UNIVERSITI PUTRA MALAYSIA

EFFECT OF MATERIAL MODIFIER AND VIBRATION ON MECHANICAL AND MICROSTRUCTURE PROPERTIES OF ALUMINIUM LM6 COMPOSITE CASTING

MOHAMMAD SH I A M I ALHAJJI

EFFECT OF MATERIAL MODIFIER AND VIBRATION ON MECHANICAL AND MICROSTRUCTURE PROPERTIES OF ALUMINIUM LM6 COMPOSITE CASTING

By

MOHAMMAD SH I A M I ALHAJJI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

February 2021

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy.

EFFECT OF MATERIAL MODIFIER AND VIBRATION ON MECHANICAL AND MICROSTRUCTURE PROPERTIES OF ALUMINIUM LM6 COMPOSITE CASTING

By

MOHAMMAD SH I A M I ALHAJJI

February 2021

Chairman : Professor Shamsuddin Sulaiman, PhD.
Faculty : Engineering

Advances in materials such as Metal Matrix Composite (MMC) are rapidly developed due to demands and applications. Reinforced particles of silicon carbide with Al-matrix composites are expected to have many applications in automotive, aircraft, aerospace, and electronics industries due to their enhancement of mechanical properties. Improvement of strength to weight ratio and corrosion resistance still need to be explored in material research activities. Therefore, in this project, the effect of different wt % of Sr on mechanical and microstructure properties of Al-SiC composite + LM6 and the use of copper as corrosion resistance were investigated. For microstructure analysis, the effect strontium was observed, and all samples were characterized on surface morphology by means of SEM equipped with EDS. In addition, the fabrication and identifying the characterizations of aluminium alloy with copper also have been carried out. The amount of copper additions was varied from 0%wt with the intervals of 3%wt for every alloying process. In the process of casting, there were two common types of moulding process; static moulding and vibrating moulding have been carried out. The results showed that the more Sr added, the greater number of alpha dendrites was present and it can clearly be seen. Same as EDS analysis where it also showed that addition of Sr increased the value of Si and Al chemical composition. Next, to fabricate Al-SiC composite, 10 wt % silicon carbide and different percentages (0.02, 0.5) wt % of Al-10Sr was added to LM6 and the particles were mixed by using sand casting vortex method. The addition of different values of Al-10Sr (0.01, 0.02, 0.5) wt % of mechanical properties of Al was also examined. Meanwhile, the analysis results found that UTS for Al increased by adding wt % of Sr and the highest value was 110.23 MPa for Al-0.5 wt % Sr. It was observed that the tensile for the

composite did not dramatically increase for each sample. It can be concluded that the weak interface between particles and matrix leads to decreasing UTS value. Strong interface between particles in the matrix showed high strength and stiffness but typically a low resistance to fracture. Moreover, from the analysis of the hardness test on every sample obtained the highest value of Rockwell number was for Al-SiC + 0.5 wt % Sr which was 73.52. This showed that by adding particulate reinforcement of SiC and Sr addition improved the LM6 microstructure and boosted the mechanical properties for better industrial applications especially in automotive and aircraft applications. The fabrication of LM6 alloy with various amounts of copper and using the mechanical vibrations moulding and without vibration moulding was successfully accomplished and the characterizations and mechanical properties of the Al-Si-Cu composite was determined. It was found that the optimum and the best percentage of copper composition in casted LM6 was found to be the 9%wt of copper.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN PENGUBAH BAHAN DAN GETARAN KEATAS SIFAT MEKANIKAL DAN STRUKTUR MIKRO DALAM TUANGAN KOMPOSIT ALUMINIUM LM6

Oleh

MOHAMMAD SH I A M I ALHAJJI

Februari 2021

Pengerusi : Professor Shamsuddin Sulaiman, PhD.
Fakulti : Kejuruteraan

Kemajuan dalam bahan seperti komposit matrik logam (MMC) dibangunkan dengan pesat disebabkan oleh permintaan dan penggunaannya. Zarah tetulang dari silikon karbida dengan Al-matriks boleh digunakan dalam pelbagai aplikasi seperti dalam automotif, pesawat, aeroangkasa, dan industri elektronik kerana peningkatan ciri mekanikal. Penambahbaikan dalam nisbah berat kepada kekuatan dan ketahanan karat masih perlu dipelopori adalam aktiviti penyelidikan bahan. Oleh itu dalam projek ini, kesan wt% Sr yang digunakan terhadap sifat mekanik dan mikrostruktur Al-SiC komposit + LM6 dan penggunakan tembaga sebagai ketahanan karat telah disiasat. Bagi analisis mikrostruktur, kesan ubah suai bijirin pada struktur mikro diperhatikan dan sampel dicirikan pada permukaan dengan cara SEM dilengkapi dengan EDS. Sebagai tambahan, pembikinan dan pencirian aloi aluminium dengan tembaga juga telah dilakukan. Jumlah tambahan tembaga berbeza dari 0%wt dengan jurang 3%wt untuk setiap proses pengaloian. Dalam proses peniuangan dua jenis acuan iaitu acuan statik dan acuan bergetar telah dilakukan. Keputusan menunjukkan lebih banyak Sr, lebih banyak nombor alpha hadir dan ia boleh dilihat dengan jelas. Sama seperti analisis EDS di mana ia juga menunjukkan bahawa penambahan Sr menambah nilai komposisi si dan Al. Seterusnya, untuk bahan Al-SiC Komposit, 10 wt% silikon karide dan peratusan yang berbeza (0.02, 0.5) wt% dari Al-10Sr ditambah pada LM6 dan zarah bercampur dengan menggunakan kaedah vortex. Peratusan ciri mekanik logam yang berbeza iaitu Al-10Sr (0.01, 0.02, 0.5) juga diperiksa. Sementara itu, keputusan analisis mendapati bahawa UTS untuk Al meningkat dengan menambah wt% Sr dan nilai tertinggi adalah 110.23 MPa untuk Al-0.5 wt% Sr dan tegangan untuk komposit itu tidak meningkat secara mendadak untuk

