DEVELOPMENT OF ADC14 HYPEREUTECTIC AlSi ALLOY BASED COMPOSITE REINFORCED WITH SiC, Al_2O_3 AND TiB_2 THROUGH STIR CASTING

AQEEL AHMED BHUTTO

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

STATUS CONFIRMATION FOR THESIS

DOCTOR OF PHILOSOPHY

DEVELOPMENT OF ADC14 HYPEREUTECTIC AlSi ALLOY BASED COMPOSITE REINFORCED WITH SiC, Al_2O_3 AND TiB_2 THROUGH STIR CASTING

ACADEMIC SESSION: 2020/2021

I, **AQEEL AHMED BHUTTO**, agree to allow this Doctoral Thesis Report to be kept at the Library under the following terms:

1. This Doctoral Thesis is the property of the Universiti Tun Hussein Onn Malaysia.
2. The library has the right to make copies for educational purposes only.
3. The library is allowed to make copies of this report for educational exchange between higher educational institutions.
4. The library is allowed to make available full text access of the digital copy via the internet by Universiti Tun Hussein Onn Malaysia in downloadable format provided that the Thesis is not subject to an embargo. Should an embargo be in place, the digital copy will only be made available as set out above once the embargo has expired.
5. ** Please Mark (√)

☐ CONFIDENTIAL (Contains information of high security or of great importance to Malaysia as STIPULATED under the OFFICIAL SECRET ACT 1972)

☐ RESTRICTED (Contains restricted information as determined by the Organization/institution where research was conducted)

☐ EMBARGO _____ until _____
(date) (date)

☐ √ FREE ACCESS

Approved by

(WRITER'S SIGNATURE) (SUPERVISOR'S SIGNATURE)

Permanent Address:
NO: 09, TAMAN BINTANG,
86400 PARIT RAJA
BATU PAHAT,
JOHOR

Date: 24-02-2021 Date: 24-02-2021

NOTE:

** If this Doctoral Thesis Report is classified as CONFIDENTIAL or RESTRICTED, please attach the letter from the relevant authority/organization stating reasons and duration for such classifications.

This thesis has been examined on 28th December 2020
and is sufficient in fulfilling the scope and quality for the purpose of awarding the Degree of Doctor of Philosophy in Mechanical Engineering.

Chairman:

ASSOC. PROF. DR. ROSLI BIN AHMAD
Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

Examiners:

PROFESSOR IR. DR. AHMAD RAZLAN BIN YUSOFF
Faculty of Manufacturing and Mechatronic Engineering Technology
Universiti Malaysia Pahang (UMP)

PROF. DR. YUSRI BIN YUSOF
Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

DEVELOPMENT OF ADC14 HYPEREUTECTIC ALSI ALLOY BASED COMPOSITE REINFORCED WITH SiC, Al_2O_3 AND TiB_2 THROUGH STIR CASTING

AQEEL AHMED BHUTTO

A thesis submitted in
fulfilment of the requirement for the award of the
Doctor of Philosophy in Mechanical Engineering
with Honours

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

FEBRUARY 2021

I hereby declare that the work in this project report is my own except for quotations and summaries which have been duly acknowledged

Student : AQEEL AHMED BHUTTO

Date : 24-02-2021

Supervisor : PROF. IR. DR. MD. SAIDIN BIN WAHAB

Date : 24-02-2021

ACKNOWLEDGEMENT

First and foremost, thanks to ALLAH ALMIGHTY the most beneficent and most merciful. I thank ALLAH for given me the life, health, wealth, power and wisdom to achieve this milestone in my life. May Allah in his mercy make this research beneficial to the entire mankind. Secondly, peace be upon our Prophet Muhammad (SAW) and may the light of his love always enlighten our hearts for this and hereafter life. This thesis would not have been possible without the support of a great number of people. On the top among them, I would like to express my profound gratitude to my supervisor Prof. Dr. Ir. M. Saidin bin A. Wahab for his inspiration and guidance throughout the period of my research endeavour. I learned a lot during my time here in the University Tun Hussein Onn Malaysia (UTHM) from his critical thinking and genuine attitude towards research. I am grateful to him for providing such wonderful support to my postgraduate career. I would also like to thanks to technical staff of the UTHM and SIRIM Rasa for their technical support and help during this research journey.

I would like to thank my entire family for their understanding, support, consolation, and genuine love. Their consistent moral support and tremendous sacrifice and prayers have empowered me to accomplish this thesis. Thanks to my friends for all the good time, we shared together.

ABSTRACT

The hypereutectic AlSi alloys contain Si more than 12.3 % (eutectic point), and possesses better mechanical properties than eutectic and hypoeutectic AlSi alloys. But the higher percentage of Si in the hypereutectic AlSi alloy caused to result primary and eutectic Si in microstructure during melting, which in turns to hitch the mechanical properties. The proper control of microstructure and addition of common reinforcement materials (SiC, Al_2O_3, TiB_2) in hypereutectic AlSi alloy will improve mechanical properties. Thus, in this research work, ADC14 hypereutectic AlSi alloy based composite reinforced with SiC (5 to 20%), Al_2O_3 (5 to 15%) and TiB_2 (2 to 8%) was developed through stir casting. The mechanical, physical and thermal properties, and microstructure were investigated for the developed composite through ASTM standards. The results showed that tensile strengths and hardness of all the three composites were increased by increasing the weight percentage of all three reinforcements. The maximum values of ultimate tensile strength and hardness were obtained as 115.81 MPa and 69 HV for 20% of SiC and 8% of TiB_2 reinforcements respectively. For physical properties, the optimum values were obtained as 2.67 g/cm^3 and 0.023% for 8% of TiB_2 and 5% of SiC respectively. For thermal properties, the optimum values were obtained as 178 W/mK and 10.7 1/ºC x 10^{-6} for 20% of SiC and 15% of Al_2O_3 respectively. Furthermore, the addition of Al_2O_3 improved the microstructure of ADC14 hypereutectic alloy based composite. And minor porosities were observed in microscopic images. Comprehensively, all three reinforced materials improved the mechanical, physical and thermal properties of the ADC14 hypereutectic AlSi alloy based composite. The development of ADC14 composite may provide some practical knowledge in materials engineering. Also, based on the results of hardness and thermal properties, the developed composite can be applied for automotive part.

ABSTRAK

Hipereutektik AlSi aloi mengandungi Si lebih daripada 12.3% (titik eutektik), dan mempunyai sifat mekanikal yang baik daripada aloi eutektik dan hipoeutektik AlSi. Tetapi peratus Si yang tinggi di dalam aloi hipereutektik AlSi disebabkan keputusan primer dan eutektik Si dalam struktur mikro ketika mencair, yang secara giliran menyekat sifat mekanikal. Kawalan struktur mikro yang baik dan penambahan bahan pengukuh (SiC, Al_2O_3, TiB_2) biasanya dalam aloi hipereutektik AlSi akan meningkatkan sifat mekanikal. Oleh itu, dalam kajian ini, bahan komposit pengukuh asas aloi ADC14 hipereutektik AlSi dengan SiC (5 hingga 20%), Al_2O_3 (5 hingga 15%) dan TiB_2 (2 hingga 8%) dibangunkan melalui proses kacauan. Sifat Mekanikal, fizikal, termal, dan struktur mikro di kaji untuk pembangunan komposit mengikut piawai ASTM. Keputusan menunjukkan kekuatan tegangan dan kekerasan untuk ketiga – tiga komposit meningkat dengan peningkatan peratus berat ketiga-tiga bahan pengukuh. Nilai maksimum kekuatan tegangan muktamad dan kekerasan yang di perolehi adalah 115.81MPa dan 69 HV untuk 20% pengukuh SiC dan 8% pengukuh TiB_2. Untuk sifat fizikal, nilai optimum yang di perolehi adalah 2.67 g/cm^3 and 0.023% untuk 8% TiB_2 dan 5% SiC. Untuk sifat termal, nilai optimum yang di perolehi adalah 178 W/mK dan 10.7 l/^{o}C x 10^{-6} untuk 20% SiC dan 15% Al_2O_3. Selain itu, penambahan Al_2O_3 memperbaiki struktur mikro bahan komposit pengukuh asas aloi ADC14 hipereutektik dan keliangan kecil dapat dilihat dalam imej mikroskopik. Secara keseluruhan, kesemua tiga bahan pengukuh memperbaiki sifat mekanikal, fizikal, dan termal bahan komposit aloi ADC14 hipereutektik. Pembangunan komposit ADC14 dapat memberi pengetahuan praktikal dalam kejuruteraan bahan. Juga, berdasarkan keputusan kekerasan dan sifat termal, komposit yang dibangunkan boleh di guna pakai untuk komponen automotif.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

HRA	-	Rockwell Hardness Test A
HV	-	Vickers Hardness
HB	-	Brinell Hardness
ADC14	-	Alternative Daily Cover
GPa	-	Giga Pascal
ASTM	-	American Society of Testing Materials
MMC	-	Metal Matrix Composite
AMMC	-	Aluminium Metal Matrix Composite
UTHM	-	Universiti Tun Hussein Onn Malaysia
FKMP	-	Fakulti Kejuruteraan Mekanikal Dan Pembuatan
gf	-	Gram force
TGA	-	Thermogravimetric Analysis
^{o}C	-	Degree centigrade

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background Study

Advancement of engineering materials is increasing day by day which not only improves the performance but also reduces the weight of the engineering parts. Researchers are focusing to introduce new materials for various engineering applications. The new engineering materials are being produced by introducing composites using many casting techniques and by varying the composition of them. The biggest advantages of composites are that they are light in weight and strong. By choosing an appropriate combination of matrix and reinforcement material, a composite can be made that exactly meets the requirements of particular applications. Composites also provide design flexibility and because many of it can be moulded into complex shapes. Not end here; the composites are lighter weight, the ability to tailor the layup for optimum strength and stiffness, physical and thermal properties, and good design practice; reduce assembly costs due to fewer detail parts and fasteners.

