Correlation of Surface Profiles and Worn Surfaces of AA6061/Graphite Metal Matrix Composites

A. Chennakesava Reddy

Professor, Department of Mechanical Engineering, JNTU College of Engineering, Hyderabad, India

Abstract: *In the present work, the AA6061alloy/graphite metal matrix composites were manufactured at 10% and 30% volume fractions of graphite. The pin-on-disc wear test was carried out with different combinations of reinforcement, sliding distance, normal load, sliding speed. Based on the experimental results surface profiles of worn surfaces were constructed and correlated.*

Keywords: *Metal matrix composite, surface profiles, AA6061 alloy, graphite, wear, sliding distance, normal load, speed.*

1. INTRODUCTION

Metal matrix composites reinforced with nano-particles are being investigated worldwide in recent years, owing to their promising properties suitable for a large number of functional and structural applications. In the literature, different kinds of matrix metals have been coupled with several types of nanoscale phases [1-17]. Aluminum-graphite composites are made by reinforcing graphite nanoparticle in molten aluminum alloy. At present the composite is being extensively field tested across world as a replacement for expensive conventional bearing alloys such as phosphor bronze for pistons, piston rings and cylinder liners [18]. Improvements in tribological properties are accompanied by a decrease in the strength and ductility of aluminum-graphite composites [19]. The dry wear characteristics of aluminum- graphite composites are influenced by the transport of graphite from the bulk to the mating surface during sliding and the plastic deformation of the subsurface. Graphite addition to aluminum alloy deteriorates the wear properties. High wear can occur in mechanisms which operate in conditions of dry friction [20-23].

The purpose of this research work was to correlate surface profiles with worn surfaces AA6061/graphite metal matrix composites. The wear tests were conducted on pin-on-disc equipment. The design of experiments was based on Taguchi techniques [24, 25].

2. MATERIALS AND METHODS

AA6061 alloy/graphite composites were fabricated by the stir casting process. The T8 heat-treated samples were machined to get cylindrical specimens of 10 mm diameter and 30 mm length for the dry wear tests. The levels chosen for the controllable wear parameters are précised in Table 1. The orthogonal array, L9 was ideal to carry out wear experiments (Table 2). A pin-on-disc wear monitor (ASTM G99) was employed to assess the wear behavior of AA6061 alloy/graphite composite specimens against hardened ground steel (En32) disc (figure 1a). Knoop microhardness was conducted before and after wear tests. The surface roughness of worn samples was measured using Talysurf surface roughness tester as shown in figure 1b.

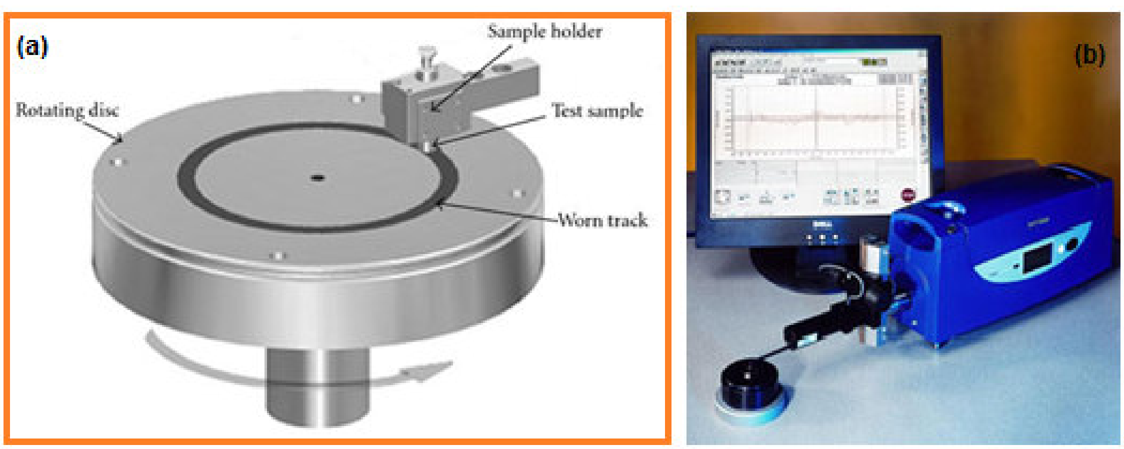

Figure 1: Tests carried out in the present work: (a) Pin-on-disc wear test and (b) Surface roughness test.