setiap sampel. Ini menyimpulkan bahawa ikatan permukaan yang lemah antara zarah dan matrik membawa pada penurunan nilai UTS. Permukaan kuat antara zarah matriks menunjukkan kekuatan yang tinggi tetapi biasanya rintangan yang rendah untuk patah. Tambahan pula, berdasarkan analisis ujian kekerasan ke atas setiap sampel diperolehi, bilangan tertinggi Rockwell adalah untuk Al-SiC + 0.5 wt% Sr iaitu 73.52. Ini menunjukkan tambahan partikel pengukuhan kepada SiC + Sr akan memperbaiki mikrostruktur dan peningkatan sifat mekanik LM6 untuk aplikasi industri yang lebih baik terutama dalam aplikasi automotif dan pesawat. Pembikinan aloi LM6 dengan jumlah tembaga berbeza dan menggunaan acuan bergetar dan tidak bergetar telah berjaya dihasilkan. Pencirian dan sifat mekanikal komposit Al-Si-Cu telah dapat dikenalpasti. Adalah didapati, peratus terbaik dan optima kandungan tembaga dalam tuangan LM6 adalah 9%wt tembaga.

ACKNOWLEDGEMENTS

In the name of Allah, the most Gracious and most Compassionate. First of all, I would like to thank ALLAH almighty for blessing and giving me strength to accomplish this thesis.

I would also like to express my deepest gratitude to my supervisor Prof. Dr. Shamsuddin Sulaiman. As supervisor, he has provided valuable information, helpful technical support and important feedback. Without this great person this thesis would have been difficult to complete.

I'm also so grateful to the members of supervisory committee, Associate Professor Ir. Dr Faieza Abdul Aziz and Associate Professor Dr Che Nor Aiza Jaafar for their help, advice and support throughout my study.

Many thanks for all the technicians in the Department of Mechanical and Manufacturing Engineering laboratories UPM for their assistances during the conducting of the research. Thanks all for their help and feedback throughout this research. Also, I would like to thank all of my friends for their support and friendship.

Finally, I would like to thank to my beloved family. Special thanks to my wife for giving moral support and looking after my children throughout my academic years.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:-

Shamsuddin Bin Sulaiman , PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Faieza Binti Abdul Aziz, PhD
Associate Professor Ir. Ts.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Che Nor Aiza Binti Jaafar, PhD
Associate Professor Ts.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 10 June 2021

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ______________________ Date: ________________

Name and Matric No: Mohammad Sh I A M I Alhajji GS49070

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

LM6	Aluminium-11.8 % silicon
MMCs	Metal Matrix Composite
Al-SiC MMC	Aluminium Silicon-Carbide Metal Matrix Composite
Al-SiC-Sr	Aluminium silicon-carbide Sr
AMC	Aluminium Matrix Composites
PAMCs	Particle-reinforced AMCs
SFAMCs	Whisker-or short fiber-reinforced AMCs
Al_4C_3	Aluminium carbide
SiC	Silicon Carbide
Al -SiC	Aluminium SiC
SEM	Scanning electron microscopy
EDS	Energy dispersive spectroscopy
Al-10Sr	Aluminium -10 Sr
UTS	Ultimate tensile stress
Sr	Strontium
Wt %	Weight percentage
α	Coefficient of thermal expansion
E	Young's modulus
V	Volume fraction
M	Matrix
σ_m	Stress in the matrix
σ_{UTC}	Ultimate tensile strength

r_f	Densities of the reinforcement
ΔLc	Change in length of the composite
Xc	Property of the composite
γ_{SG}	Energy in solid-gas
γ_{LG}	Energy liquid-gas
γ_{SL}	Energy solid-liquid
θ	Contact angle
ROM	Rule of Mixture

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Industrial technology is growing at a very rapid rate and consequently there is an increasing demand for new materials. The metal/non-metal composites represent a class of materials which can withstand high temperature and pressure besides its resistance to radiation effects and chemical reactivity. Metal matrix composites can be produced by many different techniques. One of the simplest technique is the casting process. Melting metallurgy for the production of metal matrix composite is at present of greater technical importance than powder metallurgy. It is more economical and has the advantage of being able to use well proven casting processes for the production of metal matrix composites.

