FABRICATION AND CHARACTERIZATIONS OF RECYCLED ALUMINIUM-COPPER-CULLET POWDER (Al-Cu-CP) METAL COMPOSITE

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DEDICATION

This research work is dedicated to Almighty Allah for seeing me through all the difficulties. It is also dedicated to my parents, Alhaji Hussain Bin Nuh and Hajiya Bilqis Binti Mustapha Ahmad Falaki for their zealous support, advice, inspiration and prayers which guided me towards this triumph. I am very proud of them and may Almighty Allah (S.W.T) reward them abundantly. It is also devoted to my family and my relatives (siblings, uncles and aunties) for their prayers and their unstinting support, I really appreciate it.

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ABSTRACT

Aluminium-Copper-Cullet powder (Al-Cu-CP) metal composite was fabricated from recycled materials, using recycled Aluminium (Al) obtained from scrap door and window frames, copper (Cu) wire scrap and cullet powder (CP). The research focused on fabricating the composite with improved properties which are incomparable with the constituent elements and other composites of similar components by using these inexpensive raw materials. This research is an attempt in removing solid wastes from the environment, promoting technological sustainability and also to support the zero-emission campaign for promoting green technology. The Al-Cu-CP metal composite was fabricated via stir casting method due to its simplicity and economic importance. The composite was produced with variable percentage compositions, melt holding times and casting temperatures. The composite and the unreinforced Al were analysed for physical, mechanical and morphological properties, phase analysis as well as for their chemical composition. The analyses indicated that the chemical composition of the products covered all the initial components. The optimum parameters were established as 20 wt. % of reinforcement materials (Cu and CP), 60 minutes of melt holding time and at 800 °C of casting temperature. The results of hardness tests were found to have improved significantly from 41.625 HV of the unreinforced Al to 124.704 HV for Al-Cu-CP metal composite. XRD results revealed formation of some intermetallics within the composite which strengthens the composite further. The Al-Cu-CP metal composite has shown appreciable level of wear resistance and corrosion resistance in artificial seawater (3.5 g/L NaCl) at room temperature. Heat treatment further improved these properties of the Al-Cu-CP metal composite in all aspects. Due to these enhanced properties of Al-Cu-CP composite, it could be used where high strength with less density product is required such as automobile brake shoes and brake disc as a result of the upgraded physical and mechanical properties.

ABSTRAK

Komposit logam Aluminium-Kuprum-Serbuk Pecahan Kaca telah direka daripada bahan kitar semula, menggunakan aluminium kitar semula (Al) yang diperolehi dari sekerap bingkai pintu dan tingkap, sekerap wayar tembaga (Cu) dan serbuk pecahan kaca (CP). Penyelidikan ini memberi tumpuan kepada fabrikasi komposit dengan sifat-sifat yang ditingkatkan serta tidak dapat ditandingi oleh unsur-unsur juzuk dan komposit lain dengan komponen yang serupa menerusi penggunaan bahan mentah yang murah ini. Penyelidikan ini merupakan percubaan menyingkirkan sisa pepejal dari alam sekitar, mempromosikan kelestarian teknologi dan juga untuk menyokong kempen pelepasan sifar untuk mempromosikan teknologi hijau. Komposit logam Al-Cu-CP dihasilkan melalui kaedah tuangan kacau kerana keringkasan dan kepentingan ekonomi. Komposit dihasilkan dengan pelbagai peratusan komposisi, masa rendaman lebur dan suhu tuangan. Komposit dan Al tanpa penguat dianalisis untuk sifat fizikal, mekanik dan morfologi, analisis fasa serta komposisi kimia masing-masing. Analisis menunjukkan bahawa komposisi kimia produk meliputi semua komponen permulaan. Parameter optimum telah ditetapkan sebagai 20 wt.% bahan penguat (Cu dan CP), 60 minit masa rendaman lebur dan 800 °C suhu tuangan. Hasil ujian kekerasan menunjukkan peningkatan ketara dari 41,625 HV dari Al tanpa penguat ke 124.704 HV untuk komposit logam Al-Cu-CP. Hasil XRD memaparkan pembentukan beberapa antaralogam dalam komposit yang mengukuhkan lagi komposit. Komposit logam Al-Cu-CP telah menunjukkan rintangan haus dan rintangan kakisan yang ketara dalam air laut buatan (3.5 g / L NaCl) pada suhu bilik. Rawatan haba meningkatkan sifat-sifat komposit logam Al-Cu-CP dalam semua aspek. Susulan penambahbaikan sifat-sifat tersebut, komposit Al-Cu-CP boleh digunakan bagi keperluan produk berkekuatan tinggi dengan ketumpatan rendah seperti kasut brek dan cakera brek kenderaan hasil daripada sifat fizikal dan mekanikal yang dinaik taraf.