Table 1: Wear parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Reinforcement, Vol.%	A	10	20	30
Load, N	B	10	20	30
Speed, m/s	C	2	3	4
Sliding distance, m	D	200	400	600

Table 2: Orthogonal array (L9) and control parameters

Treat No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3. RESULTS AND DISCUSSION

All process parameters are acceptable as they satisfy Fisher's test at 90% confidence level. The analysis of variance (ANOVA) is presented in Table 3. The graphite volume fraction (A) accords 53.52% of variation the wear rate. The normal load (B) affords 12.11% of variation in the wear rate. The sliding speed (C) allows 0.56% of variation in the wear rate. The sliding distance (D) cedes 33.80% of variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.999, 0.971, 0.279 and 0.991. The trend of mean values obtained by Taguchi techniques is same as that of R-squared values. The influence of sliding speed is nearly negligible on the wear rate of AA6061 alloy/graphite composites.

Table 3: ANOVA summary of the effective stress

Source	Sum 1	Sum 2	Sum 3	SS	v	V	F	P
A	1.35	1.19	1.05	1.50E-02	1	1.50E-02	9.02E+13	34.70
B	1.13	1.16	1.30	5.49E-03	1	5.49E-03	3.30E+13	12.68
C	1.15	1.22	1.22	1.09E-03	1	1.09E-03	6.54E+12	2.52
D	1.01	0.49	3.59	2.17E-02	1	2.17E-02	1.30E+14	50.10
e				-6.66E-16	4	-1.67E-16	1.00	0.00
T	4.64	4.06	7.16	4.33E-02	8			100.00

Note: SS is the sum of square, v is the degrees of freedom, V is the variance, F is the Fisher's ratio, P is the percentage of contribution and T is the sum squares due to total variation.

The wear rate was decreased with increase in volume fraction of graphite in AA6061 alloy matrix as shown in figure 2a. For a soft-hard material sliding interaction the input energy is dissipated in giving rise to intense plastic deformation in the soft substrate under dry wear conditions. The strain hardening was high in AA6061 alloy matrix and low graphite (10%) composite, while the high graphite (30%) composite shows comparatively less hardening. Under these circumstances the less ductile material tends to produce wear fragments which become more readily detached from the parent body because of fracture and at a faster rate than those of the more ductile material. Thickness of the wear fragment decreases with increasing content of graphite in the composite. As seen from figures 2b, an increase in wear rate is with increase of normal load applied. Due to increased applied load, the deformed AA6061 alloy matrix disengages from the pin's surface. The deformed matrix material adheres to the steel disc surface, consequently raising the wear rate. Under all loads the wear track on the disc became smeared with a layer of AA6061 alloy matrix within a short period. Subsequently, sliding took place between this transferred layer and the test specimen, thus promoting seizure. A number of seizure particles, the size of which decreased with the graphite content of the composite, adhered to the track. There is no significant variation in wear with sliding speed for the AA6061/graphite composites (figure 2c). The wear rate increases with sliding distance as shown in figure 2d. For long sliding distances, the shear stress at the interface exceeds the shear strength of the particle/matrix interface resulting particle debonding. Disintegration of the surface layers thus proceeds at faster rates with increasing sliding distance.

