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Development of technologies for the production of multi-component ligatures Al-Cu-B-C with high thermal characteristics

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Abstract. The purpose of research is to provide a competitive alternative to aluminum silicon alloys used in automotive applications. This alternate can be created by developing composites of Al-5%Cu alloy reinforced with B4C particulates with a low coefficient of thermal expansion. Stir casting can be used to produce Al-5%Cu alloys containing different ratios of B4C. The squeeze casting technique decreased the porosity of the final material. The composites exhibited a fairly uniform particle distribution throughout the alloy matrix.

1.Introduction

Nowadays the importance and wide application of aluminum silicon alloys is undoubtable, especially aluminum alloys with percentage of silicon greater than 10% in combustion engines as pistons[1].

Metal matrix composites(MMC) not only provide ductility, toughness as metallic properties but also acquire ceramic properties like high strength and good modulus. The size, volume fraction and distribution of matrix element as well as reinforced element are important factors on which properties of MMC depend. To have better mechanical properties like strength, hardness and dimensional stability, reinforced material should be uniformly distributed [2]. Thermal, electrical, magnetic, wear and corrosion properties have attracted significant attention for decades to use metal matrix composites. To achieve remarkable hardness, corrosion, wear resistance, anti-oxidation properties and high-temperature inertness; Al₂O₃, SiC, Cr, diamond, SiO₂, Si₃N₄, TiO₂, ZrO₂ and WC are reinforced in metal matrix [4]. Powder metallurgy route is one of the present day technologies for the production of metal matrix composites. The predominant benefit of composite fabrication is low cost and suitability for small and complex shape. The properties of the composite substances are mostly defined with the aid of the property of the master alloy. Addition alloy of the composite helps in enhancing of physical and mechanical properties of the material [7].

The particulate metal matrix composite is basically used for tribological application for its outstanding wear resistance at the point of sliding. Self-lubricating properties encounter an excessive temperature; that is why gasses and oil cannot be used. So, there is a need of notable solid lubricant which works in a broad range of temperatures.

A unique advantage of powder metallurgy is that, less material is wasted as compared to metal



casting [3]. Copper is one of the most essential materials for thermal and digital applications due to its greater electrical and thermal conductivities and a decrease coefficient of the thermal expansion (CTE) than aluminum [5]. Pure copper is used in electrical and electronic industries because of incredible electrical conductivity (5.96×10^7 S/m) and thermal conductivity (401 W/m K). For large-scale electrical equipment, it is tough to gain the transfer of current from one material to other by sliding contact on the surface. This kind of contact requires excessive contact pressure, while we need low contact pressure to minimize the wear of the material. For electrical contact, thermal and digital packing applications, Cu-based metal matrix composites are used as it possesses excessive thermal and electrical conductivity, appropriate corrosion resistance and excessive melting point [6].

Boron Carbide (B_4C) is one of the hardest materials known, ranking third behind diamond and cubic boron nitride. The special properties of B_4C like low density, good chemical resistance, extreme hardness and good nuclear properties make it a widely used structural material for a range of excessive scientific applications, such as light-duty bulletproof armors, neutron absorber in liquid-metal-cooled fast breeder reactors, wear-proof parts and cutting equipment. However, one disadvantage of the boron carbide is lower thermal conductivity (TC). Pozdniakov et al. developed Al-5% Cu alloys containing 2, 5, and 7 % B_4C by stir casting. They found that with increasing B_4C content, yield strength increased but plasticity decreased during compression test at both room and high temperatures. They also observed that significant reaction had occurred at the interface between the particles and the matrix. Zheng et al. fabricated Al matrix composites reinforced with high volume fraction of B_4C particles by mechanical milling and vacuum hot pressing followed by hot extrusion. Altinsoy et al. fabricated B_4C -reinforced Cu- B_4C metal matrix composite by powder metallurgy. They reported that the relative densities of Cu and Cu- B_4C composites sintered at 700 °C ranged from 97.5 to 90.19%. Microhardness of composites ranged from 80.65 to 87.5 HB, and the electrical conductivity of composites changed between 90.04 and 68.87% IACS.

The piston silumins (alloys of the Al-Si system) have a unique complex of properties, such as the low thermal expansion coefficient (TEC), high wear resistance and good processability upon casting. However, the level of their mechanical properties at both room and elevated temperatures is inferior to most cast aluminum alloys. The low TEC in these alloys is achieved due to the enhanced silicon concentration (above 10%), but the silicon atoms have a high diffusion mobility in aluminum and, as a result, it is impossible to achieve strength in the silumins at a level characteristic, e.g., of the Al-Cu alloys. The problem of increasing the mechanical characteristics at elevated temperatures without losing the desired complex of other properties can be solved using metal-matrix composite materials.

The researches and developments of aluminum-alloy-based MMCs reinforced with SiC, Al_2O_3 , and some other particles show the possibility of developing alloys with a higher complex of properties. Many compounds, e.g., SiC, SiO_2 , AlN, BN, Si_3N_4 and B_4C , have a TEC that is lower than that of silicon, which can allow them to be used as reinforcing particles upon the development of MMCs with a unique complex of properties.

