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A Review on Erosion of Aluminium Alloy for Various Application

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Abstract

This Aluminium is a valuable metal because of its good corrosion resistance, reflectivity, recycling properties, electrical and thermal conductivity. Materials having high strength-to-weight ratios, as well as qualities like good corrosion resistance, low weight, creep resistance, and high thermal strength, are required in aerospace applications. Cost parameters must also be considered without sacrificing quality. Al, Ti, Mg, Ni, and their alloys are often utilised in aircraft industries for most of their sub components, depending on the qualities required. Following that, several research initiatives were undertaken with the goal of gaining a better knowledge of their structural performance and developing accurate and trustworthy design. Erosion is the loss of material caused by the repetitive impact of small solid, liquid, or a mixture of solid and liquid particles on a surface. Weather-related erosion, as well as other present particles such as rain, hail, and ice, sand, volcanic ash, and dust arising from residues in the atmosphere, are all harmful to the structure of a aircraft and can reduce its lifecycle. The focus of this paper is to review of research on impact of erosion on aluminium alloys by analysing previously published work and which are used in various applications.

Keywords: *Alloys, Corrosion Resistance, Structural Aluminium Alloys, Aircraft, Solid particle erosion (SPE)*

1.0 Introduction

Aluminium has gained popularity in recent years for a variety of applications due to the overall requirement for weight reduction to reduce fuel consumption. Sheet applications for new light weight structural parts and body construction are gaining popularity, and all major producers of aluminium alloys have made significant efforts to meet the main requirements, which include sufficient strength for structural stability and durability, crash worthiness, dent resistance, good formability for stretching and joining, high corrosion resistance, recyclability, and low fabrication costs [1].

Because of its strong corrosion resistance, high electrical and thermal conductivity, superb reflectivity, and excellent recycling qualities, aluminium is a particularly important metal. With a melting point of 660°C, aluminium atoms are organised in a face-centered cubic (FCC) configuration.There are nine distinct series of aluminium, four of which are known as heat-treatable aluminium alloys because of the possibility of increasing mechanical properties by heat treatment process. The qualities of heat treatable Al-alloys can be improved even more by adding a reinforcing phase that improves the entire composite's mechanical properties.Aluminum is a nonferrous metal with a high strength-to-weight ratio as well as a low

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manufacturing cost. Aluminium alloys and composites are particularly attractive and competitive structural materials in a variety of sectors due to their characteristics.Aluminum is alloyed with metals including copper, zinc, magnesium, and manganese for applications to require higher mechanical strength.The aluminium alloy's series is determined by the alloying components. 1xxx to 9xxx are the possible series categories.

1.1 Structural Aluminium Alloys

The 2000 series alloys give strength and damage tolerance, the 6000 series alloys provide strong corrosion resistance and enhanced machinability, the 7000 series alloys provide increased strength potential, and the 8000 series alloys provide high temperature performance [2]. Applications of aluminium alloys in aircraft components are shown in Table 1 [2], and Figure 1 shows the critical parts of the aircraft [3].

1.2 Erosion Problem in Aircraft

The effects of erosion on aircraft produced by rain, sand, volcanic ash, and other erodents have been observed since the start of aviation. Attack of solid particles and liquid droplets, in particular, can change the properties of aircraft outer cover material during flight. A variety of vehicle parameters determine this influence, including the erodent's exposure time, variety of erodent,and lastly the erodent's impact speed [4]. Liquid, solid and a combination of solid and liquid impingement erosion are the three main categories to consider when discussing erosion on the aero vehicles of high-speed. The exposure of the structure to a bombardment of small liquid droplets that all contact the structure at the same time from liquid impact erosion. When an aeroplane passes through a cloud or is exposed to precipitation, such an encounter is possible.

SPE is caused by many particles types, such as ice or hail striking an aircraft's fuselage or sand particles impacting the frame of aeroplane while landing and take-off in a desert environment. Most constructions, despite their appearance, are prone to both solid and liquid erosion for a short period of time.