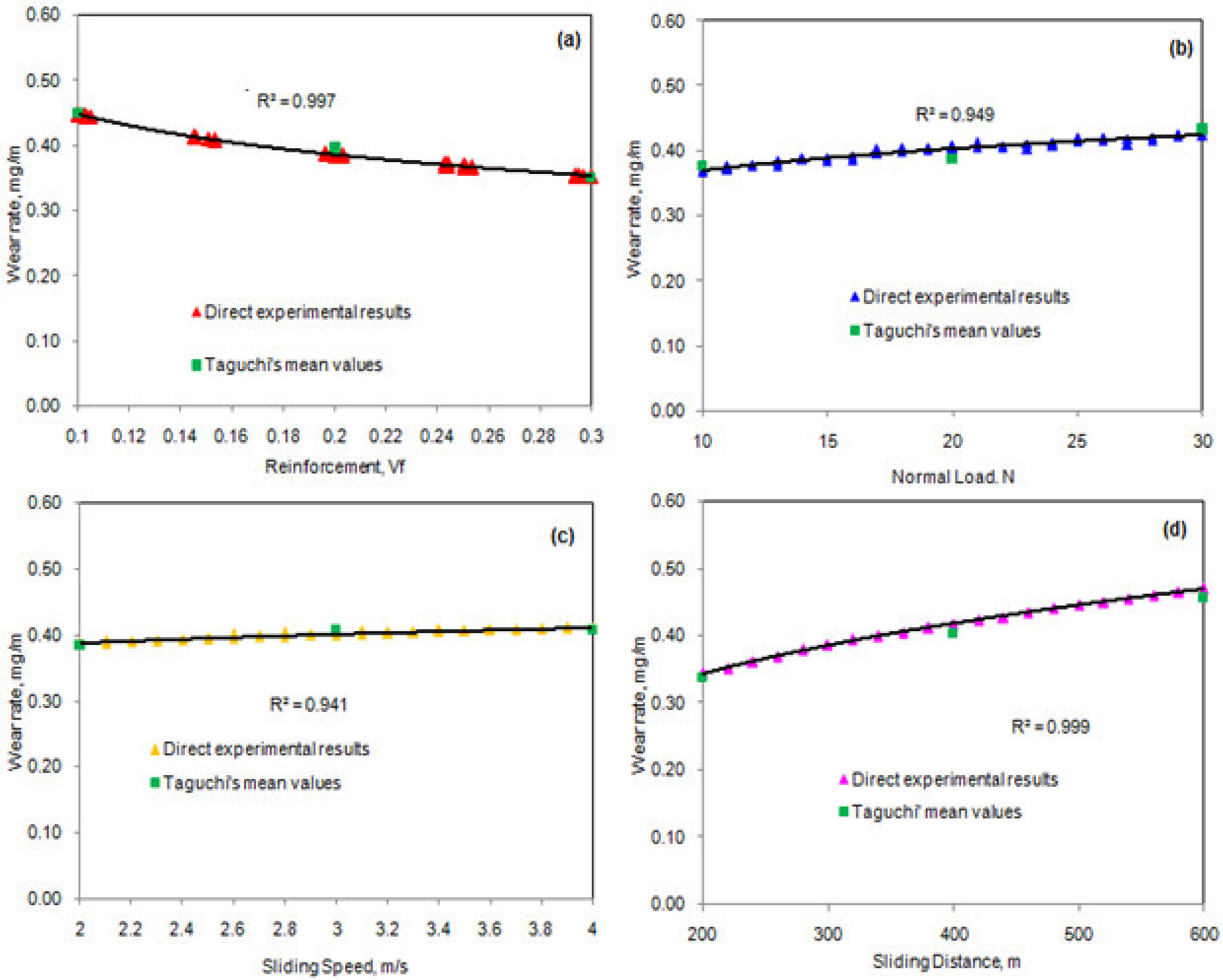

Figure 2: Wear rate as a function of (a) % reinforcement, (b) applied load, (c) sliding speed and (d) sliding distance.

The surface contour of AA6061/10%graphite composites is due to removal of the matrix alloy from the pin's surface and movement of matrix alloy onto the groove edges. Thickness of the wear fragment is high with 10% graphite in the composite. In the composites having 10% graphite content, the stain hardening and plastic deformation are also high which results the surface profile as shown in figure 4. The surface roughness contours of AA6061/20% graphite and AA6061/30% graphite composites represent the improvement of wear resistance due to addition of graphite nanoparticles (figure 4). But, in the composites having 30% graphite, the particle debonding is high causing the rough surface profile. The surface profiles coincide with the micrographs of AA6061/graphite composites.

4. CONCLUSIONS

The surface profiles of AA6061/graphite composites were successfully correlated with micrographs of the worn surfaces. The wear resistance increases with increase in volume fraction of graphite nanoparticles in AA6061 alloy matrix due to increased hardness of the composites. The sliding speed has no significance on the wear rate of AA6061/graphite composites.

