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Hybrid composites – Metallic and ceramic reinforcements influence on mechanical and wear behavior

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ABSTRACT

This experimental study is concerned with the influence of metallic (Ti) and ceramic (SiC) reinforcements in an aluminumfsilicon (AlSi) alloy, when regarding tensile properties and wear behavior. Several micron sized particulate reinforced composites were produced by hot-pressing technique: AlSi–SiC and AlSi–Ti composites and AlSi-(Ti–SiC) hybrid composites.

Regarding tensile properties, all composites presented higher ultimate tensile strength (UTS) than the AlSi matrix, with the highest UTS being attained by a hybrid composite (AlSi-11.25%Ti–5%SiC).

Regarding wear behavior, reciprocating pin-on-plate wear tests were performed for unreinforced AlSi; AlSi–Ti composites and AlSi-(Ti–SiC) hybrid composite against a gray cast iron (GCI) counterface. The wear mechanisms for all the tested tribopairs are presented and discussed. It was observed that the wear behavior of the AlSi–Ti/GCI and also AlSi-(Ti–SiC)/GCI tribopairs are improved when compared with the AlSi/GCI system. AlSi-11.25%Ti-5%SiC hybrid composite exhibited the highest improvement in wear rate.

1. Introduction

Hybrid metal matrix composites are an arising class of materials that combine two or more different types of reinforcement in a metallic matrix [1]. In these composites, properties compromises can be obtained, with some of the drawbacks of a reinforcement being compensated by an additional reinforcement.

Traditionally aluminum alloys have been reinforced with ceramics such as silicon carbide (SiC) and alumina (Al_2O_3) with the aim of increase strength and modulus. Nevertheless these beneficial effects of ceramic reinforcements are generally accompanied by a decrease in elongation to failure [2–6]. Besides strength and elastic modulus, aluminum alloys reinforced by SiC particulates (SiC_p) exhibit improved wear resistance, as compared to aluminum alloy [1]. It has been shown that the wear rate of aluminum alloys decreases with the addition of SiC [7,8], mainly due to the SiC particle that protects the aluminum matrix from wear [9,10].

Contrarily to ceramics, metallic reinforcements can improve strength without causing a too large loss of ductility [2–4,11]. Among metals, titanium is an interesting reinforcement candidate especially due to its low density and high specific strength [4,12,13]. The use of titanium for components manufacturing had a fast growth in the past years, especially in the aerospace industry [14], still the use of Ti as reinforcement in composites is not so usual. There are studies concerning Mg and Mg alloys reinforced with Ti particulates (Ti_p) [12,13,15–17] and others regarding Ti_p-reinforced Al or Al alloys [4,18–22], the majority of these using casting as processing route [4,19–21]. By adding titanium as reinforcement an additional advantage is its possible plastic deformation during load transfer [23].

It has been shown that a strong interface adhesion between matrix and particle, besides enabling load transfer to the reinforcement, can lead to an improvement in wear resistance of composites [24,25]. Ti_p reinforced aluminum composites produced by powder metallurgy have the advantage of, unlike SiC, the Ti particles react with the aluminum matrix, generating an interface that can be itself beneficial when regarding wear.

An interesting observation is that when the effect of a certain type of reinforcement reaches its saturation point (i. e. additional reinforcement causes the composite properties to decrease) an addition of another type of reinforcement may further improve the composite properties. Some studies regarding hybrids have shown that the wear resistance of hybrid composites (with two

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reinforcements) can be higher than that of single reinforced composites (with only one of the reinforcements) [26].

The present work aims to assess the contributions of metallic and ceramic reinforcements by producing aluminum–silicon hybrid composites reinforced with Ti and SiC particulates. Resistance and ductility properties (ultimate tensile strength (UTS) and elongation to rupture (ε_r)) of AlSi-(Ti–SiC) hybrids; AlSi–SiC and AlSi–Ti composites were determined. The dry sliding behavior of AlSi, AlSi–Ti and AlSi-(Ti–SiC) composites against a Gray Cast Iron (GCI) counterface was analyzed. The controlling wear mechanisms were investigated, and besides the pin, the counterface wear behavior was also studied. For comparison purposes unreinforced AlSi specimens were tested (mechanical and wear tests) under the same conditions.

Regarding the processing technology, sintering routes are interesting techniques for the production of hybrid composites because, unlike casting routes, the reaction between metallic reinforcements and metal matrix can be more easily controlled. However one of the drawbacks arising from traditional sintering processes (press and sinter) is the presence of porosity, requiring additional processing steps after sintering (e.g. extrusion). Thus, in this study, a hot-pressing method was used because it allows obtaining full densification, therefore eliminating the extrusion step. Additionally, uniformly and massively reinforced parts can be produced using this process, making it suited for the production of structural components.

