WEAR PERFORMANCES INVESTIGATION ON ALUMINIUM-BASED METAL MATRIX COMPOSITE PREPARED THROUGH THIXOFORMING

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor's Degree of Manufacturing Engineering (Hons.)

by

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FACULTY OF MANUFACTURING ENGINEERING

2022

UNIVERSITI TEKNIKAL MALAYSIA

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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Tajuk: **WEAR PERFORMNACES INVESTIGATION ON ALUMINIUM-BASED METAL MATRIX COMPOSITE PREPARED THROUGH THIXOFORMING**

Sesi Pengajian: **2022 Semester 2**

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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ABSTRACT

The recent research investigates on A356 aluminium alloy reinforced with Multi-Walled Carbon Nanotubes (MWCNTs) prepared through permanent mould casting for feedstock preparation and thixoforming in a hydraulic cylinder press to form Metal Matrix Composites (MMC). The impact of T6and T5heat treatment on thixoformed aluminum A356 reinforced with MWCNTs is explored in this study. The reinforcement (MWCNTs) content is 0.5wt% and 1.0wt%, respectively, and the wetting agent (Magnesium flakes) which helps to bind together is 0.5wt% and 1.0wt%. To uniformly disperse CNT in Al, the composition of the metal matrix and reinforcement is blended either about 10minutes or 15 minutes by a mechanical stirrer of the turbine type. Following the thixoforming procedure, the sample will be microstructural analysed before being subjected to T5 heat treatment. The T5 heat treatment consist of an artificial ageing process in which the alloy will be heated to 200 °C for 4 hours to allow precipitation to occur. The microstructure of each specimen was studied using scanning electron microscopy (SEM) and X-ray diffraction (XRD) to determine the phase of enhanced microstructure arrangement. Then a micro pod tribo tester is utilized to analyse on the wear performance of the tested specimen.

ABSTRAK

Kajian berkaitan dengan kajian aloi aluminium A356 yang Penyelidikan baru-baru ini menyiasat aloi aluminium A356 yang diperkukuhkan dengan Nanotubes Karbon Berdinding Pelbagai (MWCNTs) yang disediakan melalui pemutus acuan kekal untuk penyediaan bahan mentah dan thixoforming dalam akhbar silinder hidraulik untuk membentuk Metal Matrix Composites (MMC). Dalam kajian ini, kesan rawatan haba T5 dan T6 pada Aluminium A356 thixoformed diperkukuhkan dengan MWCNTs disiasat, dan kandungan tetulang (MWCNTs) adalah 0.5wt. % dan 1.0wt. %, masing-masing, yang akan dibalut dengan 0.5wt. % dan 1.0wt. % magnesium (Mg) serpihan sebagai agen pembasah. Untuk menyebarkan CNT secara seragam di Al, komposisi matriks logam dan tetulang dikacau selama 10 dan 15 minit menggunakan pengaduk mekanikal jenis turbin. Berikutan prosedur thixoforming, sampel akan dianalisis mikrostruktur sebelum tertakluk kepada rawatan haba T5. Untuk rawatan haba T5 kemudiannya hanya akan terdiri daripada proses penuaan buatan di mana aloi akan dipanaskan hingga 200 °C selama 4 jam untuk membolehkan pengukuhan microstrukture aluminium berlaku. Untuk mengenal pasti fasa susunan mikrostruktur yang meningkat, mikrostruktur setiap spesimen telah diperiksa menggunakan mikroskopi elektron pengimbas (SEM),dan penyebaran X-ray (XRD). Selain daripada itu, micro pod tribo tester juga digunakkan untuk mengalisasi sifat sample yang menjalani ujian geseran.

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DEDICATION

Only

my beloved father, Kuppan A/L Samikkannu

my appreciated mother, Saraswathy A/P Anggappan

my adored sisters, Kalaivani and Ramathevi

for giving me moral support, money, cooperation, encouragement and also understandings This humble work is dedicated for all of you who taught me patience in completing my work, giving support and encouragement during difficult time of this journey

Thank you very much

ACKNOWLEDGMENT

First and foremost, I want to thank God, the Almighty, for showering me with blessings during my investigation job, allowing me to complete the research successfully. I would take this opportunity to pass my profound and true appreciation to Mr Ammar bin Abdul Rahman, my esteemed supervisor, who patiently helped me throughout the entire journey for guidance and support to explore and giving important direction all through this research. I'd would like to show my thankfulness to each one of my instructors who helped me in any way along the process. In addition, I would also like to express my heartfelt gratitude to my esteemed group of panels Associate Professor Dr Mohd Shahir Bin Kasim, Associate Professor Ir. Dr. Mohamad Bin Minhat, and En.Mohd Fairuz Bin Dimin for spending their precious time reading and evaluating this study. Not only that, I also want to express my gratitude to my friends and classmates for their emotional and physical support. I also thank all the staffs of University Teknikal Malaysia Melaka for their kindness and guidance throughout this research. Finally, I would really like to convey my gratefulness to everyone who has helped me accomplish the research work, either in directly or indirectly.