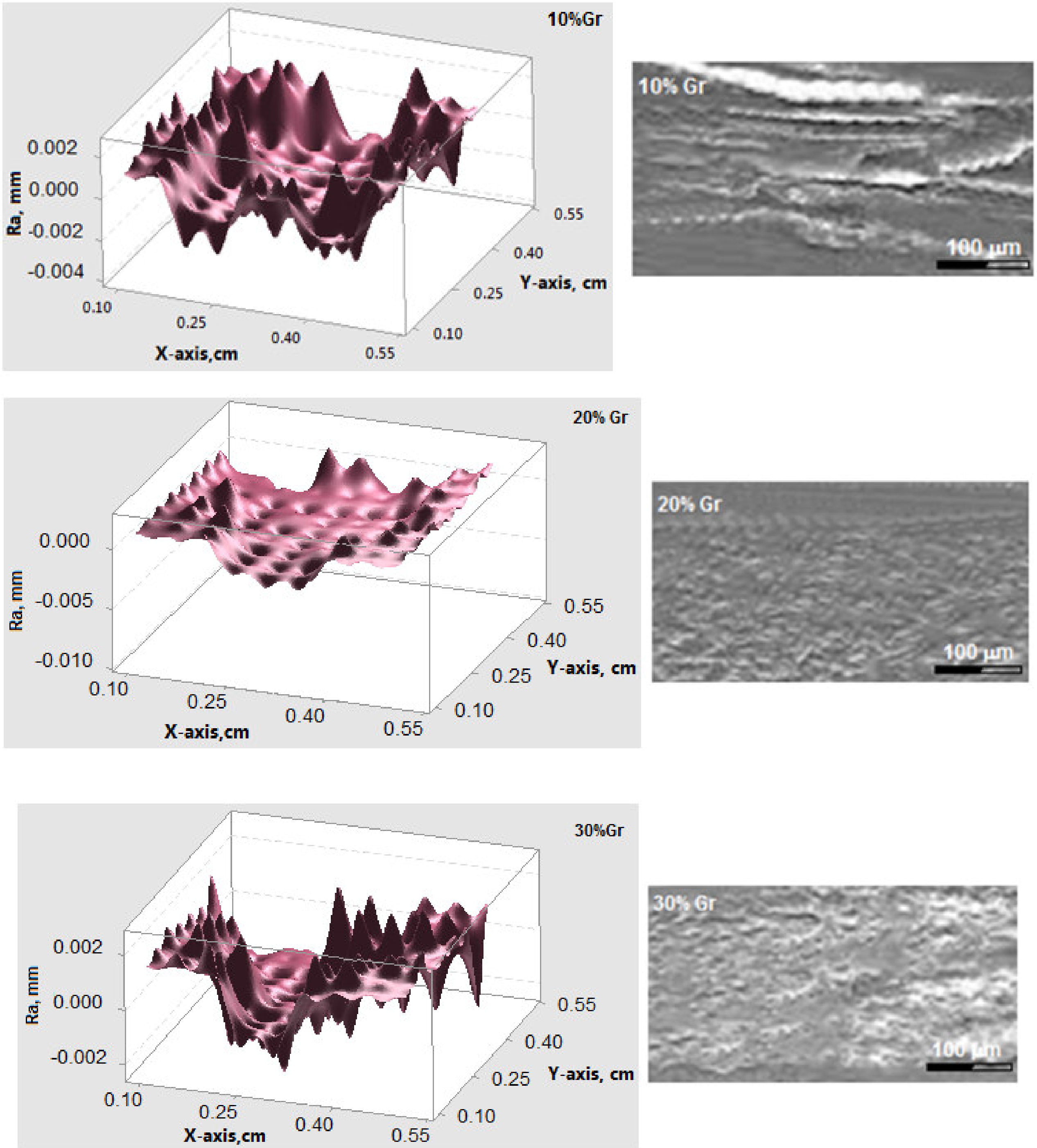

Figure 4: Surface profiles and worn surfaces of AA6061/graphite composites after wear test.

REFERENCES

1. A. Chennakesava Reddy, Fracture behavior of brittle matrix and alumina trihydrate particulate composites, Indian Journal of Engineering & Materials Sciences, 9, 2002, pp.365-368.
2. A. Chennakesava Reddy, S. Sundararajan, Influences of ageing, inclusions and voids on the ductile fracture mechanism of commercial Al-alloys, Journal of Bulletin of Material Sciences, 28, 2005, pp. 75-79.
3. A. Chennakesava Reddy and Essa Zitoun, Matrix al-alloys for alumina particle reinforced metal matrix composites, Indian Foundry Journal, 55, 2009, pp.12-16.

