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Potential of AA7075 as a Tribological Material for Industrial Applications -A Review

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Lightweight materials in general and alumunium alloys in particular are increasingly becoming important engineering materials in order to improve the sustainability aspects of engineering products. Amongst the alumunium alloys, AA7075, due to its strength to weight ratio along with other technical benefits has become a prominent material. The literature suggests that AA7075 is structurally good, however its poor tribological properties can be enhanced by introducing different reinforcements. Further, the mechanical and tribological behaviour of AA7075 relies on variety of factors such as fabrication route, quality and quantity of reinforcement, *etc.* In this work we summarize the work carried out in studying the various mechanical and tribological properties of AA7075. The paper will focus on the ceramic and solid lubricant reinforced AA7075 hybrid composites. A section also summarizes the applications of the alumunium alloys and composites in various engineering applications.

Keywords: AA7075; Composites; Tribology; Alumunium; Light Weight Materials

1 Introduction

The global energy requirements and the global sustainability goals have forced the research community to search for newer materials which are light in weight and possess better properties[1]. The global industries particularly the automotive and aerospace sectors are striving to develop new lightweight materials so as to save fuel and cost[2]. As per the previous literature, a substantial amount of work has been done to enhance the properties of conventional materials by reinforcing the metals, alloys and polymers with various reinforcements[3-5]. Lightweight metals like aluminium and magnesium can be suitable replacements and address the industry[6]. The research work has been extensively carried out on Iron, Magnesium and Aluminium based composites and the number of publications have been summarized in Fig. 1. Tribology being a common phenomenon associated with a lot of industrial products and more common in automobiles, aerospace equipments and marine machinery, gives rise to need for materials with good tribological performance in addition to good mechanical strength. Aluminium, despite being abundant in nature possesses little structural value due to its ductility and less hardness. Previously, aluminium has extensively been doped to form alloys by various agents such as zinc, copper, magnesium, manganese, silicon, *etc.* to improve the functional performance[7-8]. Further a lot of work has also been directed towards exploring the options of various heat treatments, but the properties of some alloys cannot be maneuvered much by such treatments. The favourable strength to weight ratio and other technical benefits associated with alumunium can be exploited extensively in various engineering applications by adding various reinforcing agents to the base metal/alloy.

1.1 Aluminium Based Composites

A lot of research is directed towards studying the mechanical and tribological behaviour of alumunium based composites. Ceramic materials such as SiC, B_4C, Al_2O_3, TiC, TiO_2, TiB_2, *etc.* have extensively been used in the growth of aluminium based metal matrix based composites[9-12]. The ceramic phase has been reinforced to enhance the strength of the base alloys and the strength enhancement depends primarily on the bonding of the matrix phase and the ceramic phase. In this direction, Radhika *et al.*[13] prepared Al-Si10Mg alloy based composites with

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Al_2O_3 and graphite as reinforcements. The tribo-testing of these composites revealed that Al/9wt.%Al_2O_3/3wt.%Gr has the lowest wear rate as compared to the composites with no reinforcement. In a related study Zeren[14] evaluated the impact of graphite addition on the frictional/wear properties of Al/SiC/Gr materials. The authors reported a decrease in the hardness and the density with the increment in the graphite content. Singh[15] in a recent work reviewed the fabrication routes and tribological behaviour of Al/SiC/Gr materials. The authors have documented the role of graphite in decreasing the porosity of the composites. Also, the authors have reported that the association of graphite results in the enhancement of tribological properties up to a certain extent beyond which the trend reverses. Ambigai and Prabhu[16] in an experimental study compared the frictional behaviour of Al−Gr−Si_3N_4 materials, Al−Si_3N_4 and Al−Gr nanomaterials prepared using stir casting technique. The authors have stated that Al−Gr−Si_3N_4 hybrid composite exhibited better resistance to wear along with reduced friction when compared to the Al−Si_3N_4 nanocomposites. Kaushik and Rao[17] evaluated the impact of the load on the abrasive wear of Gr/SiC/Al-Mg-Si hybrid materials. The authors suggested that the bonding at the matrix-reinforcement interface played a vital role in decreasing the wear rate of the composites. Sharma *et al.* (2017)[18] in a study related to wear behaviour of AA6101/graphite composites found that the various properties like ultimate tensile strength, hardness, and the percentage elongation decreased with the enhancement in the graphite content. However, the wear rate was found to decrease with the association of graphite particles.

