employed to reinforce fly ash with 1% to 10% wt. in the Al-Si alloy matrix. The analysis shows that as the quantity of fly ash increased, hardness and ultimate tensile strength improved by 34.7% and 44.3% respectively, while the density reduced by 13.2%. The loss of wear reduced by 33% at the peak sliding distance. But, the % elongation indicated an only a marginal reduction with different % of fly ash considered in their work. Also the surface roughness rose with the inclusion of fly ash particles.

In the study by Sathyabalan *et al* [11], an Artificial Neural Network was designed to guess the implication of the size and quantity of both fly ash and SiC dispersions on the wear loss of LM6 Al alloy. The prediction is found to be accurate as seen from the verification of test results.

The major disadvantage of the liquid state processing is the presence of chemical reactions among Al and fly ash at elevated temperatures. Precipitator fly ash substrate, produced by hot pressing in argon, was investigated by N. Sobczak *et al* [12] by TEM and EDAX. The findings proved the oxy-redox reactions among Al and such fly ash constituents as SiO_2, Fe_2O_3, Fe_3O_4 and mullite.

2. EXPERIMENTAL PROCEDURE

2.1 Fly Ash

The fly ash adapted as reinforcement in this work is a precipitator type fly ash borrowed from Bellary Thermal Power Station, Bellary, Karnataka, India which is a light gray colored fine powder that is passing 100% through 300 µm ISS sieve and has a bulk density 1.11gm /cc. Chemical analysis of fly ash is done as per IS: 1727-1967 RA 2004 and the components in it are shown in table 1. Sieve analysis data and the particle size distribution of fly ash are shown in table 2 and figure 1 respectively.

2.2 Al Alloy

AA2024 is used as matrix material whose chemical details are shown in table 3. The cast alloy was provided by MMMT Institute, MRC, Bangalore, Karnataka, India. This alloy has good specific strength and excellent fatigue resistance properties. It is extensively applied in aircraft structural parts, fittings of aircraft, hardware, wheels for truck and components in transport sector.

2.3 Synthesis of Composite

3 kg of 2024 aluminium is melted in a crucible of electric furnace. The molten liquid temperature was increased to 850°C and the scum powder in little amount is introduced to the melt for eliminating impurities. Degassing of the melt is done by adding dry hexa chloroethane of 10 gm weight (C_2Cl_6, 0.3 % by weight). The moisture in fly ash is removed by pre heating at 400°C for 1 h. Fly ash with varying % wt. is introduced to the melt vortex while stirring. The speed of the mild stirrer was in the range 350-400 rpm; duration of stirring was for 10 min to let for better mixing af alloy melt and fly ash. While stirring 0.5 % wt. of pieces of Mg is introduced to melt for enhancing the wettability between fly ash and melt. The molten alloy is held at 800-850°C while the fly ash is added. The temperature of the melt and duration were maintained at 850°C and 5 min respectively while filling the molds. The molds were preheated to around 300°C before filling them with melt. Two categories of Al-fly ash composites with 2.5 and 5 % wt. of fly ash were produced. The solidification time of the melt mix is allowed for 2 h in the open atmosphere. The cast composites are shown in figure 2.

2.4 Hardness Test

The hardness specimens prepared were first subjected to lapping to obtain a polished surface on which indentations could be made. Hardness test was then performed on the digital Vickers Hardness testing machine [model-MMT X7A].Three readings were taken per sample and the average was recorded as the hardness value for that particular sample. Table 4 gives the results of hardness test.

2.5 Tensile Test

This test was conducted as per ASTM-E8M standard in electronic tensometer (model-ER3) with computerized data acquiring unit. The online plot of Load (kN)-vs-Cross head travel (mm) is obtained through the data acquiring unit. Tables 5-6 give the results of tensile test on specimens.