Different particles or flying species may collide with an aircraft's engines and forward-facing surfaces as it flies through the atmosphere.sand, dust, ice, hailstorm, and rain

Table 1: Applications of Al alloys in aircraft components

Components	Materials	Alloys Series	Alloying Elements	Properties
Front Legs of sea	Al 2017 Al 2024	Al 2xxx	Cu\Mg	High fatigue strength, Corrosion resistance with cladding, Good machining, High strength alloy,
Wing Leading Edge	Al 2024			
Seat Ejectors	Al 2004			
Floor sections of the aircraft	Al 2090-T86 Al 2090-T62			
Seat Structure	Al 2090-T86			
Supporting members of fuselage structure	Al 2090-T651			
Backrests and armrests	Al 6xxx	Al 6xxx	Mg\Si	High strength, Corrosion resistance, good formability and Weldability.
Fuselage skins, stringers and bulkheads	Al 6013 Al 6050 Al 7050			
Wings skins, panels and covers	Al 7079	Al 7xxx	Zn/Mn/Cu	Highest strength aluminium alloy, high toughness, good machinability
Rear legs of seat and seat spreaders	Al 7075			
Wing spars, ribs	Al 7075			
Wheels and landing gear links	Al 7055-T77			
Horizontal and Vertical stabilizers				
Upper and lower wing skins				

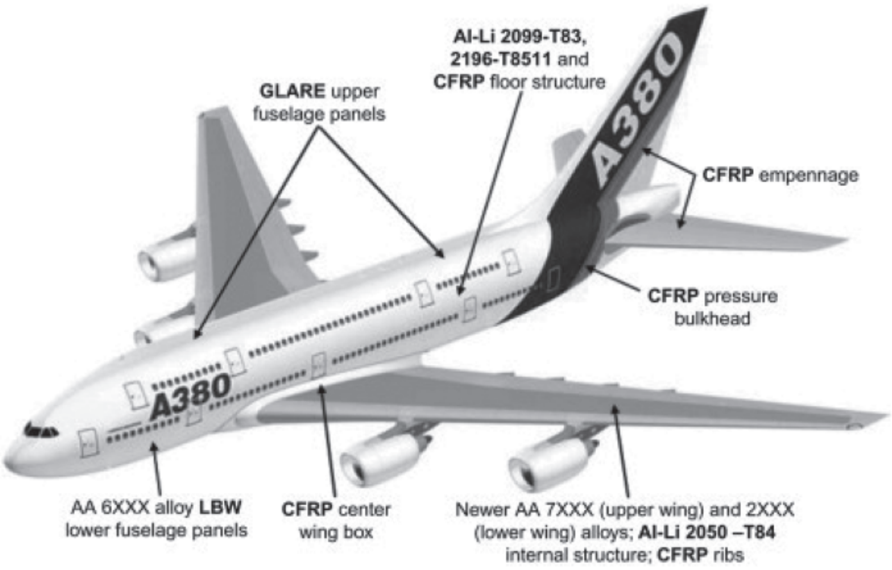

Figure 1: Advanced materialused for structural areas of the Airbus A380

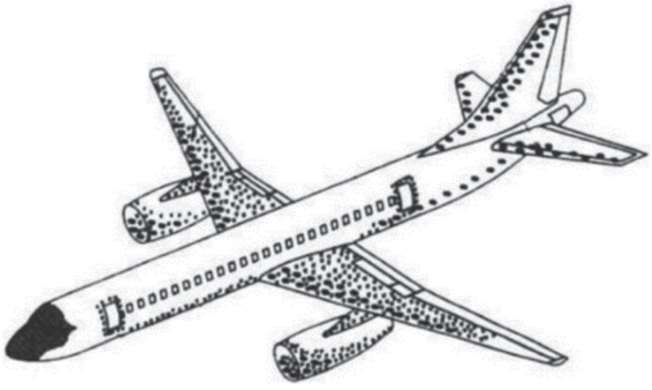

Figure 2: Impact distributionon aeroplane.
Source: Adapted from [8].

are examples of particles. The aircraft's numerous surfaces may also be subject to foreign object damage caused by insect and birdcollide [6-7]. Rain and sand, in particular, can have a severe influence on the body of the aircraft and significantly decreases the components lifecycle, as this attack can occur in a variety of conditions.

Certain areas of an aircraft are more vulnerable to damage from strikes during flight. In general, the front areas of the aircraft that face the approaching air stream suffer from a higher rate of damage since the impact speed is significantly higher there. As a result, the downstream sites only experience low-speed effects. Figure 2 depicts the impact rate distribution on the commercial aeroplane [8]. Items that move at a medium speed represent by bigger dots. The smaller dots represent impact locations for slower moving items, whereas the hatched zone depicts the impact high-speed collisions, which are common.

