

OPTIMUM PARAMETERS OF GRAPHENE REINFORCED MAGNESIUM ALLOY AND ITS INFLUENCE ON THE MECHANICAL PROPERTIES

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



MOHAMMAD NA'AIM BIN ABD RAHIM

FACULTY OF MANUFACTURING ENGINEERING 2022

DECLARATION

I hereby, declared this report entitled "Optimum Parameters of Graphene Reinforced Magnesium Alloy and Its Influence on Their Mechanical Properties" is the result of my own research except as cited in references.



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:



ABSTRAK

Graphene ialah alotrop karbon yang terdiri daripada satu lapisan (monolayer) atom yang terikat bersama dalam corak berulang heksagon. Ia digunakan sebagai pengisi nano dalam komposit bahan untuk meningkatkan sifat fizikal dan mekanikalnya. Aloi magnesium tidak mempunyai sifat mekanikal yang mengehadkannya untuk digunakan untuk aplikasi tertentu. Kelemahan ini dianggap sebagai kerugian yang ketara kerana sifat aloi magnesium menjanjikan untuk pelbagai kegunaan kerana sifat fizikal dan mekanikalnya yang sangat baik, termasuk ketumpatan rendah, nisbah kekuatan kepada berat yang tinggi, nisbah kekakuan kepada berat yang tinggi. Projek ini memfokuskan kepada kesan kandungan graphene nanoplatelets (GNPs) pada aloi magnesium AM50 menggunakan salah satu pemprosesan separa pepejal, penyinaran. Parameter yang ditetapkan untuk projek ini menggunakan Kaedah Taguchi dengan memanipulasi masa dan kuantiti kacau kandungan graphene. Kualiti tuangan yang terhasil akan ditentukan oleh ujian mekanikal (ujian kekerasan dan tegangan). Daripada penyelidikan ini, taburan mikrostruktur dijangka mempunyai saiz butiran yang lebih kecil yang akan mempengaruhi sifat peningkatan kekuatan dan kekerasan bahan.

ABSTRACT

Graphene is an allotrope of carbon consisting of a single layer (monolayer) of atoms bonded together in the repeating pattern of the hexagon. It is used as a nanofiller in the material composite to enhance its physical and mechanical properties. Magnesium alloy lacks mechanical properties that limit them to being used for specific applications. These drawbacks are considered as significant loss as the magnesium alloy properties are promising for various usages due to their excellent physical and mechanical properties, including low density, high strength to weight ratio, high stiffness to weight ratio. This project focuses on the effect of graphene nanoplatelets (GNPs) contents on magnesium alloy AM50 using one of semi-solid processing, rheocasting. The parameters set for this project using the Taguchi Method by manipulating graphene content's stirring time and quantity. The resulting quality of the cast will be determined by mechanical testing (hardness and tensile test). From this research, the microstructural distributions are expected to have a smaller grain size which will influence the increasing property of the strength and the hardness of the material.

DEDICATION

Only

my beloved father, Abd Rahim Bin Abdullah my appreciated mother, Siti Fatimah Binti Mat Piah my adored sister and brother, Sakinah and Khairi

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

Thank You So Much & Love You All Forever



ACKNOWLEDGEMENT

Alhamdulillah, throughout the 14 weeks of this semester, I managed to complete my Final Year Project with bare along the name of Universiti Teknikal Malaysia Melaka. I would like to sincerely thank my supervisor

Alhamdulillah, throughout the 14 weeks of this semester, I managed to complete my Final Year Project with bare along the name of Universiti Teknikal Malaysia Melaka. I would like to sincerely thank my project's supervisor Profesor Madya Ir. Ts. Dr. Mohd Shukor Bin Salleh for his patient and guidance.

Thanks to Allah S.W.T for his blessing and guidance that give me strength to complete my report. I would like to express my special thanks and gratitude to my fellow friends especially my partner, Philip Patrick who help me the most.

Then, I would love to thank to production department staff, managers and group leader who help me a lot through this industrial training. Also, to my friends and colleague who help me to finish this training together within the time frame.

Finally, thank you to my parents and siblings that giving me the encouragements, emotional and financial support until the last day of internship.

Finally, a lot of appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for giving me this opportunity to sharpen my knowledge and experiences my very first thesis research.

TABLE OF CONTENTS

ABSTRAK	i
ABSTRACT	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
TABLE OF CONTENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xi
CHAPTER 1	1
1.1 Research Background	1
1.2 Problem Statement	2
1.3 Objectives	4
1.4 Scopes of the Research	4
1.5 Rational of Research TEKNIKAL MALAYSIA MELAKA	5
1.6 Project report Organization	5
CHAPTER 2	6
2.1 Graphene nanoplatelets	6
2.1.1 Properties of Graphene Nanoplatelets	8
2.1.2. Importance of Graphene	8
2.1.3 Applications of Graphene Nanoplatelets	9
2.2 Synthesis of Graphene	10
2.2.1 Top-Down Graphene	12
2.2.2 Bottom-Up Graphene	12
2.3 Magnesium Alloy	13

	2.3.1 Mechanical Properties of AM50	14			
	2.3.2 AM50A Chemical Composition:	15			
	2.3.3 Microstructure Characteristic of Magnesium Alloy	16			
	2.3.4 Chemical Composition	17			
2.4	Rheocasting	18			
2.5	Stirring Speed and Time	18			
2.6	Cooling Rate Effect	20			
2.7	Mechanical Testing	20			
CHAP	PTER 3	23			
3.1	Overview of Methodology	23			
3.2	Methodology Flow Chart	24			
3.3	Design of Experiment	25			
3.4	3.4 Material and Equipment Preparation				
	3.4.1 Magnesium Alloy AM50	27			
3.5	Preparation of graphene nanoplatelets (GNPs)	27			
3.6	Fabrication of AM50/GNPs composite 29				
3.7	3.7 Microstructure characterization. 3				
3.8	3.8Material Testing Preparation3				
3.9	Hardness Test	33			
3.10	0 Tensile Test	33			
CHAP	PTER 4	36			
4.1	Microstructure Analysis	37			
	4.1.1 Optical Microscopy Analysis	37			
	4.1.3 Scanning Electron Microscopy Analysis	38			
4.2	X-Ray Diffraction (XRD)	41			
4.3	Mechanical Testing	42			
	4.3.1 Hardness Testing	42			

	4.3.2	Tensile Testing Analysis	44
4.4	Desig	n of Experiment (DOE) Analysis	47
	4.4.1	Hardness Testing Analysis	47
	4.4.2	Tensile Analysis	49
CHAP	TER 5		51
5.1	Concl	lusion	51
5.2	Recor	nmendation	52
5.3	Susta	inability Development	52
5.4	Comp	blexity	53
5.5	Life-I	Long Learning	53
REFE	RENCES	MALAYSIA	55
	A TEKN	UTEN	

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

اونيۇمرسىتى تيكنيك

ninn .

۵,

all

LIST OF TABLES

Table 2.1 Top-down graphene process (Bhuyan et al., 2016)	12
Table 2.2 Concise history of bottom-up graphene (Bhuyan et al., 2016)	12
Table 2.3: Physical properties of magnesium alloy	14
Table 2.4 Comparison mechanical properties of AM series (Ji et al., 2005b)	15
Table 2.5 Chemical composition of magnesium alloy AM50	15
Table 2.6 Annealed Tempers Mechanical Properties, Alloy C26000	16
Table 2.7: Chemical compositions of AM50 alloy ingots	17
Table 2.8 Results of distribution of hardness achieved in the cast MMC at	
different processing condition (Prabu et al., 2006)	19
Table 3.1 The conditions of parameters	25
Table 3.2 L16 Orthogonal array	26
Table 3.3 Design summary of Taguchi Method	26
Table 3.4 Small-Size Specimen Proportional to Standard	34
Table 4.1 Vickers Hardness Testing Results	42
Table 4.2 Ultimate Testing Machine results.	44

LIST OF FIGURES

Figure 2.1: SEM micrographs of GNPs at (a) low magnification (b) high	
magnification; (c) XRD graph of as received GNPs (Rashad et al., 2015)	7
Figure 2.2 A process flow chart of Graphene synthesis (Adeniji Adetayo and	
Damilola Runsewe, 2019)	11
Figure 2.3 Hot chamber die casting machine (Park and Kang, 2013)	13
Figure 2.4 Typical microstructure of AM50 alloy produced by the HPDC process	17
Figure 2.5 Tensile test setup (Farhat, 2021)	21
Figure 2.6 Schematic of Vickers Hardness Test (Mahmoud and Hegazy, 2017)	22
Figure 3.1 Methodology flow chart	24
Figure 3.2 Magnesium alloy AM50 ingots	27
Figure 3.3 Graphene nanoplatelets particles	28
Figure 3.4 Graphene nanoplatelets particles	29
Figure 3.5 VT Portable Melting Furnace 1100° C	30
Figure 3.6 Wisestir HT120AX	30
Figure 3.7 Preparation of Cylindrical Stainless-Steel Mould	31
Figure 3.8 Result of Casting	31
Figure 3.9 Etched samples before testing	32
Figure 3.10 Hardness Testing on the Samples	33
Figure 3.11 (ASTM E8M-04)	34
Figure 3.12 Universal Testing Machine (UTM)	35
Figure 3.13 Dog bone Shape	35
Figure 4.1 Optical Micrograph of sample 4, 8, and 12 and 16 of Magnesium	
AM50 after Rheocasting under $\times 100 \mu m$ magnification	37
Figure 4.2 SEM Results	38

Figure 4.3 SEM results	39
Figure 4.4 SEM results	39
Figure 4.5 SEM results	40
Figure 4.6 Intermetallic phased found in XRD	41
Figure 4.7 Mean of hardness testing results	43
Figure 4.8 Average of Yield Strength	45
Figure 4.9 Average of Ultimate Tensile Strength	45
Figure 4.10 Elongation to Break	46
Figure 4.11 Main Effect Plot for Means of Hardness Versus Graphene wt% and	
Stirring Time	47
Figure 4.12 Hardness Versus Graphene wt%, Stirring time	48
Figure 4.13 Regression Analysis of Hardness	48
Figure 4.14 Effect Plot of Tensile Versus Stirring Speed and Stirring Time	49
Figure 4.15 Taguchi Analysis for Tensile Strength versus Graphene wt%, Stirring Time	50
Figure 4.16 Regression Analysis of Tensile Strength Versus Graphene wt%, stirring time	50
UNIVERSITI TEKNIKAL MALAYSIA MELAKA	

LIST OF ABBREVIATIONS



CHAPTER 1 INTRODUCTION

This chapter describes the overview of the study for the research. This chapter contains research background, problem statement, objectives, scopes of research, rational of research, research methodology, and project report organization.

