

Erosion-corrosion Behavior of Aluminum 7075 based SiC Reinforced Nanocomposites

Adil Ahmed.S, P.L.Srinivasa Murthy



Abstract— In present study corrosion studies were conducted on Al7075/SiC nanocomposites processed by powder metallurgy and stir casting techniques. The weight percentage of SiC nanoparticles was varied from 1% to 4% for preparing the nanocomposites. The erosion-corrosion studies were conducted by means of slurry pot experiment under simulated marine environment of 3.5% NaCl. The weight losses of Al7075 alloy and its nanocomposites under various experimental conditions. The studies have been performed at the specimens through using distinct sand concentrations (10-40%) varying rotational/slurry speed (500-1500rpm) and ranging impinging particle (100-600microns) respectively. Powder metallurgy processed nanocomposites showed higher weight loss when compared to those processed using cast route. Worn-out surface analysis using scanning electron microscopy revealed ploughing, abrasion and fracture as the main erosion mechanisms for all materials processed using both the processing techniques.

Index terms: Nanocomposites; Powder metallurgy; Stir casting; erosion-corrosion.

I. INTRODUCTION

Nanomaterials are new elegance of substances that are available within the size range from 1-100nm. Utilization of reinforcement in nano scale leads to the composite called metal matrix nano composite which has big scale in several sectors. The conduct of mechanical and physical characteristics of the nano composite is very plenty varying from micro or macro reinforcements. Aluminum has made in-roads in gaining the eye of using nano reinforcement in engineering applications [1-4]. Addition of reinforcement in nano scale has huge benefits when compared to other composites. Nano scale reinforcement addition plays a position in improving strengthening mechanism together with refinement in grain, impact of load switch, hall-Petch enhancement, Orowan increment, accelerated thermal growth and modulus of elasticity and dislocation corrections. The version of residences of the composite by means of the usage of nano reinforcement could be executed by varying the quantity fraction, nature of reinforcement and processing

technique. There are numerous strategies of processing in practice inclusive of powder metallurgy, stir casting, squeeze casting and many others [5-8]. Considering the feasible houses and advantages over other production process, stir casting and powder metallurgy are the two important techniques applied for improvement of aluminum composites. Recently Aluminum based MMC's are finding potential applications in marine engineering which includes impeller, agitators, torpedo blades etc. Which are commonly subjected to slurry erosion and corrosion environment. Slurry erosion behaviour of materials depends on various parameters. In order to explore the potential applications of aluminum based MMC's, it is essential to understand the behavior of materials under various slurry erosion conditions. Various researchers have reported on slurry erosion behavior of aluminium based composites. Ramachandra et al [9] have studied slurry erosion wear behaviour of alumina composites reinforced with flyash. They have found that flyash reinforced composites exhibited improved slurry erosion resistance when compared to aluminium alloys presence of flyash in the aluminium acted as protecting sites from the slurry. Joel hemanth [10] has reported on slurry erosion characteristics of chilled aluminium A356 alloy reinforced with fused silica, strength, hardness and slurry erosion resistance of composites increased with increase in SiO_2 content. Das et al [11] have investigated erosion-corrosion behaviour of aluminum composites reinforced with SiC particles. They have noticed that composite reinforced with SiC particles exhibited better wear resistance than the alloy in matrix and acidic conditions. They have observed that the interface between matrix and reinforcement were predominant site for corrosion attack. Girish et al [12] have studied particle size effects on the slurry erosion of aluminium 6063 alloy various sized particles were used to study the effect on wear rate. They have observed that kinetic energy of impinging particles plays important role in deciding the mechanism of material removal. Ramesh et al [13] have reported on sand slurry erosive wear behaviour of Ni-P coated Si_3N_4 Reinforced Al6061 composites. They have studied the effect of experimental parameters slurry erosion behaviour of composites. Under all the test conditions studied composites possess higher slurry erosive wear resistance when compared with composites. In the light of the above, present study employs the two most popular and applicable methods of stir casting and conventional powder metallurgy for fabrication of Al7075-SiC nanocomposite. Al7075 is chosen as matrix material while hard ceramic reinforcement SiC nano particles was chosen as reinforcement.

Manuscript published on 30 September 2019

* Correspondence Author

Adil Ahmed.S*, Department of Mechanical Engineering, Islamia Institute of Technology, Bangalore, INDIA

P.L.Srinivasa Murthy, Department of Mechanical Engineering, Ramaiah Institute of Technology, Bangalore, INDIA

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license <http://creativecommons.org/licenses/by-nc-nd/4.0/>

Erosion-corrosion Behavior of Aluminum 7075 based SiC Reinforced Nanocomposites

Percentage of nano SiC was varied from 0 to 4 wt% in steps of 1wt% in both as cast and powder metallurgy processes. Synthesized nano composites were subjected to microstructural and erosion-corrosion test.

II. EXPERIMENTAL DETAILS

2.1 Materials:

Morphology of initial powders was studied using scanning

electron microscope is reported in Fig.1. From micrographs it is seen that the powder have spherical and cylindrical morphology and their size is in the range of 5 - 50 μm . similarly the EDS spectra captured on Al7075 powder particles confirmed presence of aluminium as major element (Fig.1 (c)).