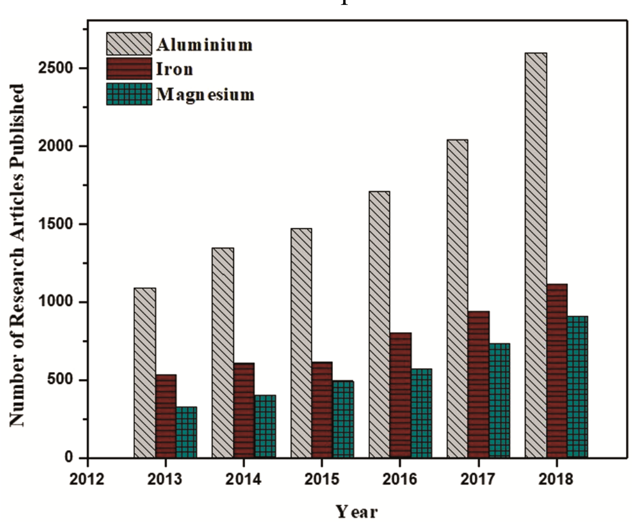

Fig. 1 — Comparison of Research Articles Published Related to Aluminium Based Composites *(Source: Scopus)*

1.2 Applications of Aluminium Composites

The metal matrix composites in general, have evolved as a new class of materials with a wide range of applications[19]. The use of aluminium based composites in automobiles in particular has seen an exponential rise in the past decade[12]. Table 1 presents various applications of aluminium based composites in different engineering sectors.

2 AA7075 as Base Matrix

AA7075 is an aerospace alumunium alloy possessing high strength aluminium having zinc as the main alloying element and its strength is similar to many steels and is strongest amongst the various alumunium alloys[20]. Further, it exhibits a good fatigue strength and finds a variety of engineering applications[21]. The AA7075 parts for tribological contacts include gears, shafts, sprockets, shaft keys, transmission and engine parts[22-23]. Nevertheless, AA7075 because of its low wear and hardness, fails to serve as a tribological material[20]. Table 2. summarizes the various applications and properties of AA7075.

3 Mechanical and Tribological Studies of Bare AA7075 Alloy

The investigations of wear/friction have been carried out on bare AA7075 alloy at different temperatures, loads, and speeds. Ruiz-Andres *et al.* [24] investigated the wear rate of AA7075 (Al-Zn-Cu),

Table 1 — Industrial Applications of Aluminium Composites

Application Sector	Details
Aerospace/ Defense/ Military	Space structures, Antennas, Engine and transmission parts, Compressor parts, helicopter parts, Aircraft skin, Airplane seat parts, *etc.*
Automotive	Gears, sprockets, keys, guide ways, propeller shafts, connecting rods, pistons, wheel parts, body parts, transmission casing, flywheels, drive shafts, brake drum, brake rotors and clutch parts, *etc.*
Sports	Rackets, ski Parts , bicycle frames and sprockets, wheel rims, golf club heads, *etc.*
Medical	Parts of medical equipments, Exoskeletal parts
Building	Off shore platforms, Roofs, partitions, Windows and seismic resistant structures, *etc.*

Table 2 — Properties and Applications of AA7075

Property	Value
Density	2.81 g/cc
Hardness	155 HV (Heat Treated Condition)
Ultimate Tensile Strength	572 MPa
Modulus of Elasticity	71.7 GPa
Poisson's Ratio	0.33
Coefficient of Thermal Expansion	23.6 µm/m°C
Melting Point	477 - 635 °C
Thermal Conductivity	130 W/m-K

