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Metal Matrix Nanocomposites (MMCs): A Review of their Physical and Mechanical Properties

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Abstract:

Metal matrix composites (MMCs) possess excellent physical and mechanical properties. The filler reinforcement into the metallic matrix improves the stiffness, specific strength, wear, creep and fatigue properties compared to the conventional engineering materials. The present work is a study of the effect of reinforcement of different types of fillers in metal matrix and their merits and demerits. Effect of different dispersion on the mechanical properties like tensile strength, strain, hardness, wear and fatigue of MMCs and its different applications are also highlighted in the paper.

Keywords: MMC, Mechanical Properties, Physical Characterization, Dispersion

Introduction:

MMCs (Metal matrix composites) uses metal matrix dispersed with other metal, ceramic or organic compounds. Reinforcements are usually done to improve the various properties of the base metal. The particle distribution plays a very important role in the properties of MMCs. Copper, Magnesium and Aluminium has attracted most attention as base metal in metal matrix composites [1]. These MMCs are widely used in aircraft, aerospace, automobiles, defence and various other fields [2]. The most commonly used reinforcements are Silicon Carbide (SiC), TiO_2, Aluminium Oxide (Al_2O_3), B_4C, Y_2O_3, Si_3N_4, AlN [3-7]. Al_2O_3 reinforcement shows good compressive strength and wear resistance. Boron Carbide is one of hardest known elements. It has high fracture toughness and elastic modulus. The addition of Boron Carbide (B_4C) in MMCs increases their hardness, but does not improve the wear resistance significantly [4]. Fibers play very important role as reinforcement, as they transfer strength to the matrix which results in the enhancement of their physical and mechanical properties as desired. Zircon is usually used in hybrid reinforcement for improving the wear resistance [5]. In the last decade, lot of work has been done on fly ash reinforced MMCs. Due to their low cost and availability as waste by-product in thermal power plants. It improves the electromagnetic shielding effect of the MMCs [6-8]. Based on the stated potential benefits of MMCs this paper investigates the affect of various dispersion on the mechanical properties of MMCs, processing methodology and their applications.

MMCs using several metallic materials as matrix have been studied by many researchers. Among all, the most interesting metals for industrial applications are Al, Mg, Ti, Cu and their alloys [8-15]. Pure and alloyed aluminium is the most investigated material as matrix in MMCs. Al-based composites are good candidates for structural application. Various nano-sized oxides like (Al_2O_3, Y_2O_3) [8-15], nitrides (Si_3N_4, AlN) [12-14], carbides (TiC,SiC) [13-16], hydrates (TiH_2) [7-9] and borides (TiB2) [8-13] have been used as dispersion. As ceramic reinforcements Carborundum, Sic and alumina are widely used in these MMCs. Moreover, different allotropes of carbon like carbon black, fullerenes and carbon nanotubes [15-20] have also been investigated by several researchers. CNTs are potential candidates as they confer very high mechanical properties to the metal matrix. They also increase the electrical conductivity, which makes MMCs very attractive materials for electrical applications. Single wall carbon nanotubes (SWCNT) and multi wall carbon nanotubes (MWCNT) both are used as reinforcement in MMCs. Copper-0.1 wt.% MWCNT composites revealed a 47% increase in hardness and bronze-0.1 wt.% SWCNT showed a 20% improved electrical conductivity [18,19]. Intermetallic compounds like (NiAl, Al_3Ti) have also been dispersed in MMCs [15-19]. Al–Al3Ti nanocomposite showed good mechanical properties at high temperature [17-20], while TiAl–NiAl MMCs revealed high hardness but poor fracture toughness [12,17].

Preparation Methods and Properties

preparation of MMnCs by conventional casting processes results in an inhomogeneous distribution of particles within the matrix due to low wettability of ceramic nano-particles. For the large-scale production of metal matrix nanocomposites, the main problem to face is the low wettability of ceramic nano-particles, which does not allow the preparation of MMCs by conventional casting processes since the result would be an inhomogeneous distribution of particles within the matrix. The high surface energy results in the agglomeration of nanoparticles, which are not effective in hindering the movement of dislocations and can hardy generate a physical-chemical bond to the matrix, thus reducing significantly the strengthening capability of nanoparticles [12-14]. Several unconventional prepatration methods have been adopted by researchers to overcome the wettability issue, either by formation of the reinforcement by in situ reaction or by ex situ addition of the ceramic reinforcement by specific techniques.

Applications

Metal matrix composites reinforced with nanoparticles or nanotubes are not yet being employed in relevant commercial applications due to their very recent development. However, nanoparticle dispersed MMCs show higher mechanical properties than micro-particles reinforced composites. No evidence of decrease in thermal and electrical conductivity [5,6]. Therefore, they are potential candidates for substituting conventional MMCs or related monolithic alloys in structural and electrical RT and HT applications. For example, CNT composites could replace carbon fibers composite in many applications, due to their higher strength and stiffness, especially in high-temperature environments. Traditional micro-reinforced MMCs have poor fracture toughness and ductility then nano-reinforced MMCs. Toughness can be substantially maintained in nano-reinforced composites owing to the reduced particle volume fraction required to achieve strengthening.

The enhanced wear resistance [9-12] and the good thermal conductivity combined to the high specific strength make MMCs attractive materials for aircraft brakes. In addition, the specific strength and elastic modulus property is of good use in sport industry, like for rackets, bicycle frames and other components. A further field of potential application is in electronic devices, for example for heat sinks and solders (thanks to their thermal properties) or as antennas (thanks to their electrical properties and stiffness). Aerospace and automotive industries may exploit all the above properties for different kind of applications such as structural radiators, gears, aircraft fins, cylinder liners, disk brakes and calipers.

The improved damping capacity of MMCs could also be exploited to reduce vibrations and noise of structures. In Mg–Al_2O_3 samples extruded at 350°C after powder milling, a significant damping ability was achieved and attributed to interface character of MMCs [7-13]. Indeed, CNT/2024 Al composites showed improved damping properties at high temperature as high as 400°C [16-19].

Conclusions

A number of synthesis methods are used for the preparation of MMCs. Metal matrix nanocomposites have a lot of potential to be used in a large number of industrial applications. Recently some researchers have highlighted the real possibility to produce composites characterized by excellent mechanical properties, which can be further improved by optimizing the particle dispersion. These MMCs also exhibit remarkable wear resistance. In terms of hardness, mechanical strength, creep behaviour and damping properties they also proved to be excellent. Adoption of these metal matrix composites, could be a good replacement of expensive conventional monolithic alloys used for structural and functional applications.

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