2.6 Heat Treatment and Post Heat Treatment Testing

After the initial pre-heat treatment testing, age hardening was performed on the rest of the specimens. First, all the remaining specimens of the 5 wt. % fly ash composition were introduced into a furnace maintained at about 550°C for about 1.5 h. After this, all the specimens were removed from the furnace and quenched in a bowl of water (25°C). One sample each of hardness, wear and tensile were taken at this stage and their individual testing was carried out to obtain the properties "as quenched". The remaining hardness specimens were again introduced into the furnace, now maintained at 150°C.One sample was taken out after each hour and tested on the Vickers testing machine until the peak hardness was achieved. In this case, that is for the 5% wt. fly ash composition, the peak hardness was achieved after 2.5 h, with peak hardness value as 145.4. Next, the remaining wear and tensile test specimen were kept in the furnace at 150°C and aged up to the peak hardened duration (2.5 h in case of the 5 wt. % fly ash composition). Similarly peak aged tensile and wear samples were removed and respective tests were performed on them so as to obtain the properties of the material at the peak hardened condition. The same process was then repeated for the 2.5% fly ash composition. The peak hardness time thus achieved in this case was 3 h 15 min and the peak hardness value was 163.4.

3. RESULTS AND DISCUSSION

3.1 Hardness Test

Figure 3 shows the variation of hardness values with increasing time. For the 5% composition there was an increase in the hardness value until the peak hardness was achieved after 150 min. For the 2.5% composition the peak hardness was achieved after 195 min. The hardness values decreased after the maximum limit was achieved. The figure 4 shows a comparison of the hardness values that were obtained in the various stages of heat treatment i.e. pre- heat treatment, as quenched and peak hardened stages. It is observed that the hardness values increased for both the 2.5 and 5 wt. % fly ash compositions as the heat treatment gradually progressed. The maximum hardness for the 5 wt. % fly ash composition came out to be 145.4 while that for the 2.5 wt. % composition it was 163.4.

3.2 Tensile Test

The figure 5 shows a comparative graph of the variation of the maximum load with displacement at various stages of heat treatment in case of the 2.5 wt. % fly ash composition. The maximum load increased with displacement up to a certain point and then it showed a decreasing trend. The peak loads were observed to be 647.2, 970.8 and 1333 N at the pre heat treatment, as quenched and peak hardened stages respectively. The figure 6 shows a comparative graph of the variation of the maximum load with displacement at various stages of heat treatment in case of the 5 wt.% fly ash composition. The maximum load increased with displacement up to a certain point and then it showed a decreasing trend. The peak loads were observed to be 764.9, 1167 and 1471 N at the pre heat treatment, as quenched and peak hardened stages respectively.

3.3 Wear Test

Wear test was conducted in a pin-on-disc tribo meter under dry sliding conditions. The normal load selected for the entire test was 10, 20 and 30 N with a constant speed of 300 rpm. The results of the wear test conducted in the laboratory conditions are shown in tables 7-8 for composite specimens containing 2.5 and 5 wt. % of fly ash respectively. Figures 7 and 8 indicate that the peak hardened AA2024+5 composite is having superior wear performance under different conditions.

4. TABLES AND FIGURES

Table 1: Chemical composition of fly ash

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
% wt.	62.63	23.35	3.93	2.04	0.46	1.34	0.032	0.030	0.39

Table 2: Sieve analysis data of fly ash sample

ISS Mesh Number	ASTM Mesh Number	Weight retained(gm)	% wt.	Particle size(μm)
106	140	0.67	1.34	105
75	75	7.78	15.56	75
53	53	0.05	0.1	53
45	45	0.07	0.14	45
0	0	41.43	82.86	< 45

Table 3: Chemical composition of AA2024

Element	Si	Mg	Cu	Mn	Fe	Ni	Ti	Zn	Pb	Sn	Al
% wt.	0.5	0.066	4.51	0.13	0.663	0.075	0.013	0.118	0.029	0.021	Rest

Table 4: Hardness of specimens

Type of specimen	VHN		
	pre-heat treatment	As quenched	Peak hardened
AA2024+2.5	125.5	126.8	163.4 (3hr 15 min)
AA2024+5	133.7	126.5	145.4 (2.5 hrs)