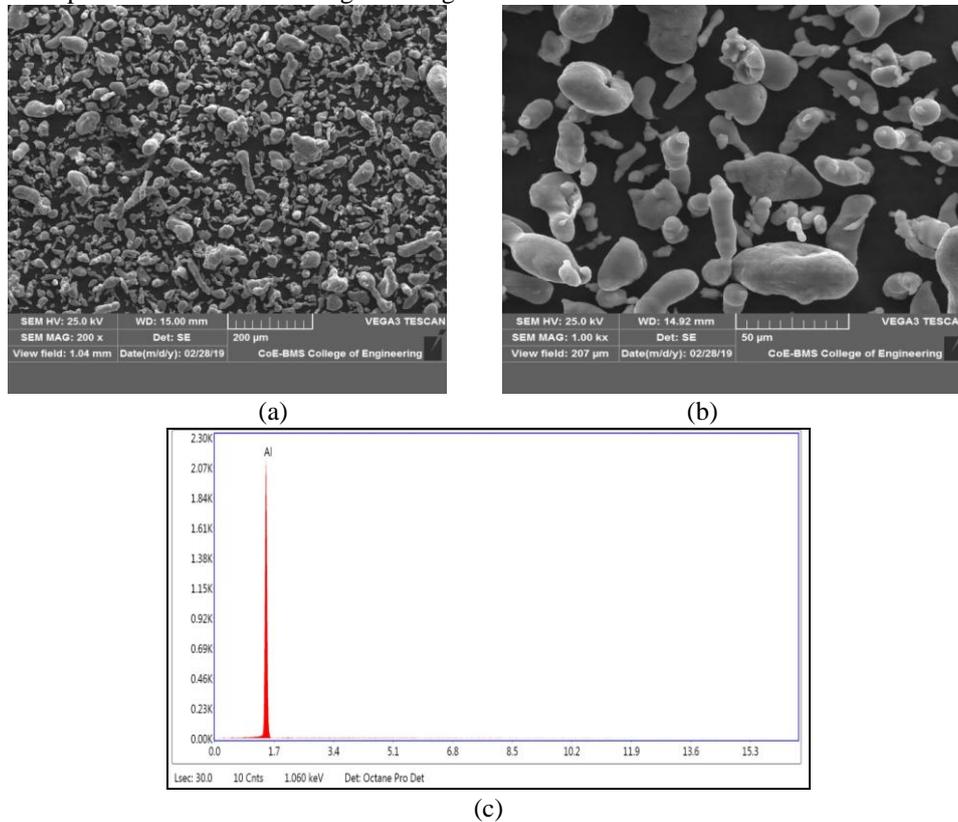
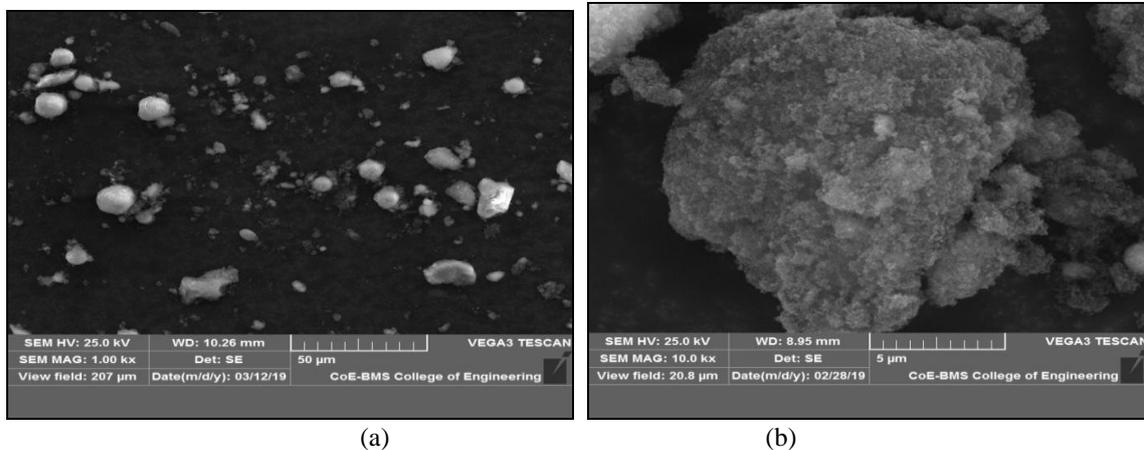
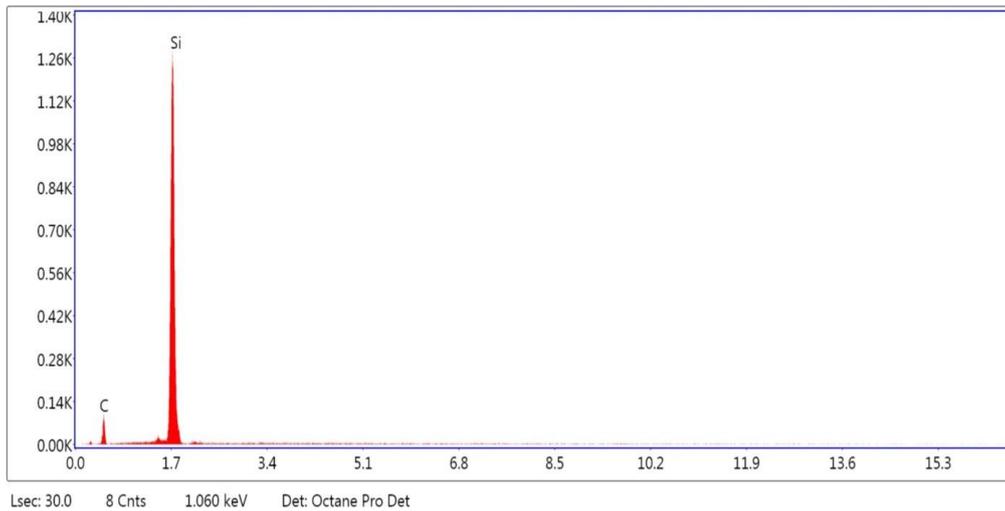


Fig. 1 SEM of as-received (a) & (b) Al7075 powder particles and (c) EDS analysis

Fig.2 shows SEM and EDS of agglomerated nano SiC particles used in the present investigation. Fig. 2 (a) shows numerous clusters of SiC nanoparticles while Fig. 2 (b) shows magnified micrograph of one such cluster. The SiC nanoparticles are having close to round morphology with some of them having flaky kind morphology. The formation

of nanoparticle clusters is attributed to Vander Waals forces which purpose the appeal between these nanoparticles. EDS spectra of SiC nanoparticles is proven in Fig.2 (c) which confirms the presence of both the constituent elements of SiC, this is Si and C.





(c)

Fig. 2 SEM of as-received (a) & (b) SiC nanoparticles and (c) EDS analysis

2.2 Stir Casting

The nano composites was fabricated by way of stir casting technique wherein Al7075 changed into melted in graphite crucible at a temperature of 750°C. Once the melting is performed, the degassing of the molten Al7075 is done using hexachloroethane pills. After degassing, preheated nano silicon carbide particles (1-4wt%) were introduced to molten steel that's being stirred at 400 rpm. The molten Al7075 melt with nano silicon carbide particles are stirred for 15 minutes so as to make certain that the dispersion is uniform. After this, the molten is injected into a cylindrical die. The solidified as cast Al7075 alloy and nano composites are then subjected to machining to make samples for metallographic evaluation, and erosion-corrosion test.