1.3 2xxx, 6xxx, 7xxx Aluminium Alloys

Muna Khethier Abbass and Shireen Amin Abdulrahman et al [9] studied a comparison of erosion and electrochemical corrosion of two high-strengthAl7075T6 and Al 2024T3 alloys. The initial corrosion test was performed in saltwater (3.5 per cent NaCl). Using the method of Tafel extrapolation and cyclic potentio-dynamic polarisation testing. The erosion test was undertaken in a slurry solution (1wt% SiO_2 sand in NaCl sol of 3.5wt% as the erodent) with different impact angles (90°, 46°, and 30°). The rate of erosion of Al2024T3 was greater than that of Al7075T6. This is owing to

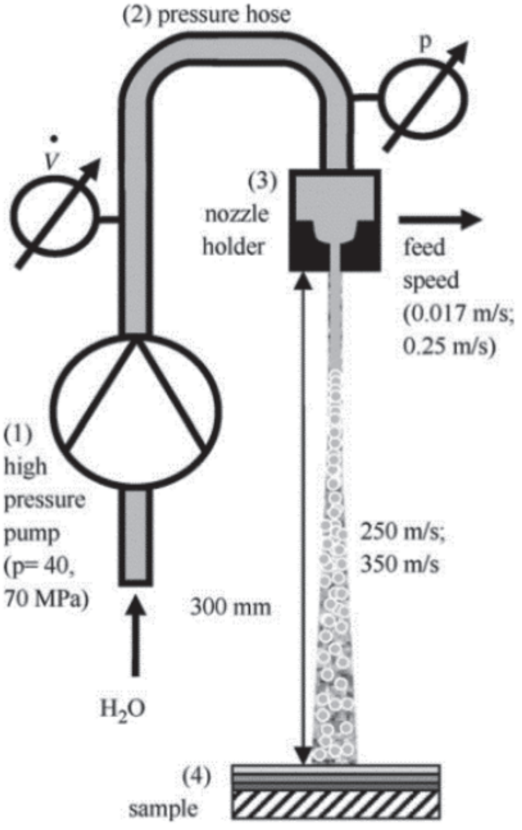

Figure 3: Stationary sample erosion test (SSET)

Al7075T6's increased hardness of HV155, compared to Al2024T3's HV137.

In the case of impact angles 30º and 46º, with increasing exposure duration, the rate of erosion in slurry solution rises, until it reaches a maximum value, further declines with longer exposure durations; for two Al-alloys, the increase in erosion rate as the angle of impact increases from 30 to 90 degree. At all impact angles of (90º, 46º, 30º), the weight loss or erosion-corrosion rate of Al7075T6 alloy was less than that of Al2024T3 alloy. In 3.5 per cent NaCl solution, the two Al-alloys have strong pitting resistance [9].

M. Grundwurmer et al [10] studied on the transparent sol–gel coatings resistant to rain erosion development. Sand erosion and rain erosion are the two main causes of erosion damage. Obtaining fundamental knowledge on the wear induced by liquid impact on these materials, two main sol-gel methods have been chosen.

Study of erosion was done using a cheap, reliable and simple test method which water jet of high velocity is shown in Figure 3. Water has been compressed from 40 and 70 MPa by a water pump athigh pressure. The generated droplet size was developed with this was 1.2mm, the stand off distance is 300mm, and jet speed of 250-350m/s.

The results of the liquid impact tests reveal that the coatings have cohesive failure without any signs of delamination. Particle reinforced hybrid sol-gel coatings outperform commercialized erosion prevention coatings in terms of rain erosion resistance. Furthermore, because sol-gel coatings minimize the needed layer thickness, the weight of the protective system is reduced [10].

Sedat Karabay et al [11]. discusses about the SPE behaviour of solutionized, annealed and artificially aged (T6) of AA2014 was done.

The erosion test was performed in sand blast type erosion tester [11]. The erodent size of 180 mesh which was driven by 3 bar air pressure and the nozzle 50mm of diameter 5mm. All the erosion test were run at 75 m/s and at impingements 45^0. the sample were weighed with the help of electronic balance with ±0.1mg accuracy after the test and also before the test.

Experiments have shown that the erosive wear of aluminum AA2014 rises as the material's hardness increases. Increased material hardness resulted in increased brittleness and decreased ductility. As a result, kinetic energy of the moving particles easily removes chip from brittle surface of the AA2014, causing material loss from the metal matrix exposed to precipitated hardness to occur at higher rates.