Table 5: Results of 2.5% wt. fly ash tensile test

l (mm)	A (mm^2)	Eng UTS (N/mm^2)	True UTS (N/mm^2)	ε	Peak load (N)	Peak disp (mm)	Break load (N)	Break disp (mm)	Peak disp (%)	Break disp (%)
pre-heat treatment										
27.4	15.13	42.8	43.2	0.01	647.2	0.24	647.2	0.24	0.87	0.87

as quenched										
28.2	15.34	63.3	64.3	0.02	970.8	0.47	970.8	0.47	1.66	1.66
peak hardened										
27	16.76	79.6	81.0	0.03	1333	0.48	1039.5	0.56	1.79	2.08

Table 6: Results of 5% wt. fly ash tensile test

l (mm)	A (mm^2)	Eng UTS (N/mm^2)	True UTS (N/mm^2)	ε	Peak load (N)	Peak disp (mm)	Break load (N)	Break disp (mm)	Peak disp (%)	Break disp (%)
pre-heat treatment										
27.5	16.91	45.2	46.0	0.02	764.9	0.47	590	0.54	1.7	1.98
as quenched										
28	16.4	71.2	72.5	0.02	1167	0.54	1167	0.54	1.94	1.94
peak hardened										
27	16.26	90.5	92.0	0.02	1471	0.47	68.65	0.58	1.73	2.14

Table 7: Wear test results for 2.5% wt. fly ash composite conducted at 300 rpm for 1 h duration in dry conditions

As quenched			
Load (N)	**10**	**25**	**35**
Initial weight (gm)	3.714	3.625	3.465
Final weight (gm)	3.625	3.465	3.255
Weight loss (gm)	0.10	0.16	0.21

Pre-heat treatment			
Initial weight (gm)	3.725	3.655	3.535
Final weight (gm)	3.655	3.535	3.365
Weight loss (gm)	0.07	0.12	0.17
Peak hardened			
Initial weight (gm)	3.711	3.661	3.571
Final weight (gm)	3.661	3.571	3.441
Weight loss (gm)	0.05	0.09	0.13

Table 8: Wear test results for 5% wt. fly ash composite conducted at 300 rpm for 1 h duration in dry conditions

As quenched			
Load (N)	**10**	**20**	**30**
Initial weight (gm)	3.721	3.641	3.511
Final weight (gm)	3.641	3.511	3.321
Weight loss (gm)	0.08	0.13	0.19
Pre-heat treatment			
Initial weight (gm)	3.728	3.658	3.548
Final weight (gm)	3.658	3.548	3.408
Weight loss (gm)	0.07	0.11	0.14
Peak hardened			
Initial weight (gm)	3.722	3.692	3.622
Final weight (gm)	3.692	3.622	3.522
Weight loss (gm)	0.03	0.07	0.10