1.1 Research Background

In recent years, the material known as graphene has emerged in advanced nanomaterial technology and is being explored deeply by scientists and engineers to utilize its advantages fully. It has contributed a lot to several applications like aerospace, building materials, mobile devices, and many others. Graphene is an allotrope of carbon consisting of a single layer (monolayer) of atoms bonded together in the repeating pattern of the hexagon. It had been arranged in a two-dimensional (2D) honeycomb lattice nanostructure. According to (Ameen et al., 2020) graphene happens to be the basic building block of other carbon allotropes such as graphite, single-walled/multi-walled carbon nanotubes, and fullerenes. The stack of monolayers on top of each other will form graphite.

The demand for innovative advanced materials has constantly been increasing due to the rapid growth of the current technologies and uses in many sectors. Graphene has attracted much attention to advance material technologies due to its unique properties. It has a remarkable combination of mechanical, thermal, chemical, and electrical properties. The study on graphene nanoplatelets (GNPs) by (Rashad et al., 2015a) states that GNPs have the potential reinforcement for strengthening metals such as Al, Cu, and Mg. It consists of several graphene layers with a thickness less than 100nm. By using graphene nanoplatelets (GNPs), various types of material can be reinforced by graphene to better enhance the material for a specific purpose. Graphene reinforced material will have higher stiffness, strength, thermal conductivity, and inert gas.

On the other hand, the usages of magnesium alloy AM50 are popular due to its lightweight property, excellent elasticity, superior energy absorbing properties, high strength, and castability. However, research has consistently shown that magnesium alloy AM50 has highly susceptible to corrosion and wear resistance. (Hussein and Northwood, 2014a) bold that magnesium alloy has low elastic modulus, limited cold workability and toughness, limited strength, and creep resistance at elevated temperature. To encounter its weaknesses, the idea of coating magnesium alloy with graphene can produce a much better new lightweight metal with high resistance corrosion.

1.2 Problem Statement

Much research on the rheocasting had been done and published to the education site. But the uncontrol parameters of the research resulted the variance size of grain in microstructural evaluations. Of cause individual decision on their research cannot be questioned, but the surface may not indicate a significant variance in grain size. The required grain size is determined by the material's intended use. (Baltzer and Copponnex, 2014) bold that the thinnest object dimension is at least 10 times larger than the grain size to achieve good mechanical stress of the material. The statement later had been supported by (Weng et al., 2015), with decreasing of grain size, the hardness value and corrosion resistance will be increased.

Magnesium alloy has lack of mechanical properties that limited them to be used for specific applications. These drawbacks are considered as big loss as the magnesium alloy properties are very promising for various usages in term of weight strength ratio (Trang et al., 2018). In the recent decade, several R&D efforts have resulted in the development of various types of magnesium alloys with an excellent balance of strength and ductility. Magnesium alloys have poor formability due to numerous causes, including the development of a strong basal roughness during rolling (thermomechanical treatment) and a restricted number of possible deformation modes due to the hexagonal close packed (hcp) structure of magnesium. Even though Mg alloys may be easily formed at warm or high

temperatures despite their poor formability at room temperature, forming at these temperatures is energy costly and inefficient.

Various of parameter had been applied to achieve the best result for graphene reinforced magnesium alloy in term of mechanical strength. All these casting techniques rely on precise control of all input parameters as well as correct metal solidification control to be successful. Because complex technologies are used in the casting process, even little changes in any of the input parameters might alter the process output and result in defective castings (Rao et al., 2014). It is very crucial to decide the parameters so that potential the defects and failure could be avoid during early stages.



1.3 Objectives

The objectives are as follows:

- (a) To evaluate the microstructural evaluation during semisolid metal processing.
- (b) To investigate the effect of the GNPs content on the mechanical properties of AM50 magnesium alloy.
- (c) To study the optimum parameter for stirring time and the value of graphene content by rheocasting process.

1.4 Scopes of the Research

The scopes of research are as follows:

This study is focusing on the effect of graphene nanoplatelets (GNPs) content on magnesium alloy specified to AM50 using rheocasting process. The parameter used for the study are stirring time and quantity of graphene used for the reinforcement. The experiment will be conducting cylindrical samples with two different diameters of 6mm and 12mm to analyse the stirring time effect, and the stirring time will be executed in four separate units. The microstructure of the casting result will be analysed through optical microscope (OM) and scanning electron microscopy (SEM). The mechanical properties of the graphene reinforced magnesium alloy will be analyse using mechanical testing which are tensile test and hardness test to determine the material's properties. All the processes will be conducted in faculty of manufacturing's laboratory in UTeM.

1.5 Rational of Research

The rational of research as follows:

- (a) Generate knowledge of the present of graphene as experiment constant to test the effect and characteristics of magnesium alloy that affected with and without it using casting process.
- (b) Graphene reinforced magnesium alloy will archive the highest strength when the composition of graphene nanoplatelets (GNPs) and magnesium alloy AM50 are in the perfect ratio and using the proper mechanical stirring
- (c) Generate scientific information and deep understanding of the study about the microstructure and its behaviour when responding to several aspects likes mechanical, thermal, chemical, and electrical.
- (d) Reduce the dependency of finding and exploring the new material that are unknowingly present that fit all the characteristic that graphene reinforced magnesium alloy probably should had.
- (e) Magnesium alloy AM50 is widely and commonly used in industry.

1.6 Project report Organization

This research is organized into several sub-topic and chapters. The introduction had begun as Chapter 1 that provides the background of the research, problem statement, objectives, scope of research, rational of research and thesis organization.

CHAPTER 2 LITERATURE REVIEW

In this chapter is mainly explains about the past research regarding the theory of experiment such as importance of tools and materials discussion, influence of parameters of casting, and microstructural characterization of the composite and mechanical testing such as hardness and tensile test.

2.1 Graphene nanoplatelets

Graphene nanoplatelets (GNPs) are a novel carbon species generated when graphite is exposed to circumstances. GNPs are two-dimensional carbon structure materials with a single or multilayer graphite plane that have several desirable properties such as high electrical conductivity, high modulus, high strength, high thermal conductivity, and high specific surface area. According to (Tiwari et al., 2020), these nanoparticles typically have a thickness of 1e15 mm and a lateral dimension of up to 100 mm. The synthesis of GNPs was carried out with the help of micromechanical graphite breaking, and it only allows for the formation of graphene nanocomposites with improved barrier properties. The conductivity percolation threshold for GNPs is 1.9 weight percent in the context of a thermoplastic matrix. Conductivity at densities of 2e5 weight percent is insufficient to provide electromagnetic shielding. After being mixed with glass fibers, polymers, or another matrix, GNPs can offer sufficient conductivity. GNPs can also improve the mechanical properties of various composites, such as stiffness and tensile strength, due to the solid interfacial interaction of nanoplates with the matrix.



Figure 2.1: SEM micrographs of GNPs at (a) low magnification; (b) high magnification; (c) XRD graph of as received GNPs (Rashad et al., 2015)

2.1.1 Properties of Graphene Nanoplatelets

Lightweight, wide aspect ratio, electric and thermal conductivity, mechanical strength, cheap cost composition, and so on are all appealing characteristics of graphene nanoplatelets. They are viable physics and engineering possibilities for replacing a variety of nano-structured preservatives, such as other carbon allotropes, steel microparticles, or clay. GNPs have a nanometer-thickness and are hence less susceptible to faults. Although GNPs have a lower surface area than single-layer graphene, they have a large interfacial area, making them ideal for creating hybrid structures with other nanoparticles (Fatima et al., 2017). These are attractive to nanocomposites because of solvent and melt counteracting. It has the melting point of 3652-3697 °C. They could be quickly and effectively included within the polymer matrices.