Material AA2014 should be utilized under low hardness conditions to avoid a greater metal-removal rate due to excessive particle impingements. On the surfaces of the solutionized, heat-treated, and annealed specimens of aluminium AA2014, embedded erodent particles were found.

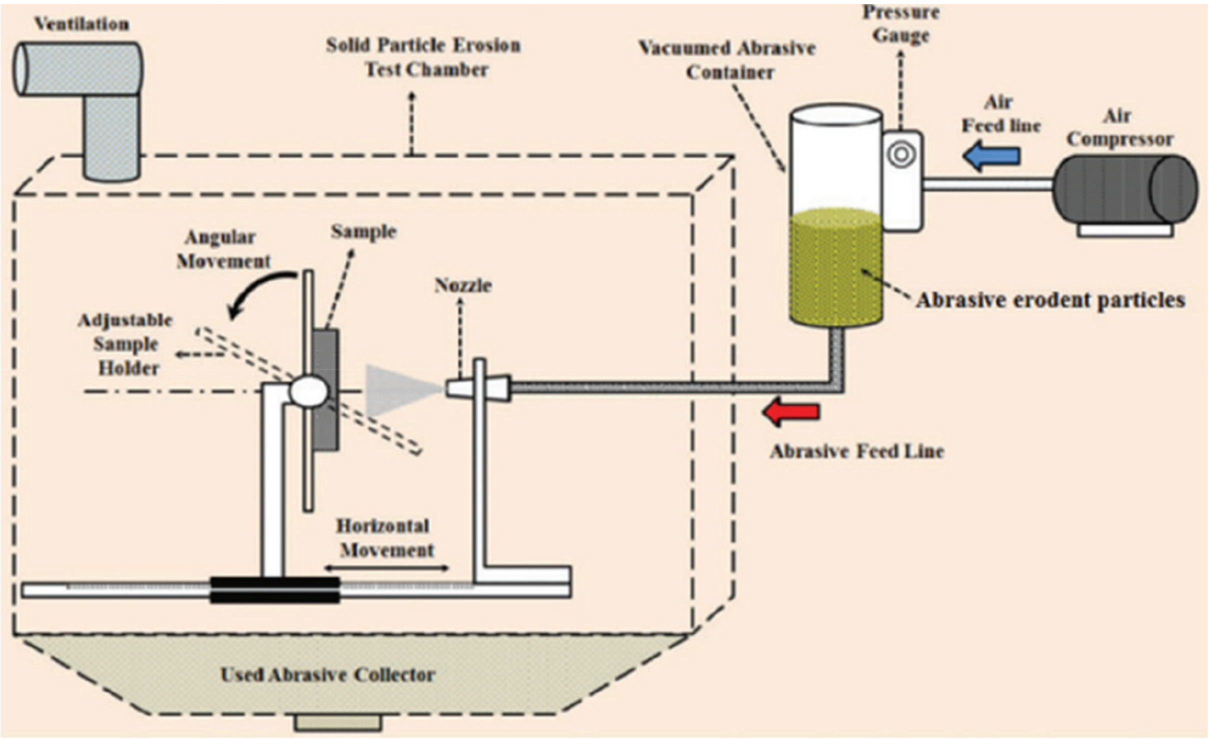

Figure 4: Erosion test rig

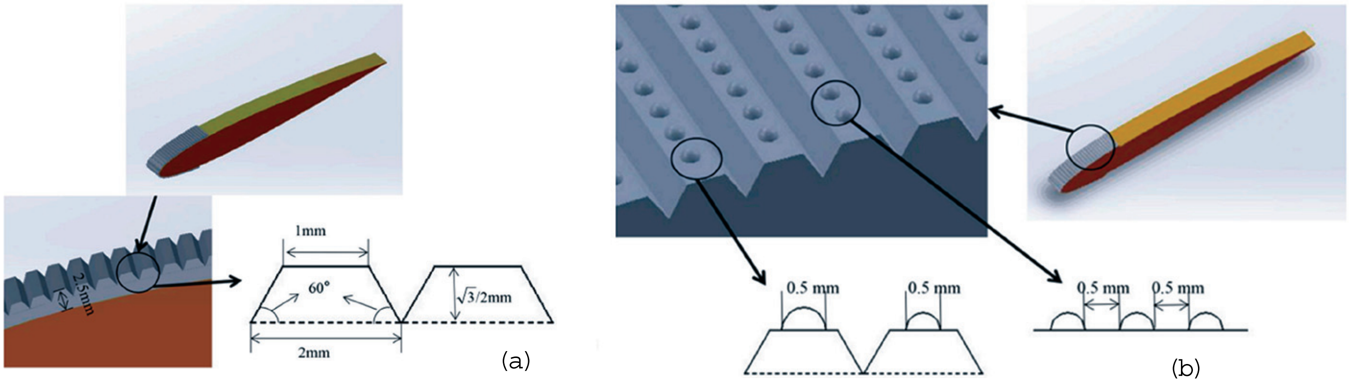

Figure 5: Bionic Coating of (a) V-Type (b) VC-type)

Due to the ductility of the samples, it was discussed that erodents may also be embedded in the surfaces of aluminum alloys at impingement angles less than 90° [11].

Aygen A Erdogan et al [12] studied on erosive behaviour of Al6082-T6. A comprehensive investigation was carried out on the Al6082-T6 aluminium alloy using aluminium oxide (Al_2O_3) erodent particles to evaluate the erosive wear at two different erodent particles size, which are 120 mesh and 60 mesh, also the sample were test at two different air pressure at 1.5 bar and 3 bar. And the erosion test standard was according ASTM G76 standard and at different impingement angles (15°, 30°, 45°, 60°, 75°, 90°). Figure 4 shows the erosion test rig used.

At a 30° angle, the most erosion was seen. At small impingement angles, the aluminium alloy was shown to be highly erodent. Wear rate reduced with the increase of impact angle, with the lowest wear rate observed at 90°.

Modi et al [15] found that the increase in wear rate as there is an increase in the erodent particle speed in their experimental investigation. A similar problem exists here. For ductile materials like Al6082-T6, the highest erosion rate appears between the particle of 15-30° impact angles.

SPD behaviour of Al6082-T6 is substantially influenced by erodent particle size. When compared to small erodent particles, erodent particles of big size caused an average higher roughness.

At impingement angles of 15 and 30 degrees, micro ploughing and micro cutting erosion processes were discovered. At small impingement angles, severe plastic deformation was created on target material's surface. The erosion rate results from SEM tests of surface of Al6082-T6 worn at many different parameters match the erosion results. Due to the flexibility of the AA6082-T6 aluminium alloy, erodent particles (Al_2O_{3-} alumina) can be embedded while SPE process on the surfaces of the sample, according to the EDS analysis [12].