2.3 Powder Metallurgy

The planetary ball mill was used for blending Al7075 powder and SiC nano particles. A measured amount of aluminum 7075 powder and silicon carbide (1- 4wt.%) were mixed together in planetary ball mill to attain a uniformly combined composite powder. earlier than mixing, bowls in planetary ball mill was cleaned with ethanol, dried to get rid of moisture. metallic bowl was into filled with SiC and Al7075 powder alongside stainless steel balls with the ball to powder ratio 8:1 and the further composite powder become blended for 3 hrs. at 300 rpm under vacuum inside the planetary ball mill. The Al7075 and ball milled composite powder had been filled into die to prepare samples. The composite powder turned into positioned inside the die and load of 400 MPa was applied on composite powder for 5 minutes for consolidation with 100T hydraulic press. For making ready the Al7075/SiC alloy composites, the composite powder was crammed into 20 mm die and compacted at a pressure of 400 MPa for a duration of five minutes. Earlier than consolidation, the axis of the die and punch aligned with spindle axis to apply uniform strain and additionally to avoid slipping. The composite specimens were sintered with the use of electric powered sintering furnace consisting of alumina tube, heating coil, controller and provision for providing argon or nitrogen gas to avoid oxidation of composites at a temperature of 400o C for

approximately 1 hour. Fig. shows the photograph of plunger and die with sample.



Fig.3a Photograph of Plunger



Fig.3b Photograph of die with sample

2.4 Erosion-Corrosion test

Erosion-corrosion behavior of cast and powder metallurgy processed Aluminum 7075 alloy and Aluminum 7075-SiC nano composites. The specimens of size 20*10*10mm were machined from the cast and powder metallurgy processed alloy and their nano composites and polished metalographically. Polished specimens were weighed with the use of precision electronic weighing scale (earlier and after erosion-corrosion test). The test setup includes an electric powered motor and a spindle made from stainless-steel. A belt force device is used for the rotation of the spindles. The polished specimens have been mounted on the spindles. All the specimens were immersed inside the slurry set by using mixing 3.5% of NaCl and sand particles with distilled water to simulate marine situations. The studies have been performed at the specimens through using distinct sand concentrations (10-40%) varying rotational/slurry speed (500-1500rpm) and ranging impinging particle (100-600microns) respectively. The weighing the specimens after the test were achieved by drying and cleaning the specimens to degree the weight reduction. Fig.4 shows the schematic diagram of test setup employed in the present study.

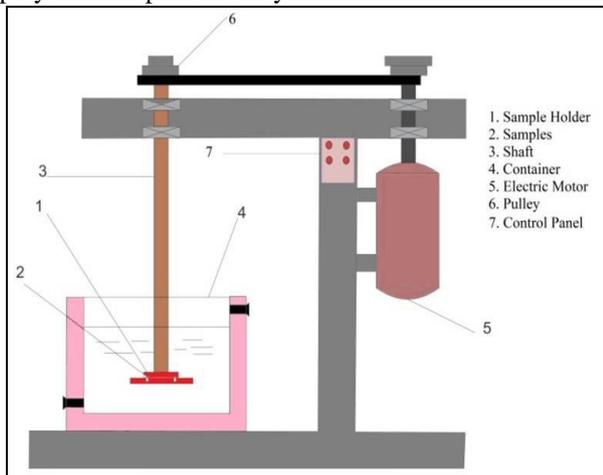
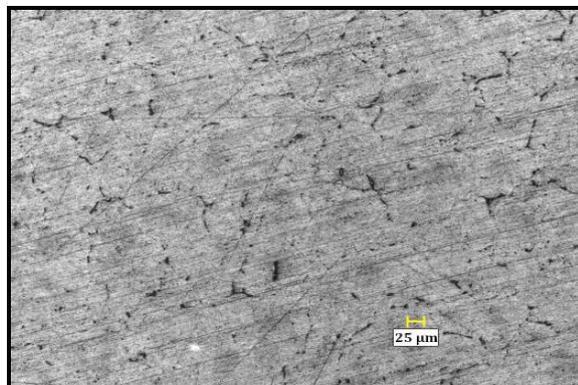


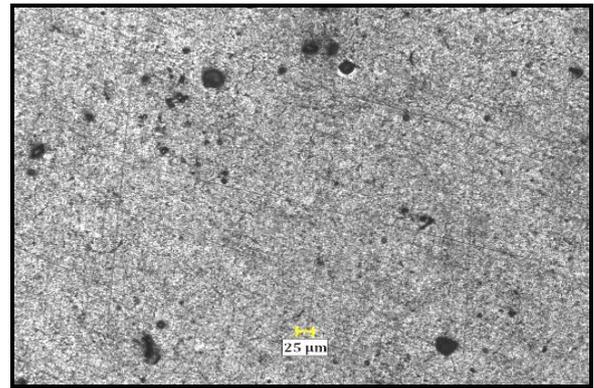
Fig.4 Schematic diagram of erosion-corrosion test setup

III. RESULTS AND DISCUSSIONS

3.1 Microstructure



5a Cast Al7075-4wt%SiC



5b PM Al7075-4wt%SiC

The microstructure of Al7075/SiC nanocomposites fabricated via stir casting and powder metallurgy techniques are presented in Fig. 5(a-b). Fig. show the microstructure of stir cast Al7075/4wt%SiC nanocomposites. Microstructure is composed of dendritic eutectic phase due to stirring, movement the dendrites are broken. Powder metallurgy processed Al7075-SiC composite shown in Fig.5(a). Dispersion of SiC nanoparticles was found to be relatively uniform throughout the Al7075 matrix. The addition of SiC nanoparticles refined the grain size of nanocomposites to some extent but some formation of clusters of SiC nanoparticles was also seen.

3.2 Hardness

Fig. 6 shows the microhardness of cast and powder metallurgy processed Al7075 alloy and its nanocomposites. it may be seen from the Fig.13 that for all cases, the microhardness for cast alloy and nanocomposites is higher than that of powder metallurgy processed ones. The microhardness for Al7075 alloy processed by way of casting and powder metallurgy resulted in values of 59 and 51 VHN. It may be seen that the as cast alloy has approximately 15.68% higher microhardness than that of powder metallurgy processed alloy. In case of nanocomposite with 1% SiC nanoparticle the microhardness values were sixty four and 54 VHN for casting and powder metallurgy routes. Right here the improvement in hardness for as cast nanocomposite turned into approximately 18.51% in comparison to powder metallurgy processed nanocomposite. With the increase in SiC nanoparticle content from one % to four% the microhardness for cast nanocomposites elevated and located to be higher than that of powder metallurgy processed nanocomposites. Higher microhardness values of 73 and 60 VHN had been located for 4% SiC nanoparticle added nanocomposites processed by means of casting and powder metallurgy. The increment in microhardness for cast nanocomposite turned into about 21.67% higher than that of powder metallurgy nanocomposite. Better microhardness values for cast alloy and nanocomposites were attributed to minimum clustering observed through better dispersion of SiC nanoparticles.