ALAYS/2

Graphene nanoplatelets are safer than carbon nanofibers and nano-tubes and equivalent to tube-like nano-fillers in altering polymers' chemical properties. In contrast, the chemical reactivity for Graphene nanoplatelets is lower than that of graphene oxide. As a result, graphene nanoplatelets are already being used in various technical fields. In practice, items made with graphene nanoplatelets have better tribology, mechanical, biological, gas barrier, flame retardant, and heat convection capabilities. Graphene nanoplatelets can convert plastic into an electrical capacitor, making it an ideal electronic material. Graphene nanoplatelets can improve the heat capacity of polymer matrixes, making them suitable as thermal interface materials

2.1.2. Importance of Graphene

Graphene nanoplatelets are frequently used as nanofillers in various matrices, including polymers, concretes, and metals (Jiménez-Suárez and Prolongo, 2020). GNPs are often used to improve the mechanical properties of polymer matrices and their chemical resistance and hence their longevity (Arribas et al., 2019). GNPs in polymers lower the ability of the polymers to absorb water, making them more resistant to harsh humid environments. A precise amount of graphene nanoplatelets delivers the best behaviour due

to this chronic propensity. It can also enhance the material's thermal conductivity, making these nanocomposites promising materials for solar energy conversion and storage.

Research from (Moosa et al., 2016) had proved that the success and remarkable synergetic effect between the GNPs and CNTs in improving the mechanical properties and electrical conductivity of epoxy composites. When squeezed into a polymer film or solid component, graphene nano-platelets drastically reduce a composite material's permeability and scattering coefficients. The particle size of the additive has a considerable impact on permeability, and large diameter particles often have smaller absorption reductions. According to test results from (Du and Pang, 2015), adding 2.5 wt% GNPs can reduce water penetration depth, chloride diffusion coefficient, and chloride migration coefficients by 64%, 70%, and 31%, respectively.

2.1.3 Applications of Graphene Nanoplatelets

Graphene nanoplatelets-based adaptable devices have been intensively investigated and appear to have already had a substantial impact. The free-standing of GPNs films and their usage in polymers are two outliers to the numerous various ways offered. Nonetheless, the most promising results have been produced by applying flexible plastic substrates with pure nano-flakes and conductive inks with polymer-Graphene nanoplatelets. Scientists gathered durable and high-performance equipment like antennas, compatible electrical electrodes for power applications, and lightweight electromagnetic resistance coatings with such approaches. Furthermore, the widespread usage of cellulose thin films, which are frequently mixed with biopolymers, has aided in the development of long-lasting, adaptable Graphene Nanoplatelets-based technologies and ecologically responsible electronic waste management. Intelligent sensors focused on Graphene nanoplatelets, on the other hand, have made promising progress. They preserve stretching ability and flexible electrical features that have made a significant impact as portable sensing technology of the future generation. Tactile apps and digital robotic skins might benefit from the growth of graphene nanoplatelets-based intelligent detectors. Strain sensing systems have evolved for various applications, ranging from structural and human health

monitoring to automotive and sports applications, as graphene-based materials have one of the most significant gauge factors ever reported.

2.2 Synthesis of Graphene

Graphene synthesis is referred as any procedure for generating or extracting graphene, depending on the required size, purity, and efflorescence of the individual result. Previously, numerous strategies for creating thin graphitic films had been discovered. Graphene has been synthesized using a variety of processes in recent years. According to (Bhuyan et al., 2016), the most often utilized methods today are mechanical cleaving (exfoliation), chemical exfoliation, chemical synthesis, and thermal chemical vapor deposition (CVD) synthesis. Unzipping nanotubes and microwave synthesis are two other techniques mentioned. Although mechanical exfoliation with an AFM cantilever was discovered to generate few-layer graphene, the procedure was limited by the graphene thickness varying between 10 nm and 30-layer graphene.

Solution dispersed graphite is exfoliated using the chemical exfoliation method by injecting large alkali ions between the graphite layers. Chemical synthesis is a procedure that involves synthesizing graphite oxide, dispersing it in a solution, and then reducing it using hydrazine. For large-scale graphene creation, catalytic thermal CVD has shown to be the essential method, just as it did for carbon nanotube synthesis. Thermal CVD is when the process is carried out in a resistive heating furnace, while plasma-enhanced CVD or PECVD is when the process is carried out with plasma-assisted growth. Because nothing is perfect in this world, all synthesis processes have some limitations depending on the final application of graphene. The mechanical exfoliation approach can produce monolayer to few-layer graphene, although the likelihood of creating a comparable structure using this method is low. Besides, thermal CVD technologies are better for large-area device production by substituting Si, and it is a promising method for future complementary metal-oxide-semiconductor technology. Chemical synthesis procedures are also lowtemperature processes that make it easier to synthesize graphene at room temperature on various substrates, notably polymeric substrates. Figure 2.2 shows all known types of graphene synthesis techniques.



Figure 2.2 A process flow chart of Graphene synthesis (Adeniji Adetayo and Damilola Runsewe,



2.2.1 Top-Down Graphene

Separation/exfoliation of graphite or graphite derivatives (such as graphite oxide (GO) and graphite fluoride) produces graphene or modified graphene sheets in a top-down process.

Method	Typical dimension		
	Thickness	Lateral	
Micromechanical exfoliation	Few layers	µm to cm	
Direct sonication of graphite	Single and multiple layers	µm or sub-µm	
Electrochemical exfoliation/functionalization of graphene	Single and few layers	500–700 nm	
Super acid dissolution of graphite	Mostly single layer	300–900 nm	
Bottom-Up Graphene		1	
کے ملبسیا ملاك	م سبح تکند	اونية	

Table 2.1 Top	o-down graphen	e process (Bhuy	an et al., 2016)
---------------	----------------	-----------------	------------------

The nature, average size, and thickness of the graphene sheets produced by different bottom-up methods are being summarized in the Table 2.2.

Method	Typical dimension		
	Thickness	Lateral	
Confined self-assembly	Single layer	100's nm	
CVD	Few layer	Very large (cm)	
Arc discharge	Single, bi and few layers	Few 100 nm to a few μ m	
Epitaxial growth on SiC	Few layers	Up to cm size	
Unzipping of carbon nanotubes	Multiple layers	few μ m long nano ribbons	
Reduction of CO	Multiple layers	Sub-µm	

Table 2.2 Concise history of bottom-up graphene (Bhuyan et al., 2016)

2.3 Magnesium Alloy

According to (Čížek et al., n.d.), magnesium alloys have been used in a wide range of applications because of their low density and excellent strength-to-weight ratio. Low inertia, which is a result of its low density, is advantageous in fast-moving parts, such as automotive wheels and other components. Manganese, aluminum, zinc, zirconium, and rare-earth metals are used in primary magnesium alloys to get the desired characteristics. Although manganese has little effect on tensile strength, it does increase the yield point marginally. It also causes a rise in resistance to the impact of seawater Manganese's solubility in magnesium limits the amount of manganese used in alloys. Die casting is a quick production method with a high degree of automation suited to certain magnesium alloys (Park and Kang, 2013)

MALAYSIA

Even though magnesium alloys meet the standards for low specific weight materials with outstanding machining and casting capabilities, they are rarely used in the die casting process to the same extent as aluminum. One of the reasons for this is that the effects of various forming factors on the die casting process are not well investigated from the standpoint of die design (Hussein and Northwood, 2014b). Most magnesium alloys have poor corrosion resistance because of magnesium's high chemical reactivity. Corrosion resistance is further weakened by impurities and any intermetallic compounds, including those that increase high-temperature mechanical qualities. Coatings have been the primary method for making more corrosion-resistant magnesium alloys.



Figure 2.3 Hot chamber die casting machine (Park and Kang, 2013).

2.3.1 Mechanical Properties of AM50

WALAYS/4

AM50 Mg alloy was often manufactured using high-pressure die casting (HPDC) for high flexibility applications. However, because of its extensive freezing range and low final solidification temperature, this alloy is prone to hot ripping and is challenging to cast. But by rheo diecasting (RDC) technique can successfully eliminate big gas pores and significantly reduce the number of hot cracks in AM50 alloy, resulting in a total porosity level well below 0.5% vol - percent (Ji et al., 2005a). Furthermore, the RDC process produces a unique microstructure. A controllable volume fraction of fine and spherical primary particles is uniformly distributed throughout the cast sample, eliminating unstandardized microstructural and common chemical segregation in traditional die casting. As a result, the RDC AM50 alloy has significantly better mechanical properties, particularly flexibility, when compared to the same alloy processed using HPDC and other semi-solid processing technologies.

Table 2.3: Physical properties of magnesium alloy			
S.No.	Material Property	Numerical Value	
1	Density (at 20 °C)	1.738 g/cm ³	
2	Melting Point	(650 ± 1) °C	
3	Boiling Point	اوييونۍ 1090 يېتي کيا	
4	Thermal Conductivity (at 27 °C)	$156 \text{ W} m^{-1} K^{-1}$	
5	Specific heat capacity (at 20 °C)	$1.025 \text{ kJ kg}^{-1} K^{-1}$	
6	Latent heat of fusion	$360 \text{ to } 377 \text{ kJ kg}^{-1}$	
7	Latent heat of vaporization	5150 to 5400 kJ kg^{-1}	
8	Latent heat of sublimation (at 25 °C)	6113 to 6238 kJ kg ^{-1}	
9	Heat of combustion	24.9 to 25.2 MJ kg^{-1}	
10	Linear coefficient of thermal expansion	$29.9 \times 10^{-6} \circ C^{-1}$	

Table 2.3: Physical properties of magnesium allow

Process	Alloy	Elongation, %	UTS, MPa	Yield stress, MPa
RDC	AM50	20. 5±1. 5	249±5	122±7
Thixocasting	AM50	20. 5±1. 5	200±3	108±6
Thixomolding	AM50	20	268.7	140
HPDC	AM50	12. 9±2. 1	241±7	128±9
HPDC	AM50	6. 7	194. 8	128.7
HPDC	AM50	6. 9	204	120
HPDC	AM60A	13	237.0	124. 7
HPDC	AM60	. 7	230	142
Thixomolding	AM60B	4–11	188.9–268. 7	112.0–146. 2
Thixomolding	AM60	18.8	278.2	150

Table 2.4 Comparison mechanical properties of AM series (Ji et al., 2005b)

2.3.2 AM50A Chemical Composition:



Table 2.5 Chemical composition of magnesium alloy AM50 UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Element	Content (%)
Mg	remainder
Al	4.7%-5.3%
Zn	0.20% Max
Mn	0.28%-0.50%
Si	0.05% Max
Fe	0.004% Max
Cu	0.008% Max
Ni	0.001% Max
Be	5-15ppm

2.3.3 Microstructure Characteristic of Magnesium Alloy

A metal's or single-phase alloy's grain size is a measurement of the average grain diameter, commonly stated in millimetres. The metal grows stronger (more resistant to plastic flow) as the average grain size drops, while the converse occurs as the grain size increases. In general, ductility rises with grain size whereas strength decreases for a given alloy and thickness. This happens because dislocations can only move a short distance when grains are tiny.