Metal matrix composites (MMC) are composed of an element of alloy matrix in which a second phase is embedded and distributed to achieve some improvement in its properties. Based on the size, shape and amount of the second phase, the property of the composite varies. Particulate reinforced composites, often called as discontinuously reinforced metal matrix composites, constitute 5 – 20 % of these new advanced materials. The microstructure of the processed composites influences and has a great effect on the mechanical properties. Generally, increasing the volume or weight fraction of the second phase (reinforcement phase) in the matrix leads to an increased stiffness, yield strength, ultimate tensile strength and other mechanical and physical properties. But the low ductility of particulate reinforced MMCs is the major drawback that prevents their usage as structural components in some applications (Hamouda et al., 1996; Rizkalla and Abdulwahed, 1996). Miller and Humphreys (1991) have carried out a detailed investigation on the strengthening mechanism of composites. They have found that the particle size and its volume fraction in metal matrix composites influence the generation of dislocations due to thermal mismatch as well as the effect influenced by the developed residual and internal stresses. The researchers have predicted that the dislocation density is directly proportional to the volume fraction and also due to the amount of mismatch. The resulting strengthening effect (quench strength) is proportional to the square root of the dislocation density. Consequently, this effect would be significant for fine particles and for higher volume fractions. Recent studies have shown that the matrix microstructure has a clear effect on the fracture details of the tested specimen.

Aluminium is one of the most common and widely used metals for number of applications in the industry or even in daily life but due to the rapid evolution of metals, the production of Al alloys is created by adding chemical elements like silicon, manganese, copper, zinc or magnesium to power up their mechanical properties in order to make sure the materials is capable of operating under harsh environmental condition as mentioned by Huynh et al., (2019). They stated that in comparison, pure Al is one of the most commonly used metals with low strength yet Al alloy creation by incorporating elements such as Mg, rubber, Cu, Zn or Mg to strengthen its mechanical properties.

In addition, since they were first developed in the 1920s, there have been dramatic improvements of Al alloys. The appeal of Al alloy is that it is a fairly low cost, lightweight metal that can be heat treated to reasonably high standards of strength, and it is amongst the most efficiently produced high-performance products that usually correlates directly with cheaper rates (Rambabu et al., 2017).

Furthermore, most Al alloy has a better weight strength ratio than high steel strength. Al alloy also has excellent formability characteristics which is important features for industry requirement, high resistance to corrosion, high electrical and thermal conductivity. In this case, with the all advanced characteristics on the Al alloy, nowadays, there are more than several hundred Al alloys used in various production and development markets, such as the automotive, marine/shipping, oil and gas, pipes (water industry) and aircraft industries (Kalpakjian and Schmid, 2008).

Regarding to this study, LM6 act as a matrix and particulate SiC were chosen as reinforcements for further investigation. Thus, Al-Si alloys can also be used in the electronics, aerospace due to their strong casting ability, robust, excellent corrosion resistance and lower thermal expansion coefficient (Ojha et al., 2008). Al base alloys are commonly used as regards their noble corrosive resistivity and strong strength to weight ratio as well as adjusted in specific industries. Si is the main alloying element, leading to noble casting capacity, toughness and strong tensile strength (Zhang et al., 2006).

Moreover, consumers are constantly subject to limits on fuel efficiency standards by the automobile industry, which seek better comfort and health. Automotive producers are moving to a light weight and developing reliable goods to satisfy these requirements (Mavhungu et al., 2017). In that effect, a major necessity is the reduction of vehicle weight and usage of Al contributes to modern production as one of the car industry's key components.

The main goal of this project is to explore the mechanical properties enhancement, and material characterization. This includes determinations of the effect by adding the grain refiner or modifier, improvement of casting process and reinforcement of SiC in Al casting alloy LM6. Thus, exploring and studying this LM6 Al cast alloy will improve the properties while at the same time creating more useful advances materials in a variety of applications by using the simplest method to minimize the manufacturing cost of this material.

1.2 Problem Statement

Alloying aluminium or field of metal matrix composites are a subject which needs to be studied thoroughly and continuously concurrent with the improvement of its materials properties to compatible in certain applications. In reality, Al casting alloy (LM6) is a great choice of Al alloy with good potential for use in industrial applications especially in the aerospace and automotive sectors. In order to overcome these problems, the Al is supplemented with SiC as a reinforcement particle and LM6 casting alloy is widely used for casting sand as well. During casting process, coarse Si phase is formed which can contribute to weak mechanical properties (Mavhungu e.al. 2017).

Production of aluminium alloys are crucial these days due to great advantages provided towards variety of industries. To reduce the material cost such that spending extra money towards material that has slightly higher properties than aluminium alloys. This can be done by investigating the effect of mechanical vibration towards the mechanical properties and microstructure (Onur et.al 2018). Copper itself have unique properties that can provided lots of benefits towards aluminium alloys, with the presence of copper does it improve its mechanical properties compare to the pure LM6. By combining these two variables such as mechanical vibration and copper composition during casting, will there be any improvement towards the mechanical properties and microstructure of LM6 (Singh et.al 2019).

Despite these properties to enhance the mechanical properties of Al, the introduction of SiC was proposed for the manufacture of composite metal matrix. Weak interface microstructure and porosity are two of the major concerns with conventional casting methods during manufacturing of composite. Porosity impacts on microstructure with pressure and tensile tension influence the ductility and the performances of the composites.

