CHARACTERIZATION OF CARBON NANO PARTICULATE METAL MATRIX COMPOSITES USING EXPERIMENTAL, ANALYTICAL AND FEA METHODS

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ABSTRACT

From the past few decades researchers tried numerous combinations of matrices and reinforcements since work strictly on MMCs began in the 1950s. This led to developments for aerospace and defense applications, but resultant commercial applications were limited. In the last 20 years, MMCs evolved from laboratories to a class of materials with numerous applications and commercial markets. After the collapse of the Berlin Wall, prevailing order in the world changed drastically and lead to the development of metal matrix composites.

Composite materials have been recognized over a long period for characterization of AA6061, AA6063 and AA7020 composites in the application of aerospace vehicles, automobile industries due to light weight and high strength. AA6061 is a precipitation hardening aluminum alloy containing magnesium and silicon as its major alloying elements. AA6063 alloy possesses good mechanical properties and enables heat treatment whereas AA7020 alloy is also a heat treatable alloy.

In this work various metal matrix composites are prepared with AA6061, AA6063 and AA7020 as base metals and carbon black nano powder as reinforcement in proportions of 10%, 20% and 30% respectively. In this work two-step stir casting method has been used for manufacturing of Al-alloy Metal Matrix Composites with reinforcement of carbon black nano particles. Before testing the Al alloy-MMC samples, a solution treatment was applied at 5000C for 1 hour, followed by quenching in cold water. The composite

samples were then aged at ambient temperature for 100 hours. The tensile specimens were placed in the grips of a Universal Test Machine (UTM) of 20-tonne capacity at a specified grip separation and pulled until failure. Wear test was performed in a pin on disc wear apparatus under different loads of 10, 20, 30N with variation in sliding speeds and sliding distances. The Micro structure analysis of these composites has been studied with the help of Scanning Electron Microscope (SEM). The Effects of carbon black amount on fracture and wear behavior of these AA6061, AA6063 and AA7020/carbon black metal matrix composites produced by stir casting route were investigated. Wear test were performed in a pin on disc wear apparatus under different loads of 10, 20, 30N with different sliding speeds and at different sliding distances. Finally experimental values are validated with finite element analysis software.

The major conclusions of this research work are given below:

1. Apart AA6061/CB, AA6063/CB and AA7020/CB metal matrix composites with different volume fraction of carbon black nanoparticles, AA 7070/CB metal matrix composites with 30% volume fraction of carbon black nano particulates found to have greatest tensile strength. the load transfer from the matrix material to CB nano particulates was 45 MPa.

2. The wear studies on the metal matrix composites showed a decreasing trend of wear rate with respect to increase in volume fraction of carbon black nano particulates. The maximum sliding wear of AA6061/CB, AA6063/CB and AA7020/CB metal matrix composites were respectively, 68.72%, 65.20% and 60.07% and attributed to the sliding distance.

1. Scope of the Research Work

There has been a continuous effort by researchers to improve the properties of materials to meet the modern technological requirements and demands of consumers for the development of advanced material systems which are more energy-efficient, lighter by weight, stronger and economical (Davis, 1993; Foltz, 2001; Anthony, 2012). The development of composite materials is one of such efforts that have changed the world of materials. The composite comprises two or more constituent materials that are microscopically combined but not soluble in each other. The materials used for the reinforcement are in the form of fibers, flakes, or particulates. The materials used for the matrix are by and large continuous (Chawla, 2001; Surappa, 1981).

During the last decade, many researchers made investigations on the metal-matrix composites (MMCs) with the use of various metallic materials. The important metals which are found to be useful for the application to industries are Al, Mg, Ti, Cu, and their alloys. Though there are various types of MMCs,

aluminium and its alloys as matrix material have been extensively employed in most of the recent applications in aerospace, automobiles, and many other engineering and domestic fields. This has been motivated by a need to decrease energy consumption in socio-economical and industrial practice with their excellent strength and low weight features (Hashim, 2002; Bayraktar, 2010). There are significant variances in published data on the properties of MMCs. This is attributed to the reality that there are no industry standards for MMCs.

Different types of reinforcements including continuous fibers, discontinuous fibers, whiskers, and particulates, from 10 to 60% vol. have been investigated by Foltz and Blackmon (1990); Reddy and Essa Zitoun (2009, 2010), and many others. The choice of reinforcement material is very important to manufacture MMCs (Mazaherin, 2013). The reinforcement material should be such that it not only should improve the properties but also should reduce the manufacturing cost of the composites. This thesis would thus explore the choice of cheaper reinforcement material, namely carbon black (CB) as shown in figure 1 to produce Al alloy-MMCs while achieving the required mechanical properties.

