THE EFFECT OF HEAT TREATMENT SCHEDULE ON MECHANICAL PROPERTIES OF DIFFERENT CARBON NANOTUBES CONTENTS IN ALUMINIUM ALLOY COMPOSITES

CAROLYN LAU YEE JIE

B051510061

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

CAROLYN LAU YEE JIE

B051510061

950620136136

FACULTY OF MANUFACTURING ENGINEERING

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This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.). The members of the supervisory committee are as follow:

……………………………………

(Dr. Mohd Shukor bin Salleh)

ABSTRAK

Kajian berkaitan dengan kajian aloi aluminium A356 yang diperkuat dengan Multi-Walled Nanotubes Karbon (MWCNTs) yang disediakan oleh pemutus acuan kekal untuk penyediaan bahan bakar dan proses pembuatan di dalam silinder hidraulik untuk membentuk Metal Matrix Composites (MMC). Kesan jadual rawatan haba T5 dan T6 pada MWCNTs / A356 telah disiasat. Kandungan MWCNTs adalah 0.5wt. % dan 0.75wt. % masing-masing, yang akan dibalut dengan 0.5wt. % daripada kalsium Magnesium (Mg) sebagai agen pembasuh. Campuran A356 dan MWCNTs diaduk dalam 10 dan 15 minit dengan menggunakan pengikis mekanikal jenis turbin. Selepas proses thixoforming, rawatan haba T6 dilakukan untuk komposit MWCNTs / A356 dengan rawatan haba penyelesaian pada 540 ℃ selama 8 jam, proses pelindapkejutan pada 24 ℃ dan diteruskan oleh penuaan tiruan pada 150 ℃ selama 4 jam, manakala rawatan haba T5 juga akan berusia pada 150 ℃ selama 4 jam tetapi tanpa rawatan haba penyelesaian. Struktur mikro setiap spesimen dicirikan dengan Mikroskop Optik (OM), Pengimbasan Mikroskopik Elektron (SEM) dan Difraksi X-ray (XRD). Penguji Mesin Universal (UTM) dan Vickers Kekerasan Penguji adalah peralatan yang digunakan untuk menjalankan ujian kekerasan dan uji tegangan mengikut standard ASTM: E8M. Pengoptimuman aloi MWCNT-A356 komposit proses fabrikasi proses fabrikasi menggunakan DOE Kaedah Taguchi. Hasil jangkaan menunjukkan pembentukan mikrostruktur bukan dendritik dan mencapai fasa pengagihan homogen untuk komposit MWCNTs / A356 yang dirawat haba. T6 haba yang dirawat spesimen mendedahkan kekerasan yang lebih tinggi dan kekuatan tegangan berbanding dengan spesimen yang dirawat haba T5.

ABSTRACT

The present research deals with the study of A356 aluminium alloy reinforced with Multi-Walled Carbon Nanotubes (MWCNTs) prepared by permanent mould casting for feedstock preparation and thixoforming process in a hydraulic cylinder press to form Metal Matrix Composites (MMC). The effect of T5 and T6 heat treatment schedule on thixoformed MWCNTs/A356 are investigated. The contents of MWCNTs are 0.5wt. % and 0.75wt. % respectively, which will be wrapped with 0.5wt. % of Magnesium (Mg) flasks as a wetting agent. The mixture of A356 and MWCNTs is stirred in 10 and 15 min by using a turbine type mechanical stirrer. After thixoforming process, T6 heat treatment is performed to thixoformed MWCNTs/A356 composites with solution heat treatment at 540 ºC for 8 hours, quenching process at 24 ℃ and continued by artificial ageing at 150 ℃ for 4 hours, while T5 heat treatment also will be aged at 150 ℃ for 4 hours but without solution heat treatment. The microstructure of each specimens are characterised with Optical Microscopy (OM), Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD). Universal Testing Machine (UTM) and Vickers Hardness Tester are the equipment that used to conduct the hardness test and tensile test according to ASTM: E8M standard. Optimization of the MWCNT-A356 alloy composites feedstock fabrication process parameters using DOE of Taguchi Method. The results showed the formation of non-dendritic microstructure and achieved a homogeneous distribution phase for the heat-treated thixoformed MWCNTs/A356 composites. T6 heat-treated specimens revealed higher hardness and tensile strength compared to the T5 heat-treated specimens.