Aluminium alloys are the preferred material for many automobile parts (combustion chamber parts) due to their specific characteristics: low density, high thermal conductivity, simple net-shape fabrication techniques (casting and forging), easy machinability, high reliability and very good recycling characteristics (Hirsch, 1997). But AlSi alloys are most commonly used in many automobile parts (Nakata and Ushio, 2001). Furthermore, AlSi alloys are characterized into three major groups: hypoeutectic (<12% Si), eutectic (12-13% Si) and hypereutectic (14-25% Si) (Lee, 2003). Hypereutectic AlSi alloys are one of the widely used alloys in cylinders, cylinder heads, cylinder liners and pistons of the automobile engines. It is because of

many good properties such as: corrosion resistance, excellent wear resistance, low density, low coefficient of thermal expansion, high specific strength and many more (Dwivedi, 2010 and Hou et al, 2010). Furthermore, the proper control of the chemical composition, the processing conditions, and the final heat treatment can ensure the required mechanical and thermal performance (Imam et al. 2015). Hypereutectic aluminium alloys are stronger, resist scuffing and seizure, and reduce groove wear and cracking of the crown at extremely high temperatures (Aqeel et al., 2016 and Saaminathan and Antony, 2017). Additionally, the adequate combination of Al-Si-Cu-Mg-based Al-Si hypereutectic alloy could produce good flowability, low coefficient of thermal expansion, low density, high strength, and good high-temperature performance characteristics (Li et al. 2017). Furthermore, hypereutectic AlSi alloys are very resistant to expansion because the high percentage of silicon essentially "insulates" the piston from the effects of heat (Kumar and Ramesha, 2018). Higher content of silicon in hypereutectic AlSi alloy makes ideal for modern engines with tight clearance requirements. Also the introduction of AlSi based composites may provide better properties by tailoring proper percentage and inclusion (Pankaj and Srivastava, 2019). Nonetheless, the continuing development of modern gasoline engines leads to specific objectives for further piston development: reduction of piston weight, an increase of mechanical and thermal load capacity, lower friction, and thus improved scuffing resistance, etc. As Sroka and Dziedzioch (2015) defined the concept of downsizing engine in their research. There are mainly three ways of downsizing such as reducing the displacement of engine (W_d= 1-A), diameter of the piston (W_d= 1-B^2) and by reducing both (W_d = 1-AB^2). Such downsizing of engine caused to produce heavy mechanical and thermal forces during combustion and led to premature failure of the piston. The downsize engine concept and simulated result of piston is shown in Figure 1.1. Thus, it seems to proceed for a better piston material which can sustain such mechanical and thermal stresses. And such objects can be achieved by a targeted combination of high-performance aluminium piston composite materials.

The alloy typified by ADC 14 (Alternative daily cover 14) (Japanese designation, corresponding to an aluminium alloy casting) die-cast aluminium alloy for the automotive engine block, the cylinder block, the swashplate, brake blocks, pulleys, and other thermal cracking resistance high wear resistance requirements of die casting is one of the high-silicon aluminium die-casting is currently the most widely used (Goran, 2019). On the other hand, although the resulting product is more efficient,

the raw materials are often expensive (Pooja et al. 2019). Furthermore, the cast ADC14 microstructure consists of coarse αAl, needle shaped eutectic phase and primary silicon, which improve the mechanical properties (Okayasu et al., 2013). Such microstructure characteristics make ADC14 to utilize in numerous applications. However, the use of ADC14 is still restricted due to lower strength as compared to steel for many automobile applications (Yoon-Seok et al., 2020).

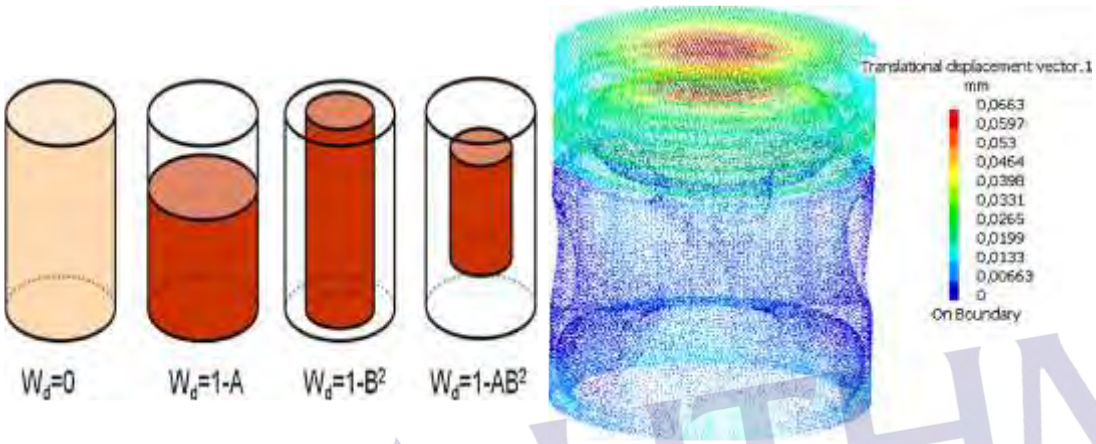


Figure 1.1: Downsize concept and simulation results (Sroka and Dziedzioch, 2015)

The large number of research studies investigating the effect on mechanical and other properties of aluminium alloys have been reported by using the different types of reinforcements like SiC, Al_2O_3, TiB_2 (Surappa, 2003). From these studies, it has been observed that such reinforcement increases the mechanical and thermal properties of the aluminium-based composites (William, 2007). Furthermore, the addition of SiC leads to a decrease in the density of aluminium alloys because of the agglomeration of SiC particles (Sanjeev et al. 2015). Whereas, the mechanical properties could be reduced if SiC added in AlSi alloy beyond than critical values. The addition of SiC beyond critical values form clusters and reduce mechanical properties of AlSi alloy / SiC composite (Don et al. 2016). While, the reduction in density of AlSi / SiC composite is due to difference in density values of matrix and reinforcement (Nuruzzaman and Kamaruzaman, 2016). As SiC is a ceramic material and its addition has a significant effect on the hardness of the matrix and increased hardness owing to the hard nature of ceramic particles. Also, it was revealed that small-sized SiC particles give more hardness than large-sized SiC particles because of fewer defects in the fine-grained structure (Mohammad and Gajendra, 2017). But overall, the addition of SiC increased the mechanical properties of the AlSi alloy based composite (Gourav et al.

2018 and Vijaya et al. 2018). Furthermore; Al_2O_3 (Alumina) is a single crystal material that poses many excellent properties such as high corrosion resistance, high dielectric strength, high thermal conductivity and stability, and high strength and hardness; therefore, it is a preferred material for high-performance systems used in plenty of application in automobile, aerospace, electronics, optics, advanced sensing, and other engineering parts (Kai-Peng et al. 2017). Also, the Al-TiB_2 composite exhibited higher values of hardness, tensile strength, and young's modulus than the base alloy (Suresh et al. 2012 and Derek et al., 2013). Additionally, TiB_2 reinforcement reveals outstanding features such as high melting point (2790 ºC) high hardness (86 HRA or 960 HV) and high elastic modulus (530 x 10^3 GPa) and good thermal stability. TiB_2 is a ceramic particle and does not react with molten aluminium, thereby it avoids the formation of brittle reaction products at the reinforcements-matrix interface (Johny et al. 2014).

In focusing the above facts; a better composite material is the right choice for parts that are directly facing high mechanical and thermal stresses. Furthermore, the importance and attractive characteristics of hypereutectic AlSi alloy demanding research for manufacturing composite reinforced with ceramic materials. Thus in this regard, the modern research attention to the development of new aluminum-based composite for the manufacturing of it. Though the conventional materials are still used, but this is the time to introduce new composite materials based on hypereutectic AlSi alloy and research trend in composite materials.

1.2 Problem Statement

Materials that are most commonly used for manufacturing pistons include cast iron, alloy steel, aluminium-silicon (Al-Si) alloys, an aluminium-copper (Al-Cu) alloys (Tomasz and Piotr, 2015). These alloys are characterized by low density, which is advantageous due to the less weight, and a large thermal conductivity and lower thermal coefficient (Rafsanjani and Rezaeezadeh, 2016). The cast iron and alloy steel can provide higher mechanical properties but they have higher density and are poor in thermal conductivity (heat conduction) during the combustion process (MAHLE GmbH, 2012). Al-Si and Al-Cu alloys have light density and are better in thermal conductivity than but not as strong as the previous materials (steel and cast iron) for

manufacturing piston and other engine parts (Uthayakumar et al., 2008; Ajay and Pushpendra, 2014 and Sheelam and Agrawal 2018). Furthermore, resistance to expansion is a key, as the modern engines are designed with very tight piston and cylinder wall tolerances. Higher expansion and contraction of a piston can result in lower tolerances which decrease the performance, efficiency and increases fuel consumption and leads to a higher amount of exhaust emissions.

The recent advancement in engine technologies such as downsizing engine and others are applied, abnormal combustion phenomenon appears commonly which led to the high amplitude and high-frequency pressure oscillations (Anren et al. 2015). This abnormal combustion phenomenon is alarming to many engine problems including complications for the materials of piston and other engine parts (Heywood, 1998). The best design and material for the automobile piston are the main challenges in the downsizing of the engine (Lee, 2003) and other new engine technologies (Yun-liang et al. 2015). As Sroka and Dziedzioch (2015) found thermal loading (mean effective pressure), mechanical loadings, high levels of stresses in the combustion chamber of the downsize engine. Almost an increment of 41.7% increment in the translation vector displacement and 35.9% in Huber–Mises stress of the downsize engine piston then the normal piston.

These advancements in engine technologies are attractive research areas in automobile engineering, and still various problems generated due to unaccustomed issues like: generation of high-pressure waves cause to fail the piston material prematurely, improper combustion, unwanted exhaust gases, and increment in the usage of fuel. Moreover, despite so significant progress in the engine design, the types of engine failures that can be found are still similar. One of the most frequently occurring engine breakdowns is the failure of the engine pistons due to different causes. These failures are caused by material defects and engineering and operational errors. The most common causes of piston failures include insufficient cooling, insufficient lubrication of the piston guiding part, thermal fatigue of the piston head surface, failures due to an incorrect combustion process, and mechanical damage (Tomasz and Piotr, 2015). But the introduction of proper materials like aluminium-based composites can at least provide solutions for premature failure of piston material due to high-pressure shock waves.