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LIST OF SYMBOLS AND ABBREVIATIONS

ºC	-	Degree Celsius
d	-	Spacing between diffraction planes
gcm^{-3}	-	Gram per centimetre cube
h	-	Hour
mm/year	-	Millimetre per year
n	-	An integer
wt. %	-	Weight percentage
λ	-	Wavelength
θ	-	Angle
µm	-	Micrometer
Al	-	Aluminium
Al-Cu-CP	-	Aluminium-copper-cullet powder
Al-MMCs	-	Aluminium metal matrix composites
ASM	-	American Society for Metals
ASTM	-	American society for testing and materials
CP	-	Cullet powder
Cu	-	Copper
EDX	-	Energy dispersive X-ray spectroscopy
HV	-	Vickers's hardness number
MMCs	-	Metal matrix composites
OM	-	Optical microscope
SEM	-	Scanning electron microscope
XRD	-	X-ray diffraction spectroscopy

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CHAPTER 1

INTRODUCTION

1.1 Background

The increasing need for engineering materials with strength, stiffness, and lightweight to meet the requirements of the technological advancement has led scientists, researchers, industries and other relevant parties to strive hard and dive deep into research and innovations in order to satisfy those demands. That led to the evolution of composites. Composites are materials which are made up of two or more materials of distinct properties with desirable attributes (Ranjan *et al.*, 2014; YC & Shankar, 2012).

Composite materials are evolving essentially as answers to unprecedented demands from technology due to swiftly advancing accomplishments in aircraft, aerospace, automotive sports, defence, constructions and domestic applications. These materials have a low specific gravity that makes their properties particularly superior in strength and modulus if compared to that of traditional engineering materials such as metals. As a result of in-depth investigations into the essential nature of materials and a better perception of their structure-property and relationship, it has become possible to obtain new composite materials with highly enhanced physical and mechanical properties (Prasad, 2006). Composite materials play vital roles in every aspect of the present-day technology. Composites are appreciated in every aspect of science and technology due to their outstanding performances.

The only setback in the general applications of composites is the cost of the raw materials and also their cost of production. This problem is immediately being attended by scientists and researchers through the use of recycled materials for the fabrication of composite materials. Another advantage of using recycled materials for composite fabrication is given relief to the non-renewable resource and getting rid of the scrap materials off the environment, apart from producing relatively low-cost materials (Oladele & Okoro, 2016; Abd Rahim, Lajis & Ariffin, 2015; YC & Shankar, 2012). Several innovative suggestions on the utilization of industrial wastes in fabricating new products have been presented in the previous literature works, for example, as filler or additives in concrete, incorporated in ceramic materials to produce glass–ceramics or in roads and pavement construction (Srivastava, Rai & Tiwari, 2014).

In recent technology, conventional products that manufacturing process requires expensive virgin raw materials are now being replaced with composites obtained from recycled materials. These composites produced from recycled materials display better qualities and also perform in better ways. Despite the fact that the composites are manufactured from much cheaper components and possess relatively lower weights as revealed by many researchers (Agbeleye *et al*., 2017; Doifode & Kulkarni, 2017; Koleva & Zheglova, 2011).

Recycling processes engage the recovery and reprocessing of waste materials into derivatives or secondary products. These retrieved materials can be separated at their source by the waste producers or can be collected separately and sent for recycling. A major percentage of the dry component of the solid wastes stream can potentially be recycled, with the most frequently retrieved materials being paper, cardboard, metals (ferrous and non-ferrous), plastics, textiles and glasses (Turner, 2016). Scrap metals have value, which encourages people to stockpile them for sale to recycling operation centres. Metals are valuable materials that can be recycled repeatedly without relegating their metallic properties. Metals recycling preserves natural resources and also requires less energy to process than the manufacture of new products using virgin raw materials (Wan *et al*., 2017).