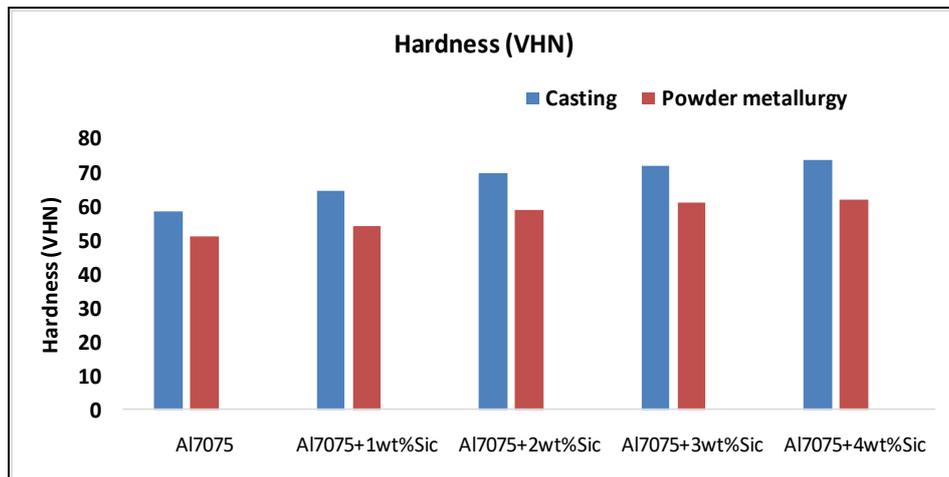


Fig.6 Microhardness Al7075 alloy and its nanocomposites

3.3 Erosion-Corrosion Analyses

3.3.1 Effect of Reinforcement

Fig.7 shows erosion-corrosion behavior of Al7075 and its nanocomposites under different processing conditions. Rotational speed, test duration and impinging particle size were kept constant with values being 100 rpm, 9 Hours and 425 microns. It is seen that for a given processing conditions; there is an increase in the erosion-corrosion resistance with increase in the content of nano silicon carbide. Maximum weight loss of 0.16 and 0.11 gms was seen for unreinforced Al7075 alloy processed under powder metallurgy and cast conditions. Cast alloy exhibited 32% higher erosion-corrosion resistance compared to alloy processed by powder metallurgy technique. However, with addition of nano silicon carbide particles weight loss appears to be significantly lower for both the processing techniques. Least weight loss is recorded for composite materials reinforced with 4wt% of nano silicon carbide particles. Weight loss of 0.058 and 0.08 grams was recorded for powder metallurgy and cast

processed Al7075-4wt%SiC nano composites respectively. When compared with powder metallurgy processed nano composite, cast composite has demonstrated a maximum of 38% erosion-corrosion resistance. Significant improvement in the microhardness is the primary reason for enhancement in the erosion-corrosion resistance of nano composites when compared with their alloys. It is clear seen from the previous section that reinforcing nano silicon carbide particles from 1wt% to 4wt% in the Al7075 alloy in cast and powder metallurgy conditions have raised hardness remarkably. Al7075 alloy reinforced 4wt% nano SiC particles have exhibited highest microhardness in particular cast nano composite has displayed maximum hardness due to its lower porosities. The influence of microhardness on erosion-corrosion resistance is clearly reflected for both cast and powder metallurgy processed nano composites. It is also important specify that under identical conditions studied when evaluated with cast alloy and their nano composites powder metallurgy processed alloy and composites demonstrated inferior erosion-corrosion resistance.

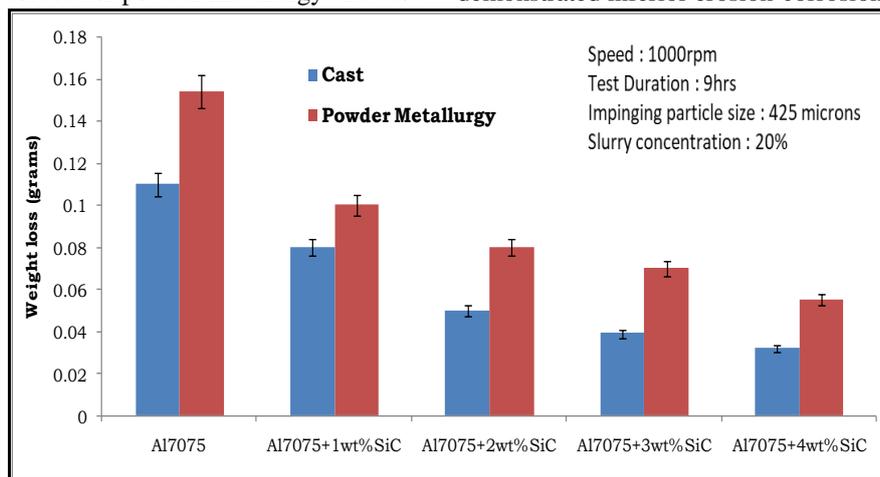


Fig.7 Erosion-corrosion behavior of Al7075 and its nanocomposites

3.3.2 Effect of Impinging Particle Size

Fig.8 shows the effect of impinging particle size on erosion-corrosion behavior of Al7075 alloy and its nano composites under cast and powder metallurgy conditions. Experiments were carried out under varied impinging particle size by keeping 10% slurry concentration for 3 hours duration at 500 rpm. Impinging particle size was varied from 200 microns to 400 microns. It is seen from the graph that increase

in the impinging particle size has increased the weight loss for both the processing conditions. In case of cast alloy, the weight losses for Al7075 alloy recorded were 0.020, 0.0235 and zero.026 gms respectively for 200, 300, 400µm impinging particle sizes.