An AlSi alloy that is saturated with silicon is known as “eutectic” (12.3% of Si) and when the alloy contains silicon at a percentage that is less than saturated, it's

called “hypoeutectic” (less than 12.3% of Si) and if contains more silicon that then saturation limit, it's called “hypereutectic” (less than 12.3% of Si). The characteristics of AlSi alloy in each of these categories are very distinct. Hypoeutectic alloys are less strong, less resistant to scuffing and seizure, and cannot withstand to groove wear and cracking of the crown at extremely high temperatures. The lower percentage of silicon cause to reduce the resistance to the expansion and results easily heavily impacts on the piston crown due to thermal forces and heat during combustion. Whereas, hypereutectic alloys are stronger, resist scuffing and seizure, and reduce groove wear and cracking of the crown at extremely high temperatures and the high percentage of silicon essentially provides insulation to the piston from the effects of thermal forces and heat during combustion especially when the engine design and combustion parameters varied/altered. Hypereutectic designs also allow for decreased distance between ring grooves, which improve the "seal" between the rings and the cylinder wall and improves efficiency. Finally, because hypereutectic pistons don't expand or contract, they're ideal for modern engines with tight clearance requirements. Thus, if generally speaking, modern engine pistons must use hypereutectic aluminium alloy. But the main problem is to withstand the high mechanical and thermal stresses generated on account of latest advancement in engine technologies. And to settle this issue, it is prime important to introduce hypereutectic AlSi alloy based composite material. The most common reinforcements are SiC, Al_2O_3, TiB_2, and others. Bu the main challenge in the development of hypereutectic AlSi alloy base composite is to control the microstructure, mechanical, physical, and thermal properties (Lee, 2003). On the other hand, A1Si alloys (hypoeutectic) are still used for piston manufacturing but these alloys are not suitable for high-temperature applications because tensile and thermo-mechanical strengths are not as high as desired in the temperature range of 250°C-350°C. Thus, as based on it, it is prime important to develop hypereutectic AlSi alloys based composite material to endure the better mechanical and thermal properties for the piston, especially; when the design of the engine is modified/changed. And in this context, this research is focusing on the development of ADC 14 hypereutectic AlSi alloy based composite reinforced with SiC, Al_2O_3, and TiB_2.

1.3 Objectives

The ultimate aim of this research is to develop ADC14 hypereutectic AlSi alloy based composite reinforced with SiC, Al_2O_3, and TiB_2 separately. To achieve this ultimate aim of the study, the following objectives are to be done:

i. Development of ADC14 hypereutectic AlSi alloy based composite reinforced with SiC, Al_2O_3, and TiB_2 through stir casting.
ii. To investigate the mechanical, microscopic, physical and thermal properties of ADC14 hypereutectic AlSi alloy based composite reinforced with SiC, Al_2O_3, and TiB_2.
iii. To investigate the mechanical, microscopic, physical and thermal properties of ADC14 hypereutectic AlSi alloy based composite reinforced with Al_2O_3.
iv. To investigate the mechanical, microscopic, physical and thermal properties of ADC14 hypereutectic AlSi alloy based composite reinforced with TiB_2.

1.4 Scope of Study

Al-Si alloys are commonly used for commercial aluminium casting parts and have been utilized extensively in automotive, aerospace, transportation, and defence industries, as they have low weight, good specific strength, good thermal conductivity, good machinability, and excellent corrosion resistance. This research is focused on the development of ADC 14 hypereutectic AlSi alloy based composite material. In light of the above-highlighted objectives, the following is the main scope of the current research:

i. ADC14 hypereutectic AlSi alloy will be used for the development of composite material.
ii. Three reinforcement materials such as SiC Al_2O_3 and TiB_2 were used for fabricating ADC14 hypereutectic AlSi composite.
iii. Stir casting technique will be used for developing composite material.
iv. ASTM standards will be followed for mechanical, physical, and thermal properties.
v. Mechanical properties such as ultimate tensile strength, yield strength, breaking strength, elongation, and hardness will find by using ASTM standards.

vi. Physical properties; experimental density and porosity of the composite will be found through the Archimedean principle.

vii. Thermal properties, coefficient of thermal expansion will be found, however, the thermal conductivity of the composite material will be found on a single temperature.

viii. For microscopic investigation; SEM analysis will be carried out by the following standard.

1.5 Significant of study

This research is conducted to develop ADC14 hypereutectic AlSi alloy based composite reinforce with different ceramic materials such as SiC, Al_2O_3, and TiB_2 through stir casting. The different weight percent of such ceramic materials has been added in ADC14 hypereutectic AlSi alloy. A wide range of research has been conducted on hypoeutectic AlSi alloy reinforced with different ceramic materials, however; very few research was conducted on hypereutectic AlSi alloy reinforced with ceramic materials. As per the best knowledge of author, even such research on hypereutectic AlSi alloy did not discuss well the inclusion of SiC and its effect on mechanical properties. Also, the inclusion of Al_2O_3 and TiB_2 in hypereutectic AlSi alloy did not research yet to a class where any conclusions could be drawn about physical, thermal, and mechanical properties. At the end of this research, three different composite materials will be developed and their property evaluation like mechanical, physical, thermal, and microscopic properties will provide a wide range of knowledge, ideas, and recommendations for the hypereutectic AlSi alloy based composite material. Moreover, in the light of obtained such properties of the ADC14 hypereutectic AlSi alloy based composite, the utilization of hypereutectic AlSi alloy based composite could be differentiated from hypoeutectic AlSi alloy based composites.

1.6 Outline of the thesis

The thesis comprises of five chapters in total. Following this chapter, Chapter 2 is devoted to providing the essential background information to this research work. The literature relevant to this research is also summarized in Chapter 2. Chapter 3, defining the details of the methodology carried out for conducting this research. The details about the method of stir casting carried for producing ADC 14 hypereutectic AlSi alloy reinforced with SiC, Al_2O_3, and TiB_2 composite has been defined. Furthermore, a comprehensive methodology for conducting experimental work to find mechanical, physical, and thermal properties of composite materials. Moreover, details about SEM analysis carried out 2for composite materials have been defined. In chapter 4, the results and discussions have been defined regarding mechanical properties, SEM analysis, physical and thermal properties of the composite materials. It is important to highlight here that, in chapter 4; all the results and discussions have been defined separately for SiC, Al_2O_3, and TiB_2 inclusion in ADC 14 hypereutectic AlSi alloy. Finally, chapter 5 provides conclusions and recommendations based on the obtained results. The conclusions in this chapter have been drawn separately for SiC, Al_2O_3, and TiB_2 reinforcement in ADC 14 hypereutectic AlSi alloy. Finally, the recommendations have been highlighted for future research work related to this current research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The most common material used for automotive pistons is aluminium due to its lightweight, low cost, good wear & corrosion resistance, and acceptable strength. Although other elements may be present in smaller amounts the core alloying element of concern in aluminium for pistons is silicon. The point at which silicon is fully and exactly soluble in aluminium at operating temperatures is around 12%. Either, more or less silicon than 12% will result in two separate phases in the solidified crystal structure of the metal. When significantly more silicon is added to the aluminium than 12%; the properties of the aluminium alloy change in a way that is useful for pistons for combustion engines. However, at a blend of 25% silicon, there is a significant reduction of strength in the metal, so hypereutectic pistons commonly use a level of silicon between 14% and 19%. The other elements such as iron, magnesium, manganese, zinc, etc. are also added within 10% of alloy by weight depending on the kind of aluminium piston alloy (Fayomi et al. 2017).

2.2 Aluminium Piston Alloy

In earlier days, steel and cast iron were mostly used for making pistons due to their high strength. But in the recent times, these both materials are being replaced by aluminium alloys because of the promising properties of aluminium (normally AlSi) alloys over them such as low density, excellent thermal conductivity (Javidani and Larouche, 2014), high strength at elevated temperature (Love et al. 2018), high

strength to weight ratio (Dwivedi, 2010), low thermal expansion coefficient (Alshmri et al. 2014) and excellent corrosion resistance (Feyzullahoğlu et al. 2013) for piston manufacturing. Due to excellent thermal conductivity and low thermal expansion of aluminium-silicon alloys, these alloys can sustain high thermal loads acting during the thermal cycle of combustion of fuel in which temperature of piston and cylinder pair changes from -30 °C in cold winter to 300 °C in a very short interval of time (Javidani and Larouche, 2014). Also due to its low density, aluminium-silicon alloys provide the same strength as provided by cast iron and almost by steel at less weight. This reduces the weight of IC engines and improves the efficiency of automobiles. However, the issue concerning the use of aluminium alloys is the high wear rate and more strength are demanding to withstand high-pressure thermal forces during combustion especially for new combustion technologies.

For piston application, mostly aluminium-silicon alloys are used and generally categorized as hypoeutectic and hypereutectic aluminium-silicon alloys based on silicon wt%. An aluminium and silicon equilibrium diagram is shown in Figure 2.1 (Fayomi et al. 2017).