AA5754 (Al-Mg), and AA6082 (Al-Mg-Si) aluminium alloys at low sliding speeds (<0.01 m/s). The authors have observed that at speeds (>0.01 m/s), the alloys have shown oxidative and delamination wear. Yang *et al.* [25] performed sliding wear tests for 7075 Al alloy under dry sliding conditions. The authors have concluded that with the increment in temperature, the wear rate decreases at a uniform rate under low loading conditions (less than 50 N). Moreover, the authors have documented that AA7075 offers high wear resistance at higher temperatures and low loads. Shanmughasundaram[26] studied the effect of heat treatment, velocity and load on the wear behaviour of AA7075 Alloy. The analysis revealed that the normal load to be the critical parameter. Moreover, the wear increased at increased loads and the sliding speed. Liu *et al.* [20]investigated the corrosion as well as wear behavior of AA7075 using three different environments of ethanol, de-ionized water and seawater. The studies performed by these researchers revealed that under seawater conditions the wear rate is maximum. In addition to the aforementioned studies some studies have been carried out on AA7075 to study its fretting wear behaviour under different conditions and in different media[27]. The aforementioned studies however suggest that AA7075 in unreinforced form cannot be used for critical applications due to its comparatively poor wear resistance.

4 Mechanical and Tribological Studies on AA7075 Composites

In order to enhance the strength, hardness, and wear performance at high temperature, the preferred reinforcements amongst various ceramics are silicon carbide, alumina, *etc.* Researchers have focused upon the impact of SiC on 7075 material and witnessed an increment in the tensile strength, density and hardness with the SiC. In this study, Si C content was varied from 2-6 wt.% and the samples were prepared by liquid metallurgy method. The authors also reported a remarkable development in the wear resistance of the developed materials[28]. An investigation carried out by the authors[29] revealed a significant enhancement in hardness and wear behaviour with the association of the AA7075 with SiC particles. The friction/ wear studies were carried out using a reciprocating test rig. Additionally, the authors have documented enhancement in the contact temperature with an increased number of strokes. Rajan *et al.*[30] in a study related to AA7075/TiB_2 materials prepared via in situ process have described that an increase in the TiB_2 content resulted in low wear. The TiB_2 content was added in different weight percentages of (0, 3, 6 and 9 wt.%). The authors have also reported that TiB_2 particles are instrumental in improving the high temperature wear of these materials as these particles offer resistance to metal flow and sub-surface deformation. Researchers also studied the impact of B_4C on AA7075 and found that the mechanical properties exhibited an improvement at increase reinforcement content[31]. Moreover, the friction and wear rate was less as compared to the base material. The authors have also observed the MML formation and have opined that MML is influential in improving the wear properties of the composites. The mechanical behaviour of AA7075 based hybrid metal based materials with TiC and SiC as the reinforcing particles was investigated[32] and the authors observed a development in the mechanical properties. Saravanan *et al.*[33] in their study examined the tribological properties of AA7075-TiC powder metallurgy based composites. The statistical analysis revealed that sliding speed is the most influencing parameter in case of wear.

The impact of TiO_2 on the mechanical behaviour and microstructure of AA7075 was also investigated by researchers[34]. The study reported a decrease in the grain size with increased TiO_2 content. Moreover, enhancement in hardness, tensile/compression strength was reported as the content of TiO_2 is increased. Kumar and Dwarkadasa[35] have studied the fracture properties of Al-Zn-Mg/SiC and reported a decreased yield strength (compression) with the increased volume fraction of SiC. In a study by Yilidirim and Ozyurek [36]related to AA7075 added 4wt. % Ti and varied the content of B_4C by using powder metallurgy process for fabrication. They have reported less density with the increase of B_4C particles. However, the hardness and wear resistance