2. Experimental

2.1. Fabrication of AlSi-(Ti–SiC); AlSi–SiC and AlSi–Ti composites

In this study several composites were produced, namely three Al–Ti reinforced composites: AlSi-5 wt.%Ti; AlSi-11.25 wt.%Ti and AlSi-16 wt.%Ti; two Al–SiC reinforced composites: AlSi-5 wt.% SiC; AlSi-10 wt.%SiC and two hybrid composites: AlSi-7.8 wt.%Ti-3.45 wt.%SiC; AlSi-11.25 wt.%Ti-5 wt. %SiC. The composites were produced from Aluminum–Silicon (AlSi) spherical powder (88.352% Al; 11.500% Si; 0.145% Fe and 0.003% Cu (wt. %)), with maximum particle diameter of 45 μm, pure Titanium spherical powder (99.715 wt. % Ti), with maximum particle diameter of 45 μm, both purchased from TLS Technik and SiC particles with 13 μm in size.

AlSi and reinforcing powders were mechanically mixed in a blender for 20 min. The obtained mixture was divided and placed inside graphite moulds, with 8 mm width, and 43 mm length. The samples were then sintered by hot-pressing, using a vacuum (10^{-2} mBar) pressure-assisted sintering system [27], with a high frequency induction furnace, according to the following procedure. The mould was placed inside the chamber, where the sample was compressed at 1 MPa, and then heated up to 500 °C, with a heating rate of 25 °C/min. When the temperature reached 500 °C the pressure on the sample was raised to 35 MPa (while the heating proceeds at 25 °C/min till 550 °C). The sample was maintained at 550 °C with 35 MPa pressure, for 15 min. Afterwards the samples were allowed to cool inside the mould, in vacuum, till room temperature. The obtained samples had average dimensions of: 3.4 × 8 × 43 mm. Unreinforced AlSi samples were also produced, for comparison purposes, following the same procedure.

2.2. Microstructural and chemical characterization

The obtained specimens were characterized in terms of chemical composition of matrix, particle and interface, by means of *Scanning Electron Microscopy (SEM)/Energy Dispersive Spectrometer (EDS)*. The spatial distribution of the particles in the matrix (polished specimens) and the fracture surface (after tensile tests) were obtained by means of *SEM*.

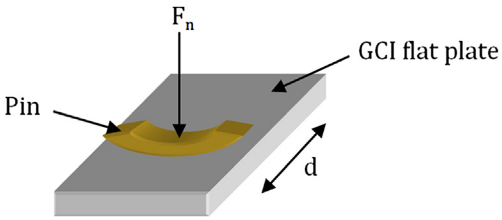

Fig. 1. Schematic test configuration: Fn – Normal applied load; d – alternated displacement amplitude.

2.3. Tensile tests

Tensile tests were performed at room temperature (~23 °C), with a crosshead speed of 0.02 mm/s, in a servohydraulic machine (Instron 8874), equipped with a 25 kN capacity load cell. The results are the average values obtained from five tensile tests.

2.4. Wear tests

A reciprocating pin-on-plate tribometer PLINT-TE67/R was used to evaluate the wear characteristics of AlSi, AlSi-(Ti–SiC) and AlSi–Ti composites/GCI sliding pairs.

Pins were machined from the produced composites and unreinforced specimens with the geometry presented in Fig. 1. The dimensions of the pins are: radius of curvature 40 mm, thickness 3.5 mm and the arc length 20 mm.

The counterpart consisted in flat plates (40 × 18 × 5 mm) of GCI with a hardness of 338 HV. The microstructure and chemical composition of the GCI plates are shown in Fig. 2 and Table 1 respectively.

Fig. 1 shows a schematic representation of the test performed in this work: applied normal load (F_n) on the pin and alternative displacement (d) of the flat specimen. Experiments were carried out with a normal load of 10 N and relative displacement amplitude of 10 mm, for a sliding distance of 148 m. During the tests compressed air was flown to the contact zone in order to remove loose wear debris. The frequency of the reciprocating motion was 1 Hz for all tests. All wear tests were carried out under the same conditions. All tests were performed in laboratory environment. The results were taken as the average from at least three tests.

The data acquisition system associated to the tribometer recorded different testing variables including coefficient of friction

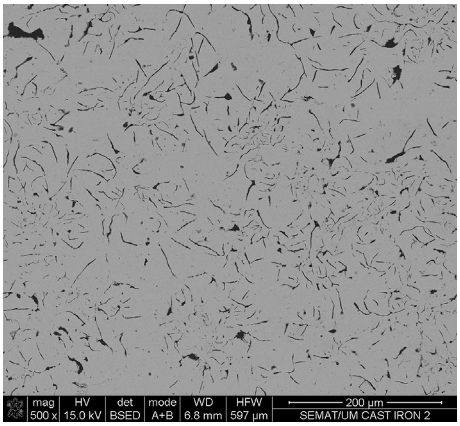

Fig. 2. SEM image of the GCI plate microstructure.