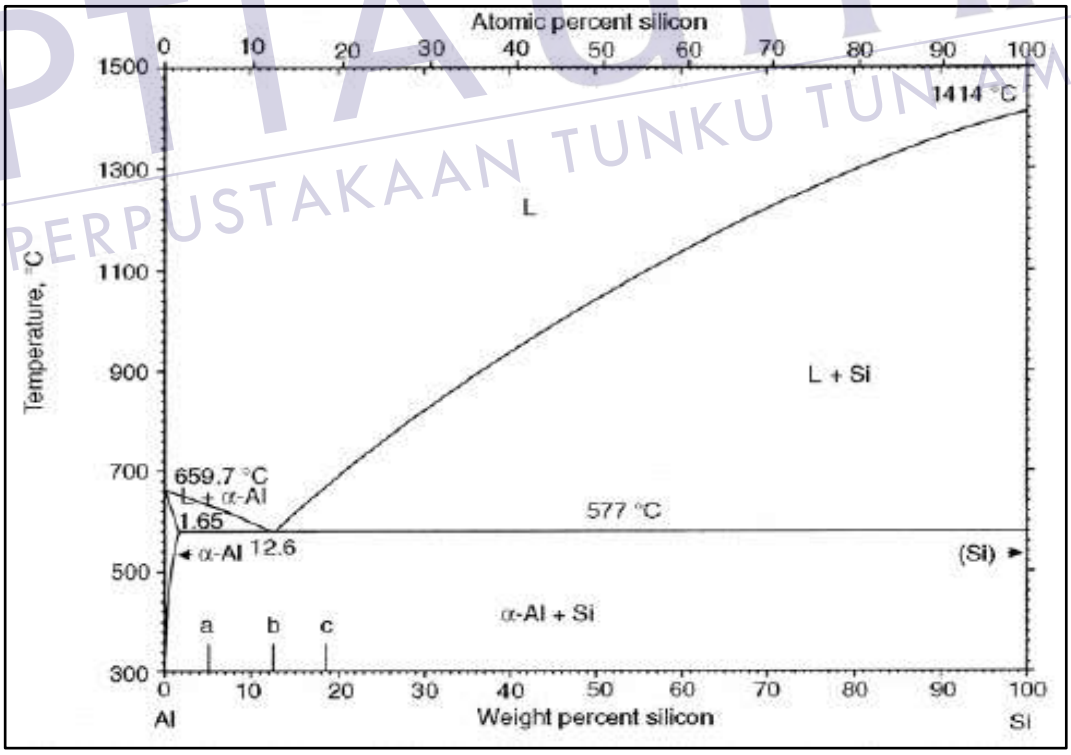
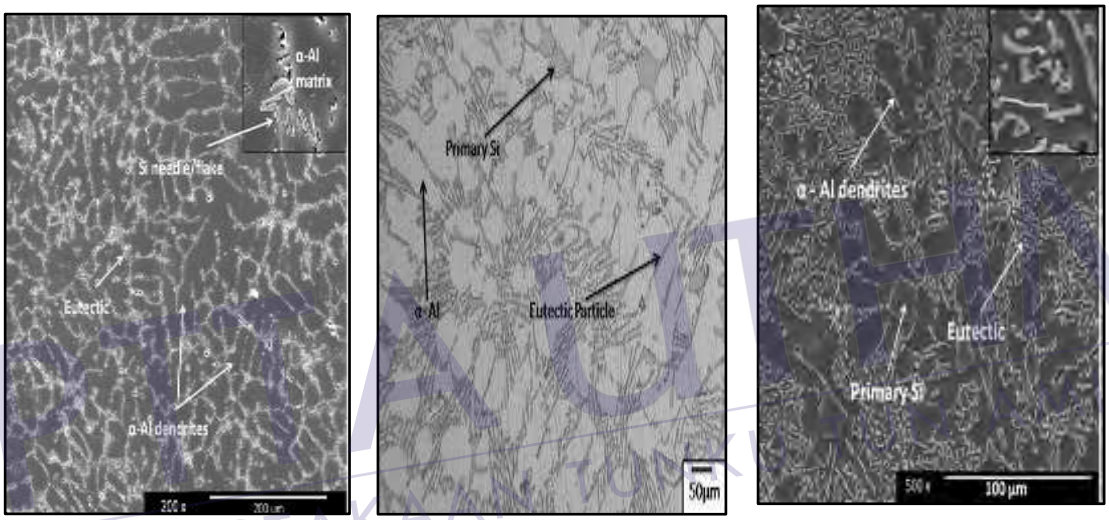


Figure 2.1: Aluminum-Silicon Equilibrium Diagram (Fayomi et al. 2017)

Depending on the Si concentration in weight percent (wt.%), the Al-Si alloy systems fall into three major categories: hypoeutectic (<12% Si), eutectic (12-13% Si)

and hypereutectic (14-25% Si). Typical hypoeutectic aluminum-silicon alloys possess two major microstructural components, namely, aluminum matrix and an aluminum-silicon eutectic. The hypoeutectic Al-Si alloys contain ductile primary Al which forms and propagates dendritically, and a needle-like brittle hard eutectic Si phase as shown in Figure 2.2 (a). Eutectic Al-Si alloys composed of an Al-Si eutectic phase. In eutectic phase, the primary Si has a cuboidal form which can be seen in the micrograph (Figure 2.2 (b)). The eutectic mixture, though, is non-lamellar in form and appears, in section, to consist of separate flakes. Further, hypereutectic alloys normally hold coarse, primary angular Si particles together with a eutectic Si phase (Fayomi et al. 2017) as shown in Figure 2.2 (c).



(a) (b) (c)

Figure 2.2: Microstructure of (a) Hypoeutectic Al-Si alloy (<12% Si), (b) Eutectic Al-Si alloys (12.6% Si) and (c) Hypereutectic Al-Si alloy (>12.6% Si) (Fayomi et al. 2017).

A hypereutectic piston is an internal combustion engine piston cast using a hypereutectic alloy and has a composition beyond the eutectic point. Hypereutectic pistons are made of an aluminium alloy which has much more silicon percent than is soluble in aluminium at the operating temperature. Hypereutectic aluminium has a lower coefficient of thermal expansion, which allows engine designers to specify much tighter tolerances. They are not as strong as forged pistons but are much lower cost due to being cast. Hypereutectic pistons are stronger than most common cast aluminium pistons and used in many high-temperature applications and advanced combustion technologies. In recent years, the development of diesel and direct fuel

injection gasoline engines with high specific powers has resulted in a big performance impact on piston materials due to increased combustion pressures and piston temperatures.

Table 2.1: Chemical Composition of Hypoeutectic, Eutectic, and Hypereutectic AlSi Alloys (Aluminium Association Incorporation, 2013 and International Alloy Designations, 2001).

Al-Si Alloys		**Chemical Components (wt%.)**									
		Si	**Fe**	**Cu**	**Mg**	**Ni**	**Zn**	**Ti**	**Mn**	**Cr**	**Al**
Hypoeutectic AlSi Alloys	**2024**	0.5 Max:	0.5 Max:	3.8-4.9	1.2-1.8	-	0.25 Max:	0.15 Max:	0.3-0.9	0.1 Max:	Bal
	2618	0.10-0.25	0.9-1.3	1.9-2.7	1.3-1.8	0.9-1.2	≤0.10	0.04-0.1	-	-	Bal
	6061	0.4-0.8	0.7 Max:	0.15-0.4	0.8-1.2	-	0.25 Max:	0.15 Max:	0.15 Max:	0.04-0.35	Bal
	7075	0.4 Max:	0.5 Max:	1.2-2	2.1-2.9	-	5.1-6.1	0.2 Max:	0.3 Max:	0.18-0.28	Bal
	A319	5.5-6.5	0.1 Max:	3-4	0.1 Max:	0.35 Max:	1.0 Max:	0.25 Max:	0.5 Max:	-	Bal
Eutectic AlSi Alloy	**AC8A**	11-13	≤0.8	0.8-1.3	0.7-1.3	-	≤0.15	-	≤0.15	-	Bal
	4032	11-13.5	1.0 Max:	0.5-1.3	0.8-1.3	0.5-1.3	0.25 Max:	-	-	0.1 Max:	Bal
Hypereutectic AlSi Alloy	**B390**	16-18	1.3 Max:	4-5	0.45-0.65	0.1 Max:	1.5 Max:	0.1 Max:	0.5 Max:		Bal
	A390	16-18	0.5 Max:	4-5	0.45-0.65	-	0.1 Max:	0.2 Max:	0.1 Max:	-	Bal
	ADC14	17-18	0.75-1.0	4-5	0.50-0.65	≤ 0.30	≤ 1	≤0.10	≤0.50	-	Bal

Most of the AI-Si cast alloys to date are intended for applications at temperatures of not higher than about 121°C. Above this temperature, the alloy's microstructure strengthening mechanisms will become unstable, rapidly coarsen and dissolve resulting in an alloy having an undesirable microstructure for high-temperature applications. Such alloys have little practical application at elevated temperatures because the alloy lacks the coherency between the aluminium solid solution lattice and the precipitated strengthening particles (Belov et al. 2005 and Robles and Sokolowski, 2006). However; the most common AlSi alloys used for piston manufacturing are shown in Table 2.1 along with their chemical compositions (Aluminium Association Incorporation, 2013 and International Alloy Designations, 2001).

The main mechanical, thermal and physical properties of such AlSi piston alloys are shown in Table 2.2 and Table 2.3.

Table 2.2: Hypereutectic and Eutectic AlSi Alloys Characteristics (Aluminium Association Incorporation, 2013).

Characteristics	**Hypereutectic AlSi Alloys**			**Eutectic AlSi Alloy**	
	A390	**B390**	**ADC14**	**4032-T6**	**AC8A-T6**
Ultimate Tensile Strength (MPa)	190-290	320	260	390	250-320
Tensile Strength, Yield (MPa)	190-290	250	258	320	190-300
Hardness, Vickers	110-140	130-160	135	120	110-130
Thermal Conductivity (W/m-K)	130	130	134	140	120
CTE, linear (µm/m-°C)	20	20	19	19	19
Density (g/cm^3)	2.7	2.8	2.6	2.6	2.8

Table 2.3: Hypoeutectic AlSi Alloys Characteristics (International Alloy Designations, 2001).

Characteristics	**Hypoeutectic AlSi Alloys**				
	2024-T3	**2618-T61**	**6061-T6**	**7075-T6**	**A319**
Ultimate Tensile Strength (MPa)	483	441	310	572	190-240
Tensile Strength, Yield (MPa)	345	372	276	503	110-180
Hardness, Vickers	137	130	107	175	78-84
Thermal Conductivity (W/m-K)	121	164	167	130	110
CTE, linear (µm/m-°C)	24.7	22.3	25.2	25.2	22
Density (g/cm^3)	2.78	2.76	2.7	2.81	2.9

2.3 Alloying Elements

Mostly Al-Si alloy is used for the manufacturing of piston because of having low density, high specific strength, and low coefficient of thermal expansion, excellent wear, and corrosion resistance. These properties can be further improved by varying the amount of other alloying elements (Cu, Mg, Zn, Ni, Mn) (Aqeel et al., 2016).

2.3.1 Addition of Silicon

It is determined that above 230 ºC, the Al-Si alloy microstructure will be unstable, and the desired properties will be reduced. Si is the main ingredient of the Al-Si alloy to achieve better mechanical properties and varying the distribution and particle size will affect the mechanical properties. The mechanical properties like micro-hardness may increase when Si dissolved in the α-Al matrix (Zou et al. 2015). The effect of the Si content on the mechanical properties is depicted in Figure 2.3.

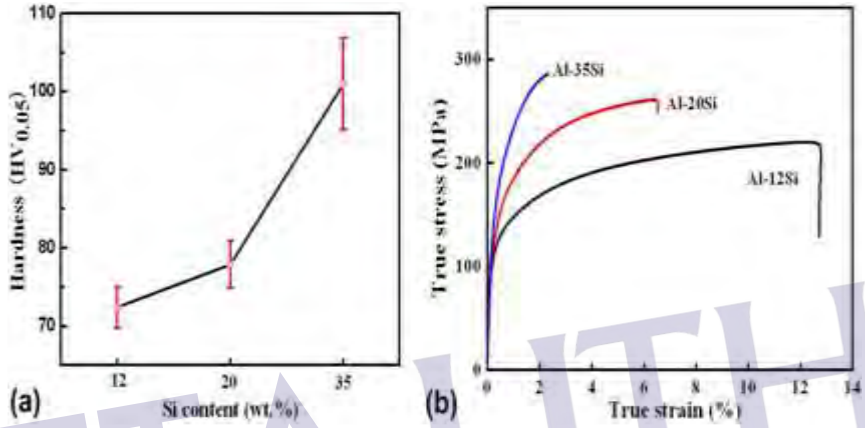


Figure 2.3: Mechanical properties of the three different Al-Si alloys: (a) Hardness data, (b) tensile strain–stress curves (Ma et al. 2017).