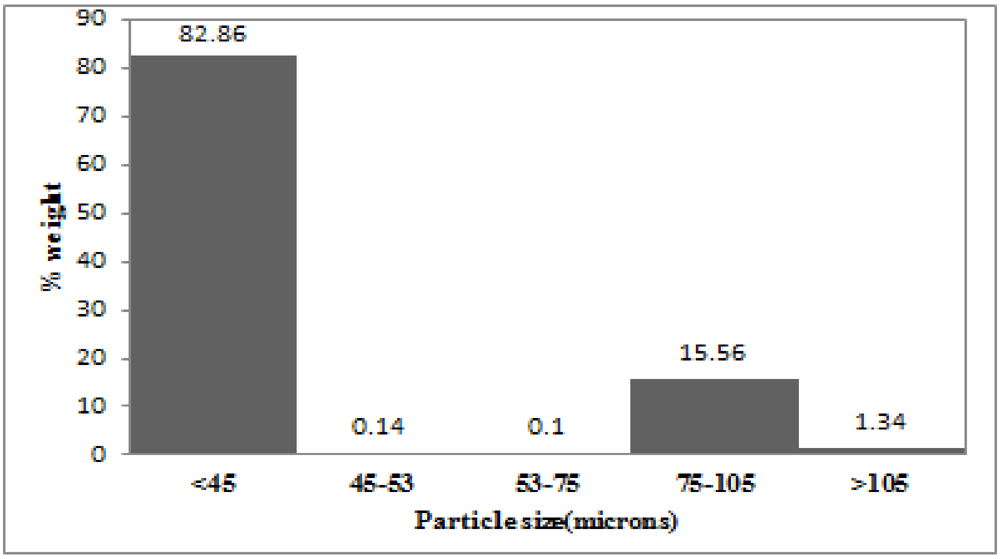

Fig. 1: Fly ash particle size distribution

Fig. 2: As cast specimens solidified in the crucible

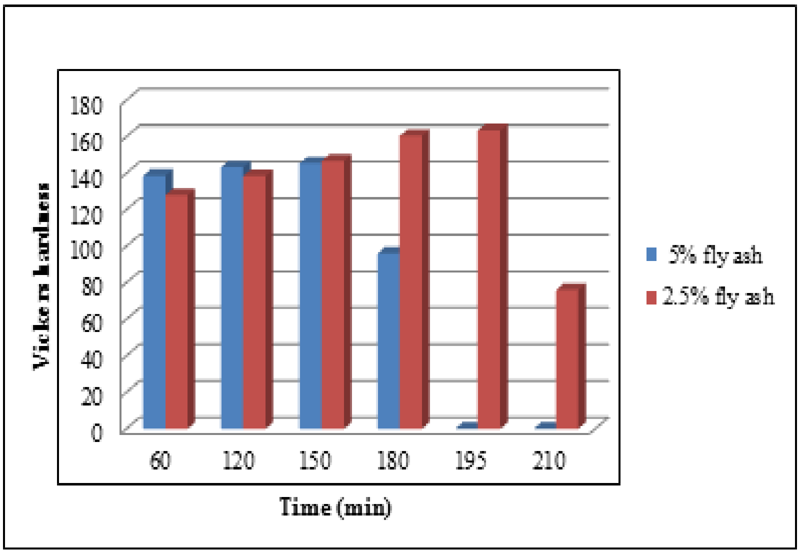

Fig. 3: Variation of hardness values with time (Obtaining the peak hardened state)

