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Enhancement of wear and ballistic resistance of armour grade AA7075 aluminium alloy using friction stir processing

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Abstract

Industrial applications of aluminium and its alloys are restricted because of their poor tribological properties. Thermal spraying, laser surfacing, electron beam welding are the most widely used techniques to alter the surface morphology of base metal. Preliminary studies reveal that the coating and layering of aluminium alloys with ceramic particles enhance the ballistic resistance. Furthermore, among aluminium alloys, 7075 aluminium alloy exhibits high strength which can be compared to that of steels and has profound applications in the designing of lightweight fortification structures and integrated protection systems. Having limitations such as poor bond integrity, formation of detrimental phases and interfacial reaction between reinforcement and substrate using fusion route to deposit hard particles paves the way to adopt friction stir processing for fabricating surface composites using different sizes of boron carbide particles as reinforcement on armour grade 7075 aluminium alloy as matrix in the present investigation. Wear and ballistic tests were carried out to assess the performance of friction stir processed AA7075 alloy. Significant improvement in wear resistance of friction stir processed surface composites is attributed to the change in wear mechanism from abrasion to adhesion. It has also been observed that the surface metal matrix composites have shown better ballistic resistance compared to the substrate AA7075 alloy. Addition of solid lubricant MoS_2 has reduced the depth of penetration of the projectile to half that of base metal AA7075 alloy. For the first time, the friction stir processing technique was successfully used to improve the wear and ballistic resistances of armour grade high strength AA7075 alloy.

Keywords: Armour grade aluminium alloy; Friction stir processing; Boron carbide; Molybdenum disulphide; Wear; Ballistic resistance

1. Introduction

Steel is globally accepted as primarily used material for the construction of military and non-military vehicles. It is attributed to the features associated with steel, such as high energy absorbing properties, high strength, greater notch toughness and high hardness [1−3]. Selection of suitable armour materials for defence applications is very crucial with respect to increasing mobility of the systems as well as maintaining safety. Therefore, determining the material with the lowest possible areal density that resists the predefined threat successfully is required in armour design studies. A number of various material systems can be considered in this perspective, especially substituting the steels with light metal and alloys [4]. The aluminium and its alloys have profound application in the design due to their of lightweight fortification structures and integrated protection system low density, high specific strength, high specific energy absorption capability, good corrosion resistance, good thermal conductivity, less sensitivity to adiabatic shear banding and thermoplastic