Scrap metals are not waste or trash, instead, it should be considered as a continuous resource generated from old automobiles, appliances, buildings, bridges, airplanes and more. Scrap metals may, as a matter of fact, be one of our most precious resources. This is because the metals can be re-melted and reshaped into new products countless times, scrap metals are a stream of resources that will never be drained (Turner, 2016). Scrap metals such as aluminium (Al), copper (Cu), steel, brass and iron (Fe) can be reused many times to make many new products. Recycling scrap metals cuts-down the quantity of solid waste generated and simultaneously preventing the need for continuous mining to obtain new metals for manufacturing and other engineering uses. After the scrap metals are recycled, the products can be used for a wide range of applications which includes automobiles, aerospace, homes and construction industries (Abd Rahim *et al*., 2015).

Al is relatively unique because of its economic flexibility. This metal can be reclaimed, refined and reused at a low energy cost of just 5% if compared to that required to produce the same quantity from the ore (Al-Imari, 2014). There are many advantages to the environment when Al is produced by recycling rather than by primary products from original ores like bauxite. Firstly, it is established that the re-melting of recycled Al saves almost 95% of the energy needed by manufacturing pure Al from bauxite ore. Secondly, European estimates that the mass of solid waste generated per ton of recycled Al is 95% lower than that for primary metal. Thirdly, the primary Al productions generate both hazardous and non-hazardous emissions. Presently, a large amount of Al products is made of recycled Al wastes.

The production of primary Al is an energy-expensive process, involving bauxite mining, purification of alumina by a Bayer process and a molten salt electrolyte founded on cryolite. With climate change being of utmost concern, the recycled Al is becoming a highly significant trend in Al production and it is attractive due to its environmental and economic advantages. Increasing demand for Al-based products and further globalization of the Al industry have extensively promoted the consumption of Al scrap higher for the reproduction of Al alloys (Jacob, Shajin & Gnanavel, 2016; Xiong, 2015; Rana, Purohit, & Das, 2012).

Presently, Al metal matrix composites (Al-MMCs) are being reinforced with waste materials from both domestic and industrial processes like metallic components, cullet, fly ash and also from agro-based waste materials such as rice husk ash, bamboo leaf ash, coconut shell ash, groundnut shell ash, bagasse, among others (Doifode & Kulkarni, 2017; Pinto *et al*., 2016). Due to the enumerated benefits earlier mentioned and many more, Al-MMCs have become highly admired. Al is also among top choice metal matrix materials for a wide range of engineering applications by virtue of its excellent combination of material properties, easy processing, inexpensiveness and accommodation of waste materials as reinforcement components (Doifode & Kulkarni, 2017; Navin & Deivasigamani, 2015).

The composites produced from recycled materials are competing positively with monolithic materials and their alloys and composites. Oladele and Okoro (2016) mentioned that, due to the relentless efforts by researchers in material science and engineering in making recycled materials to partially or fully replace the expensive conventional materials, several successes have been recorded in these respects and more efforts are being made in order maximise the functional benefit of waste recycling and sustainable development. Ordinarily, unreinforced Al is much too soft to be used in many sophisticated applications. For example, Al does not have the high tensile strength that is needed for airplanes and helicopters. As a result, unreinforced Al is made into an alloy or a composite by combining it with other materials (reinforcements) in order to fashion the desired qualities in it. So, products from Al alloys and composites are used extensively in aircraft due to their high strength-to-weight ratio.

The particulate reinforced Al-MMCs are very important engineering materials not only because of their improved mechanical and wear properties but also due to their economic feasibility. As a result, Al-MMCs are now dominating the MMCs market. The particulate-reinforced Al-MMCs have found many applications in the aerospace and automotive industries (Onat, Akbulut & Yilmaz, 2007). Copper (Cu) is one of the best component element since the beginning of the Al-MMCs which complements the challenges faced when pure Al is used by adding more strength to the composite (Kumar & Devi, 2014). Al-Cu composite proved to have strong bond between the Al matrix and the Cu particles as a result of homogeneous distribution of the reinforcement. This combination gives the composite high strength and toughness (Alizadeh & Talebian, 2012).

According to Wzorek *et al*. (2017), researchers asserted that Al-MMCs which are homogeneously reinforced with Cu are with improved conductivity and decent corrosion resistance. Leszczynska-Madej, Madej and Wasik (2019) observed and reported that Cu reinforcement helped in lessening the friction coefficient in Al composites. They further stated that the tribological properties of Al composites might be improved by the introduction of Cu into the Al matrix. The weight loss investigated in tribological tests was lower for alloys-containing Cu. Similarly, it was also examined that the wear loss in Cu-containing alloys was lower than the Cu-free alloys.