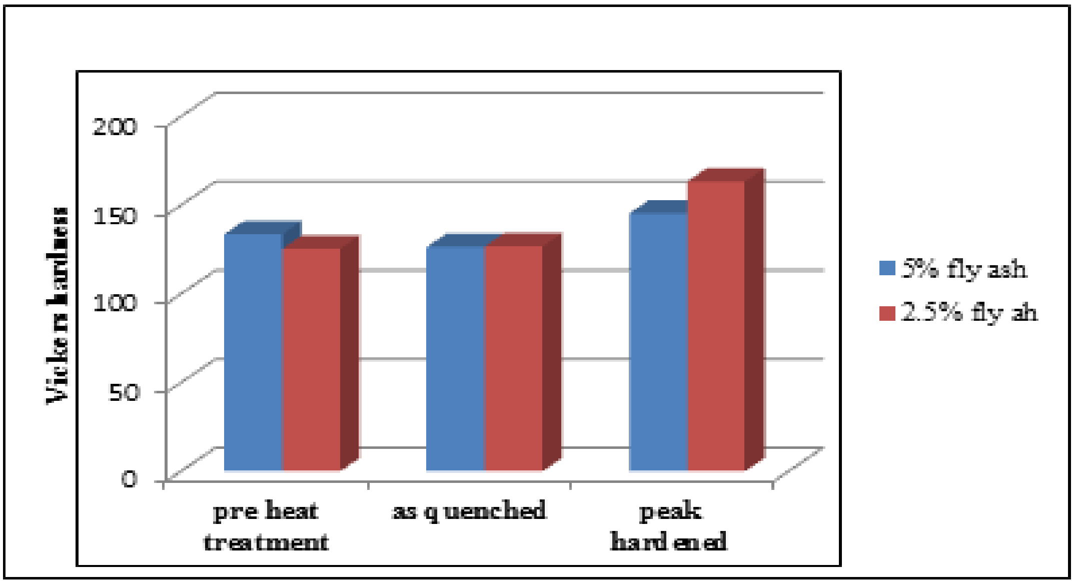

Fig. 4: Comparison of hardness values at various stages of heat treatment

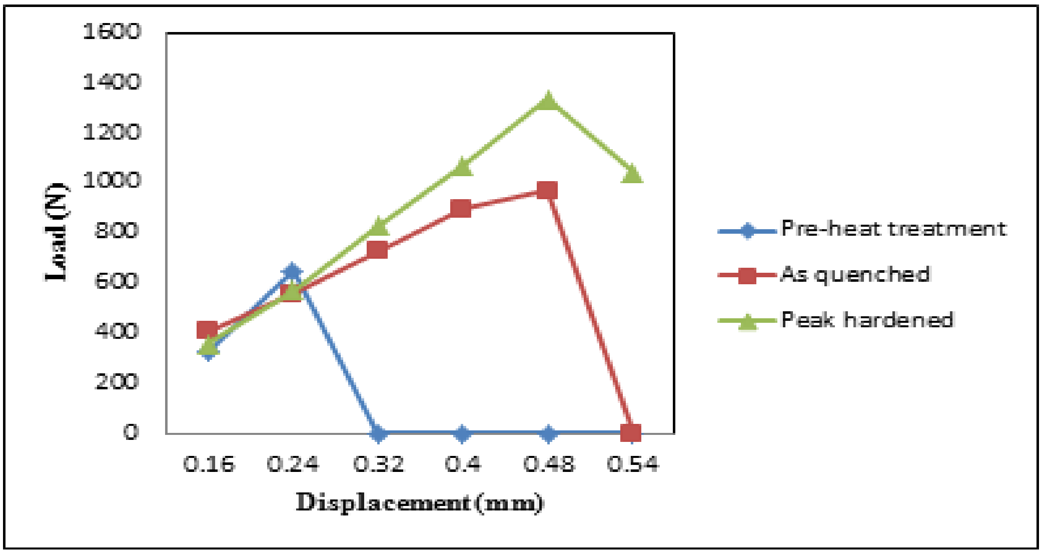

Fig. 5: Comparison of tensile test results at various stages of heat treatment for 2.5% wt. fly ash composite

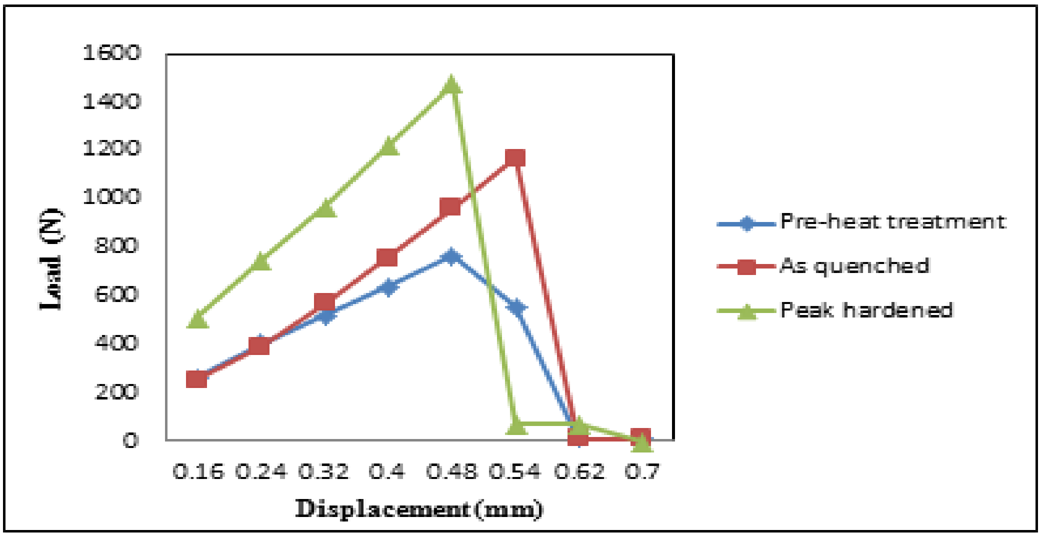

Fig. 6: Comparison of tensile test results at various stages of heat treatment for 5% wt. fly ash composite