Temper Grain Size	Tensile Strength ksi	Yield Strength (0.5% Ext.) ksi	Elongation in 2.0 inches, %	
0.070 mm	46.0	14.0	65	
0.050 mm	47.0	15.0	62	
0.035 mm	49.0	17.0	57	
0.025 mm	51.0	19.0	54	
0.015 mm	53.0	22.0	50	
Eight Hard	50.0	35.0	43	
Quarter Hard	54.0	40.0	23	

Table 2.6 Annealed Tempers Mechanical Properties, Alloy C26000

UNIVERSITI TEKNIKAL MALAYSIA MELAKA The typical microstructure of AM50 alloy produced by the HPDC method is shown

in Figure 2.4 below. The α -Mg phase could be seen in the shape of massive dendritic segments. The microstructures of the die-cast samples were substantially separated from the edge to the center. Dendrite segments were abundant in the sample's center and depleted as they approached its surface. In the HPDC samples, there were several gas pores induced by gas entrapment and hot fractures caused by solidification shrinkage.



Figure 2.4 Typical microstructure of AM50 alloy produced by the HPDC process

2.3.4 Chemical Composition

Optical mass spectroscopy was used to determine the chemical composition of cast samples produced by the High-Pressure Die Casting (HPDC) and Rheo-die Casting (RDC) procedures. The chemical compositions of the RDC samples differed little from those of the alloy ingots, with the difference being well within the experimental error. Table 2.6 shows that harmful impurity elements including Fe, Cu, and Ni remained unchanged following the RDC process, indicating that the RDC procedure does not introduce any quantifiable contamination into the alloys during processing.

	Mg	Be	Al	Mn	Fe	Ni	Cu	Zn
Ingot	Balance	0.0008	4.749	0.411	< 0.002	< 0.005	0.047	0.047
HPDC	Balance	0.0008	4.603	0.377	< 0.002	< 0.005	0.051	0.051
RDC	Balance	0.0007	4.587	0.381	< 0.002	< 0.005	0.049	0.049

Table 2.7: Chemical compositions of AM50 alloy ingots

2.4 Rheocasting

The rheocasting (RDC) is a one-step SSM processing technique for producing near net form, high-integrity components directly from liquid magnesium alloys. According to (Ji, Zhen and Fan, 2005) these approaches adopts the twin-screw mechanism's well-known high shear dispersive mixing action to the task of creating SSM slurry (with fine, spherical solid particles) in situ, followed by direct shaping of the SSM slurry into a near-net-shape component utilizing the existing cold chamber HPDC process. A pair of screws rotate within a barrel in the twin-screw slurry producer. Co-rotating, fully intermeshing, and selfwiping profiles had been designed into the screws. The slurry maker's fluid flow was characterized by a high shear rate and turbulence intensity. Casting is a cost-effective liquid state processing method. On the other hand, solid-state techniques like forging or extrusion produce wrought components which are superior to castings, but manufacturing costs are significantly higher .

2.5 Stirring Speed and Time

Stirring speed and duration can influence the cast results' microstructure and mechanical strength. It is very crucial to control the stirring time and rate for getting the stability and mixability of the rheocasting. In the study of the effect of stirring current and stirring time on microstructure and mechanical properties in rheo die casting process by (Seo et al., 2006), hey investigated the impact of die filling velocity on semisolid diecasting of the A356 aluminium alloy. Because the laminar flow is significantly more stable at a low flow velocity, it had been discovered that a lower die filling velocity has an exemplary die filling character. Low filling velocity also reduced porosity shrinkage. They conclude that a non-dendritic structure can be created by combining quick heat extraction from the melt with a short stirring duration below liquidus temperature. Increasing the stirring time through the earliest solidification phases has little effect on the primary particle shape. As the stirring time is increased, the average size of the primary particles grows larger. However, it appears that the most significant effect on particle development occurs during the early phases of solidification when a higher concentration gradient in front of the solid-liquid interface creates more driving force for particle growth. Although

substantial differences in stirring speed have little effect on the average shape factor of primary particles, higher stirring speeds make primary particle shape and size more uniform. As the stirring speed increases, the agglomerates of primary particles become smaller and more rounded.

According to (Prabu et al., 2006) the higher stirring speeds resulted in smaller and more spherical primary particle agglomerates. The results of the two stability models imply that primary particles formed during the early stages of solidification can achieve growth stability before pouring and maintaining it during the second cooling stage. It was discovered that particle clustering occurred in some regions when the stir speed and time were reduced. And that some areas were detected without the presence of SiC. The homogenous distribution of SiC in the Al matrix was improved by increasing the stirring speed and stirring time. At 600 rpm and a 10-minute stirring duration, SiC distributions were better. The hardness of the composite is influenced by speed and time, according to the hardness test results. Compared to the as-cast condition, a higher stirring speed and time results in a higher hardness composite of MMC. The processing conditions of 600 rpm and 10 min stirring time resulted in a more rigid composite.

با ملاك	کل ملیسہ	i con	اوىيۇم سى	
Table 2.8 Results of distr	ribution of hardness	achieved in the ca	ast MMC at differe	ent processing
UNIVERS	condition (Pr	rabu et al., 2006)	IA MELAKA	

1.1 (

Stirring time (min)	Brinell hardness value (BHN)	Percentage of hardness distribution at different stirring speed on cast specimen			
		500 rpm	600 rpm	700 rpm	
5	Up to 80.6	45	10	55	
	80.7-100	30	50	25	
	101–107	25	40	20	
10	Up to 90	40	5	15	
	91-100	25	25	60	
	101–107	35	70	25	
15	Up to 90	10	5	30	
	91–100	60	40	55	
	101–107	30	55	15	

2.6 Cooling Rate Effect

A study from (Luo et al., 2018), the impact of cooling rate and Al–5Ti–1B on semisolid slurry microstructure and temperature field resulted in slow cooling rates being effective in lowering the slurry temperature gradient. When the cooling rate was reduced from 1.63 to 0.69 °C/min, the temperature difference between slurry center and edge decreased from 8.3 to 4.1 °C. However, a slower cooling rate resulted in coarser grain. Grain refiner changed the morphology and size of the grains. A trace amount of Al–5Ti– 1B significantly altered grain shape and size, and the uniformity of the slurry microstructure was found. The grain size was reduced from around 800 to 115 and 75 μ m when the Ti concentration was increased from 0.01 to 0.12 percent.

2.7 Mechanical Testing

Mechanical testing is the most essential step to determine the mechanical properties of any objects or designs. The information regarding the properties of the object or design would determine if they were suitable to be a final product in specific used without causing any defections or failure until specific times. Through mechanical testing, engineers can build a cost effective and optimum potential efficiency of designs. Typical mechanical testing that available are tensile testing, hardness testing, fatigue testing, hardness testing, fatigue testing, wear testing etc.



One of the most crucial is surface hardness, which indicates a material's resistance to penetration and has lately been connected to the film's useful life, particularly in regard to delamination(Libório et al., 2017). There are generally multiple types of mechanical tests that can be used to assess a mechanical feature. The methods for determining hardness are an example of this. To determine the hardness of a material, Vickers, Brinell, and Rockwell hardness tests can all be employed. A Charpy V-notch test or an Izod test can be performed to determine the toughness of a material. Because mechanical testing methods used to evaluate the same material quality varied slightly, study should be conducted to discover which form of mechanical testing is optimal for the application under consideration.




CHAPTER 3 METHODOLOGY

This chapter will focus on the flow of the experiment and the steps of procedures that show essential steps to attain the specified research goals. To fulfil and complete the research objective, the principle of the method was included in the methodology. The methods chapter will also include raw materials, characterization, experimental procedures for sample preparation, and sample analysis as a primary topic. Standard Operation Procedure (SOP) had been used to study the testing and analysis that were linked to the title of the research, whereas American Society for Testing and Materials (ASTM) standards were used to learn about the testing and analysis that were relevant to the title of research.

اونيۇم سيتى تيكنيكل مليسيا ملاك

3.1 Overview of Methodology KNIKAL MALAYSIA MELAKA

There were two different critical stages that would be emphasized in the methodological procedures to comply with all objectives as stated in Chapter 1. The overall experimental flow of this research was summarized as in the following Figure 3.1. Several tests were being conducted for characterization analysis, including morphological analysis and mechanical testing analysis. The morphological analysis has been performed under the Optical Microscope (SEM) and Scanning Electron Microscopy (SEM). For mechanical tests analysis, there were consisted tensile test and hardness test using Universal Testing Machine (UTM) and Vickers Hardness Test (VHS). The research will be done according to the parameters set before. Finally, the results and observations collected from all experimental tests would be assessed before making a final decision.

