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The Synthesis and Properties of Advanced Aluminium and Copper Based Metal Matrix Composites

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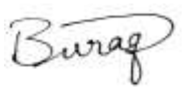
Declaration

I, **Buraq AL-Mosawi**, declare that this thesis, "**The Synthesis and Properties of Advanced Aluminium and Copper based Metal Matrix Composites**", is submitted to fulfill the requirements for the degree of '**Doctor of Philosophy- integrated**', in the Faculty of Engineering and Information Sciences, University of Wollongong, Australia, is my personal work unless otherwise referenced or acknowledged. This thesis has not been submitted for qualifications at any other academic institutions, and I am responsible for any errors and deficiencies in this thesis.



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Published work as part of this thesis work:

1. B.T. AL-Mosawi, D. Wexler, A. Calka, Characterisation and mechanical properties of α-Al_2O_3 particle reinforced aluminium matrix composites, synthesised via Uniball magneto-milling and uniaxial hot pressing, Adv. Powder Technol. 28 (2016) 1054–1064.

2. B.T. AL-Mosawi, D. Wexler, A. Calka, Development of aluminium reinforced milled carbon fibres composites via magnetically controlled ball mill: manufacturing and characterization, 5^{th} International Conference on Nano and Materials Science (ICMENS-2017), Singapore.

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Forthcoming papers under preparation:

1. B.T. AL-Mosawi, D. Wexler, A. Calka, Characterisation and mechanical properties of aluminium hybrid composite reinforced milled carbon fibres and α-Al_2O_3 particles.

2. B.T. AL-Mosawi, D. Wexler, A. Calka, Development of copper hybrid composite reinforced by milled carbon fibres and α-Al_2O_3 particles: synthesis, characterization, and properties.

3. B.T. AL-Mosawi, D. Wexler, A. Calka, Characterisation and mechanical properties of Cu-Al_2O_3 composites, synthesised via Uniball magneto-milling and uniaxial hot pressing.

Dedication to…

My Imam Awaited Al-Mahdi (Peace be upon him), my dear parents, my lovely wife Shaymaa, and my little Angels, Azal, Ali, and Zain Alabideen.

Abstract

This thesis studies the influences that submicrometric alumina particles (α-Al_2O_3) and milled carbon fibres (MCFs) have on the microstructure, hardness, mechanical properties, and wear of aluminium and copper matrices. The direct use of particulates (micrometric and nanometric scale) and carbon fibres (continuous and chopped) as reinforcement materials in Al-based and Cu-based alloys can potentially result in significant improvements in their property compared to existing Al-based and Cu-based alloys. In this research, dual phase and hybrid (three-phase) composites were manufactured by introducing hard ceramic particles (α-Al_2O_3) and recycled MCFs (< 100 µm long) into Al and Cu matrices. An advanced powder metallurgy processing method was also developed to prepare precursor powder blends for consolidation by uniaxial hot pressing, after which their performance was investigated and compared. This research is divided into: (i) the preparation of precursor composite powders using the magnetically controlled Uniball milling, (ii) a synthesis of monolithic Al and Cu composites using the uniaxial hot pressing, and (iii) advanced characterisation using X-ray diffractometry, field emission scanning electron microscopy (FSEM) equipped with energy dispersive spectroscopy (EDS), Archimedes density, electrical conductivity, resistivity, universal compression testing, Vickers micro-hardness, Ultra-micro indentation testing (UMIS), and wear testing. All the mechanical testing and wear testing of monolithic products was carried out at ambient temperature and atmosphere.