The influence of SiC, SiO_2 , and Al_2O_3 particles on the properties of the aluminum-based MMCs has been studied well enough. The introduction of nitrides into the aluminum melt requires extensive time-consuming preparation in order to deposit coating of particles for providing good bonding between them and matrix [6]. The B_4C particles can be the most promising candidates, since their addition into the aluminum melt does not require a time-consuming pre-treatment. Most studies of the development of MMCs with B_4C are aimed at obtaining alloys for nuclear-power industry, since boron in the B_4C compound has the property of absorbing (capturing) thermal neutrons.

These MMCs can replace the currently used steels with high boron contents. In this paper, we prepared the Al-5% Cu-alloy based MMCs using the method of mechanical mixing-in and studied the effect of the content of B_4C particles on the microstructure, phase composition, density, and TEC of the obtained MMCs. As the matrix alloy, the model alloy Al-5% Cu was selected, which can serve as the basis for developing an MMC base with high mechanical properties at room [8] and elevated temperatures [3]. The only disadvantage of this matrix is its low processability upon casting [9].

Aluminum silicon alloys are important in automotive and engine piston applications because of

their low density, high fluidity, good castability, low thermal expansion, and high corrosion resistance. Al-Si alloys have the lowest coefficient of thermal expansion (CTE) among aluminum alloys but the presence of Si results in a lack of desirable YS and UTS, especially at high temperature [9].

Over the past few years, aluminum matrix composites have been gaining more and more attention in automotive applications because of changing operational requirements, such as fuel consumption and weight reduction. For these reasons, ceramic particles add to aluminum alloys, with their high specific strength, low CTE, and superior thermal stability, are used extensively in pistons [6].

Boron carbide, B_4C is one of the most promising ceramic materials due to its attractive properties, including high strength, low density 2.52 g/cm^3 , extremely high hardness, the third hardest material after diamond and boron nitride, good chemical stability and neutron absorption capability. Due to its high hardness, B_4C could be an alternative to SiC and Al_2O_3 as a master alloy in AMC for applications where a good wear resistance is a major requirement. Boron carbide, chemical formula approximately B_4C , is an extremely hard boron carbon ceramic material used in tank armour, bulletproof vests, and numerous industrial applications.

Most researchers discuss the effect of adding SiC, Al_2O_3 and various ceramic particles on the thermal expansion of aluminum based alloys[8]. However, few researchers have investigated the effect of B_4C particles on the CTE of aluminum based alloys. Among the various ceramic particles, B_4C particles are one of the most promising because of their high strength, low density, extremely high hardness, good chemical stability, and neutron absorption capability.

2. Materials and method

The MMCs will be produced by the method of mechanical mixing-in in an electrical-resistance furnace using aluminum of grade A85, copper of grade M0, and B_4C particles with an average size of $5 \mu\text{m}$. Figure 1 shows the schematics of the mechanical mixing-in of particles in the melt.

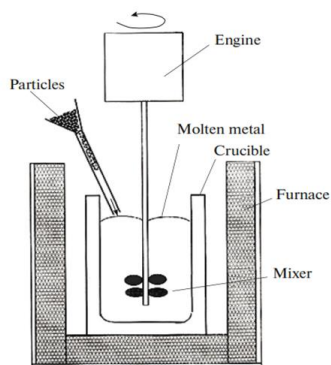


Figure 1. Schematics of mechanical mixing of the particles into the melt.

The specimens will be prepared by cutting to the dimensions $12 \times 10 \times 9 \text{ mm}$ using Leco MSX 250A cutting machine shown on figure 2.



Figure 2. Cutting machine LECO MSX 250A.

Specimens were wet ground with 220 and 500 SiC papers using Struers grinding machine KNUTH-ROTOR2 at constant speed of 250 rpm. Specimens were rinsed with water and ethanol then

dried rapidly using a hot air blow drier. This yielded a smoother and cleaner surface.

Light microscope, on figure 3, was employed to examine the microstructure, structure and substrate at magnifications between 50x to 500x.



Figure 3. Light optical microscope (LECO LX 31) connect with camera (Pax cam) to image analysis software (Pax-it).

A Vickers microhardness test will be conducted using the (LECO LM700) microhardness tester at a magnification of 50x and applying a 50gf load for 10sec. The polished and etched specimens were then examined at higher resolution using the SEM (FEI INSPECT 50S).

The SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. X-ray scattering technique is one of the non-destructive analytical techniques, which reveal information about the crystal structure, chemical composition, and physical properties of materials and thin films. These techniques are based on measuring the scattered intensity of an X-ray beam hitting a specimen as a function of the incident and scattered angle, polarization, and wavelength or energy.



Figure 4. X-Ray Diffraction machine model PANalytical X'pert BRO.

The alloy Al-5%Cu can be used as a matrix due to its excellent castability compatible with a lot of applications, which can be developed by using of master alloys as boron carbide particles with different percentages.

Conclusion

The squeeze casting technique would be successful route in decreasing the porosity and improving the wettability between the matrix and the addition alloys particulates.

The coefficient of thermal expansion (CTE) for both the stir and squeezed cast samples would be decreased as the percentage of master alloys increased and increased as the temperature range increased.

Increasing the concentration of B₄C would increase YS and US; however, the plasticity would decrease during compression test at both room and elevated temperatures.

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