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LIST OF ABBREVIATION

ASTM	-	American Society for Testing and Materials
AFM	-	Atomic Force Microscopy
Al	-	Aluminium
AMC	-	Aluminium Matrix Composite
AFM	-	Atomic Force Microscope
CNT	-	Carbon Nanotubes
CNT-Al	-	Aluminium reinforced Carbon Nanotube
CG-Al	-	Coarse Grained Aluminium
DSC	-	Differential Scanning Calorimetry
DOE	-	Design of Experiment
EDX	-	Energy Discharge X-ray
Mg	-	Magnesium
MMC	-	Metal Matrix Composite
MWCNT	-	Multi Walled Carbon Nanotube
NC-Al	-	Nanocrystalline Aluminium
OM	-	Optical Microscopy
PM	-	Powder Metallurgy
SWCNT	-	Single Walled Carbon Nanotube
SEM	-	Scanning Electron Microscope
SSP	-	Semi Solid Processing
UTM	-	Universal Tensile Machine

LIST OF SYMBOLS

Wt%	-	Weight Percentage
Min	-	Minutes
°C	-	Degree Celcius
mg	-	milligram
MPa	-	Mega Pascal
HV	-	Vickers Pyramid Numbe
mm	-	millimeter
kW	-	kilowatts
A/min	-	Ampere per minute
kN	-	Kilo Newton
kN-m	-	Kilo Newton meter
rpm	-	Revolution Per Minute
kHz	-	kilohertz

CHAPTER 1

INTRODUCTION

This chapter discusses the overview of the research work's introduction, which includes the background study, problem statement that encouraged to the investigation, objective, scope, and significance of the study. The whole research focused on the wear performances investigation of Al-CNT prepared through thixoforming.

1.1 Background Of Study

The Metal matrix composites (MMCs) are widely applicable due to the enhanced characteristics such as hardness, elongation strength at room and high temperatures, fatigue strength, and significant lightweight. A classic composite material is made up of 2 or more specific components. These composites are often made up of reinforcement that are bonded together with a matrix. The reinforcement is held in place by the matrix while the reinforcement improves the matrix's strength. Due to the fact that the majority of industrial sectors, specifically the automotive and aerospace industries, are focusing on structural weight reduction in order to improve fuel efficiency and to employ more reliable materials that are not harmful to the environment. The Aluminium Metal Matrix Composite (AMMC) study can make this achievable as it has the potential to accelerate the metal's strength and physical properties while preserving its lightweight nature.

Aluminium (Al) is one of the most commonly referred lightweight steels due to its high toughness ratio, chemical stability, and machinability. By increasing the capacity of Al and its alloys (AMCs), the Al matrix composites may be used as structural components that are low in weight. As for CNTs which discovered by Iijima S.,(1991), seems to be one of the high demanded reinforcement materials due to its wide range of applications in nanotechnology, optics, electronics, and other domains. The high aspect ratio of this CNTs, allows them to change the microstructure of their matrix accordingly based on the composite. CNTs are classified as either single-walled carbon nanotubes (SWCNTs) or multi-walled carbon nanotubes (MWCNTs). The enhanced or uniform dispersibility in composites and low-cost criteria dominate the MWCNT over SWCNT. Despite the differences both have the same goal to improve the mechanical characteristics, strengthens the microstructure and thermal reactions of metal matrix composite materials.

When compared to the unreinforced alloy matrix, the reinforced aluminium metal matrix composite has significantly improved features such as high strength, stiffness, and damping capacity. One of the variables that are determining the mechanical characteristics of materials is the grain structure. In general, the spherical grain structure will improve material impact strength, strain property, and shock absorption capabilities. Thixoforming appears to be the most often utilized approach for achieving spherical grain structure via Semi Solid Processing (SSP) The thixoforming methods relates to metal shaping at temperatures between solidus and liquidus where the subjected metal is heated to an elevated temperature until it approaches the semisolid state and ramming it through the mold. In terms of strength, the new composite material outperforms if the composite is correctly produced. Babalola, *et al*.,(2017)

On the other hand, grain refinement technique is also widely used technique to improve the strength of thixoformed alloy. The heat treatment has shown its ability to enhance the microstructure by without changing its initial identity. The heat treatment procedure alters the microstructure, dissolves, and homogenizes soluble components, and so strengthens and prevents catastrophic composite breakdown Hanizam, *et al*., (2019). Heat treatment is a process that involves heating a metal to a particular temperature and then cooling it to alter its structural features to achieve the desired degree of physical and mechanical properties, such as fragility, hardness, and softness. It facilitates in the reinforcement of composites and the avoidance of catastrophic failure. Since T5 is the most convenient heat treatment for the composition of aluminium alloy and the most quick and easy heat treatment for microstructure modification in the application of aluminium alloy. This heat treatment is often used in hot working materials or samples to cool down and processed artificially. This treatment appears to be ideal for improving a product's internal and external characteristics such as hardness, strength, temperature resistance, and ductility.