In line with the development of sustainable technology, it is important to produce MMCs such as Al-MMCs at low cost and one of the ways to do that is by using inexpensive reinforcement materials. These inexpensive materials can be sourced from industrial, domestic and agricultural wastes. Broken glassware, also termed as cullet, is available in both industrial and domestic wastes and could be used to fabricate composite through recycling processes. The cullet disposal can be recycled as particulate reinforcement in Al-MMCs to develop new useful materials such as low-cost composite which could open doors for new applications of the Al composites (Jamaludin *et al*., 2013).

Cullet is a ceramic material that has gotten attention from many researchers to be used as a reinforcement material in Al-MMCs. This is attributable to its ease of accessibility, low cost and a very good ability is being used as a reinforcing phase along with a wide variety of Al alloys. It is also obvious that cullet particulate reinforced Al-MMCs demonstrate better mechanical properties as contrasted to their monolithic matrices (Hiremath *et al*., 2018). Rao and Parmar (2014); Pinto, Sujaykumar and Sushiledra (2016) have also described cullet particulate as one of the various discontinuous reinforcements used, which is considered as one of the most inexpensive and low-density dispersoids. The addition of cullet particles lowers the cost and density of Al and its alloys. Another means to further improve performances of Al-MMCs after the addition of reinforcement materials is via heat treatment.

Heat treatment technology also has an obvious influence on the microstructure and consequently the mechanical properties of Al-MMCs (Pei *et al*., 2015). Even though it is a collective effect of heat treatment and reinforcements types that plays a crucial role in determining the final mechanical performances of the composite, there is limited information available regarding heat treatment of Al-based composites with Cu or cullet as reinforcement.

This research is aimed at combining these worthy components (Al, Cu and Cullet Powder, CP) to fabricate a composite that will possess all the distinct features of all the three (3) components and more. Essentially, it would be a composite with outstanding properties. The Al-Cu-CP metal composite was characterised to evaluate its properties and potentials in order to ascertain its prospective applications. The outcome of the research has proven that the Al-Cu-CP metal composite possesses some outstanding properties better than combining either of the two components or other composite fabricated from similar raw materials. It is also an additional way of recycling solid waste materials, reducing the mining activities for virgin and non-renewable raw materials, making the environment tidier as well as producing a relatively cheaper composite.

1.2 Problem statement

Metal matrix composites and the other types of composites as well, are purposely designed to meet the requirement of the present-day technological advancement which appears to be impossible to achieve by using the traditional monolithic engineering materials. Remarkable achievements have been recorded due to the advent of the composite materials in various fields of science and technology (Zulfia *et al*., 2017; Soni & Pandey, 2014; Velmurugan *et al*., 2014). However, some obstacles surfaced between the glaring advancement to be achieved through composite technology and its realisation. One of these obstacles is the cost of raw materials for manufacturing the metallic composites. To overcome this obstacle of expensive raw materials in composites manufacturing and also to complement the ever-growing demand for sophisticated materials, recycled materials were introduced in the manufacturing of the composite materials. This will reduce the cost of buying the virgin monolithic raw materials in manufacturing the composites by using the recycled materials (Oladele & Okoro, 2016; Raut, Ralegaonkar & Mandavgane, 2011).

Different Al-based composites were fabricated using different reinforcement materials and improved properties were achieved for the targeted design of the composites. Some of the Al-MMCs were fabricated from waste materials. Al from waste beverage containers was used to fabricate a composite reinforced with rice-hull ash (Escalera-Lozano *et al*., 2008), Al composite reinforced with fly ash (Selvam *et al*. 2013), Al-cullet composite (Al-Imari, 2014), Al-clay composite (Agbeleye *et al*., 2017), Al-SiC composite (Iqbal & Amierah, 2017). Malik *et al*. (2017) and Agunsoye *et al*. (2014) fabricated Al composite from recycled Al-cans reinforced with eggshell.

All these researchers reported significant improvement in the respective properties of the composites fabricated. For example, when Cu is added to Al as reinforcement material, it improves the strength and toughness of the composite as well as its wear resistance (Mahmoud & Al-Qozaim, 2016; Mittal & Muni, 2013). Improvements in physical and mechanical properties of cullet reinforced Al-MMCs were reported by different researchers (Yoshikawa *et al*., 2005; Al-Imari, 2014; Rao

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