However, the modification of the Sr may improve the properties of ductility, fracture, and impact. Modification alloys by Sr has an important role in the presence of porosity in casting (Gautam and Somasekharan , 2013). Sr, as an alloy additive that can be beneficial for improving the grain size microstructure and rising porosity in LM6 as well (Iyer, 2011). Zulfia and Putriana (2019) discovered in their research that Sr also significantly contributed to reducing size of coarse primary Mg_2Si and transformed Mg_2Si binary Chinese script into polyhedral or finer fibrous type. So, the optimal amount of alloy addition applied to the Al matrix compound would be analysed based on the previous description. Moreover, Al cast alloy also still needs a continuous improvement as it can be used in wider applications in the industry sector for the future.

During the last decade, because of their improved properties, MMCs have been extensively studied for high performance applications. One of the obstacles of its emergence as a major product on the market is the added cost of fabrication. Traditional trial-and-error techniques has been used to run the possible combination of variation of MMCs but definitely the process is difficult and complicated to complete with which the manufacturer is deemed to be unable to compete resulting a high manufacturing cost, which do not yet outweigh the improvement obtained in properties over the already proven materials (Jung et al., 2008).

Basically the MMCs can be produced using various manufacturing methods including casting, powder metallurgy and foil-and-fibre (Lynch & Kershaw, 2018). Hence, in these days, massive high-quality products are consistently available in the market at a low price. The characteristics of MMCs itself allow it to be designed into material, custom-made, reliant on the application; hence it is considered as innovative materials which are able to unlock unlimited possibilities for modern material science and technology. The MMCs deemed flexible to suit and match any conceptual plan of the materials designer. In the case of vibration during solidification, it is reported mechanical vibration Ultrasonic vibration and Electromagnetic applied may increase the mechanical properties of aluminium alloy in comparison with the unapplied vibration. Aluminium-11.8% silicon alloys or called LM6 are the major material used in casting and used in automotive and aerospace applications. In the past years, limited study has been reported on the research of the effect of mould vibration during solidification on aluminium/silicon (11.8%) with titanium carbide as particulates. The mechanical mould vibration was seen to be an interesting alternative to other particulates, considering its significantly lower density, grain refinement, increase density, degassing, shrinkage, distribution of the second phase and uniform distribution of particle in the matrix than without vibration. Furthermore, the research work tries to obtain the correlation of grain refiner and vibration mould and accuracy.

Therefore, this research explores the mechanical properties and microstructure analysis for aluminium alloy LM6, with silicon carbide and copper particulates using mechanical mould vibration casting process. The data and outcome information from this research would be useful for material advances in manufacturing industry.

1.3 Objectives

The objectives of the project are:

i. To find the behaviour of Al-SiC metal matrix composite (MMC) by using sand casting (vortex) method.
ii. To determine the characteristic of Al-SiC and Al-Si-Cu alloy composite through mechanical testing and microstructure analysis
iii. To find the effect of addition Sr and copper on LM6 alloy for both microstructure and mechanical properties.
iv. To analyse the effect of Sr and SiC addition on microstructure and mechanical properties of Al LM6.

1.4 Scope of Study

In order to focus the research and outcome effectively, the scope of work has to be determined. In this research, LM6 alloy is used as a matrix material due to its better fluidity and castability. It contains 11.8% Silicon as a major alloying element in the aluminium metal matrix. It is a eutectic alloy having the lowest melting point as per the aluminium-silicon equilibrium phase diagram and available at reduced cost in the market. This research is focus on the materials, the fabrication process, mechanical properties, phySiCal properties, and microstructure of the aluminium- 11.8% silicon alloy is used as a matrix material and titanium carbide is added as reinforced particles. CO_2 process in employed to produce sand moulds for casting TiC-particulate reinforced LM6 alloy composites. The advantages of CO_2 sand cast products possess good dampening properties, uniform strength in all directions and cheaper when compared to other manufacturing processes such as forging, welding, and rolling.

Some other scope criteria are listed below:

i. Work and analysis into the impact of Sr on LM6.
ii. Analysis and comparison of mechanical properties and microstructure of LM6 between unmodified LM6 with LM6 and addition of Sr as well as LM6 with reinforcement of SiC and Sr.
iii. Determine the mechanical properties of the components, several test methods were developed to find the hardness of the sample and microstructure of the Al-MMC reinforced by SiC particles. The composite's hardness number was specified using Rockwell Hardness test while EDX attached SEM and optical microscopy

detects its microstructure properties and tensile measured by INSTRON 3382, a tensile tester machine.

1.5 Thesis Outline

The thesis consists of five chapter which including chapter 1 until chapter 5. The first chapter covers the background of cast Al alloys (LM6), addition Sr in the process of the sand casting to enhance the mechanical properties, reinforcement particles of SiC, the objectives of study, problem statements, scope of study and the structure of the study.

Chapter 2 covers the details literature review related to the investigation on the properties or behaviour of LM6 and also mechanical properties of cast aluminium alloys with addition of strontium and reinforcement of silicon carbide.

Chapter 3 covers the methodology and process flow for the whole project. This also will show the processes of experiment conducted and data obtained from mechanical testing and SEM micrograph upon the specimens.

In addition, for Chapter 4, the outcomes from the studies performed in conjunction with Chapter 3 are presented in this chapter including all the discussion, analysis, and comparison of the effects on addition Sr and reinforcement of SiC towards LM6.