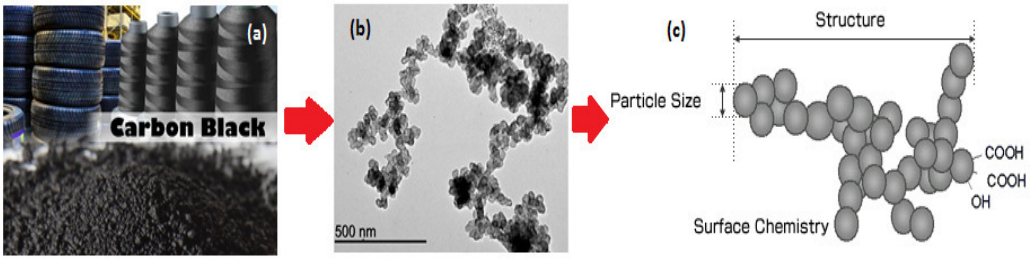

Figure 1: Carbon black

2. Research Justification

This research was aimed at the manufacture of Al alloy-MMCs using carbon black (CB) as reinforcement particulate resulted from the incomplete combustion of petroleum products. This research was also concerned to validate CB reinforced MMCs for wear-resistant applications. In general, particulate reinforced Al-MMCs (PR-Al-MMCs) are manufactured by the stir casting method. In this method, accomplishing a uniform distribution of reinforcement particulates within the matrix alloy is a principal task that influences directly the properties and the quality of Al alloy-MMCs as shown in figure 2. In the case of (PR-Al-MMCs), the dispersal of the reinforced particulates in the matrix alloy is affected by numerous factors during stir casting. These consist of the rheological performance of the liquid matrix alloy, the reinforcement mixing method, chemical reactions of the

reinforcement and the matrix, and altering reinforcement distribution through solidification.

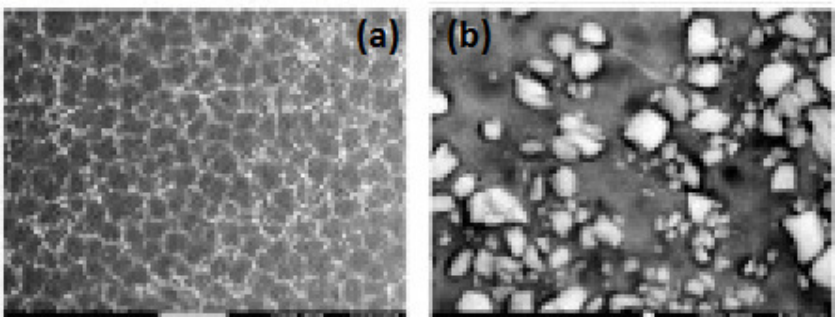

Figure 2: Uniform and non-uniform distribution of particulates in MMCs.

The constituents namely, matrix and reinforcement of the MMC should bond strongly with each other without any adverse chemical reactions. In Al-MMCs reinforced with non-metal carbides such as silicon carbide, boron carbide, etc., or carbon fibers, the aluminium carbide (Al_4C_3) often forms as an unwanted product or compound as per studies conceded by Greenwood and Earnshaw (1997). The chemical reaction of carbon and aluminium is shown in figure 3. Aluminium carbide (Al_4C_3) particles which are finely spread in the Al-alloy matrix, diminishes the susceptibility of the material to creep as stated by Zhu et al. (1998).

$$4Al + 3C \xrightarrow{t°C} Al_4C_3 \qquad (1.1)$$

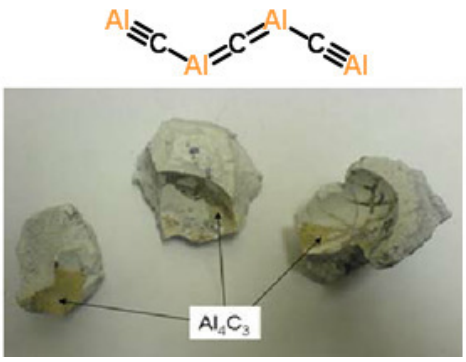

Figure 3: Product formed during the reaction between carbon and aluminium.

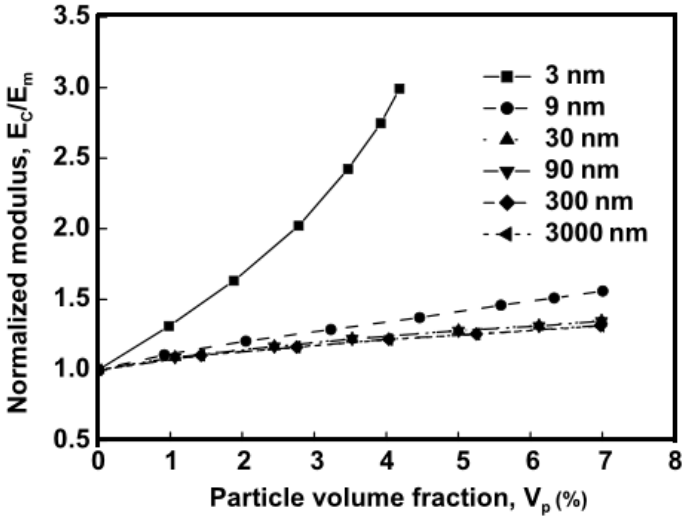

Figure 4: Effect of particulate size on the elastic modulus of the composite.