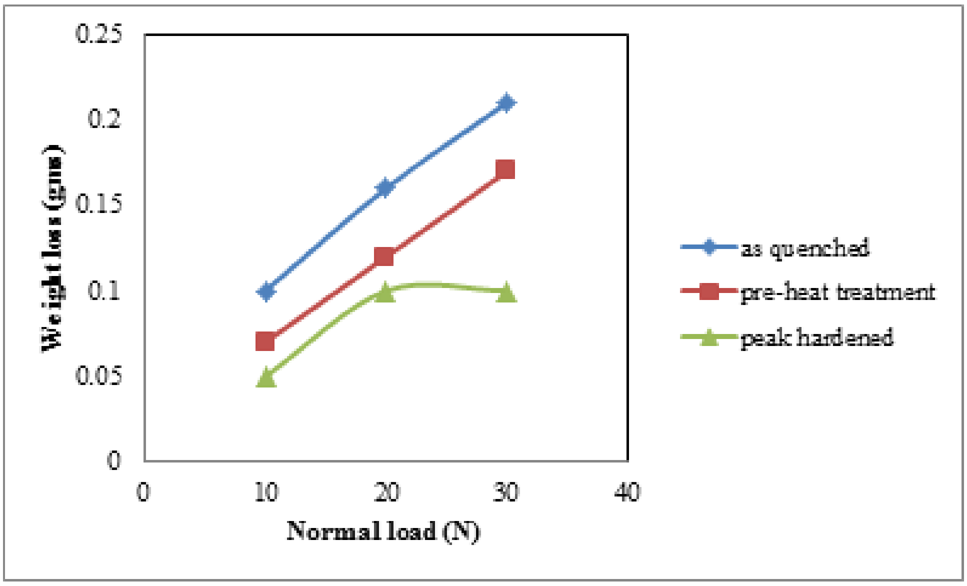

Fig. 7: Wear behaviour for 2.5% wt. fly ash composite

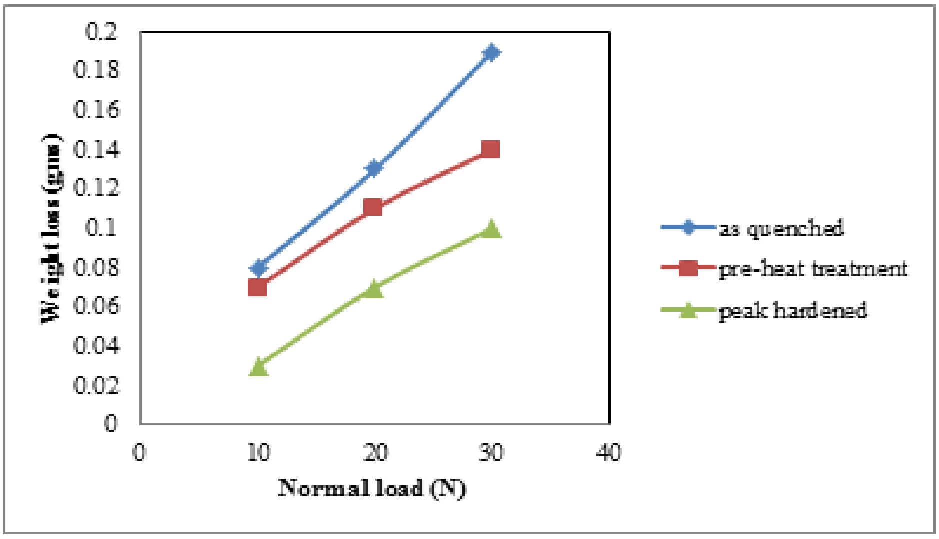

Fig. 8: Wear behaviour for 5% wt. fly ash composite

5. CONCLUSION

1) Composite containing 2.5 and 5% by wt. of fly ash were successfully produced by stir casting with homogeneous dispersion of fly ash in the aluminium alloy matrix.
2) The composite containing 5% by wt. of fly ash showed superior mechanical properties than that containing 2.5 wt. %.
3) Composite were successfully heat treated in different conditions like quenching in water (25°C) and peak hardened state.
4) The hardness (VHN), tensile strength and wear characteristics were improved much in the peak hardened state.
5) Aluminium fly ash composites can be used in wear resistant applications there by reducing the cost of components in various applications.

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