Erosion-corrosion Behavior of Aluminum 7075 based SiC Reinforced Nanocomposites

Compared to powder metallurgy processed alloy the cast alloy confirmed higher erosion resistance. Then again the lower weight losses of 0.01, 0.05 and 0.018 gms turned into exhibited with the aid of nanocomposite with 4% SiC content in cast conditions accompanied via its powder metallurgy counterpart with weight losses of 0.012, 0.05 and 0.023 gms respectively for 200, 300 and 400 μm impinging particle sizes. In all the cases the cast processed alloy and nanocomposites showed much less weight reduction while as compared to that in their powder metallurgical specimens. This may be attributed to higher microhardness of solid samples whilst compared to that of powder metallurgy

samples. Cast samples with high microhardness provide better erosion resistance while compared to that of powder metallurgy processed samples. Then again with the increase in impinging particle dimensions, the weight loss of all samples regardless of processing conditions or SiC content material increased. With the increase in impinging particle size their kinetic energy is also anticipated to increase appreciably. Because of enhancement in kinetic energy the impinging particle are able to increasing the weight loss of each Al7075 alloy and its nanocomposites.

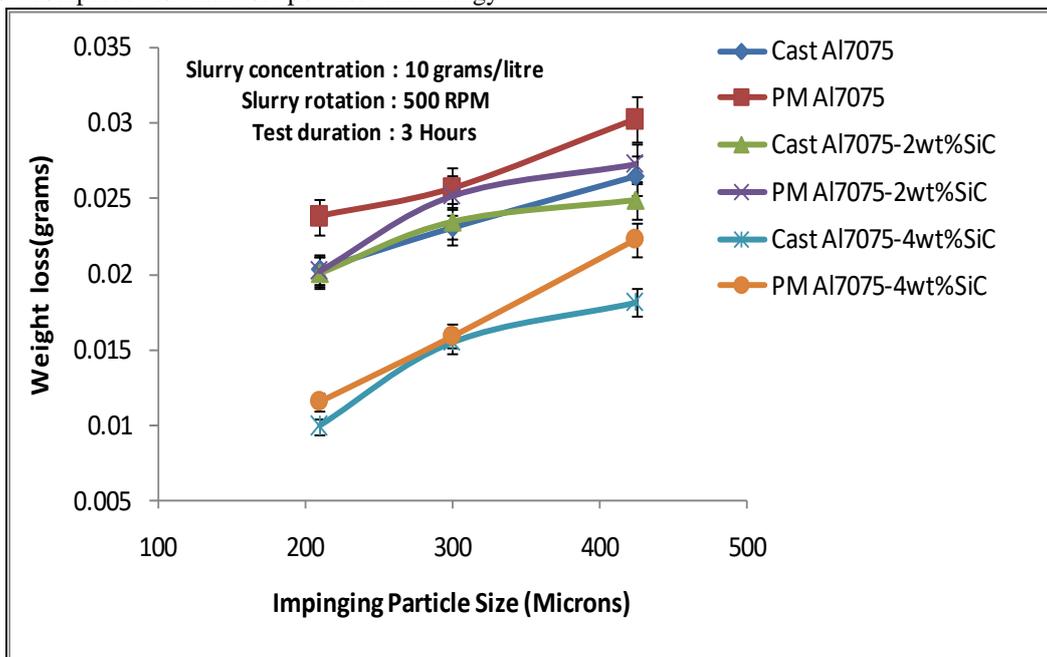


Fig. 8 Variation of weight loss with impinging particle

3.3.3 Effect of Slurry Rotation

Fig.9 presents the erosion-corrosion conduct of Al7075 and its nanocomposites with various slurry rotation speed for both the processing situations. Here, time, impinging particle size and slurry concentration were constant to three hours, 210 μm and 10% respectively as the slurry rotational velocity was varied from 500 to 1500 rpm within the steps of 500 rpm. It is discovered that for both the processing situations, the increase in slurry rotation has brought about increase in weight loss of all samples. Highest weight loss of 0.024, 0.026 and 0.030 gms became determined for Al7075 alloy processed using powder metallurgy under slurry rotation of 500, 1000 and 1500 rpm respectively. On the other hand the cast Al7075 alloy showed a weight loss of 0.021, 0.024 and 0.029 gms for 500, 1000 and 1500 rpm respectively. As compared to powder metallurgy processed alloy the cast alloy showed better erosion resistance. But with the addition of SiC nanoparticles the weight reduction of Al7075 reduced considerably. The erosion resistance of nanocomposites accelerated in addition with the increase in SiC content from 1% to 4%. Lowest weight loss of 0.01, 0.016 and 0.017 gms was recorded for Al7075 nanocomposite with 4% SiC content material processed with casting method and tested in slurry rotation of 500, 1000 and 1500 rpm respectively. Even in case

of powder metallurgy the Al7075 nanocomposite with 4% SiC content showed minimum weight loss of 0.016, 0.022 and 0.027 gms respectively for slurry rotation of 500, 1000 and 1500 rpm. Those observations sincerely suggest that the addition of SiC nanoparticles enables in enhancing the erosion resistance of Al7075 but with the increasing slurry rotation the weight reduction for those nanocomposites additionally has a tendency to increase. It's far well known fact that the erosive wear takes place because of relative motion among the surface of alloy/nanocomposite and impinging particles [14-15].