Table 2.4: Tensile Properties of Al-Si Alloys after Hot Extrusion (Ma et al. 2017).

Alloy	UTS (MPa)	YS (MPa)	δ (%)
Al–12Si	219.8 ± 1.8	127.5 ± 1.1	12.1 ± 0.8
Al–20Si	261.5 ± 2.1	173.2 ± 1.5	5.8 ± 0.1
Al–35Si	287.5 ± 2.7	199.4 ± 1.6	1.2 ± 0.1

Both the hardness and the tensile strength increase significantly with increasing Si content. The hardness values are found to be 72.4 ± 0.4 HV0.05, 77.9 ± 0.5 HV0.05, and 101 ± 0.7 HV0.05 for Al–12Si, Al–20Si, and Al–35Si alloys, respectively (Ma et al. 2017). The tensile property results showed in Table 2.4 in the form of true stress-strain curves. As observed, the ultimate tensile strength (UTS) and the yield strength

(YS) of these alloys increase with increasing Si content, whereas the elongation shows an adverse trend (Ma et al. 2017).

2.3.2 Addition of Copper

Copper has the influence to affect the hardness and strength of aluminium piston alloy at either heat treated or non-heat treated and also at ambient or at elevated temperature. Copper also increases the hardness and cause improvement in the machinability of the aluminium piston alloy (Yang et al. 2011).

2.3.3 Addition of Magnesium

The next element Mg in the aluminium piston alloy provides a considerable strength and also improves the work hardening characteristics. Mg also imparts good corrosion resistance, provides extremely high strength, and cause good weldability. The addition of Si and Mg together in the aluminium piston alloy improves the weldability, however; the maximum addition of Mg can be 4-8 wt% because of good thermo-mechanical properties (Yang et al. 2011).

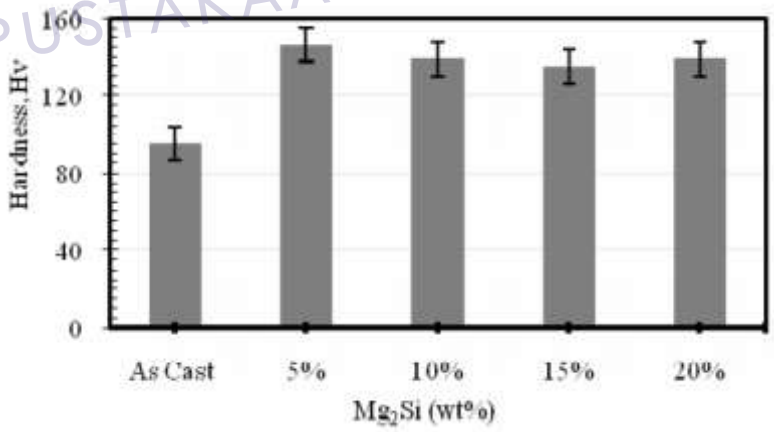


Figure 2.4: The micro hardness of as-cast and Mg_2Si (p)/AA332 Composite (Fizam et al. 2016).

Figure 2.4 depicts the hardness values of the alloy due to the addition of Mg_2Si together, it can be seen that the maximum value of the hardness achieved at 5 wt% of it (Fizam et al. 2016).

2.3.4 Addition of Nickel

Nickel causes to improve the hardness and other mechanical properties of aluminium piston alloy. Figure 2.5 shows the mechanical properties and tensile stress-strain curves of squeeze cast alloys at different temperatures.

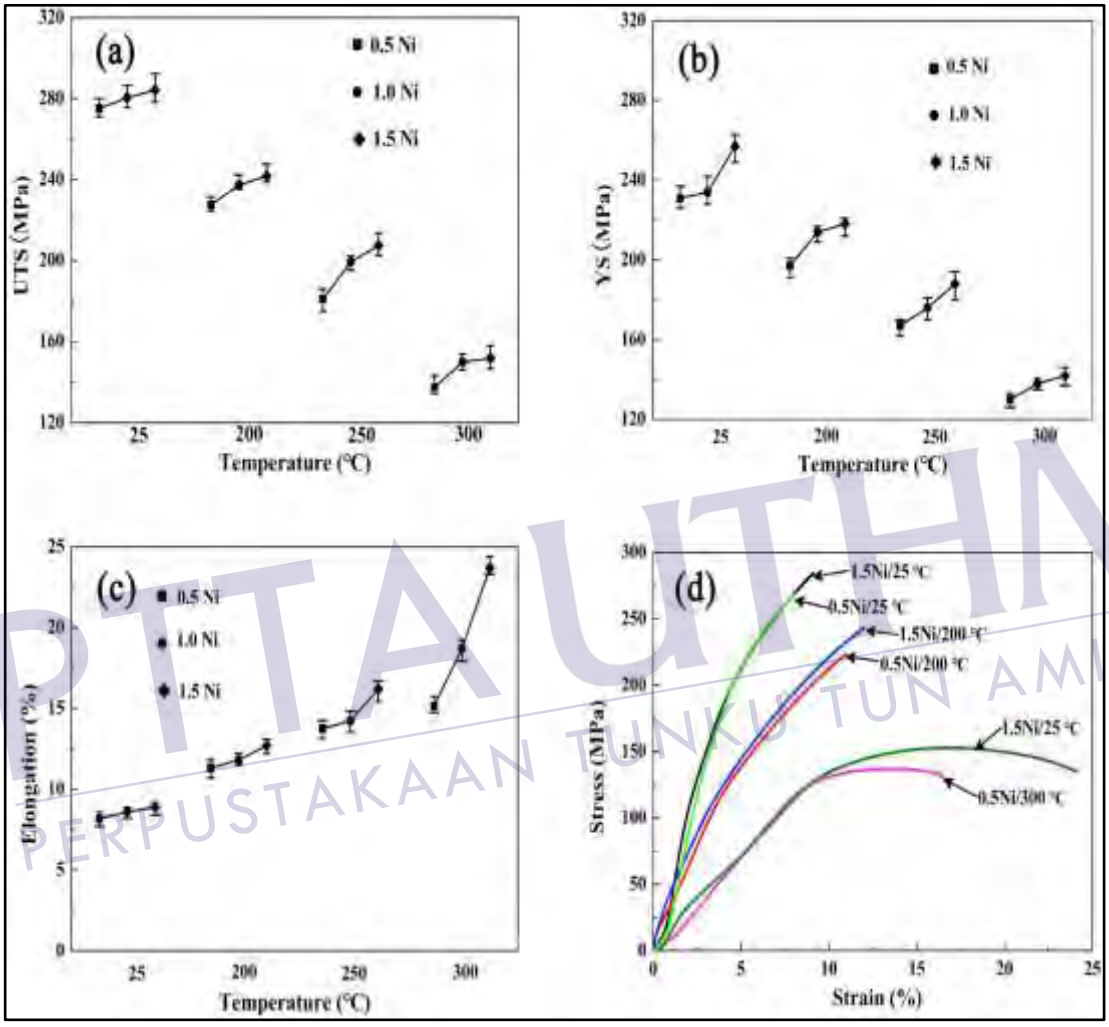


Figure 2.5: Mechanical properties of squeeze cast alloys at different temperatures: (a) UTS; (b) YS; (c) EL; (d) Tensile stress-strain curves (Bo et al. 2019).

The strength decreased and elongation increased as the tensile temperature increased. Both strength and elongation at room temperature and elevated temperatures increased with an increase in Ni content from 0.5% to 1.5%. At an elevated temperature of 300 °C, the squeeze cast 1.5 Ni alloy had tensile properties that were superior to those of the 0.5 Ni alloy, especially in terms of elongation. UTS, YS, and ductility of the squeeze cast 1.5 Ni alloy at 75 MPa were recorded as 152 MPa, 142 MPa, and 23.7%, respectively. These values correspond to increases of 16

MPa, 12 MPa, and 56%, respectively, compared to the respective values for the 0.5 Ni alloy (Bo et al. 2019).

Figure 2.6 shows the micro-hardness of the squeeze cast alloys with different Ni contents and temperatures. The micro hardness of the α (Al) matrix increases gradually with an increase in Ni content at the same tensile load temperature.

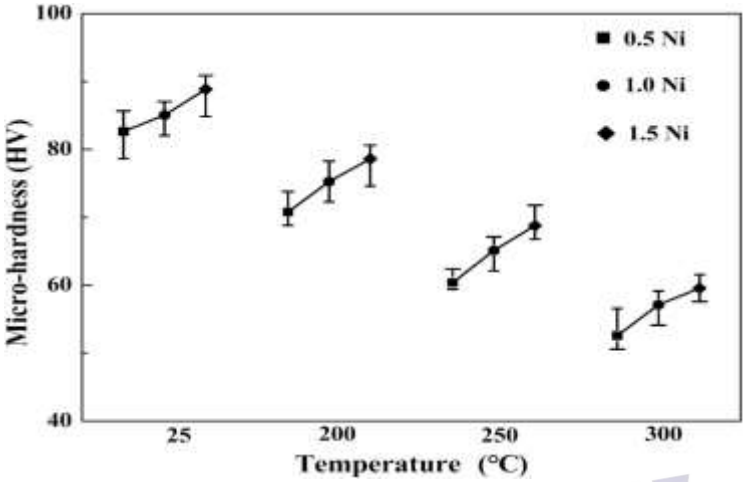


Figure 2.6: Micro-hardness of the squeeze cast alloys with different Ni contents and temperatures (Bo et al. 2019).