Sunday Aribo et al [13] studied Al6063 with varying composition of silicon carbide and snail-shell-ash (SSA) reinforced which was developed by mechanical stir-casting method. Erosion test was done on submerged impinging jet rig as given in [14].

The test rig was made of glass-reservoir with capacity of 1.5l and water pump power 0.5Hp. This is the simulation of a rig with a single nozzle that has been changed based on the test rig which was utilized by Aribo et al [14]. The system's input voltage was varied to adjust motor speed. The experiment employed varying speeds of 3.5 m/s and 2 m/s, with 0.1 g/L sand input for properties of erosion enhanced corrosion.

Erosion test was undertaken in four different environment which (1) pure tap water (2) tap water + 0.1g/L sand (3) tape water + 0.1g/L sand + 20 wt.% MEG (4) tape water + 0.1g/L sand + 20 wt.% MEG + 1wt.% NaCl.

The magnitude of hardness increased to a max by adding 7.5 wt per cent SiC+7.5 wt per cent SSA. Erosion resistance was higher in the composite with highest hardness value but the erosion resistance is not better than monolithic alloy. Ploughing and indentation were shown to be the dominant degradation mechanisms in SEM pictures of the composites' damaged surfaces [13].

S. Karabay et al [15] studied a solid particle of erosion behaviour on Al7075 which is solutionized, artificially aged (T6) and annealed. The samples were eroded by erosion tester at 45° impact angle, speed 75m/s, erodent particles size 180 mesh (garnet particles) static air pressure at 3 bar.

Increase in erosion rate with increased hardness value of AA7075 alloy. Hardening of material causes rise in brittleness. Thus, the moving particle damages the surface more easily and causes material loss. To avoid erosion or material loss of AA7075, material should be in ductile state. Solutionizing heat treatment increase the ductility of the material.