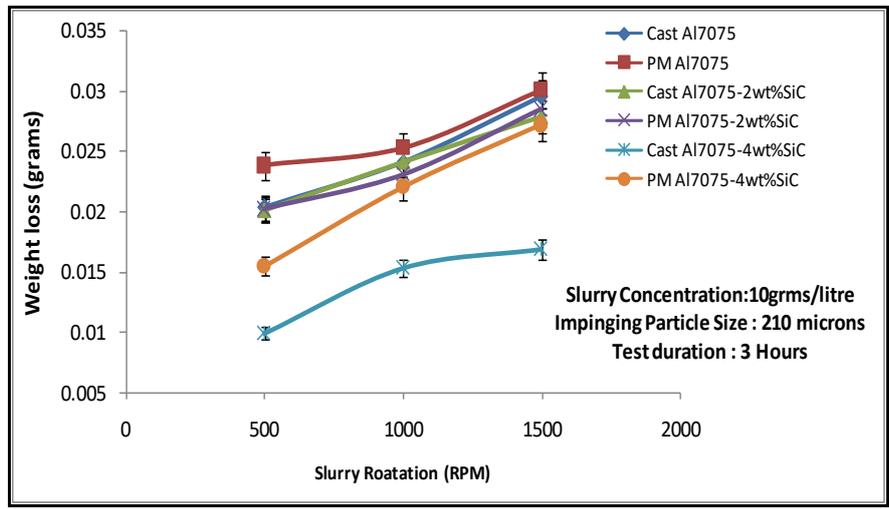


Fig. 9 Variation of Erosion-corrosion with varying slurry rotation speed

3.3.4 Effect of Test Duration

Fig.10 shows the erosion-corrosion conduct of Al7075 and its nanocomposites with varying test duration for both the processing conditions. Here the impinging particle size, slurry rotation and slurry concentration was maintained to 210 μm, 500 rpm and 10% respectively while the test duration was varied from three to nine hours. It is determined that for each the processing situations, the increase in test period has caused increase in weight reduction of all samples. But, it's miles determined that addition of SiC nanoparticles to Al7075 has led to decrease in extensive weight loss. to begin with, maximum weight loss of 0.024, 0.038 and 0.043 gms was found for Al7075 alloy processed with use of powder metallurgy for test period of 3, 6 and 9 hours respectively. on the other hand the cast Al7075 alloy showed a weight loss of 0.020, 0.030 and 0.031 gms for test duration of 3, 6 and 9 hours respectively. The erosion resistance of nanocomposites improved with the increase in SiC content from 1% to 4%. Lowest weight loss of 0.01, 0.013 and zero.014 gms was found for Al7075 nanocomposite with 4% SiC content processed using casting method and tested under duration of

3, 6 and 9 hours respectively. Even in case of powder metallurgy the Al7075 nanocomposite with 4% SiC content confirmed minimum weight reduction of 0.016, 0.017 and 0.020 gms respectively for test length of 3, 6 and 9 hours respectively. Those observations really imply that the addition of SiC nanoparticles enables in increasing the erosion resistance of Al7075 by means of increasing their microhardness. But with the increasing test length from three to nine hours the weight loss for those nanocomposites also tends to increase. With the increase in test time there could be continuous impact of abrasive particles at the surface of Al7075 alloy/nanocomposite. Because of this continuous impact the surface of both Al7075 and its nanocomposites suffered from stress hardening. With increase in test period from 3 to 9 hours, the quantity of strain hardening is so severe that it ends in fracture of specimen surface. This why the weight losses at larger intervals is substantially better than that of weight losses recorded at lower test durations. Especially in case of Al7075 alloy the weight loss is quite better than that of nanocomposites for both the processing situations.

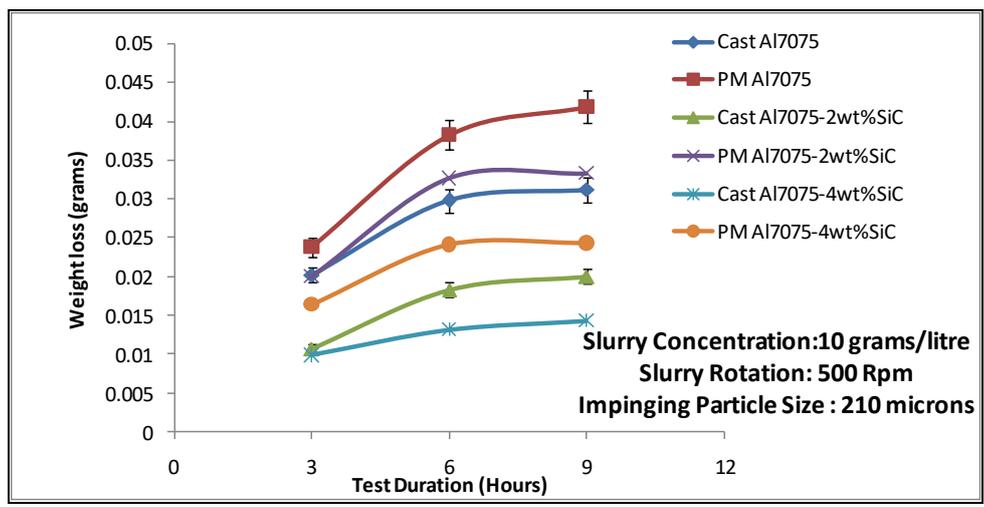


Fig.10 Variation of weight loss with slurry concentration

3.3.5 Effect of Slurry Concentration

Fig.11 indicates the erosion-corrosion behavior of Al7075 and its nanocomposites with various slurry concentrations for both the processing conditions. Right here, the impinging particle size, slurry rotation velocity and test period being 210 μm , 500 rpm and three hours respectively while the slurry concentration changed from 10% to 30% within the steps of 10%. It's discovered that for both the processing situations, the increase in slurry concentration has led to increase in weight reduction of all samples. But, it's found that addition of SiC nanoparticles to Al7075 has brought about decrease in weight loss. first of all, highest weight loss of 0.024, 0.027 and 0.033 gms was recorded for Al7075 alloy processed the usage of powder metallurgy for slurry attention of 10, 20 and 30% respectively. Then again the solid Al7075 alloy showed a weight loss of 0.021, 0.027 and 0.032 gms for slurry attention of 10, 20 and 30% respectively. The erosion resistance of nanocomposites increased with the addition of SiC content material from 1% to 4%. Lowest weight loss of 0.01, 0.016 and 0.018 gms was found for Al7075 nanocomposite with 4% SiC content processed with casting approach for slurry attention of 10, 20 and 30% respectively.

Even in case of powder metallurgy the Al7075 nanocomposite with 4% SiC content material showed minimal weight loss of 0.012, 0.019 and 0.020 gms respectively for slurry concentration of 10, 20 and 30%. Those observations absolutely suggest that the addition of SiC nanoparticles enables in increasing the erosion resistance of Al7075 by increasing their microhardness. The variety of impinging particles placing the surface of Al7075 and its nanocomposites additionally will increase. Further, the performance of particles striking the surface is pretty excessive in any other case in lots of instances the particles impacting the surface may lose their direction because of mutual collisions. Due to this the number particles impacting the surface might be less and erosion rate would possibly decrease for excessive concentrations of slurry. However, in present case because of increase in range of impinging particle the erosion rate multiplied for Al7075 and its nanocomposites. But it is seen that the cast alloy and nanocomposites were found to have advanced erosion resistance than that of their powder metallurgy counter parts.