Lastly, the Chapter 5 is about conclusion and recommendation of the project. In fact, this chapter also includes a few guidelines for potential research on the developments of Al use in the industry of engineering and also assessment on implication of the improvement of the LM6 to the society and environment.

REFERENCES

Afifeh, M., Hosseinipour, S. J., & Jamaati, R. (2019). Nanostructured copper matrix composite with extraordinary strength and high electrical conductivity produced by asymmetric cryorolling. *Materials Science and Engineering: A*, *763*

Ahmad. R. Talib, N.A & Asmael, M.B.A. (2013). Effect of pouring temperature on microstructure properties of Al-Si LM6 alloy sand casting. *Applied Mechanics and Materials*. Vol315. Page: 856-860.

Akhtar, K., Khan, S. A., Khan, S. B., & Asiri, A. M. (2018). Scanning Electron Microscopy: Principle and Applications in Nanomaterials Characterization. In S. K. Sharma (Ed.), *Handbook of Materials Characterization* (pp. 113–145).

Alaneme, K. K., & Odoni, B. U. (2016). Mechanical properties, wear and corrosion behavior of copper matrix composites reinforced with steel machining chips. *Engineering Science and Technology, an International Journal*, *19*(3), 1593–1599.

Archana Somnath Sangale, A.M.K. (2019). Effect of Heat Treatment on Hardness of Aluminium Alloy Reinforced with Rice Husk Ash Archana Somnath Sangale. *International Journal of Engineering Research and Technology (IJERT)*.page:754.

ASTM Standard E18 (2018). Standard Test Methods for Rockwell Hardness of Metallic Materials. *ASTM International*, West Conshohocken, PA

ASTM Standard B557M (2002). Standard Test Methods of Tension Testing Wrought and Cast Aluminium and Magnesium Alloy Products. *ASTM International*, West Conshohocken, PA.

ASTM Standard E466 (2007). Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials. *ASTM International*, West Conshohocken, PA.

Barbosa, J., Puga, H., Oliveira, J., Ribeiro, S., & Prokic, M. (2014). Physical modification of intermetallic phases in Al–Si–Cu alloys. *Materials Chemistry and Physics*, *148*(3), 1163–1170.

Bangaru, S. S., Wang, C., Hassan, M., Jeon, H. W., & Ayiluri, T. (2019). Estimation of the degree of hydration of concrete through automated machine learning based microstructure analysis – A study on effect of image magnification. *Advanced Engineering Informatics*, *42*

Campbell, F. C. (Ed.). (2013). *Inspection of metals: Understanding the basics*. Materials Park, Ohio: ASM International.

Carbide, S. & Material, S.(2013). Silicon Carbide, SiC Ceramic Properties. *Accuratus*. Available from web: https://accuratus.com/silicar.html. Accessed date 25th July 2020.

Cayron, C. & Buffat, P.A. (2000). Structural phase transition in Al-Cu-Mg-Si and Al-Mg-Si alloys: Ordering mechanisms and crystallographic structures. *Materials Science Forum*. Vols 331-337. page:1001-1006.

Chaitanya, K. L., & Srinivas, K. (2018). A Review on Use of LM Based Aluminium Alloys in Automobile Components. *American International Journal of Research in Science, Technology, Engneering & Mathematics*, ISSN (Online): 2328-3580.

Chawla, K.K. (2012). Composite materials: Science and engineering, third edition. *Composite Materials: Science and Engineering, Third Edition*. page:7-71.

Chen, J., Chen, X., & Luo, Z. (2018). Effect of mechanical vibration on microstructure and properties of cast AZ91D alloy. *Results in Physics*, *11*, 1022–1027.

CustomPart. (2018). Sand Casting Process, Defects, Design. Available from web https://www.custompartnet.com/wu/SandCasting. Accessed date 23th August 2020.

David Roylance (2008). Mechanical properties of materials, *MIT 200*8

Davim, J.P. (2012). Metal matrix composites. *Metal Matrix Composites*. page: 21-34.

Davis, J. R. (2001). Alloying: Understanding the basics, *ASM International*

Davis, J. R., & Davis, J. R. (2004). Tensile testing. *Materials Park, Ohio: ASM International.*

Diaspro, A., & Usai, C. (2006). Optical Microscopy. In M. Akay (Ed.), *Wiley Encyclopedia of Biomedical Engineering* (pp.1), John Wiley & Sons, Inc.

Dwyer, F., Adrian S., & Richard T. (2012) Material and Design Optimization for an Aluminium Bike Frame. *Worcester Polytechnic Institute.* page:1-19.

Extrand, C.W. (2016). Origins of Wetting. *Langmuir*. page:7697-7706.

Eyres, D.J. (2007). Aluminium alloy. *Ship Construction*. page:50-54.

Farkašová, M., Tillová, E. & Chalupová, M. (2013). Modification of Al-Si-Cu cast alloy. *FME Transactions*, 41(3). page: 210-215.

Gautam Krishnan, R. & Somasekharan Nair, E.M. (2013). Study of Strontium Modification in Aluminium Alloy. *International Journal of Emerging Technology and Advanced Engineering*, Vol(3). page: 753-760.

Grubb, D.T. (2012). Optical Microscopy. *Polymer Science: A Comprehensive Reference, 10 Volume Set*. page: 465-478.