4. A. Chennakesava Reddy, Mechanical properties and fracture behavior of 6061/SiCp Metal Matrix Composites Fabricated by Low Pressure Die Casting Process, Journal of Manufacturing Technology Research, 1, 2009, pp.273-286.
5. A. Chennakesava Reddy and B. Kotiveerachari, Effect of aging condition on structure and the properties of Al-alloy / SiC composite, International Journal of Engineering and Technology, 2, 2010, pp.462-465.
6. A. Chennakesava Reddy, Tensile properties and fracture behavior of 6063/SiCp metal matrix composites fabricated by investment casting process, International Journal of Mechanical Engineering and Materials Sciences, 3, 2010, pp.73-78.
7. A. Chennakesava Reddy and Essa Zitoun, Tensile behavior 0f 6063/Al_2O_3 particulate metal matrix composites fabricated by investment casting process, International Journal of Applied Engineering Research, 1, 2010, pp.542-552.
8. A. Chennakesava Reddy, Stir Casting Process on Porosity Development and Micromechanical Properties of AA5050/Titanium Oxide Metal Matrix Composites, 5th National Conference on Materials and Manufacturing Processes, Hyderabad, 9-10 June 2006, pp. 144-148.
9. A. Chennakesava Reddy, Effect of Porosity Formation during Synthesis of Cast AA4015/Titanium Nitride Particle-Metal Matrix Composites, 5th National Conference on Materials and Manufacturing Processes, Hyderabad, 9-10 June 2006, pp. 139-143.
10. A. Chennakesava Reddy, Role of Porosity and Clustering on Performance of AA1100/Boron Carbide Particle-Reinforced Metal Matrix Composites, 6th International Conference on Composite Materials and Characterization, Hyderabad, 8-9 June 2007, pp. 122-127.
11. A. Chennakesava Reddy, Effect of Clustering Induced Porosity on Micromechanical Properties of AA6061/Titanium Oxide Particulate Metal matrix Composites, 6th International Conference on Composite Materials and Characterization, Hyderabad, 8-9 June 2007, pp. 149-154.
12. B. Kotiveera Chari, A. Chennakesava Reddy, Bottom-Up Pouring and its Effect on Porosity and Clustering in Casting of AA1100/Silicon Nitride Particle-Reinforced Metal Matrix Composites, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9 August 2008, pp. 110-114.
13. Essa Zitoun, A. Chennakesava Reddy, Microstructure-Property Relationship of AA3003/Boron Nitride Particle-Reinforced Metal Matrix Composites Cast by Bottom-Up Pouring, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9 August 2008, pp. 115-119.
14. S. Pitchi Reddy, A. Chennakesava Reddy, Effect of Needle-like Brittle Intermetallic Phases on Fracture Behavior of Bottom-up Poured AA5050/Titanium Carbide Particle-Reinforced Metal Matrix Composites, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9 August 2008, pp. 127-132.
15. S. Pitchi Reddy, A. Chennakesava Reddy, Synthesis and Characterization of Zirconium Carbide Nanoparticles Reinforced AA2024 Alloy Matrix Composites Cast by Bottom-Up Pouring, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12 December 2009, pp. 211-215.
16. Essa Zitoun, A. Chennakesava Reddy, Analysis of Micromechanical Behavior of AA3003 Alloy - Graphite Metal Matrix Composites Cast by Bottom-Up Pouring with Regard to Agglomeration and Porosity, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12 December 2009, pp. 216-220.
17. P. Rami Reddy, A. Chennakesava Reddy, Processing of AA4015-Zirconium Oxide Particulate Metal Matrix Composites by Stir Casting Technology, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12 December 2009, pp. 221-224.
18. B.P. Krishnan, N. Raman, K. Narayanaswamy, and P.K. Rohatgi, Performance of An Al-Si Graphite Particle Composite Piston in a Diesel Engine, Wear, 60, 1980, pp. 205–215.
19. O.P. Modi, A.H. Yegneswaran, R. Asthana, and P.K. Rohatgi, Thermomechanical Processing of Aluminum-based Particulate Composites, Jouranl of Materials Science, 23, 1998, pp. 83–92.
20. A. Chennakesava Reddy , S. Madahava Reddy, Evaluation of dry sliding wear characteristics and consequences of cast Al-Si-Mg-Fe alloys, ICFAI Journal of Mechanical Engineering, 3, 2010, pp.1-13.
21. A. Chennakesava Reddy, M. Vidya Sagar, Two-dimensional theoretical modeling of anisotropic wear in carbon/epoxy FRP composites: comparison with experimental data, International Journal of Theoretical and Applied Mechanics, 6. 2010, pp. 47-57.
22. A. Chennakesava Reddy, Wear and Mechanical Behavior of Bottom-Up Poured AA4015/Graphite Particle-Reinforced Metal Matrix Composites, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, 8-9 August 2008, pp. 120-126.
23. A. Chennakesava Reddy, Sliding Wear and Micromechanical Behavior of AA1100/Titanium Oxide Metal Matrix Composites Cast by Bottom-Up Pouring, 7th International Conference on Composite Materials and Characterization, Bangalore, 11-12 December 2009, pp. 205-210.
24. A. Chennakesava Reddy, V.M. Shamraj, Reduction of cracks in the cylinder liners choosing right process variables by Taguchi method, Foundry Magazine, 10, 1998, pp. 47-50.
25. A. Chennakesava Reddy , V.S.R. Murti, S. Sundararajan, Control factor design of investment shell mould from coal flyash by Taguchi method, Indian Foundry Journal, 45, 1999, pp. 93-98.