Many attempts were recorded in terms of its wear performance on various materials including aluminium, Zinc and magnesium as matrix while polymers, carbon, and CNT as composite for the thixoformed metal process. Choosing materials with excellent wear properties is critical because it affects the product's performance in all aspects. Products manufactured with low-wear materials may not be capable of withstanding field pressures such as friction between parts or climate changes. Material with poor wear properties might become easily worn or damaged, reducing the product's survival. The existing research shows that aluminium alloy has been tested with different composites for its wear behavior, tensile strength, and fracture properties. Therefore, the present research focuses on the wear performance investigation of thixoformed A356 aluminium alloy mixed with Multi-walled Carbon Nano tube (MWCNT), which may reveal the optimal parameters for the entire process and form interfacial bonding between MWCNT and Al matrix, which may contribute to the thixoformed samples' quality.

1.2 Problem Statement

The traditionally, die cast components have widely recorded faults such as porosity, and uneven microstructure due to the reason of imbalanced dispersion on metal matrix with reinforcement. The stirring effect have not been fully investigated not on CNTs but also for other reinforcing materials too. When the matrix and reinforcement achieve uniform dispersion of CNTs in the matrix and good bonding at the interface, this feature can be achieved. However, CNT segmentation or any non - uniformity dispersion will eventually result in material defects that will impact the overall characteristics. The controlled stirring action in the liquid matrix creates a vortex condition where it tends to form a cavity, which aids in the homogenous dispersal of the reinforcement material into the melt. Therefore, it is well worth investigating the stirring effect on composite production.

Wear performance analysis is generally about investigating a material and/or component’s strength in terms of withstanding a cyclic load to determine the root problem from varying load performance under real - time operating environments. The situation can arise due to the random nature of the load, which causes tiny material weaknesses (flaws) to grow, eventually ending in a massive fracture (initiation phase). The crack could then expand to a very dangerous size, forcing the component's structure or force boundaries to fail. In comparison to homogeneous metal, forecasting wear performance of aluminum composite materials appears to be significantly more challenging. The microstructural systems were disrupted in the form of fiber breaking, matrix cracking, and debonding transverse ply cracking, as well as delamination. This reasoning has a significant impact on both the material and the testing conditions. Consequently, it is crucial to focus on the wear performance characteristics of thixoformed Aluminum A356-based metal matrix combined with CNT composite.

On the other hand, the mechanical qualities of the thixoformed components are poorer than those of the ordinary grade. Whereas the torsional strength of the thixoformed aluminium alloy is similar to that of the forged component, the yield strength is far lower B.Chen, *et al.*,(2020) Therefore, is strongly necessary for the metal matrix composite to undergo heat treatment as well. It is also known that changing the shape of the grain from columnar to equiaxed enhances the mechanical characteristics and uniformity of a formed alloy. Heat treatment has been proven to affect microstructures by refining the grain structure without changing the entity's form through heating and cooling process. T5 and T6 heat treatments are the most common heat treatments for aluminium alloys. This is a crucial stage since it contributes significantly to the fatigue failure analysis. Despite the fact, that many researchers have investigated on the mechanical properties for composite materials, relatively few studies only have been conducted to examine the microstructure and wear performances of aluminium reinforced CNT composites using T5 heat treatment.

1.3 Objective

The following is the objective of the research based on thixoformed aluminium alloy A356 reinforced with MWCNT composite:

(1) To develop an optimized feedstock fabrication process parameter of thixoformed Al-MWCNT composite. using DOE Taguchi Method.

(2) To investigate the effect of T5 on microstructure evolution and wear performance of thixoformed heat treated aluminium A356-MWCNT composites.

(3) To characterise the influence of CNT % and stirring duration on the wear performances of the heat treated thixoformed A356-MWCNT alloy composite.

1.4 Scope

This study is primary focused on aluminium industries. Aluminium alloyA356 was chosen from the group of aluminium because it is castable and increasingly popular in aviation and automobiles. A356-based alloys appear more desirable than other Al alloys due to its significant ductility, strength, elongation, hardness, and toughness at room temperature. Hence the samples are produced using permanent mould die casting technique and then thixoformed to the required temperature of 700°C.

After that, the present phases and microstructures of heat treated thixoformed A356-MWCNT composites are characterised using Scanning Electron Microscopy (SEM) under the magnification of 200 and verified by using X-ray diffraction (XRD) analysis. This technique is also helpful in identifying the composition as well as dispersion of MWCNT in the melt. The DOE of Taguchi analysis is performed to design the optimal MWCNT content, wetting agent(Mg) content, stirring time parameter and heat treatment of the thixoformed A356-MWCNT aluminium alloy composite.