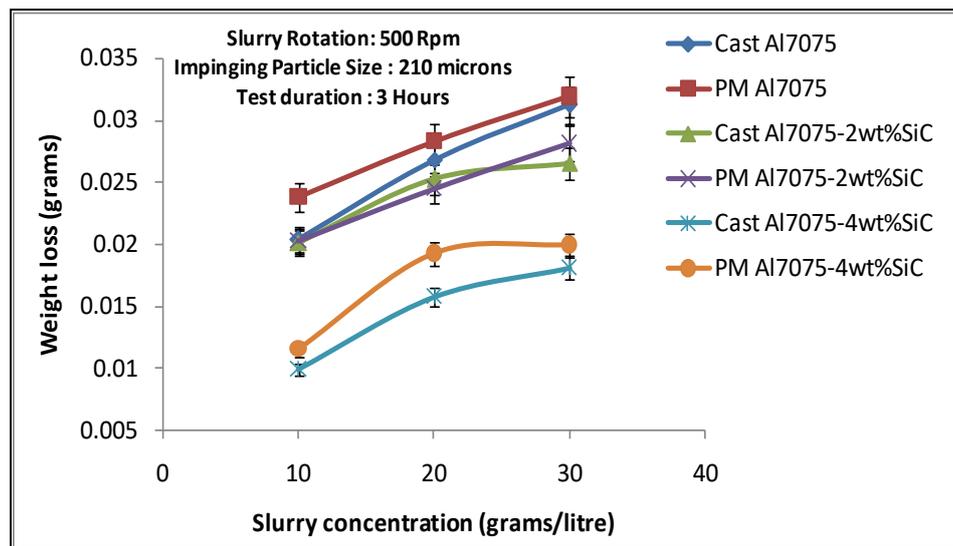


Fig. 11 Variation of weight loss with slurry concentration

3.4 Erosion Surface Analysis

Fig. 12 (a) - (f) shows the SEM micrographs of eroded surfaces of Al7075 and its nanocomposites with 2% and 4% SiC content material. The eroded surfaces have been acquired for slurry rotation, impinging particle size, time and slurry concentration of 500 rpm, 210 μm , three hours and 30%. The SEM micrographs of all of the samples explain that ploughing, abrasion and fracture as the main erosion mechanisms. First initially Al7075 alloy, the eroded surfaces as shown in Fig. 12 (a) and (b) indicates deep ploughing marks followed by micro-cutting marks. The yellow dotted line indicates the deep and huge ploughing marks in each the SEM micrographs. Due to deep ploughing and micro-cutting the cloth elimination is discovered to be larger in the case of Al7075 alloy processed in powder metallurgy and cast conditions. Especially in case of powder metallurgy processed Al7075 alloy the micro-slicing and micro-indentation was observed to higher whilst in

comparison to that of cast counterpart. Those micrographs have been captured while the slurry concentration was at maximum percent (30%) indicating that the excessive content of abrasive particles accountable for deep micro-reducing and ploughing marks. This is what happens in case of ductile materials where the erosion takes place via excessive plastic deformation followed through micro-slicing. Al7075 alloy has passed through as this alloy is ductile in nature and promotes erosion by way of plastic deformation and micro-slicing. Alternatively the eroded surface of nanocomposites as shown in Fig. 12 (c) – (f) changed into somewhat just like that of Al7075 alloy however the quantity of microploughing and micro-slicing become less. first of all the ductile Al7075 matrix of nanocomposite underwent large scale plastic deformation because of repetitive impact of impinging particles.

Because of this the fragmentation of surface layer of nanocomposites is really determined indicating ductile erosion.

In addition, the volume of fragmentation is quite higher for powder metallurgy processed nanocomposites due to high porosity content and presence of SiC clusters as compared to its cast counterpart. The pores on the surface of powder

metallurgy processed nanocomposites helps in the formation of crater while the impinging particles strikes those pores. The surface of nanocomposite on and surrounding the crater are removed as platelets because of repetitive movement of impinging particles. In addition to this there's high opportunity of formation of cracks at the encompassing the pores due to which they act as stress concentrators.