Guo, H. & Zhang, Z. (2018). Processing and strengthening mechanisms of boron-carbide-reinforced aluminium matrix composites. *Metal Powder Report*, Vol (73). page:62-67

Hamasaiid, A., Dargusch, M. S., & Dour, G. (2019). The impact of the casting thickness on the interfacial heat transfer and solidification of the casting during permanent mold casting of an A356 alloy. *Journal of Manufacturing Processes*, *47*, 229–237.

Hamouda, A. M. S., Sulaiman, S., and Hashmi, M. S. J. (1996). Fast upsetting of circular cylinders of aluminium metal matrix composites: Experimental results and numerical analysis. *Journal of Materials Processing Technology, 60*(1-4), 723-727.

Hurtalova, L., Tillova, E., & Chalupova, M. (2013). The Structure Analysis of Secondary (Recycled) AlSi9Cu3 Cast Alloy with and without Heat Treatment. *Engineering Tran*saction 61(3):1897-218.

Hurtalová L., Tillová, E., Chalupová M., Ďuriníková E. (2012) Effect of chemical composition of secondary al-si cast alloy on intermetallic phases, *Scientific Proceedings IX International Congress "Machines, Technologies, Materials"* 2012, pp23-26.

Huynh, L. A. T., Pham, C. H., & Rasmussen, K. J. R. (2019). Mechanical properties and residual stresses in cold-rolled aluminium channel sections. *Engineering Structures*, *199*

Iyer, A. (2011). Squeeze Casting: The Future. *International Specialised Skills Institute*. page:27-63.

Jarfors, A.E.W. & Seifeddine, S. (2015). Metal casting. *HandBook of Manufacturing Engineering and Technology*. page:309-410.

Jiang, W., Fan, Z., Chen, X., Wang, B., & Wu, H. (2014). Combined effects of mechanical vibration and wall thickness on microstructure and mechanical properties of A356 aluminium alloy produced by expendable pattern shell casting. *Materials Science and Engineering: A*, *619*, 228–237

Jung, C. K., Jang, J. H., and Han, K. S. (2008). Numerical Simulation of Infiltration and Solidification Processes for Squeeze Cast Al Composites with Parametric Study. *Metallurgical and Materials transactions A, 39*(11), 2736-2748.

Kabnure, B. B., Shinde, V. D., & Patil, D. C. (2019). Quality and yield improvement of ductile iron casting by simulation technique. *Materials Today: Proceedings*

Kalhapure, M. G., & Dighe, P. M. (2013 Kalpakjian, S. & Schmid, S. (2006). Manufacturing engineering and technology (5th ed.). *Prentice Hall*. page:1141-1186.

Kalpakjian, S. & Schmid, S. (2008). Metal-casting processes and equipment; heat treatment. *Manufacturing Processes for Engineering Materials*. page:32-36.

Kocatepe, K. (2007). Effect of low frequency vibration on porosity of LM25 and LM6 alloys. *Materials & Design*, *28*(6), 1767–1775.

Konen, R., & Fintov, S. (2012). Copper and Copper Alloys: Casting, Classification and Characteristic Microstructures. In L. Collini (Ed.), *Copper Alloys—Early Applications and Current Performance—Enhancing Processes.*

Kopeliovich, D. (2012, May 31). *Materials Engineering*. Sand casting [SubsTech]https://www.substech.com/dokuwiki/doku.php?id=sand_casting. Accessed date 26 Dec 2019.

Krupiński, M., Król, M., & Maniara, R. (2018). Heat Treatment of Al-Si-Cu Alloys. *Solid State Phenomena*, *275*, 15–29

Kumar, G.B.V., Rao, C.S.P., Selvaraj, N. & Bhagyashekar, M.S. (2010). Studies on Al6061-SiC and Al7075-Al2O3 Metal Matrix Composites. *Journal of Minerals & Materials Characterization & Engineering*. page:43-55.

Kumar, P. (2013). A Study on Mechanical Properties of Aluminium Alloy (LM6) Reinforced with SiC and Fly Ash. *IOSR Journal of Mechanical and Civil Engineering* 8(5). page:13–18.

Lasa, L., & Jose, R.I. (2004). Evolution of the main intermetallic phases in Al-Si-Cu-Mg casting alloys during solution treatment. *Journal of Material Science.* 39(4). page:1343-1355.

Latypov, M. I., Kühbach, M., Beyerlein, I. J., Stinville, J.-C., Toth, L. S., Pollock, T. M., & Kalidindi, S. R. (2018). Application of chord length distributions and principal component analysis for quantification and representation of diverse polycrystalline microstructures. *Materials Characterization*, *145*, 671–685.

Lasa, L., & Jose, R.I. (2004). Evolution of the main intermetallic phases in Al-Si-Cu-Mg casting alloys during solution treatment. *Journal of Material Science.* 39(4). page:1343-1355.

Lloyd, D.J. (1989a). The solidification microstructure of particulate reinforced aluminium/SiC composites. *Composites Science and Technology*. page: 159-179.

Lloyd, D.J. (1989b). The solidification microstructure of particulate reinforced aluminium/SiC composites. *Composites Science and Technology* 35(2).page: 159–179.

Li, S., Yishi S., Qiubao O & Di, Z. (2016). In-situ carbon nanotube-covered silicon carbide particle reinforced aluminium matrix composites fabricated by powder metallurgy. *Materials Letters.* Vol 167. page: 118-121.