The experiment will be conducted using T5 heat treatment using nabertherm electric furnace. The speciments will be heat treated for 4 hours under 200°C and after that it will be artificially aged. The mechanical properties of the heat treated thixoformed A356-MWCNT composite is obtained by wear testing using micro pod tribo tester.

1.5 Significant/Important of Study

The thixoforming method is being studied in this research project to improve mechanical characterisation and fatigue failure of thixoformed materials after heat treatment. Although, thixoforming process and heat treatment have the ability to improve mechanical characteristics of metal, but then the combination of MWCNTs with an aluminium metal matrix has received little attention, particularly in terms of fatigue failure and optimal process parameters. So that, through this research study it is significant to focus on the thixoformed aluminium alloy which mixed with the CNT composite and to identify which heat treatment would be the best choice for material strengthening.

1.6 Summary

This investigation is done to specify the metal matrix, which in this case is an aluminium alloy that will be merged with a composite material (MWCNT). The MWCNT serves as a reinforcement to the aluminium alloy in order to strengthen the material, which will later undergo semi-solid processing (Thixoforming) to strengthen the sample's mechanical characteristics. The goal of this study is to discover the ideal heat treatment method. for improving the internal and external quality of the samples, as well as to test on the wear performance in order to evaluate its wear resistance characteristics after the reinforcement of MWCNT into A356.

CHAPTER 2

LITERATURE REVIEW

This chapter has been divided into sections which will demonstrate the detailed notes and key points which has related to this title. This section also contains summaries of papers written by various authors on related cluster as this will help the project the knowledge that gained through reviewing their journals. So that, in the process of organizing those contents this chapter has various subtopics such as overview of semi solid metal processing

2.1 Metal Matrix

The metal matrix is a homogeneous, monolithic material that acts as a binding and gripping medium for the reinforcements, allowing them to form as a solid. It guards the reinforcements from environmental damage, transfers load, and gives finish, texture, colour, durability, and performance since it is entirely continuous. Although we could find various kind matrixes that were developed over the years, but then aluminium based matrixes are most studied as they are widely in application. According to Brough and Jouhara, (2020) aluminium is the highest metal manufactured and most produced non-ferrous metal.

2.1.1 Aluminium (7075)

According to the study Almotairy, *et al.*, (2019), describes the inquiry into the thixoformability of a high-performance alloy 7075. In this experiment, the alloy was extruded with a 16:1 ratio and treated with T6511 (i.e., T5 followed by stress-relief by stretching, followed by minor straightening, to comply with standard tolerances and eliminate the distortion caused by quenching). Differential scanning calorimetry (DSC) was used to estimate the liquid fraction versus temperature curve using a Dupont 910 DSC machine. The experiment carried out on microstructure testing in the semi-solid state, which comprises of tiny spheroidal solid grains surrounded by liquid, in the experiment. The results of thixoforming with one, two, and three steps of induction heating are reported, and the data projects that lower thixoforming temperatures results in defects such as vortex, liquid partitioning, midline porosity, and uncrystallized grains arise which potentially restricting flow. Three-step heating and thixoforming temperatures in the 616–618 °C range to produce better results. A ram velocity of 750 mm/s usually produces lesser defects than 1000 mm/s. Although both a graphite die, and a heated tool steel die provide good die filling, the mechanical qualities of the thixoformed products are superior with the former. When compared to unreinforced aluminium thixoformed under the same circumstances, thixoformed samples with homogeneous dispersion of Silicon carbide (SiC) nanoparticles improve microhardness by roughly 364 %.

2.1.2 Aluminium (A319)

Based on the study conducted by Alhawaria, *et al.*, (2013), demonstrates that thixoforming is a promising process for forming semisolid metals into near net-shaped objects. The influence of a thixoforming process on the microstructure and mechanical characteristics of A319 aluminium alloy was explored in this study and is reported in this paper. By how, after maintaining at 571 °C for 5 minutes, the ingots collected from the cooling slope were thixoformed in a press, enabling a microstructure mainly consisting of a-Al globules and inter-globular Si particles. Some of the thixoformed samples were aged artificially by T6 heat treatment before hardness and tensile samples were generated from the as-cast, as-thixoformed, and thixoformed T6. This experiment was initially conducted in the way of where The A319 alloy was chopped into tiny pieces (about 30 mg) for testing with the Netzsch-STA (TG-DSC) 449 F3 simultaneous thermogravimeter. To avoid oxidation, the sample was heated in nitrogen at 10 °C/min. The liquid fraction was calculated by evaluating the partial integral of the area under the endothermic curve. The findings