Table 3 — Summary of Literature related to AA7075 based composites

Author	Composition	Major Findings
Kumar and Dwarkadasa [35]	Al-Zn-Mg/ SiC	Decrease in the yield strength in compression as the volume fraction of SiC increases
Daoud *et al.*[40]	AA7075 /Al_2O_3	Linear hike in the hardness and wear resistance.
Cai *et al.*[41]	7075 Aluminum alloy induced by torsional fretting	Oxidative debris plays a vital role.
Sudagar *et al.*[42]	AA7075-T6 + Ni-P coating	Low wear for heat treated samples at 400°C.
Kumar *et al.*[28]	AA7075/ SiC	SiC reinforcement resulted in i) low wear rate ii) high hardness, iii) high tensile strength.
Baradeshwaran *et al.*[31]	Al7075+B_4C(5,10,15,20 vol.%)	Minimum wear rate at 10 wt.% B_4C (11% less as compared to base alloy)
Baskaran *et al.*[43]	AA7075/TiC	Load and sliding velocity most significant parameters.
Murali *et al.*[34]	AA7075/TiO_2	Decrease in the size of grains with the hike in TiO_2 content. Enhancement in properties like hardness, compression/ tensile strength with increase in TiO_2.
Kountouras *et al.(2015)*[37]	AA7075/ fly ash	Around 45 % decrease in the expansion coefficient. Increased wear rate at high percentage f the fly ash particles (40 %).
Ruiz-Andrés *et al.*[24]	AA7075, AA5754 and AA6082	At relatively low speeds (>0.01 m/s), the alloys exhibited oxidative and delamination wear.
Yang *et al.*[25]	AA7075 alloy	Mild-to-severe wear transition observed with an increase in load.
Sambathkumar *et al.*[32]	AA7075/ TiC / SiC	Improvement in the mechanical properties such as tensile strength and microhardness.
Yilidirim and Ozyurek[36]	AA7075/4wt. % Ti + B_4C (3, 6 and 9 wt.%)	Hardness and wear resistance exhibited an increasing trend.
Saravanan *et al.*[33]	AA7075/TiC	Sliding speed is the most influencing parameter in case of wear behaviour.

exhibited an increasing trend. Kountouras *et al.*[37]employed pressure infiltration method to fabricate AA7075/ fly ash composites and investigated the various properties such as corrosion, macro-hardness, wear, *etc* of these composites. The authors reported an increased wear rate for high contents (40 vol %) of the fly ash particles.

The influence of graphite reinforcement on the mechanical and frictional behaviour of AA7075 had been studied by authors [38]. The study revealed that 5 wt% graphite reinforcement in the cast materials led to low wear rate. In a study on AA7075/TiB_2/Gr, authors reported enhanced mechanical behaviour of the developed materials as compared to the base material[39]. The hardness, as well as bending strength reported by the authors, exhibited an increasing trend. The authors also reported a decreased grain size with the increase in TiB_2 content. Table 3 presents a summary of various studies carried out on AA7075 based composites.

The studies suggest that the favourable properties of AA7075 can be tailored by adding ceramic reinforcements to enhance the mechanical behaviour and the wear resistance whereas the addition of solid lubricants can help to decrease the friction. The optimal selection of the content of the reinforcements and the type of reinforcements can help in expanding the application arena of this important aerospace alloy.

5 Conclusions

AA7075 is a potential base matrix material for the development of alumunium composites, and has not been explored much for the fabrication of metal matrix composites. Further, the tribological properties of AA7075 based composites have not been explored much. The work carried till date suggests that although the mechanical properties are improved by incorporating ceramic materials, however the anti-friction properties are not altered much by the addition of these reinforcements. To address this issue, a lot of solid lubricants have been tried as secondary reinforcements, however, the improvement in the frictional characteristics is countered by the drop in the hardness of the materials by the association of the solid lubricant. Moreover, the effect of various parameters controlling the friction/ wear behaviour like load, sliding speed, sliding distance has not been explored in detail.

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