Lynch, C.T. & Kershaw, J.P. (2018). Metal matrix composites. *Metal Matrix Composites*. page: 180-181.

Makhlouf, M. M., & Guthy, H. V. (2001). The aluminium–silicon eutectic reaction: Mechanisms and crystallography. *Journal of Light Metals*, *1*(4), 199–218.

Mathers, G. (2002). The welding of aluminium and its alloys. *Woodhead Publ*. pp1.1

Martín, I., Ortega, P., Colina, M., Orpella, A., López, G. & Alcubilla, R. (2013). Laser processing of Al2O3/a-SiCx:H stacks: A feasible solution for the rear surface of high-efficiency p-type c-Si solar cells. *Progress in Photovoltaics: Research and Applications*.page: 1-5.

Mavhungu, S.T., Akinlabi, E.T., Onitiri, M.A. & Varachia, F.M. (2017). Aluminium Matrix Composites for Industrial Use: Advances and Trends. *Procedia Manufacturing*.page:178-182.

McDonald, S.D., Dahle, A.K., Taylor, J.A. & StJohn, D.H. (2004). Eutectic grains in unmodified and strontium-modified hypoeutectic aluminium-silicon alloys. *Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science*.page: 1829-1837.

Meena, K.L., A. Manna, D., S.S. Banwait, D. & Jaswanti, D. (2013). An Analysis of Mechanical Properties of the Developed Al/SiC-MMC's. *American Journal of Mechanical Engineering*. page:14-19.

Mencin, P., Van Tyne, C.J. & Levy, B.S. (2009). A method for measuring the hardness of the surface layer on hot forging dies using a nanoindenter. *Journal of Materials Engineering and Performance*. page: 1067-1072.

Meneghetti, G., Tovo, R., Patricolo, M. & Volpone, L.M. (1999). Experimental determination of fatigue strength of structural details in welded light alloys). *Welding International*. page: 461-464.

Miller, W. S., and Humphreys, F. J. (1991). Strengthening mechanisms in particulate metal matrix composites. *Scripta Metallurgica et Materialia, 25*(1), 33-38

Mishra, R. K. (2020). Study the effect of pre-corrosion on mechanical properties and fatigue life of aluminium alloy 8011. *Materials Today: Proceedings.* Vol 25, Part 4, pp 602-609.

Mouritz, A. P. (2012). Introduction to aerospace materials. *Oxford: Woodhead Publ.* (pp 1.2-13)

Murphy, D. B. (2001). Fundamentals of light microscopy and electronic imaging. (pp 1. 1-14) New York: *Wiley-Liss*

Njeh, C.F., Nicholson, P.H. & Rho, J.Y. (2016). Mechanical testing. *The Physical Measurement of Bone*. page: 37.

Numan, A.D., Khaisheh, M., Saito, K., & Male, A. (2005). Silicon morphology modification in the eutictic Al-Si alloy using mechanical mold vibration. *Materials Science and Engineering A*, 393(1-2), 109-117.

Ojha, K. V., Tomar, A., Singh, D. & Kaushal, G.C. (2008). Shape, microstructure and wear of spray formed hypoeutectic Al-Si alloys. *Materials Science and Engineering A*.page: 591-596.

Ozben, T., Kilickap, E. & Çakir, O. (2008). Investigation of mechanical and machinability properties of SiC particle reinforced Al-MMC. *Journal of Materials Processing Technology*.page: 220-225.

Onur, O., Armakan, E. & Alper K. (2018). The Mechanical Properties of Sr Modification on Aluminium Casting Alloys, *ICETI2018*. page:1-6.

Polmear, I.J. (2005). Cast aluminium alloys. *Light Alloys*.page:109-156.

Prasad Reddy, A., Vamsi Krishna, P., Narasimha Rao, R. & Murthy, N. V. (2017). Silicon Carbide Reinforced Aluminium Metal Matrix Nano Composites-A Review. *Materials Today: Proceedings*. page: 3959-3971.

Rambabu, P., Eswara Prasad, N., Kutumbarao, V. V. & Wanhill, R.J.H. (2017). Aluminium Alloys for Aerospace Applications. *Aerospace Materials*. Springer. page: 29-52.

Ramnath, B.V., Elanchezhian, C., Annamalai, R.M., .Aravind, S., Atreya, T.S.A., Vignesh, V. & Subramanian, C. (2014). Aluminium metal matrix composites - A review. *Rev. Adv. Mater. Sci*.:55-60.

Raza, M.A., Rehman, Z.U. & Ghauri, F.A. (2018). Corrosion study of silane-functionalized graphene oxide coatings on copper. *Thin Solid Films*.page: 93-99.

Rana, R. S., & Purohit, R. (2012). Effect of magnesium enhancement on mechanical property and wear behaviour of lm6 aluminium alloy. *IJSER*. *3*(7), 5.

Reimers, W. (2008). Neutrons and synchrotron radiation in engineering materials science: From fundamentals to material and component characterization. *Wiley-VCH Verlag GmbH & Co*. KGaA.

Rizkalla, H. L., and Abdulwahed, A. (1996). Some mechanical properties of metal-nonmetal Al---SiO2 particulate composites. *Journal of Materials Processing Technology, 56*(1-4), 398-403.