3.2 Methodology Flow Chart



Figure 3.1 Methodology flow chart

3.3 Design of Experiment

The Taguchi method of quality control is an approach to engineering that emphasizes the roles of research and development (R & R&D) in lowering the occurrence of faults and failures in manufactured goods and product design and development. It is used to determine the stirring speed and stirring time parameters. The Taguchi is designed with two factorials with four levels. There will be a total of 16 runs of the experiment. After conducting the mechanical testing and microstructure analysis, the optimization of the experiment parameters can be determined.

Table 3.1 The conditions of parameters

Input Parameter	Level 1	Level 2	Level 3	Level 4
Graphene Content (wt%)	0.10	0.25	0.50	0.6
Stirring Time (min)	1	2	4	8
THE REAL PROPERTY LEVEL	L		8	M
		MALAY	مىيى SIA M	ويبوم ملام

-	No. Pup	Graphene	Stirring Time	
-	1			
	1	0.10	1	
	2	0.10	2	
	3	0.10	4	
	4	0.10	0	
	5	0.25	1	
	0	0.25	2	
	/ 0	0.25	4	
	0	0.25	0	
	9	0.50	1	
	10	0.50	2	
	11	0.50	4	
	12	0.50	0	
	13	0.00	1	
MALAY	S/4 15%	0.60	4	
23	16	0.60	- 8	
-	10	0.00	0	
=				
F Ta	ble 3.1 Des	ign summary	of Taguchi Meth	od
* SAIND		Design Sum	mary	
det (+ +		innar y	
سا ملاك	Taguch	i Array	L16(4^2)	اوىيۇم,
48	Factors	-	2	0
UNIVERS	Runs:	NIKAL N	ALAYSI6	IELAKA
	Colum	ns of L16(4'	5) array: 1 2	

Table 3.2 L₁₆ Orthogonal array

3.4 Material and Equipment Preparation

Magnesium alloy AM50 and graphene nanoplatelets will be prepared before the rheocasting process. The chosen magnesium alloy AM50 and graphene nanoplatelets GNPs are based on the project's scope. Furthermore, the availability of these materials is broad, and they are easy to get in Malaysia.

3.4.1 Magnesium Alloy AM50

Raw magnesium alloy AM50 ingot had been cut to smaller pieces using a band saw machine, wearing proper PPE and following the SOP. Later, they were packed in sealed plastics for precisely 200 grams for 16 batches using digital scaling.



Figure 3.2 Magnesium alloy AM50 ingots

3.5 Preparation of graphene nanoplatelets (GNPs)

Graphene nanoplatelets had been weighting accurately using analytical balances for four varieties of contents. They were 0.1wt%, 0.25wt%,0.5wt% and 0.6wt%. Each of the content had four packets according to the given parameters. The substance had been handled with proper PPE and safely stored when not used. Proper labelling of each content was essential to avoid being careless during the rheocasting process.



Figure 3.3 Graphene nanoplatelets particles

During the casting process, graphene nanoplatelets were taken out from the plastic and then wrapped into aluminium foil to be mixed with the molten slurry without difficulty. The wrap of aluminium foil will quickly melt in the magnesium molten and would not give any effect as the quantity of the foil are just too tiny, and any effect from it can be neglected. For better casting experiences, the wrapped graphene nanoplatelets were going through preheating on the top of the crucible. The preheat was done to ensure that it would not attach to the mould wall because of the vast difference in temperature between the aluminium wall and inside the crucible.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA



Figure 3.4 Graphene nanoplatelets particles

3.6 Fabrication of AM50/GNPs composite

Rheocasting will be used to make the AM50/GNPs composites. First, 200g of AM50 alloy and calcium granular will be melted in a VT Portable Melting Furnace 1100°C type. The magnesium alloy will be cooled to 660°C in the semi-solid state. The GNPs were then quickly incorporated into the molten matrix alloy. A mechanical stirrer WiseStir HT120AX will be used to stir the molten slurry at a constant speed (VS) of 450 rpm during the temperature drop to 650 °C. After specific minutes of a semi-solid stirring base on the different duration parameters, the casting mould was prepared to pour the molten. The experiment was repeated numerous times with varying amounts of graphene contents and stirring duration to study the impact of GNPs on the microstructure characterization and mechanical properties of AM50 alloy.



Figure 3.6 Wisestir HT120AX



Figure 3.7 Preparation of Cylindrical Stainless-Steel Mould



Figure 3.8 Result of Casting

3.7 Microstructure characterization.

The optical microscopy (OM model: Olympus-GX51) and scanning electron microscopy (SEM model: Zeiss EVO LS15 SEM) are used to evaluate the microstructural characterization. The microstructural characterization of graphene reinforced magnesium alloy was supported by X-Ray Diffraction analysis to show the chemical composition of the casting. Microstructure characterizations were investigated in both the transverse and longitudinal directions for cast and extruded samples. In the transverse direction, phase analysis of extruded samples was done. Microstructural Image Processing (MIP)

determined the average grain size and volume fraction of the β eutectic phase, and precipitates were determined using Microstructural Image Processing (MIP). The fundamental strong particles' volume, size, and sphericity will be estimated multiple times on a similar space of 2×2mm² for every sample using an optical and scanning electron magnifying lens.

3.8 Material Testing Preparation

The feedstocks were cut into three sections based on the different testing used. The testing involved is microstructural analysis, hardness testing, and tensile testing. For hardness and microstructure analysis, the feedstocks were cut 6 mm on both sides of the feedstock using a band saw machine. Then, the sample had to undergo a grinding process of different sizes, which are 200,400,600,800 and 1200 grit. The sample for the hardness test had been ready to be tested. For microstructural analysis, extra steps are required to finish the testing conditions. It will be polished using DIAMANT PC Polycrystalline Suspension from 6 microns to 1 micron. The surface will become apparent as a mirror and should not be touched to avoid fingerprints on the feedstock. After that, the etching process was applied to the samples using etchant (Keller's reagent) for 10 seconds to eliminate the impurities and clear the surface's contamination. Lastly, the samples need to be bathed using an ultrasonic bath to be shaken up the dirt on the surfaces. The samples are now ready for microstructural analysis.



Figure 3.9 Etched samples before testing

3.9 Hardness Test

The hardness test was measured by a Vickers hardness tester provided in the Faculty of Mechanical Engineering on polished samples. It is one of the methods used to study the mechanical properties of the rheocast graphene reinforced AM50 magnesium compounds according to the ASTM: E92 standard. A pyramid-shaped indenter with an applied load of 2kg will be pressed for 10 seconds. A pyramid-shaped indentation will be displayed using the microscope. The depth of indentation caused by the indenter is measured in the depth measurement methods. For each sample, an average of five measurements at different locations are reported.



Figure 3.10 Hardness Testing on the Samples

3.10 Tensile Test

Tensile testing is destructive and provides information on a material's strength and flexibility when subjected to uniaxial pliable stresses. The tensile specimens will be machined to ASTM E8 specifications using EDM wire cut and CNC turning to get the dog

bone shapes, as shown in Figure 3.11. The specimen will be measured and recorded to determine the minor point's cross-sectional region. Place gauge flaws at the correct gauge length on the test tests. The percent extension at the limit is determined by the gap between the gauge marks after the example is broken. The gauge lengths should be around the same. The 6mm specimen will be inserted first into the grips. The test will be carried out until the specimen breaks or fails. The specimen will be removed, and the operation will be repeated with the 12mm, with all different processing properties.



34



Figure 3.12 Universal Testing Machine (UTM)



Figure 3.13 Dog bone Shape

CHAPTER 4 RESULTS AND DISCUSSIONS

This chapter includes the results and discussions based on the microstructure and mechanical testing obtained on the graphene-reinforced magnesium alloy through the rheocasting process. Optical Microscope and Scanning Electron Microscopy were used for the microstructure analysis. Then, it was supported by X-ray Diffraction Analysis to identify the compound present in the microstructures. Lastly, mechanical testing used were tensile and hardness testing using Vickers Hardness Test and Universal Testing Machine. This chapter exposed the result of 16 samples of graphene reinforced magnesium alloy that had been gone through the material characterization and mechanical properties.

اونيۈم سيتى تيكنيكل مليسيا ملاك UNIVERSITI TEKNIKAL MALAYSIA MELAKA

4.1 Microstructure Analysis

4.1.1 Optical Microscopy Analysis



Figure 4.1 Optical Micrograph of sample 4, 8, and 12 and 16 of Magnesium AM50 after Rheocasting under $\times 100 \mu m$ magnification

The microstructure of Mg AM50-GNPs composites with different parameters is shown in Figure 13 above. The most prolonged stirring duration (8 minutes) was chosen for each variety of the graphene contents because, according to Raei et al., 2016). The microstructures revealed that a longer stirring time would result in higher reinforcement content in the as-cast microstructure. To prove the statement, each sample with various graphene content was analysed with 0.1wt%, 0.25%, 0.5wt% and 0.6wt% with the same stirring speed and duration. All the samples show that while the dispersion of alloy elements near the eutectic phase is segregated, it is almost uniform in the matrix grains. As seen in Figure 4.1, the grains of the as-cast Mg AM50 alloy typically consist of semicoarse dendrites surrounded by finer ones. The microstructures of the as-cast composites exhibit large, semi-globular grains encircled by smaller ones. The particulars of semi-solid casting influence the presence of coarse grains close to fine ones. In the crucible, coarse α -Mg grains are created at the beginning of the solidification process, where they have time to grow. More refined α -Mg grains are produced in the cavity of the mould. Adding GNPs significantly changes how the α -Mg grains look. The larger α -Mag becomes, it indicates that the dendritic type of microstructure had been turned into the rosette type microstructure. The microstructure becomes closely packed, less gaps between boundaries, and the presence of porosity will be reduced. This will enhance the mechanical properties of magnesium alloy. From Figure 4.1, we can see that sample 8 had the biggest α -Mg compared to the others, while the graphene had been distributed uniformly all over the microstructure in the red circles.