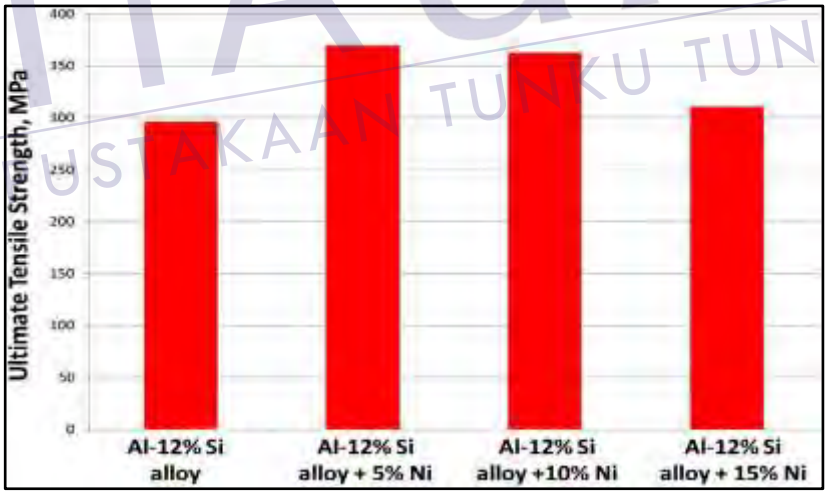


Figure 2.7: Effect of Ni particle addition on ultimate tensile strength (UTS) of produced composite materials (Labban et al. 2014)

The increase in micro hardness of the α (Al) matrix with an increase in Ni content can be attributed to the increment in $Al_{20}Cu_2Mn_3$ in the α (Al) matrix (Bo et al. 2019). Thus, Ni addition can increase the mechanical properties but as per Labban et al. (2014), the higher percentage addition of Ni reduces the UTS as shown in Figure 2.7. The maximum value of UTS achieved at 5% of Ni.

2.3.5 Addition of Iron

Iron is added to some pure alloys to provide the increment in strength which is the most common impurity found in aluminium alloys. Though the quantity of iron in aluminium piston alloys is less than 1% by weight, it provides enough strength to sustain pressure generated during combustion.

Moreover; generally, discussion on other alloying elements, titanium is added to aluminium alloy to serves as a grain refiner. Titanium is a common addition to aluminium weld filler wire as it refines the weld structure and helps to prevent weld cracking. The fine precipitate of intermetallic particles that inhibit recrystallization is produced when Zirconium is added to aluminium (Fayomi et al. 2017).

2.4 Aluminium Alloy and Reinforcement Elements

Aluminium alloys have high corrosion resistance, high thermal conductivity, sufficient strength characteristics, recyclability, ductility, durability, and especially low density (Campbell, 2015; Tan et al. 2015 and Yuksel et al. 2016). Therefore, it can be widely used in many areas of industry such as aerospace, architectural construction, marine industries, and particularly in automotive applications (Al Hawari et al. 2014). Nowadays, especially in the automotive industry, demands are increasing day by day and aluminium piston alloys do not satisfy in some cases. So that the production industry has begun to look for alternative engineering materials.

One of the engineering materials is composite. Composite materials consist of two or more materials. One of these materials is called reinforcement and the other one is called the matrix (Kandpal et al. 2014). Fibers, particulates or whiskers are examples of reinforcements and metals, plastics or ceramics are examples of the matrix material. In metal matrix composites systems, aluminium and its alloys have been drawn attention especially for the last 20 years (Garg et al. 2012; Kandpal et al. 2014 and Ramnath et al. 2014). Silicon carbide (SiC), aluminium oxide (Al_2O_3), titanium di-boride (TiB_2), boron carbide (B_4C), zirconium, and some more are the most commonly used reinforcements (Ramnath et al. 2014). In this research work; the literature was reviewed about aluminium metal matrix composites in which SiC, Al_2O_3, and TiB_2 used as reinforcements materials.

2.4.1 Aluminium Metal Matrix Composite with SiC

SiC is one of the most researched reinforcement materials, many research has pointed out its merits with many ferrous and non-ferrous metals. Although the SiC is denser than AlSi piston alloys which cause difficulty to reinforce for metal matrix composite, powder metallurgy, stir casting and few more casting techniques can provide the solution for such difficulty. Prabu et al. (2006) studied the effect of different stirring speeds at 500, 600, and 700 rpm and durations of 5, 10, and 15 minutes for aluminium metal matrix composite with 10 wt% SiC with an average particle size of 60 µm. They determined that the stirring speed and time causes clustering of SiC particles and got better distributions of reinforcement material after 10 minutes and stirring at 600 rpm as shown in Figure 2.8.

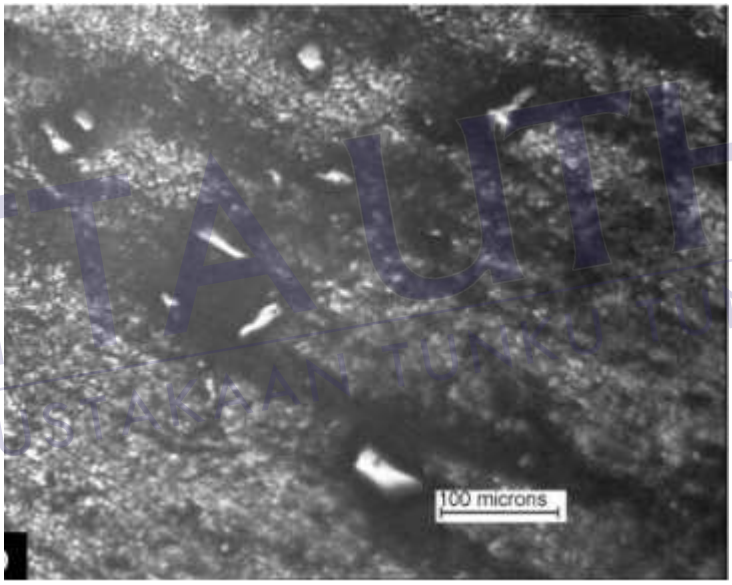


Figure 2.8: Microstructure of Al–10% SiCp MMC fabricated at 600 rpm with 10 min (Prabu et al. 2006)

Their research shows that the hardness value of composite is non-uniform for short stirring time and speed such as 5 minutes and 500 rpm respectively. The same conclusions were drawn at higher speed such as 700 rpm. Thus, they determined that mechanical properties can be directly affected by stirring speed and time. They concluded that better hardness of composite could be obtained at 10 minutes stirring time and 600 rpm stirring speed as shown in Figure 2.9 and 2.10.

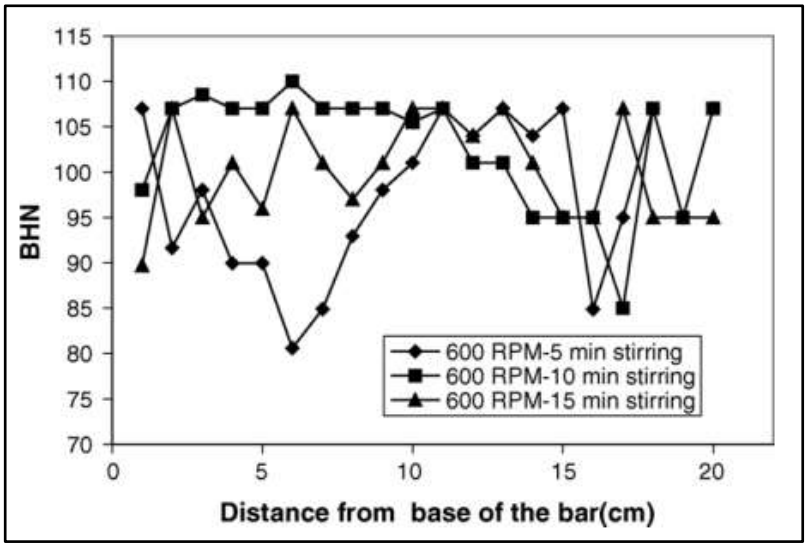


Figure 2.9: Effect of stirring time on the hardness of Al–SiC MMC fabricated at 600 rpm (Prabu et al. 2006).

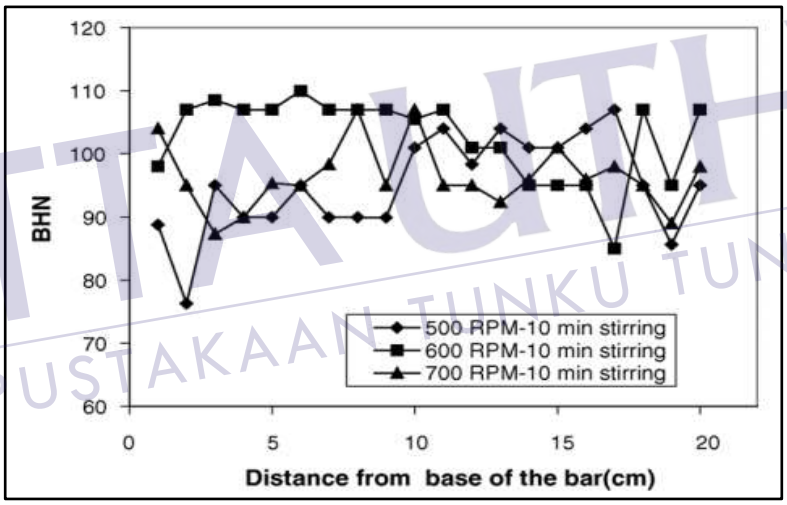


Figure 2.10: Effect of stirring speed on the hardness of Al–SiC MMC fabricated at 10 min stirring (Prabu et al. 2006).

Ozben et al. (2008) studied the mechanical properties of aluminium metal matrix composite with different ratios: 5, 10, and 15% wt% of SiC reinforced. They obtained maximum hardness as 65 HB with 15 wt% SiC as shown in Figure 2.11. However, they determined that maximum tensile strength obtained in 10 wt% SiC as shown in Figure 2.12 and over this interface bond between particles and matrix was inadequate. They concluded that increasing of reinforcement ratio improves mechanical properties such as hardness but tensile strength indicated different properties for the same reinforced additives.