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instability [5]. Backman et al. [6] and Corbett et al. [7] revealed that aluminium and its alloys possess Young's modulus, strength and ductility, lower melting point and less sensitivity to strain rate forbids it's usage as armour material. Multi-layering of target or spaced structures, in extruded products or in combination with other materials, is effective measures towards improving the penetration resistance. It can be inferred that an effective combination of surface hardness to blunt or deform the projectile and subsequent dissipation of kinetic energy by supporting tough layer is primary requisite for an armour material [8–11]. Discontinuously reinforced metal matrix composites are typically a two-component system consisting of a dispersed ceramic phase in a metallic matrix, which exhibits desirable mechanical properties, including high specific stiffness, high plastic flow strength, good thermal expansion, thermal stability, creep resistance, and good oxidation and corrosion resistances, suitable for automobile, aerospace, and defence industries [12]. Earlier investigations on incorporating the sandwich of hard facing alloy and depositing a soft buttering layer in between base metal (Austenitic stainless steel) improved the ballistic immunity of steel armour welds by hindering the affect of hydrogen induced cracking (HIC) and heat affected zone (HAZ) softening introduced during weld thermal cycle used in combat vehicle construction [13–19]. Coating metallic substrates with carbides is an effective solution in prolonging the service life of a metallic component in abrasive or erosive environments. The mechanical performance of carbide coating strongly depends on the degree of dissolution of carbide in the matrix and the type of reaction layer [20]. Extensive work has been carried out for production of protective coating of silicon carbide (SiC) and tungsten carbide (WC) using surface modification techniques such as high energy laser melt treatment, high energy electron beam irradiation and plasma transferred arc process. Among these techniques, laser melt treatment is the widely used surface modification process. During this process, laser melts the surface of substrate along with the deposited material which is usually either carbide powder (SiC, or WC) or combination of carbide powders and a binding material (Co, Al, or Ni) [21–30]. In aforesaid techniques (liquid phase processing or fusion route), it is difficult to avoid the interfacial reaction between reinforcement and metal matrix, and the undesirable and detrimental phases may form at the surface. It also leads to defects such as pores, pin holes, shrinkage cavities, segregation, and grain coarsening [31]. Hence those cited problems can be addressed by adopting such a technique which is based on solid state. A technique that is receiving renewed attention and development all over the world is friction stir processing, which is a solid state process. Surface composite fabricated by incorporating nano sized alumina into AA6082 aluminium alloy revealed the existence of defect free interface and the perfect bonding between surface composite and substrate. It was also found that the wear rate is reduced to one third of that of as received AA 6082 [32]. Silicon carbide reinforced AA 2024 alloy composite has been introduced onto the surface of A356 Al–Si alloy using friction stir processing. The obtained surface composite exhibited excellent wear resistance and metallurgical bonding with the substrate [33]. Wear characteristics of surface hybrid composites processed through friction stir processing revealed the significant improvement in wear resistance compared to that of substrate [34,35]. Keeping the afore mentioned in view, the present investigation assumes significance as studies on enhancement of wear and ballistic resistances by using friction stir processing, which have not been reported on this class of armour grade AA 7075 aluminium alloy.

2. Material and methods

Base metal AA7075-T6 aluminium alloy (substrate) of size 500 × 500 × 40 mm was used in the present investigation and its chemical composition is given in Table 1.

The surface of substrate was subjected to a depth of 3 mm using friction stir processing with a specially designed friction stir welding machine (make — ETA Technology, Bangalore, India). It was done with the help of two hot working tools made of high carbon steel (H13). The first tool, a straight cylindrical friction stir tool, having shoulder Ø 20 mm without pin was employed to compact the powder in the previously drilled holes on the substrate surface and to avoid scattering of the boron carbide particles during FSP. The second tool, a straight cylindrical friction stir tool (3 mm in pin length, Ø 6 mm in pin diameter, Ø 20 mm in shoulder diameter), was inserted into already processed surface, i.e., first step of friction stir processing of flat cylindrical surface. Tool rotational speed of 960 rpm, transitional speed of 50 mm/min, and plunging speed of 30 mm/min were employed.

A section cut from unprocessed and friction stir processed alloys, i.e., surface composites were prepared for microstructural examination. The polished surfaces were etched with Keller's reagent. Microstructural examination was carried out using optical microscope. The friction stir processed material was subjected to micro hardness testing employing Vickers indentation at 0.3 kgf load. The pin specimens (in the form of cylinders of Ø 4 mm and 25 mm in length) were subjected to dry slide wear test using Ducom pin-on-disc wear tester. The counterpart disc was made of hardened alloy steel with surface hardness of 65Rc. The applied load was 0.5Kgf and the sliding speed was kept constant at 640 rpm. The total sliding distance for the test was 6 km. Surface composites (targets) produced by incorporating different sizes of boron carbide particles using friction stir processing for ballistic testing are shown in Fig. 1.

Ballistic testing of friction stir processed plates was carried out as per the military standard (JIS.0108.01). The experimental setup is given in Fig. 2. The target plates were tested with 7.62 mm lead projectiles located at 10 m from the

Table 1
Nominal composition of AA7075 alloy.

Element	Zn	Mg	Cu	Cr	Mn	Ti	Si	Fe	Al
Weight/%	5.6	2.5	1.6	0.23	0.3	0.2	0.4	0.5	rest