4.1.3 Scanning Electron Microscopy Analysis ALAYSIA MELAKA



Figure 4.2 SEM Results



Figure 4.3 SEM results



Figure 4.4 SEM results



Figure 4.5 SEM results

Three samples of AM50 with various GNP contents had been characterized using high magnification FE-SEM. Five intermetallic phase had been identified using FE-SEM. They are α -Mg, β (Mg₁₇Al₁₂), β (Mg₁₇Al₁₂) + α Mg, Al-Mn, and Al₈Mn₅. The images seem the presence of some element in Mg-matrix which are Mg, Si, Cu, Al and Fe, they can be distinguished from one another by the morphology of the Mg₁₇Al₁₂ (β -eutectic) phase in micrographs shown in Figure 4.2, 4.3, 4.4, and 4.5. Both composites show both fully and partially divorced morphologies, and the Mg₁₇Al₁₂ phase in the AM50 alloy exhibits divorced eutectic morphology. The well blend of β -(Mg₁₇Al₁₂) + α -Mg into α Mg increase the mechanical properties of the casting and the presence of some agglomerated GNPs in the AM50 were circled in the red. It happened due to lower deformation heat as more content of GNPs with high thermal penetration leads to the further decrease of temperature. The amount of Mg₁₇Al₁₂ phase is reduced after GNPs addition according to (Torabi Parizi et al., 2019).

4.2 X-Ray Diffraction (XRD)



The Figure 4.6 shows the XRD pattern of Mg-GNPs from one of the rheocasting samples. XRD is used to support and confirming the presence of intermetallic phase at the Scanning Electron Microscopy by observing the intensity and degree of crystallinity of the phases. The results indicate that α -Mg is major compound found in the casting due to dissolution of Mg₁₇Al₁₂ in α -Mg. Besides, no diffraction peaks for GNPs were detected in the final composite due to the low content of GNPs. Furthermore, absence of peaks of the interfacial product proved that AM50 would not react with GNPs. The intensity of MgO peaks after casting process is high because of the high temperature used during melting process.

4.3 Mechanical Testing

4.3.1 Hardness Testing

The result data of the Vickers Hardness Test for all 16 samples of the composites Mg-GNPs had been tabled below. The hardness measurement had been taken and the average of the data had been calculated to get the most accurate results.

_			Hardn	ess, HV		
Run no	1	2	3	4	5	Average
1	84.32	83.82	82.23	83.96	82.33	83.33
2	83.78	84.54	83.10	83.99	82.97	83.68
3	86.60	86.23	86.43	85.91	85.70	86.17
4	86.57	85.49	86.90	86.69	87.11	86.55
5	98.34	98.30	97.89	97.40	97.83	97.95
6	104.40	104.60	103.91	104.52	103.82	104.25
7	115.00	114.86	114.79	115.16	114.82	114.93
8 🖄	116.30	115.86	116.30	115.79	116.22	116.09
9	78.30	77.65	78.35	78.27	78.30	78.17
10 UN	77.95	78.12	78.19	78.64	77.98	78.18
11	79.12	79.19	79.21	78.93	79.03	79.10
12	81.20	80.98	80.61	80.80	80.90	80.90
13	80.71	80.76	80.71	80.68	80.72	80.72
14	87.70	87.72	86.79	86.81	87.59	87.32
15	89.40	89.42	89.41	89.27	88.98	89.30
16	90.43	89.92	91.20	91.18	89.85	90.52

Table 4.1 Vickers Hardness Testing Results



Figure 4.7 Mean of hardness testing results

The average of the hardness testing value had been plotted in the bar graph in Figure 4.7 to visualize the data outcome. The lowest value of hardness obtained from sample 9. In meanwhile, the highest value of hardness obtained among of the 16 is 116.09 HV which is sample 8 with the parameter of 0.25wt GNPs and composites stirring time of 8 minutes. Then, followed by sample 7 and 6 with the hardness value of 114.93 HV and 104.25 HV. These results show an enormous change in mechanical properties in term of hardness as the hardness of raw Mg AM50 is just 60 HV which means that it increases 93.5% of hardness. The huge difference of the hardness value is caused by the difference parameter used during rheocast. The microstructure characterizations from SEM and OM had explained the main reasons that influent the hardness of the composites. In OM, the fragmentation of the dendrites arms in the microstructure evolved to rosette type after being perfectly distribute during stirring process under the optimum parameter. The growing of globular microstructure makes them become closely pack between boundaries and prevent porosity from occurring. In SEM well blend of β -(Mg₁₇Al₁₂) + α -Mg into α Mg increase the mechanical properties of the casting.

4.3.2 Tensile Testing Analysis

The result from Ultimate Testing Machine (UTM) for the dog-bone shape of Mg-GNPs composite had been recorded in the table below. Each of the results used different parameter during casting process and were taken twice for three categories which are yield strength, ultimate tensile strength and strain. Then, the average had been calculated as shown in Table 4.2.

					Tensile				
Run no		YS			UTS			Strain	
	1	2	Avg	1	2	Avg	1	2	Avg
1	99.81	101.38	100.60	236.11	238.57	237.34	5.97	6.36	6.17
2	102.32	103.20	102.76	237.45	238.10	237.78	6.97	7.35	7.16
3	114.36	113.50	113.93	240.11	240.51	240.31	9.54	9.10	9.32
4	117.33	118.01	117.67	240.56	240.63	240.60	11.36	10.78	11.07
5	125.91	125.36	125.64	256.36	256.87	256.62	18.36	18.97	18.67
6	138.27	140.30	139.29	260.75	260.88	260.82	21.36	20.90	21.13
7	142.84	141.08	141.96	264.81	263.70	264.26	23.00	22.14	22.57
8	145.12	145.31	145.22	265.23	266.38	265.81	23.45	22.65	23.05
9	75.63	76.00	75.82	230.59	230.49	230.54	3.03	3.52	3.28
10	76.89	77.31	77.10	230.99	231.17	231.08	3.65	3.85	3.75
11	77.36	77.84	77.60	231.78	232.45	232.12	3.79	3.95	3.87
12	112.39	112.72	112.56	239.28	239.77	239.53	8.44	8.31	8.38
13	98.30	97.36	97.83	235.78	235.14	235.46	4.85	4.72	4.79
14	97.94	98.81	98.38	236.78	236.84	236.81	5.54	5.61	5.58
15	120.33	121.40	120.87	241.50	242.16	241.83	13.54	12.95	13.25
16	123.67	123.74	123.71	243.68	242.59	243.14	16.57	17.10	16.84

Table 4.2 Ultimate Testing Machine results.



Figure 4.9 Average of Ultimate Tensile Strength



Figure 4.10 Elongation to Break

Figure 4.8, Figure 4.9, and Figure 4.10 visualize bar chart of Ultimate Testing Machines for all the 16 samples that had been done. According to research paper by (Peng et al., 2007), raw magnesium alloy AM50 has the value of 228 MPa in Ultimate Tensile strength, 124 MPa in Yield Strength and 15% of elongation. The journal had been set as benchmark for this study. According to the Figure 20, the highest Yield Strength (YS) achieved among the samples is sample 8 with the value of 145.22 MPa. Then followed by sample 7 and sample 6 with the value of 141.08 and 140.30. Yield strength can be defined as an indication of maximum stress that can be developed in a material without causing plastic deformation according to (Bancroft et al., n.d.). It had shown that the optimum parameters to get the highest results is by using graphene content of 0.25wt% with stirring duration of 8 minutes. It had been known that the Yield Strength, Ultimate Tensile Strength and the Elongation toward fracture should be corresponding to each other according to (Marsavina et al., 2019). So, the UTS and elongation toward fracture for sample 8 had been proven to have the highest value among the others. The UTS value shown is 265.81 MPa and the longest elongation is 23.05%. The YS increased from 124 MPa to 145.22 MPa. Then, UTS increased from 228 MPa to 265.81 MPa. Lastly, the elongation to fracture increased from 15% to 23.05%.

4.4 Design of Experiment (DOE) Analysis

The Design of Experiment (DOE) used for this experiment was Taguchi Method to investigate the most influent parameters toward the mechanical properties of the Mg-GNPs composites in order to achieved. Two parameters had been set which were the graphene contents and the stirring time. The experiments had been tested for all 16 samples to get the optimum graph results.

4.4.1 Hardness Testing Analysis

Implying Taguchi method to analyse the data will summarize the effectiveness of the given parameters on the hardness of the composite Mg-GNPs by using line graphs. The details of on the main parameter influent the hardness indicates the highest point of the graph.