DEDICATION

Only

my beloved father, Lau Chit Chin

my appreciated mother, Hii Mee Ping

my adored sisters, Patricia Lau Ee Yii and Phyllisia Hii Wang Ying

for giving me moral support, money, cooperation, encouragement and also understandings

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LIST OF ABBREVIATIONS

ANSI	-	American National Standard Institute
ASTM	-	American Society for Testing and Materials
AFM	-	Atomic Force Microscopy
Al-MMCs	-	Aluminium Metal Matrix Composites
ANSI	-	American National Standards Institute
CMCs	-	Ceramic Matrix Composites
CNC	-	Computed Numerical Control
CNTs	-	Carbon Nanotubes
CS	-	Cooling Slope Casting
CVD	-	Chemical Vapour Deposition
DC	-	Direct Current
EDX	-	Energy Dispersive X-ray
EDM	-	Electrical Discharge Machine
HIP	-	Hot Isostatic Press
HRTEM	-	High-Resolution Transmission Electron Microscopy
MMCs	-	Metal Matrix Composites
MWCNTs	-	Multi-Walled Carbon Nanotubes
NRC	-	New Rheocasting
OM	-	Optical Microscopy
PM	-	Powder Metallurgy
PMCs	-	Polymer Matrix Composites
PRMMCs	-	Processing Parameter on Metal Matrix Composites
SC	-	Squeeze Casting
SEM	-	Scanning Electron Microscopy
SIMA	-	Strain Induced Melted Activation
SSM	-	Semi Solid Metal Processing
SWCNTs	-	Single-Walled Carbon Nanotubes
UTM	-	Universal Testing Machine
UTS	-	Ultimate Tensile Strength

XRD	-	X-ray Diffraction
XRF	-	X-ray Fluorescence
YS	-	Yield Stress

LIST OF SYMBOLS

%	-	Percentage
µm	-	Micrometre
Bal.	-	Balanced
ºC	-	Degree Celsius
cm	-	Centimetre
g	-	Gram
g/cm^3	-	Gram Per Cubic Centimetre
HV	-	Vickers Hardness
Kw	-	Kilowatt
L/min	-	Litre per Minute
Kn	-	Kilo Newton
m/s	-	Metre Per Second
mm	-	Millimetre
min	-	Minutes
MPa	-	Mega Pascal
Mm	-	Millimetre
nm	-	Nanometre
rpm	-	Rotation Per Minute
Tpa	-	Tera Pascal
wt. %	-	Weight Percentage

CHAPTER 1

INTRODUCTION

1.0 Background of Study

A composite material is a duplex and a multifunctional material that made when more than one constituent materials are combined microscopically to produce a different characteristic of the material. These constituent materials have significantly distinct in physical, chemical, and mechanical properties. The two constituents work together to produce a unique composite material that has enhanced the properties when compared to the individual components that used alone. The great advantages of composite materials are that they are light weight, high strength and stiffness, and high resistance to creep and corrosion. A composite material is composed primarily of a matrix to increase the mechanical strength and stiffness and a reinforcement which is usually the discontinuous phase or secondary phase. In recent year, metal matrix composites (MMCs) have attracted more attention by the researchers and become the vital materials reliant on the requirement. Specifically, the particulate reinforced Aluminium metal matrix composites have received significant attention due to the improved mechanical and tribological properties such as strength, stiffness, impact resistance and wear resistance (Vinay *et al*., 2018).

Aluminium and its alloys have been dominating the market for the aerospace and automotive industries. Some of the intrinsic properties and characteristics contributed to its widespread use include lightness, low toxicity, good formability, better thermal stability and corrosion resistance. As a potential candidate for structural applications, these materials required high specific strength and stiffness. However, further strengthening of aluminium is still required (Toozandehjani *et al*., 2015). The Al-Si alloys are more typical of all aluminium alloys available for commercial use. This can be due to their extensively useful options, such as high strength to weight magnitude relation, exceptional solidity and pressure tightness, low thermal expansion coefficient, good mechanical properties and resistance to corrosion (Aithal *et al*, 2016).