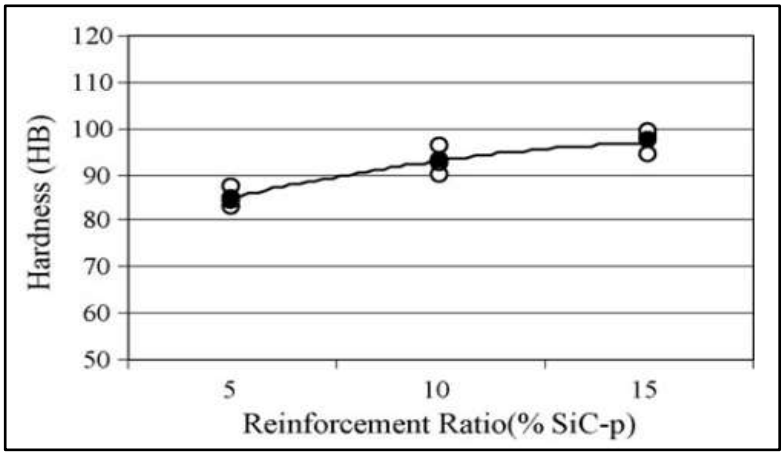


Figure 2.11: Brinell hardness values of composite material (Ozben et al. (2008)

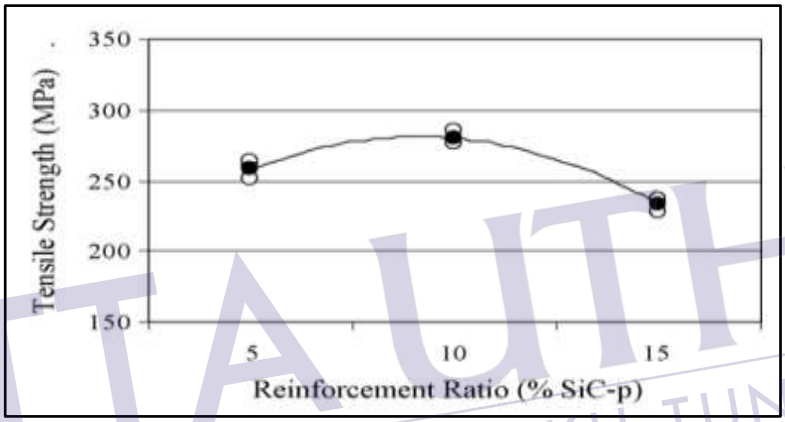


Figure 2.12: Tensile strength values of composite material (Ozben et al. (2008)

Singla et al. (2009) studied the effect of different amounts of SiC (5%, 10%, 15%, 20%, 25%, and 30% wt) on the hardness and other mechanical properties. They used preheated aluminium scraps at 450 ºC for 3-4 hours and preheated SiC particles at 1100oC for 1-3 hours and applied two steps of the stirring process. At first step, they heated aluminium scraps above the liquidus then cooled just below liquidus to get semi-solid state then added SiC particles and mixed manually. At the second step, they reheated and stirred by automatic stirrer. They came to the conclusion that the hardness increase by increasing in weight percentage of SiC and obtained maximum hardness as 45.5 BHN with a 25% weight fraction of SiC as shown in Figure 2.13.

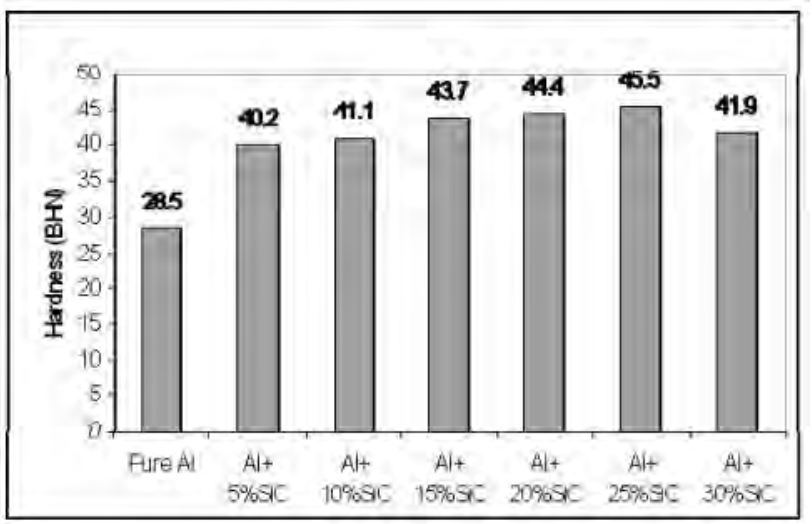


Figure 2.13: Comparative bar chart (Hardness) (Singla et al. (2009).

Sujan et al. (2012) investigated both Al_2O_3 and SiC reinforced aluminum matrix composite by stir cast method. They used different weight fraction of SiC such as 5, 10, and 15% and determined that hardness and tensile strength increased 30, 45, and 50 HR and 258.8, 293.3 and 310.5 MPa, respectively as shown in Table 2.5.

Table 2.5: Hardness and Tensile Strength of Metal Matrix Composites of Different Compositions (Sujan et al. (2012)

Composition with SiC wt%	**Rockwell Hardness (HR)**	**Brinell Hardness (HB)**	**Tensile Strength (MPa)**
Al with 5%SiC	30.0	75.0	258.8
Al with 10%SiC	45.0	85.0	293.3
Al with 15%SiC	50.0	90.0	310.5

Meena et al. (2013) investigated SiC reinforced aluminium with different weight fractions (5, 10, 15, and 20%) and particle size (220, 300, and 400 mesh) by using the melt stir technique. They determined that the hardness and tensile strength were increased but elongation at fracture was decreased by increasing reinforced weight fraction as shown in Figure 2.14 to 2.16 respectively.

REFERENCES

Abdulhaqq A. H, Ghosh. P. K, Jain. S. C and Ray. S. (2008). The influence of porosity and particles content on dry sliding wear of cast in situ Al(Ti)–Al2O3(TiO2) composite. *Wear,* 265 (1–2), 14–26.

Ajay R. S, Dr. Pushpendra. K. S. (2014). Design, Analysis and Optimization of Three Aluminium Piston Alloys Using FEA. *Journal of Engineering Research and Applications*, 4 (1), 94-102.

Akeel D. S and Hussein N. A. (2018). Effect of Al2O3 Particles and Precipitation Hardening on the Properties of Cast 332 Aluminium Alloy. *Al-Khwarizmi Engineering Journal*, 14 (4), 125- 132.

Aksoz S, Ocak Y, Maras N, Cadirli E, Kaya H and Boyuk U. (2010). Dependency of the thermal and electrical conductivity on the temperature and composition of cu in the al based al–cu alloys. *Experimental Thermal and Fluid Science*, 34 (8), 1507–1516.

Al Hawari, A., Khader, M., Hasan, W., Alijla, M., Manawi, A.W., and Benamour, A. (2014). A Life Cycle Assessment (LCA) of Aluminium Production Process. *World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 8*, 704-710.

Alaneme. K and Aluko. A. O. (2012). Production and age hardening behavior of borax premixed SiC reinforced Al-Mg-Si alloy composites developed by double stir casting technique. *The West Indian Journal of Engineering*, 34 (1-2), 80 – 85.

Alaneme, K. and Bodunrin, M. (2013). Mechanical Behaviour of Alumina Reinforced AA 6063 Metal Matrix Composites Developed by Two Step-Stir Casting Process. *Acta Technica Corviniensis-bulletin of Engineering*, 6(3), 105-110.

Alaneme. K and Sanusi. K. (2015). Microstructural Characteristics, Mechanical and Wear Behaviour of Aluminium Matrix Hybrid Composites Reinforced with

Alumina, Rice Husk Ash and Graphite. *Engineering and Science Technology International Journal*, 18 (3), 416–422.

Alshmri, F., Atkinson, H. V., Hainsworth, S. V., Haidon, C., and Lawes, S. D. A. (2014). Dry Sliding Wear of Aluminium-High Silicon Hypereutectic Alloys. *Wear*, 313 (1–2), 106–116.

Aluminum Standards and Data, Aluminium Association Incorporation. (2013). *Aluminium Alloys*. https://www.makeitfrom.com/material-group/Aluminum-Alloy. Cite on March, 2020.

Angadi. B. M, Hiremath. C. R, Reddy. A. C, Katti. V. V and Kori.S.A. (2014). Studies on the Thermal Properties of Hypereutectic Al–Si Alloys by Using Transient Method. *Journal of Mechanical Engineering Research and Technology*, 2 (1), 536-544.

Anilkumar H.C, Hebbar H.S and K.S Ravishankar. (2011). Mechanical properties of fly ash reinforced aluminium alloy (Al6061) composites. *International Journal of Mechanical and Materials Engineering*, 6 (1), 41-45.

Anne Z. S., Nadella. S, Donanta. D, and Budi. W. U. (2018). The effect of nano-SiC on characteristics of ADC12/nano-SiC composite with Sr and TiB_2 addition produced by stir casting process. *AIP Conference Proceedings 1964, 020024*. doi: 10.1063/1.5038306.

Anren. Y, Han. X and Chunde. Y. (2015). Analysis of pressure waves in the cone-type combustion chamber under SI engine knock. *Energy Conversion and Management,* 96, 146–158.

Anupama. H and Joel. H. (2017). Experimental Evaluation of the Coefficient of Thermal Expansion of Chilled Aluminium Alloy-Borosilicate Glass (P) Composite. *Journal of Materials and Environmental Sciences*, 8 (12), 4246-4252.

Aqeel A, Wahab. M. S, Raus. A. A, Kamarudin. K, Qadir. B and Ali. D. 2016. Mechanical Properties, Material and Design of the Automobile Piston: An Ample Review. *Indian Journal of Science and Technology*, 9 (36), 1-7.

Aqeel A, Wahab. M. S, Raus. A. A, Kamarudin. K, Qadir. B and Ali. D. 2016. Thermal Effect on the Automobile Piston: A Review. *Indian Journal of Science and Technology*, 9 (36), 1-5.

Azadi M and Shirazabad M.M. (2013). Heat treatment effect on thermo-mechanical fatigue and low cycle fatigue behaviours of A356.0 aluminium alloy. *Materials and Design*, 45, 279–285.

AZoM. (2009). *Properties of Titanium Di-boride (TiB2) For Machining*. https://www.azom.com/article.aspx?ArticleID=5069. Cite on March, 2020.

Belov. N. A and Eskin. D. G and Avxentieva. N.N. (2005). Constituent phase diagrams of the Al–Cu–Fe–Mg–Ni–Si system and their application to the analysis of aluminium piston alloys, *Acta Materialia*, 53 (17), 4709–4722.

Bharath V., Mahadev N., V. Auradi. (2012). Preparation Characterization and Mechanical Properties of Al2O3 reinforced 6061 Al. Particulate MMCs. *International Journal of Eng. Research and Technology*, 1 (6),1-6.

Bhatia R. S and Kudlipsingh. (2017). An experimental analysis of aluminium metal matrix composite using Al2O3/B4C/Gr particles. *International Journal of Advanced Research in Computer Science*, 8 (4), 83-90.