Figure 4.11 Main Effect Plot for Means of Hardness Versus Graphene wt% and Stirring Time

Figure 4.11 shows that the quantity of graphene content influent the most parameter to get highest hardness value for the composites. But the graph plot was start fluctuated at 0.5 wt% till 0.6 wt%. This may happen because of to much graphene content affect the

standardization of the whole process. For examples, the molten slurry become saturated with graphene and then the stirring process give bad influence on the microstructure distribution. Based on the experiment that had been done, the temperature of the molten slurry during stirring are hard to control when more and more GNPs were put into it. According to the journal by (Senapati et al., 2020), the different casting temperature would influent the microstructure distribution. For stirring time, the result illustrates that increasing stirring time give corresponding slightly increasing hardness of the composites.



Figure 4.12 Hardness Versus Graphene wt%, Stirring time

Regression Ed	quation	1				
Hardness = 9	92.46 - 18	.8 Grapher	ne wt% + 1.	.11 Stirring	Time	
Coefficients						
Term	Coef	SE Coef	T-Value	P-Value	VIF	
Constant	92.46	7.57	12.22	0.000		
Graphene wt%	-18.8	15.2	-1.24	0.238	1.00	
C	1.11	1.12	0.99	0.340	1.00	
Stirring lime						

Figure 4.13 Regression Analysis of Hardness

4.4.2 Tensile Analysis

Taguchi analysis had been implemented to identify the most influence factor that bring up the mechanical properties of Mg-GNPs using line graphs. The details of the main parameter influent the tensile strength.



Figure 4.14 shows that the quantity of graphene content influent the most parameter to get highest hardness value for the composites. But the graph plot was start fluctuated at 0.5 wt% till 0.6 wt%. The reasons are still same with the problem faced in the hardness plot graph in which the unstandardized casting temperature would affect the mechanical properties of the composites. For stirring duration, the higher the duration, the tensile properties increased steadily.

guch	i Analysis: Te	ensile St	rength versus Graphene wt%, Stirring Time
Respo	nse Table for S	ignal to	Noise Ratios
Nomina	al is best (10×Log1	10(Ybar^2/	5^2))
Level	Graphene wt%	Stirring Time	
1	*	*	
2	*	*	
3	*	*	
4	*	*	
Delta	*	*	
Rank	1.5	1.5	
Respo Level	nse Table for N Graphene wt%	Aeans Stirring Time	
1	239.0	240.0	
2	261.9	241.6	
3	233.3	244.6	
4	239.3	247.3	
Delta	28.6	7.3	
		-	

Figure 4.15 Taguchi Analysis for Tensile Strength versus Graphene wt%, Stirring Time

.7

Regression Equation Tensile Strength = 247.15 - 20.9 Graphene wt% + 1.02 Stirring Time Coefficients Coefficients Term 247.15 Tilde Al.67 Ondot Ondot Graphene wt% P-Value Yeight 1.43 Yeight 1.06 Olde 0.354 Model Summary S S R-sg (adi) R-	eg <mark>r</mark> ession A	nalysis: Tensile Strength versus Graphene wt%, Stirring Time
Regression Equation Tensile Strength = 247.15 - 20.9 Graphene wt% + 1.02 Stirring Time Coefficients Term Coefficients Constant 247.15 7.13 34.67 0.000 Graphene wt% R-20.91 14.3 K 1-1.46 A0.168 1.00 LAY SIA MELAKA Stirring Time 1.02 1.06 0.96 0.354 1.00	Eq	
Tensile Strength = 247.15 - 20.9 Graphene wt% + 1.02 Stirring Time Coefficients	Regression E	Juation
Coefficients Coefficients <thcoefficients< th=""> Coefficients <thc< td=""><td>Tensile Strength</td><td>= 247.15 - 20.9 Graphene wt% + 1.02 Stirring Time</td></thc<></thcoefficients<>	Tensile Strength	= 247.15 - 20.9 Graphene wt% + 1.02 Stirring Time
Constant 247.15 7.13 34.67 0.000 Graphene wt% R 20.9 14.3 K 1.46 A0.168 1.00 LAYSIA MELAKA Stirring Time 1.02 1.06 0.96 0.354 1.00 Model Summary S R-sg R-sg(adj) R-sg(pred)	Coefficients	Lunda Gi Gi in a sinal
Graphene wt% -20.9 14.3 -1.46 O.168 1.00 LAY STA MELAKA Stirring Time 1.02 1.06 0.96 0.354 1.00 Model Summary S R-sg (adj) R-sg(pred)	Term	Coef SE Coef T-Value P-Value VIF
Stirring Time 1.02 1.06 0.96 0.354 1.00 Model Summary S R-sg R-sg(adj) R-sg(pred)	Term Constant	Coef SE Coef T-Value P-Value VIF 247.15 7.13 34.67 0.000
Model Summary S R-sq R-sq(adj) R-sq(pred)	Term Constant Graphene wt%	Coef SE Coef T-Value P-Value VIF 247.15 7.13 34.67 0.000 R 20.971 14.3 K 1.46 A0.168 1.00 LAYSIA MELAKA
S R-sq R-sq(adj) R-sq(pred)	Term Constant Graphene wt% Stirring Time	Coef SE Coef T-Value P-Value VIF 247.15 7.13 34.67 0.000 R 20.97 14.3 K-1.46 0.168 1.00 LAYSIA MELAKA 1.02 1.06 0.96 0.354 1.00 1.00 1.00
S R-sq R-sq(adj) R-sq(pred)	Term Constant Graphene wt% Stirring Time	Coef SE Coef T-Value P-Value VIF 247.15 7.13 34.67 0.000 R-20.91 14.3 1.46 0.168 1.00 LAYSIA MELAKA 1.02 1.06 0.96 0.354 1.00
	Term Constant Graphene wt% Stirring Time Model Summ	Coef SE Coef T-Value P-Value VIF 247.15 7.13 34.67 0.000 R 20.91 14.3 K-1.46 A0.168 1.00 LAYSIA MELAKA 1.02 1.06 0.96 0.354 1.00 Arrow Arrow

Figure 4.16 Regression Analysis of Tensile Strength Versus Graphene wt%, stirring time

Figure 4.15 and Figure 4.16 show the raw data of regression analysis to plot the line graph of tensile strength for the Mg-GNPs composites corresponding to the processing parameters of graphene content and stirring time. By using these methods, the most impact factor between graphene content and stirring time can be known theoretically using regression formula as above.

CHAPTER 5 CONCLUSION AND RECOMMENDATION

This chapter will conclude all the results obtained from this experiment work within the objectives and scopes. It also includes other elements like recommendations, sustainability development and lifelong learning for future works.

5.1 Conclusion

To summarize this project, all the objectives have been achieved, which are to evaluate the microstructural evaluation during semisolid metal processing, to investigate the effect of the GNPs content on the mechanical properties of AM50 magnesium alloy, and to study the suitable parameter for mechanical stirring duration of the rheocasting process.

- 1. The microstructure discovered on the Mg AM50 sample combined with graphene was a rosette particle type, which is closely packed, has a smaller gap between boundaries, and results in less porosity.
- Uniform distribution of Mg-GNPs composites during stirring can enhance the mechanical properties of the samples. It has been proven based on the result of tensile and hardness testing.
- The Ultimate Tensile Strength of sample 8 indicates the highest value of 265.81 MPa, highest Yield Strength 145MPa, elongation to fracture, which is 23.05% and hardness of 116.09 HV

- Therefore, the optimum parameter is sample 8, which got the highest hardness and mechanical properties by using 0.25 wt% graphene with a stirring duration of 8 minutes.
- 5. All objectives of the study above were achieved based on the results above. From the microstructure study, had been proved that content wt% of Graphene Nano Platelets and stirring duration have a huge impact on the mechanical properties of the casting.

5.2 **Recommendation**

After experiencing the research, some suggestions can be made for promising future research in approaching works regarding graphene reinforcement on magnesium alloy. The suggestions are:

- 1. Increasing stirring duration will resulting better microstructure distribution and increased mechanical properties of the graphene reinforced magnesium alloy.
- 2. Higher GNPs content must use a longer stirring time for better microstructural distribution.
- Study the effect of using high wt% of graphene nanoplatelets on magnesium alloy AM50 with the variable of stirring speed and duration.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

5.3 Sustainability Development

For sustainability development regarding magnesium alloy, the scrap can be sold and downgraded for recycling in other sectors, such as steel desulphurization, to reduce the usage demand for the magnesium alloy. A remelting process on the magnesium chips from machining of die castings, considering that, due to high magnesium susceptibility to oxidize and fine forms of chips, chips remelting could produce further dross quantity. Lastly, internal or external recycling of the scraps is made possible by a closed-loop recycling system, which can cut the need for primary raw materials by up to 50% when casting automotive parts and up to 85% when making electronic die-cast products. The number of recycled scraps and optimization of the recycling ratio should take into account several factors, including the amount of material lost during the melting cycle, the variety of components that are cast, the percentage of cast parts that have been rejected during production, the final quality of process scrap, and the efficiency of the recycling operation.

5.4 Complexity

In this research, some problems have been faced regarding the rheocasting process. Firstly, the research of this thesis was implemented during the MCO due to the pandemic Covid-19. So, the laboratory had to close for several days after receiving an infected user for sanitization procedures. Then, GNPs are identified as a highly dangerous substance that can cause cancer if exposed to skin or breath. It needs to be handled carefully for the whole casting process. Personal Protective Equipment plays a vital role in ensuring the safety of the users. Lastly, the stirring temperatures were hard to maintain at 650 degrees Celsius because the stirring process can only be done in the open air, where the temperatures will drop rapidly once exposed to the atmosphere.