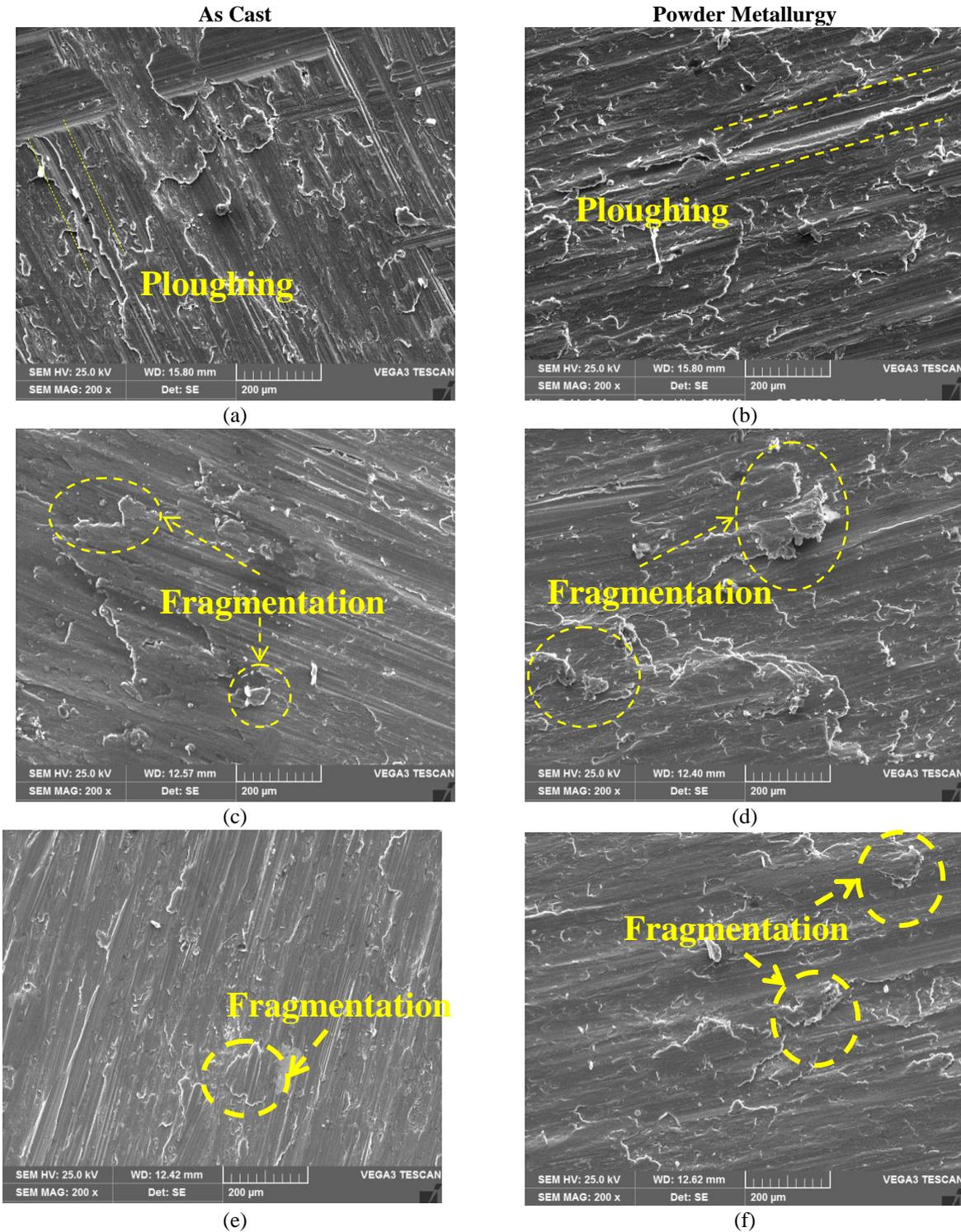


Fig. 12 SEM micrographs of eroded surfaces of (a, b) Al7075, (c, d) 2%SiC and (e, f) 4% SiC nanocomposites

Those strain concentration points can result in formation of cracks which in addition propagate through the matrix inflicting fragmentation of surface layer. Similarly the extent of microcutting in case of nanocomposites with higher SiC content material (4%) may be attributed to presence of SiC

nanoparticles.

Erosion-corrosion Behavior of Aluminum 7075 based SiC Reinforced Nanocomposites

Those nanoparticles protrude out of matrix as the time progresses due to which the ploughing or micro-slicing is constrained. However, no pull out of SiC nanoparticles is visible in case of 4% SiC strengthened nanocomposites. Typically the presence of pores and SiC clustered areas enables in starting up in addition to increasing erosion rate of powder metallurgy samples in comparison to that of cast specimens. Addition of SiC debris has shown massive advantage to counter the erosion of Al7075 alloy.

IV. CONCLUSION

- Erosion-corrosion test was conducted in under marine environment of 3.5% NaCl on powder metallurgy and stir cast Al7075/SiC nanocomposites.
- Observations showed that the weight loss in case of nanocomposites was lower when compared to that of Al7075 alloy irrespective of processing technique.
- Powder metallurgy processed showed higher weight loss than that of alloy and nanocomposites processed using cast route. Cast alloy and composites exhibited superior erosion corrosion resistance under all the test conditions studied.

REFERENCES

1. SJN Kumar, R Keshavamurthy, MR Haseebuddin, PG Koppad "Mechanical properties of aluminium-graphene composite synthesized by powder metallurgy and hot extrusion" Transactions of the Indian Institute of Metals 70 (3), 605-613.
2. HM Mallikarjuna, CS Ramesh, PG Koppad, R Keshavamurthy "Effect of carbon nanotube and silicon carbide on microstructure and dry sliding wear behavior of copper hybrid nanocomposites" Transactions of Nonferrous Metals Society of China 26 (12), 3170-3182.
3. C. Borgonovo and D. Apelian, "Manufacture of Aluminum Nanocomposites: A Critical Review", Materials Science Forum, Vol. 678, pp. 1-22, 2011.
4. Md. Tanwir Alam ,Akhter Husain Ansari,Sajjad Arif &Md. Naushad Alam "Mechanical properties and morphology of aluminium metal matrix nanocomposites-stir cast products" Advances in Materials and Processing Technologies, Pages 600-615. Volume 3, 2017 - Issue 4.
5. R Keshavamurthy, JM Sudhan, N Gowda, RA Krishna "Effect of Thermo-Mechanical Processing and Heat Treatment on the Tribological Characteristics of Al Based MMC's" IOP conference series: materials science and engineering 149 (1), 012118.
6. RV Kumar, R Keshavamurthy, CS Perugu "Microstructure and mechanical behaviour of Al6061-ZrB2 In-situ metal matrix composites" IOP Conference Series: Materials Science and Engineering 149 (1), 012062.
7. Massoud Malaki , Wenwu Xu, Ashish K. Kasar , Pradeep L. Menezes, Hajo Dieringa, Rajender S. Varma and Manoj "Gupta Advanced Metal Matrix Nanocomposites" Metals 2019, 9, 330, 1-39.
8. P.B.Pawar, R.M.Wabale, A.A.Utpat "A Comprehensive Study of Aluminum Based Metal Matrix Composites: Challenges and Opportunities" Volume 5, Issue 11, Part 3, 2018, Pages 23937-23944.
9. M Ramachandra, k.Radhakrishna,"Effect of reinforcement of flyash on sliding wear, slurry erosive wear and corrosive behaviour of aluminium composites" wear 262(2007) 1450-1462.
10. Joel Hemanth,"Abrasive and slurry wear behaviour of chilled aluminium alloy (A356)reinforced with fused silica(sio2) metal matrix composites ": part B 42(2011)1826-1833.
11. S, Das, Y.L. Sraswathi, D.P Mondal "Erosive corrosive wear of aluminium composites" Influence of slurry composition and speed : wear 261(2006) 180-190.
12. Girish R. Desale, Bhupendra K Gandhi, S.c.Jain "Particle size effects on slurry erosion of aluminium alloy(AA6063)" wear 266(2009) 1066-1071.
13. C.S. Ramesh, R. Keshavamurthy "slurry erosive war behaviour of Ni-P coated Si3N4 reinforced Al6061 composites. Materials&Design, Vol.32, Issue 4, 2011, PP 1833-1843.
14. BE Naveena, R Keshavamurthy, N Sekhar "Slurry erosive wear behaviour of plasma-sprayed flyash-Al2O3 coatings" Surface Engineering 33 (12), 925-935.
15. CS Ramesh, N Sekhar, R Keshavamurthy, S Pramod "A study on slurry erosion and corrosion behaviour of HVOF sprayed titania coatings" International Journal of Surface Science and Engineering 9 (1), 55-68.
16. Ramesh, R Keshavamurthy, BH Channabasappa, S Pramod "Influence of heat treatment on slurry erosive wear resistance of Al6061 alloy" Materials & Design 30 (9), 3713-3722.