Xupeng bai et al [16] studied three different materials used for construct of shell model of blades of helicopter rotor which are made Al7075-T6, Mg-Li9-A3-Zn3,Ti-4Al-1.5Mn and were subjected to SPE test to determine the erosion rate.

The erosion test was done at different impact angle (6°, 3° and, 0°) the particles velocity (70, 150, and 220 m/s) using discrete phase method, finite volume method and erosion model. Blades rotor's leading-edge were coated with two different bionic anti erosion coating layer which are VC and V-type as shown in Figure 5, to improve the erosion resistance.

With increasing particle velocity, the erosion rate increased considerably. With modifications in the angle of impact, the erosion rates of three materials were essentially constant. As a result, we believe that fluctuates in the impact angle may only alter the blade's erosion area. The V-type coating has a much stronger erosion resistance than VC-type coating. The angle of impact had only a little effect on the degradation rate of the two types of bionic coatings [16].

Suganeswaran Kandasamy et al [18]. focus on fabrication of Al7075 Surface Hybrid Composites with reinforcements with Al_2O_3 and SiC using the method of method of friction stir process. The erosion resistance is evaluated for the specimen with high micro-hardness value. When compared to base Al7075, the study of surface morphology displays that homogeneous distribution and grain refinement of reinforcing particles have reduced surface deterioration. Selected erosion parameters are jet angle (30°, 60°, 90°), jet pressure (3, 4, 5 bar), erodent particle size (50, 100, 150 mesh).

During the incubation period, the reinforced particles in the specimen reduce erodent kinetic energy and protect the composite from erodent particles. Small pits and material loss from the lip region characterized the parent matrix AA7075 eroded surface. Microcracks, plastic deformation bands and stretch marks were visible in the SEM image of the deteriorated optimal specimen [18].

L. Rama Krishna et al [19] studied about dense ceramic oxide coating on a AA7075 aluminium alloy around 100µm thick by using microarc oxidation coating technique. Ateston dry sand abrasion, a SPE test, and a pinondisc test were used to assess the coatings' tribological performance. In the comparison of results with the aluminium oxide coating sprayed by detonation and the bulk alumna- Al_2O_3.

At two distinct impact angles (30° and 90°), erosive volume loss per kg of erodent is taken. The bulk Al_2O_3 exhibit high material loss than other coating at both impact angles and at the both the angle the MAO and DSC coating has same steady state mass loss, while bulk aluminium oxide has greater material at 90°rather than at 30°.

Marý´a-Dolores Bermu´dez et al [20], studied erosion on the Al 2011,Al6061 and Al7075 aluminium alloys in an IL 1 (ionic liquids) of 90 wt. % in the presence of aluminium oxide particles. Test samples were dipped in solution of 90% of IL1 (water) with aluminium oxide particles of 80 g/l, under stirring speed of 400 rpm by using stirrer (which is magnetic). All tests were done at normal room temperature. Ionized distilled water was taken use in all cases. The erosion rates are roughly 0.2 mm/year or less, and they rise with increasing copper concentration, giving Al 6061 has greater corrosion resistance than Al 7075 and is greater than Al2011, The Al 7075, Al 6061 and Al 2011 shows a good erosion resistance in concentrated solution of IL1 in water in the presence of aluminium oxide (Al_2O_3) particles. And the corrosion resistance increases when content of copper in the alloy increases [20].

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3.0 Conclusions

In this paper, we studied about impact of erosion on aluminium alloy mainly 2xxx, 6xxx, 7xxx series alloys which are analysed previously published work and which are used in various industrial applications.

- These Al alloys offer opportunity for decrease in the weight of aircraft. 2xxx serries alloys provide good strength and damage tolerance, whereas 6xxx series alloys provide good corrosion resistance and improved machineability, furthermore, 7xxx series alloys offer hight strength and high temperature performance.
- Material should be utilized under low hardness conditions to avoid a greater metal-removal rate due to excessive particle impingements.
- When compared to small erodent particles, the big erodent particles caused a higher erosion rate.
- Erosion resistance was higher in the composite with highest hardness value.
- To avoid erosion or material loss, material should be in ductile state. Solutionizing heat treatment increase the ductility of the material.
- As the impact velocity of particles increases, the erosion rate increases significantly.
- To lower the material loss or erosion rate material coating is preferred.

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