5.5 Life-Long Learning | TEKNIKAL MALAYSIA MELAKA

By conducting this research, a student can learn some value of humanity. Firstly, do not be afraid to ask or give opinions regarding knowledge. Some people have so many experiences that can be shared with others, making the whole process go smoothly. Then, material and apparatus must always be clean after use. For example, graphene is a highly dangerous substance that the air can easily lift because of the nanosized particles. The effects of graphene on living things can cause fatality when it touches or enters the respiratory system. So always be aware of its presence by wearing personal protective equipment like a particles filter mask, gloves and lab coat. Besides, always ensure nobody without PPE comes closer to the experimental place until the cleaning process has been done. Lastly, a student should always have a natural drive to explore the utilities and machines that have been provided at UTeM. For example, programming, hand skills, material testing, and even soft skills. These are very important to growth in education for future demand.



REFERENCES

- Ameen, S., Godbole, R., Akhtar, M.S., Shin, H.-S., 2020. An Introduction to Graphene Materials, in: Graphene Production and Application. IntechOpen. https://doi.org/10.5772/intechopen.90407
- Arribas, C., Prolongo, M.G., Sánchez-Cabezudo, M., Moriche, R., Prolongo, S.G., 2019.
 Hydrothermal ageing of graphene/carbon nanotubes/epoxy hybrid nanocomposites.
 Polymer Degradation and Stability 170.
 https://doi.org/10.1016/j.polymdegradstab.2019.109003
- Baltzer, N., Copponnex, T., 2014. Properties and processing of precious metal alloys for biomedical applications, in: Precious Metals for Biomedical Applications. Elsevier Ltd, pp. 3–36. https://doi.org/10.1533/9780857099051.1.3
- Bancroft, C.L., Caceres, C.H., Griffiths, J.R., n.d. ON THE RELATION BETWEEN HARDNESS AND YIELD STRENGTH IN A SAND CAST AZ91 ALLOY.
- Bhuyan, Md.S.A., Uddin, Md.N., Islam, Md.M., Bipasha, F.A., Hossain, S.S., 2016. Synthesis of graphene. International Nano Letters 6, 65–83. https://doi.org/10.1007/s40089-015-0176-1
- Čížek, L., Greger, M., Dobrzański, L.A., Juřička, I., Kocich, R., Pawlica, L., Tański, T., n.d. Mechanical properties of magnesium alloy AZ91 at elevated temperatures.
- Du, H., Pang, S.D., 2015. Enhancement of barrier properties of cement mortar with graphene nanoplatelet. Cement and Concrete Research 76, 10–19. https://doi.org/10.1016/j.cemconres.2015.05.007
- Farhat, H., 2021. Materials and coating technologies. Operation, Maintenance, and Repair of Land-Based Gas Turbines 63–87. https://doi.org/10.1016/B978-0-12-821834-1.00007-1

- Fatima, S., Ali, S.I., Iqbal, M.Z., Rizwan, S., 2017. The high photocatalytic activity and reduced band gap energy of la and Mn co-doped BiFeO3/graphene nanoplatelet (GNP) nanohybrids. RSC Advances 7, 35928–35937. https://doi.org/10.1039/c7ra04281g
- Hussein, R.O., Northwood, D.O., 2014a. Improving the performance of magnesium alloys for automotive applications, in: WIT Transactions on the Built Environment. WITPress, pp. 531–544. https://doi.org/10.2495/HPSM140491
- Hussein, R.O., Northwood, D.O., 2014b. Improving the performance of magnesium alloys for automotive applications, in: WIT Transactions on the Built Environment. WITPress, pp. 531–544. https://doi.org/10.2495/HPSM140491
- Ji, S., Zhen, Z., Fan, Z., 2005a. Effects of rheo-die casting process on the microstructure and mechanical properties of AM50 magnesium alloy. Materials Science and Technology 21, 1019–1024. https://doi.org/10.1179/174328405X51820
- Ji, S., Zhen, Z., Fan, Z., 2005b. Effects of rheo-die casting process on the microstructure and mechanical properties of AM50 magnesium alloy. Materials Science and Technology 21, 1019–1024. https://doi.org/10.1179/174328405X51820
- Jiménez-Suárez, A., Prolongo, S.G., 2020. Graphene nanoplatelets. Applied Sciences (Switzerland). https://doi.org/10.3390/app10051753

0.0

- Libório, M.S., da Silva Dias, A.M., Souza, R.M., 2017. Determination of film thickness through simulation of vickers hardness testing. Materials Research 20, 755–760. https://doi.org/10.1590/1980-5373-MR-2015-0783
- Luo, M., Li, D., Qu, W., Liang, X., Fan, J., 2018. Effects of cooling rate and grain refiner on semi-solid rheocasting slurries of Al–Zn–Mg alloy, in: Lecture Notes in Mechanical Engineering. Pleiades Publishing, pp. 829–837. https://doi.org/10.1007/978-981-13-0107-0_81
- Mahmoud, G.M., Hegazy, R.S., 2017. Comparison of GUM and Monte Carlo methods for the uncertainty estimation in hardness measurements. International Journal of Metrology and Quality Engineering 8. https://doi.org/10.1051/ijmqe/2017014
- Marsavina, L., Iacoviello, F., Dan Pirvulescu, L., di Cocco, V., Rusu, L., 2019. Engineering prediction of fatigue strength for AM50 magnesium alloys. International Journal of Fatigue 127, 10–15. https://doi.org/10.1016/j.ijfatigue.2019.05.028

- Moosa, A., Ramazani, A.S., Nabil Ibrahim, M., Moosa, A.A., Ramazani A, A.S., 2016. Mechanical and Electrical Properties of Graphene Nanoplates and Carbon-Nanotubes Hybrid Epoxy Nanocomposites. https://doi.org/10.5923/j.materials.20160606.03
- Park, J., Kang, C., 2013. Microstructure and mechanical properties of AM50 alloy according to thickness and forming condition of the products by a high pressure diecasting process. Journal of Mechanical Science and Technology 27, 2955–2960. https://doi.org/10.1007/s12206-013-0809-0
- Peng, L.M., Fu, P.H., Jiang, H.Y., Zhai, C.Q., 2007. Microstructure and Mechanical Properties of Low Pressure Die Cast AM50 Magnesium Alloy. Materials Science Forum 546–549, 167–170. https://doi.org/10.4028/www.scientific.net/msf.546-549.167
- Prabu, S.B., Karunamoorthy, L., Kathiresan, S., Mohan, B., 2006. Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite. Journal of Materials Processing Technology 171, 268–273. https://doi.org/10.1016/j.jmatprotec.2005.06.071
- Raei, M., Panjepour, M., Meratian, M., 2016. Effect of stirring speed and time on microstructure and mechanical properties of Cast Al–Ti–Zr–B4C composite produced by stir casting. Russian Journal of Non-Ferrous Metals 57. https://doi.org/10.3103/S1067821216040088
- UNIVERSITI TEKNIKAL MALAYSIA MELAKA Rao, R.V., Kalyankar, V.D., Waghmare, G., 2014. Parameters optimization of selected casting processes using teaching-learning-based optimization algorithm. Applied Mathematical Modelling 38, 5592–5608. https://doi.org/10.1016/j.apm.2014.04.036
- Rashad, M., Pan, F., Hu, H., Asif, M., Hussain, S., She, J., 2015a. Enhanced tensile properties of magnesium composites reinforced with graphene nanoplatelets. Materials Science and Engineering A 630, 36–44. https://doi.org/10.1016/j.msea.2015.02.002
- Rashad, M., Pan, F., Yu, Z., Asif, M., Lin, H., Pan, R., 2015b. Investigation on microstructural, mechanical and electrochemical properties of aluminum composites reinforced with graphene nanoplatelets. Progress in Natural Science: Materials International 25, 460–470. https://doi.org/10.1016/j.pnsc.2015.09.005

- Senapati, A.K., Panda, S.S., Dutta, B.K., Mishra, S., 2020. Effect of Stirring Speed During Casting on Mechanical Properties of Al–Si Based MMCs, in: Smart Innovation, Systems and Technologies. Springer, pp. 703–710. https://doi.org/10.1007/978-981-15-1616-0_68
- Seo, P.K., Kang, C.G., Kim, B.M., 2006. The effect of stirring current and stirring time on microstructure and mechanical properties in rheo die casting process. Solid State Phenomena 116–117, 526–529. https://doi.org/10.4028/www.scientific.net/SSP.116-117.526
- Tiwari, S.K., Sahoo, S., Wang, N., Huczko, A., 2020. Graphene research and their outputs: Status and prospect. Journal of Science: Advanced Materials and Devices. https://doi.org/10.1016/j.jsamd.2020.01.006
- Torabi Parizi, M., Ebrahimi, G.R., Ezatpour, H.R., 2019. Effect of graphene nanoplatelets content on the microstructural and mechanical properties of AZ80 magnesium alloy. Materials Science and Engineering A 742, 373–389. https://doi.org/10.1016/j.msea.2018.11.025
- Trang, T.T.T., Zhang, J.H., Kim, J.H., Zargaran, A., Hwang, J.H., Suh, B.C., Kim, N.J., 2018. Designing a magnesium alloy with high strength and high formability. Nature Communications 9. https://doi.org/10.1038/s41467-018-04981-4
- Weng, S., Huang, Y.H., Xuan, F.Z., Luo, L.H., 2015. Correlation between Microstructure, Hardness and Corrosion of Welded Joints of Disc Rotors, in: Procedia Engineering. Elsevier Ltd, pp. 1761–1769. https://doi.org/10.1016/j.proeng.2015.12.325