Unreinforced Al, unreinforced Cu, and the composites were synthesised via advanced magnetic controlled milling followed by uniaxial hot pressing. Reinforcement materials of submicrometric scale α-Al_2O_3 particles and MCFs in their different volume fractions were added separately and together to study their effects on the mechanical behaviour and properties of the Al and Cu matrices. The composites consist of : Al + (2, 4, 7, 10 vol. % α-Al_2O_3), Al + (5, 10, 15, 20 vol. % MCFs), hybrid composite of (Al+ 5 vol. % α-Al_2O_3) + (5, 10, 15, 20 vol. % MCFs), Cu + (5, 10, 15, 20 vol. % α-Al_2O_3), Cu + (5, 10, 15, 20 vol. % MCFs), and hybrid composites of (Cu + 10 vol. % α-Al_2O_3) + (5, 10, 15, 20 vol. % MCFs). The elemental powders of matrices and reinforcement materials were weighed according to the selected amounts

and then charged to the magnetic control Uniball mill, with stearic acid (2 wt. %) added to stop the particles of powder from becoming agglomerated via cold welding. The milling parameters were developed to enable the α-Al_2O_3 particles and MCFs were mixed homogenously along the Al and Cu matrices. Different milling times were also investigated to determine how the milling time affected on the final properties of Al-based and Cu-based composites. The submicrometric particles of α-Al_2O_3 and MCFs had dispersed uniformly into the Al and Cu matrices for the precursor powders after 50 hours of milling. Uniaxial hot pressing was used to ensure the Al and Cu composites were completely dense. The selected consolidation temperatures were close to the melting points of the Al and Cu matrices. The Al-based composites were hot pressed for 15 minutes whereas the Cu-based composites were consolidated for 60 minutes. These parameters resulted in composites with more than 99 % and 95 % of the theoretical density for Al-based Cu-based composites respectively.

These research outcomes were interpreted in the light of structural defects and strengthening mechanisms induced a controlled magneto milling technique with hard ceramic particles of α-Al_2O_3, and/or MCFs phase with a high aspect ratio. Additional effects included the dispersion of milling impurities, and the effects of oxygen introduced during the milling, and after uniaxial hot pressing. Correlations between the microstructure and mechanical properties were obtained as functions of the quantities of α-Al_2O_3 and MCFs in the multiphase and hybrid composites. The magnetically controlled milling by the Uniball mill resulted in a uniform distribution of α-Al_2O_3 and MCFs along the Al and Cu matrices, an acceleration of Al and Cu particles fracturing, and accumulated strain hardening by the Al and Cu matrices. Furthermore, it was found that segregation and clustering mainly at the grain boundaries increased as the milling time increased. The properties of these composites were enhanced by adding submicrometric α-Al_2O_3 particles and MCFs to the Al and Cu matrices. The Vickers microhardness, the ultimate compression strength, the yield strength, Young's modulus of elasticity, wear resistance, electrical conductivity, and resistivity of the monolithic products increased as the amount of α-Al_2O_3 and MCFs increased. The mechanical properties and wear resistance of the Al-based and Cu-based hybrid composites showed more improvement than the multiphase composites and unreinforced matrices, and moreover, the rate abrasive wear was related to amounts of particulates and MCFs and their distribution along the Al and Cu matrices. The Al and Cu based hybrid composites had better wear resistance than the dual phase composites and unreinforced matrices due to the dual effect of hard α-Al_2O_3 particles and MCFs. The strength and Young's modulus of these composites increased noticeably compared to unreinforced Al and Cu samples, although their ductility decreased as the amounts of the reinforcement materials increased.

Finally, the submicrometric α-Al_2O_3 particles and MCFs proved to be better reinforcement than traditional micrometric or nanometric particles with regards to the improved strength, ductility, and wear resistance of the composite. The production route via advanced milling that were developed directly for metal (Cu or Al) reinforced with both α-Al_2O_3 particles and MCFs has not been reported elsewhere. This technique was used to fabricate powder metallurgy Al-based and Cu-based MMCs with consistent mechanical properties and improved wear resistance. It has been suggested that a combination of this magnetically controlled milling technique followed by uniaxial hot pressing would result in good quality Al-based and Cu-based composites for the automobile industry and for spot welding electrodes. The use of submicrometric α-Al_2O_3 particles and MCFs as reinforcement materials, stearic acid as process control agent, and a combination of the magnetically controlled Uniball milling and uniaxial hot pressing resulted in an overall improvement of the wettability and dispersion of α-Al_2O_3 particles and MCFs along the Al and Cu matrices. Finally, the short processing time with very fast heating and cooling rates during uniaxial hot pressing at higher temperature also improved the wettability and mechanical properties.

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