Cocen and Onel (2002) have reported that the microstructures of as-cast Al-SiC MMCs, manufactured by the stir casting method, show a uniform distribution of SiC particulates with some local clusters and some degree of porosity. During the microstructural investigation of SiC particulates reinforced AA6063 alloy-MMCs, Alaneme and Aluko (2012) have detected that the volume per cent of SiC particulates would not stimulus its pattern of distribution in the as-cast condition. Also, the elastic modulus of PR-Al-MMCs is insensitive to particle size as stated by Jing et. al (2002). However, when the particulate size is reduced to a critical size of 20 nm, there would be the effect of particulate size on the elastic modulus as shown in figure 4.

Boopathi et al. (2013) have observed non-uniformity in the distribution of reinforced particulates in the case of Al-SiC, Al-fly ash, and Al-SiC-fly ash composites produced by stir casting method. The wettability at the interface between the matrix and reinforced particulates plays another important role in determining the mechanical properties of Al-MMCs. Wettability of the particulates can be boosted by coating the particles with metals such as Ni and Cu, or addition of active elements such as Mg into liquid aluminium, or preheating of the particulates before addition into liquid aluminium (Kolsgaard, 1993). In the present research work, nickel-coated carbon black nanoparticulates were used.

The durability, emissions, and fuel economy of internal combustion engines are associated with lubrication efficiency. Ineffective lubrication can lead to friction and wear losses, which could negatively impact the fuel consumption and the lifetime of engines. Solid lubricants lodge an exceptional place in enhancing wear-resistance in situations where the liquid lubricants are inept like in aerospace or automotive applications. Normally, the size of reinforced particulates influences mechanical properties such as strength, stiffness, ductility, and fracture of self-lubricating composites. MMCs reinforced by larger particulates are vulnerable to the formation of defects, such as porosity

and cracking, which results in premature failure of the composites. But, it is expected to have excellent properties when the reinforced particulate size is in the nano-scale (Bakunin, et. al, 2004; Tevet, et. al, 2011).

To reach the said goals of the present research work, the foremost difficulties such as the uniform distribution of the reinforced particulates in the Al-alloy, wettability with the Al-alloy, and the reaction of carbon black (CB) with the Al-alloy are to be addressed. The research work was also aimed at the self-lubricating capacity of nano-scaled CB reinforced Al alloy-based MMCs. The experimental results were also validated using the finite element approach.

3. Aim and Objectives

This research aims to develop Al alloy-based MMCs reinforced with carbon black nanoparticulates to understand the material properties, process characteristics, microstructural characteristics needed to obtain optimal and reliable properties. The key objectives include:

(i) Development of composite materials from AA6061, AA6063, and AA7020 alloys reinforced with the carbon black (CB) nanoparticulates by using stir casting methods.

(ii) Evaluation of the effect of the CB nanoparticulates on the mechanical and metallurgical properties.

(iii) Evaluation of the effect of the CB nanoparticulates on the tribological properties.

(iv) Understanding the reaction of the CB nanoparticulates with the Al alloys.

(v) Validation of experiment results with those obtained from the finite element analysis (FEA).

4. Overview of the Thesis

The thesis is organized into the following chapters mentioned below:

Chapter 1 is an outline of the thesis.

Chapter 2 is to review and critical examination of relevant literature to explore the use of carbon black as the reinforcement particulate.

Chapter 3 focuses the experimentation and methodology adopted for the research.

Chapter 4 discusses the results of mechanical and metallurgical experimentation. It also includes the validation of experimental test results with FEA results.

Chapter 5 discusses the results of tribological experimentation.

Chapter 6 focuses on the conclusions and introduces areas for future research.

5. Summary

The composite material comprises two or more physically and chemically distinct constituents namely, matrix and reinforcement. The MMC is an engineered blend of metal (matrix) and hard particulate reinforcement to get explicit properties such as tensile strength, wear resistance, corrosion resistance, etc., for various engineering applications. In Al-MMCs the reinforced non-metal carbides (silicon carbide, boron carbide, etc.) or carbon fibers, aluminium carbide every so often form precipitated compounds. The vivacious problems during the manufacturing of PR-Al-MMCs are uniform distribution and wettability of reinforced particulates. Also, more resourceful lubrication requires accomplishing the highly demanding working conditions of automotive engines. It aimed the present work at manufacture and explore the performance of PR-Al-MMCs based on aluminium alloy as a matrix and carbon black (CB) nanoparticulates as a reinforcement substitute for carbides. It also deliberated the present research wok to validate experimental results with those found by empirical models and finite element analysis (FEA).

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