Carbon nanotube (CNT) is the composed of sheets of carbon atom in nano-sized cylindrical tubes (Iijima 1991). The mechanical properties of CNT such as high elastic modulus, bending strength and tensile strength become the focus of attention because it is useful as a reinforcement (Zhang *et al*., 2001). The dispersion and high processing temperature of CNTs are the challenges which have restricted the reinforcement of CNTs into metal composites. The challenges making the reinforcement become complicated and even taking more time. Although CNTs have high thermal and electric conductivity and high tensile strength (Harris *et al.*, 2004). However, the development of CNT-metal composites for thermal management and potential application has grown significantly. The CNTs in the matrix must in the uniform dispersion, and excellent bonding at the interface between the matrix and reinforcement which are the main requirement to accomplish the two properties (Esawi *et al*., 2011).

Thixoforming is one of the semi-solid metal processing that used to explain about a partial melted non-dendritic alloy slug with the near net shaping between a metal die (Fan, 2002). Thixoforming involve feedstock preparation and continued by partially re-melting before near net shaped products is form. For thixoforming it is necessary to have a spheroidal non-dendritic structure of the solid phase, this microstructure can be obtained by some methods such as mechanical stirring, magneto hydrodynamic stirring, grain refinement and cooling slope (CS) method. Among all methods, CS method possesses some advantages in comparison with other methods. The technique is simple and does not need complicated equipment. The non-dendritic microstructure is produced by pouring the molten alloy with a modest amount of superheat on an inclined plate (Abdulrazaq *et al.*, 2017).

Heat treatment is a process where metals and metal matrix composites are repeatedly heated and cooled to achieve some improved properties. Cooling rate and heating temperature are the major factors which influences the changes in the microstructure of metals, which further affect the mechanical properties of heat treated metals (Kakani and Kakani, 2004). The most commonly used heat treatments for aluminium alloys are T5 and T6 heat treatment. T5 heat treatment is including cooled after casting or hot working and artificially aging, while T6 heat treatment required of solution heat treatment, quenched in water and artificially aging.

In this study, the aluminium matrix will be reinforced with the MWCNTs by using permanent mould casting with the weight ratio parameters, 0.5 and 0.75wt. % and the aid of Magnesium as wetting agent with 0.5 wt. %. Reheating process will be applied to semisolid temperature range to get spheroidal solid particle in liquid matrix before thixoforming (Birol, 2007). After the feedstock MWCNTs/Al composites is formed, the composites are then undergoing thixoforming process to form a cylindrical shape. T5 and T6 heat treatment is then carried out using electric furnace with a temperature control of ± 2 ℃. In T6 heat treatment, the solution treatments are performed at 540 ℃ for 8 hours and the samples are then quenched in water at 24 ℃. Hence, artificially aging are performed at 150 ℃ for 4 hours in each T5 and T6 heat treatment.

Furthermore, the effect of heat treatment on microstructure evolution of thixoformed CNTs/Al composites samples are studied by using material characterisation equipment, for example optical microscopy, Scanning electron microscopy (SEM) with energy dispersive X-ray (EDX) and X-ray diffraction (XRD). After characterisation, the heat treated of thixoformed CNTs/Al composites are undergone mechanical tests, including hardness tests and tensile tests. Thus, T-test and F-test are conducted for statistical analysis which used to compare the effect of T5 and T6 heat treatment of the thixoformed CNTs-reinforced A356 aluminium alloy composite.

1.2 Problem Statement

Carbon nanotube (CNT) has been considered as an ideal reinforcement for the development of a superior class of metal matrix composites due to its low density, high Young's modulus, tensile and shear strength. However, CNTs reinforced aluminium matrix composites are still in exploration stage with no available commercial applications as previous researches. Hence, the reinforcement in composite materials has not focused much on CNT reinforced metal matrix composites and very limited work has been done on CNT/Al composite foams (Ma *et al*., 2018).

The achievement of a uniform distribution of CNTs reinforcement into the metal matrix is one of the challenge in fabrication of CNT-reinforced MMCs. Attaining a homogeneous mixture is difficult due to strong Van Der Waals forces and the attractive or