Roger Lumley (2010). Fundamentals of Aluminium Metallurgy *Woodhead Publ. .* (pp 1-3. 1-51)

Sanusi, K.O. & Oliver, G.J. (2009). Effects of grain size on mechanical properties of nanostructured copper alloy by severe plastic deformation (SPD) process. *Journal of Engineering, Design and Technology*. Vol. 7(3), page: 335-341.

Sarada, B.N. & Srinivasamurthy, P.L. (2013). Microstructural Characteristics of Sr And Na Modified Al-Mg-Si Alloy. *International Journal of Innovative Research in Science, Engineering and Technology*.page:3976-3982.

Sarro, P.M. (2000). Silicon carbide as a new MEMS technology. *Sensors and Actuators, A: Physical*.page:210-218.

Scheu, C. & Kaplan, W.D. (2012). Introduction to Scanning Electron Microscopy. *In-Situ Electron Microscopy: Applications in Physics, Chemistry and Materials Science*.page:68-78.

Schoff, C.K. (2006). Optical microscopy. *CoatingsTech*. Available from web https://www.thefreelibrary.com/Optical+microscopy.-a0143478517. Accessed date 24 July 2019.

Sijo, M.T. & Jayadevan, K.R. (2016). Analysis of Stir Cast Aluminium Silicon Carbide Metal Matrix Composite: A Comprehensive Review. *Procedia Technology*.page:379-385.

Singh, M. K., Gautam, R. K., & Ji, G. (2019). Mechanical properties and corrosion behavior of copper-based hybrid composites synthesized by stir casting. *Results in Physics*, *13*, 102319.

Sivananthan, S., Ravi, K., & Samson Jerold Samuel, C. (2019). Effect of SiC particles reinforcement on mechanical properties of aluminium 6061 alloy processed using stir casting route. *Materials Today: Proceedings*

Stojanovic, B., Bukvic, M., & Epler, I. (2018). Application of Aluminium and Aluminium Alloys in Engineering. *Applied Engineering Letters : Journal of Engineering and Applied Sciences*, *3*(2), 52–62.

Sulaiman, S., Marjom, Z., Ismail, M. I. S., Ariffin, M. K. A., & Ashrafi, N. (2017). Effect of Modifier on Mechanical Properties of Aluminium Silicon Carbide (Al-SiC) Composites. *Procedia Engineering*, *184*, 773–777.

Sulaiman, S., Sayuti, M., & Samin, R. (2008). Mechanical properties of the as-cast quartz particulate reinforced LM6 alloy matrix composites. *Journal of Materials Processing Technology*, *201*(1–3), 731–735.

Surappa, M.K. (2003). Aluminium matrix composites: Challenges and opportunities. *Sadhana - Academy Proceedings in Engineering Sciences*.page:319-334.

Syed Affan Ahmed, Motgi (2015) A Study on Mechanical and Tribological Properties Al LM6 MMCs Reinforced with Nano SiC, Fly Ash and Red Mud. *Int. Journal for Scientific Research & Development*. Vol. 3. Issue 08. ISSN (online): 2321-0613.

Talamantes-Silva, M. A., Rodríguez, A., Talamantes-Silva, J., Valtierra, S., & Colás, R. (2008). Characterization of an Al–Cu cast alloy. *Materials Characterization*, *59*(10), 1434–1439.

Thurber, C.R., Ahmad, Y.H., Calhoun, M.C., Al-Shenawa, A., D’Souza, N., Mohamed, A.M.A. & Golden, T.D. (2018). Metal Matrix Composite Coatings of Cupronickel Embedded with Nanoplatelets for Improved Corrosion Resistant Properties. *International Journal of Corrosion*.page:1-11.

Timpel, M., Wanderka, N., Schlesiger, R., Yamamoto, T., Lazarev, N., Isheim, D., Schmitz, G., Matsumura, S. & Banhart, J. (2012). The role of strontium in modifying aluminium-silicon alloys. *Acta Materialia*.page: 3920-3928.

Vijeesh, V. & Prabhu, K.N. (2014). Computer aided cooling curve analysis and microstructure of cerium added hypereutectic Al-Si (LM29) alloy. *Transactions of the Indian Institute of Metals*.page: 541-549.

Warmuzek, M. (2004). Aluminium-silicon casting alloys: An atlas of microfractographs, (pp 1. 1-9) *ASM International Publ*.

Zhang, X.N., Geng, L. & Wang, G.S. (2006). Fabrication of Al-based hybrid composites reinforced with SiC whiskers and SiC nanoparticles by squeeze casting. *Journal of Materials Processing Technology*.page:146-151.

Zhou, W., & Wang, Z. L. (Eds.). (2007). *Scanning microscopy for nanotechnology: Techniques and applications*. New York, NY: Springer.

Ziólkowski, E., Wrona, R. & Smyksy, K. (2010). Analysis and assessment of foundry moulding sand preparing process using the dynamic power measurement method. *Archives of Metallurgy and Materials*.page:4-6.

Zulfia, A. & Putriana, L.T. (2019). Effect of strontium on the microstructure and mechanical properties of aluminium ADC12/Nano-SiC composite with Al-5TiB grain refiner by stir casting method. *Materials Research Express*.page:116-123.