Bo. L, Wenxin. Z, Xiaoping. Z, Yuliang. Z, Zhaohui. L and Weiwen. Z. (2019). Developing high performance mechanical properties at elevated temperature in squeeze cast Al-Cu-Mn-Fe-Ni alloys. *Materials Characterization*, 150, 128–137.

Cai. Z, Li. F, Rong. M, Lin. L, Yao. Q, Huang. Y, Chen. X and Wang. X. (2019). Chapter 1 – Introduction, *Novel Nanomaterials for Biomedical, Environmental and Energy Applications, Micro and Nano Technologies*, 1-36.

Campbell, J. (2015). *Complete Casting Handbook: Metal Casting Processes, Metallurgy, Techniques and Design*. Elsevier Science.

Cao. R, Jiang. J. X, Wu. C and Jiang. X. S. (2017). Effect of addition of Si on thermal and electrical properties of Al-Si-Al2O3 composites. *IOP Conference Series: Materials Science and Engineering 213*, 012001.

Ceschini L, Morri A and Sabatino M. D. (2015). Effect of thermal exposure on the residual hardness and tensile properties of the EN AW-2618A piston alloy. *Materials Science and Engineering A*, 639, 288–97.

Chawla N and Shen Y. (2001). Mechanical Behaviour of Particle Reinforced Metal Matrix Composites. *Advanced Engineering Materials*, 3 (6), 357 – 370.

Chen. C, Zhang. G. L and Yu. H. S. (2012). The microstructure and thermal conductivity of the high volume fraction of SiCp/Al-Si Composites. *Functional Material*, 19, 102-6.

Dam K, Prusa F, Vojtech D. (2014). Structural and Mechanical Characteristics of the Al–23Si–8Fe–5Mn Alloy Prepared by Combination of Centrifugal Spraying and Hot Die Forging. *Materials Science and Engineering A*, 610, 197–202.

Derek S. K, William G. F. and Greg E. H. (2013). Silicon Carbide-Titanium Di-Boride Ceramic Composites. *Journal of the European Ceramic Society,* 33 (15-16), 2943-2951.

Devi, C.N., Selvaraj, N., and Mahesh, V. (2012). Micro Structural Aspects of Aluminium Silicon Carbide Metal Matrix Composite. *International Journal of Applied Science and Engineering Research,* 1, 250-254.

Dinesh K. K, Geeta. A and Rajesh. P. (2015). Advanced Aluminum Matrix Composites: The Critical Need of Automotive and Aerospace Engineering Fields. *Materials Today: Proceedings,* 2, 3032 – 3041.

Dobrzanski L.A, Kremzer M. and Nagel A. (2007). Aluminium EN Al-SiC Alloy Matrix Composite Reinforced by Al2O3 Preform. Achieves of Materials Science and Engineering, Volume 28, Issue 10, 2007, Pp 593-596.

Don. H, David. T, Andrew. T, Jeffrey. C and Charles. P. (2016). Discontinuously Reinforced Aluminum MMC Extrusions. *Metal Powder Report,* 72 (4), 252-258.

Dwivedi, D. K., 2010. Adhesive Wear Behaviour of Cast Aluminium-Silicon Alloys: Overview. *Materials Design (1980-2015)*, 31 (5), 2517–2531.

Dwivedi, S.P., Sharma, S. and Mishra, R.K. (2014). Comparison of Microstructure and Mechanical Properties of A356/SiC Metal Matrix Composites Produced by Two Different Melting Routes. *International Journal of Manufacturing Engineering*, Vol 2014, 1-13.

El Mahallawi, I. Shah, Egenfeld. K, Kouta, F. H, Hussein. A, Mahmoud. T. S, Rashad. R. M, Shash. A. Y and Abou-AL-Hassan W. (2008). Synthesis and Characterization of New Cast A356/(Al2O3) p Metal Matrix Nano- Composites. *In Proceedings of the 2nd Multifunctional Nanocomposites & Nanomaterials: International Conference& Exhibition MN2008, Cairo, Egypt*, 11–13 January 2008.

El Mahallawi. I, Shash. Y, Rashad. R. M, Abdelaziz. M. H, Mayer. J and Schwedt. A. (2014). Hardness and Wear Behaviour of Semi-Solid Cast A390 Alloy Reinforced with Al2O3 and TiO2 Nanoparticles. *Arabian Journal of Science and Engineering*, 39 (6), 5171–5184.

El-Kady, O. and Fathy, A., (2014). Effect of SiC particle size on the physical and mechanical properties of extruded Al matrix nanocomposites. Materials & Design (1980-2015), 54, 348-353.

El-Mahallawi, I, Abdelkader. H, Yousef. L, Amer. A, Mayer. J and Schwedt. A. (2012). Influence of Al2O3 nano-dispersions on microstructure features and mechanical properties of cast and T6 heat-treated Al Si hypoeutectic alloys. *Material Science and Engineering A*, 556, 76–87.

El-Mahallawi. I, Shash. Y, Eigenfeld. K, Mahmoud. T, Rashad. R, Shash. A and El Saeed. M. (2010). Influence of Nano-dispersions on Strength Ductility Properties of Semi-Solid Cast A356 Al Alloy. *Material Science and Technology*, 26, 1226–1231.

Fathy A and El-Kady O. (2013). Effect of SiC particle size on the physical and mechanical properties of extruded al matrix nanocomposites. *Materials Design,* 54, 348–353

Fayomi, O. S. I, Popoola, A. P. I. and Udoye. N. E. (2017). Effect of Alloying Element on the Integrity and Functionality of Aluminium-Based Alloy. *In: Aluminium Alloys – Recent Trends in Processing, Characterization, Mechanical behaviour and Applications. INTECH.*

Fei. X and Zhong-hua. X. (2013). Characterizing an in situ TiB2 particulates reinforced aluminium based composite and its heat treatment. *In: International Federation for Heat Treatment and Surface Engineering 20th Congress Beijing, China*, *23-25 October 2012. Physics Procedia 50*, 13 – 18.

Feyzullahoğlu, E., Ertürk, A. T., and Güven, E. A. (2013). Influence of Forging and Heat Treatment on Wear Properties of Al-Si and Al-Pb Bearing Alloys in Oil Lubricated Conditions. *Transaction of Nonferrous Metals Society of China (English Ed.)*, 23(12), 3575–3583.

Fizam. Z, Khairel. R. A and Ruslizam. D. (2016). The effects of Mg2Si(p) on microstructure and mechanical properties of AA332 composite. *Advances in Materials Research*, 5 (1), 55-66.

Garg. H.K, Verma. K, Mana. A and Kumar. R. (2012). Hybrid Metal Matrix Composites and further Improvement in their Machinability-A Review. *International Journal of Latest Research in Science and Technology*. 1(1), 36-44.

Goran D. 2019. *Aluminium Alloys in the Automotive Industry: A Handy Guide. Report in Aluminium Insider.* https://aluminiuminsider.com/aluminium-alloys-automotive-industry-handy-guide/.

Gourav. G, Pranav. K, Ankush. R and Mir. I. U. (2018). Effect of SiC reinforcement on mechanical behaviour of aluminium alloys – A review. *AIP Conference Proceedings 2006, 030051*. doi: 10.1063/1.5051307.

Graca. S, Trababdelo. V, Neels. A, Kuebler. J, Nader. V. L, Gamez. G, Dobeli. M and Wasmer. K. (2014). Influence of mosaicity on the fracture behaviour of sapphire. *Acta Material*, 67 67-80.

Gu. Z, Sen. W. S, Ping. A, Wu. M. Y and Zha. L. S. (2010). Microstructure and Properties of High Silicon Aluminium Alloy with 2% Fe Prepared by Rheo-Casting. *Transaction of Nonferrous Metals Society China*, 20 (9), 1603−7.

Hanim M. A. A, Chung S. C, Chuan O. K. (2011). Effect of a two-step solution heat treatment on the microstructure and mechanical properties of 332 aluminium silicon cast alloy. *Materials and Design,* 32 (4), 2334–8.

Hashim J. (2001). The production of cast metal matrix composite by a modified stir casting method. *Journal Teknologi*, 35 (1).

Hassan. S, Vahid. E, Morteza. T, Amirreza. K and Ermia. A. (2017). Effect of SiC particles on thermal conductivity of Al-4%Cu/SiC composites. *Heat Mass Transfer*, 53, 3621–3627.

Heywood JB. (1988). *Internal combustion engine fundamentals 1988*. New York: McGraw-Hill.

Himanshu. K, Mer. K. K. S and Kumar. S. (2014). A Review on Mechanical and Tribological Behaviours of Stir Cast Aluminium Matrix Composites. *Procedia Materials Science*, 6, 1951 – 1960.

Hirsch. J. R. (1997). Aluminium Alloys for Automotive Application. Materials Science Forum, 242, 33-50.

Hou. L. G, Cui. C and Zhang. J. S. (2010). Optimizing microstructures of hypereutectic Al–Si alloys with high Fe content via spray forming technique. *Materials Science and Engineering A*, 527 (23), 6400–6412.

Huber. T, Degischer. H. P, Lefranc. G and Schmitt. T. (2006). Thermal Expansion Studies on Aluminium-matrix Composites with Different Reinforcement Architecture of SiC Particles. *Composites Science and Technology*, 66 (13), 2206 – 2217.

Huimin. X, Zhihai. F, Zhongping. L, and Yanchun. Z. (2015). Temperature-dependence of structural and mechanical properties of TiB2: A first principle investigation. *Journal of Applied Physics*, 17 (22), 225902.

Imam. M. F. I. A, Rahman. M. S and Khan. M. Z. H. (2015). Influence of Heat Treatment on Fatigue and Fracture Behaviour of Aluminium Alloy. *Journal of Engineering Science and Technology*, 10 (6), 730 – 742.

Iman S. E, Ahmed. Y. S and Amer. Eid. A. (2015). Nano reinforced Cast Al-Si Alloys with Al2O3, TiO2 and ZrO2 Nanoparticles. *Metals*, 5, 802-821.

Jasim. M. AA. H, Abthal A. A-R and Mamoon A. A. Al- J. (2018). Studying the effect of Different wt % AL2O3 Nanoparticles of 2024Al Alloy / AL2O3 Composites on Mechanical Properties. *Al-Khwarizmi Engineering Journal*, 14 (2), 147 – 153.

Javidani, M., and Larouche, D. (2014). Application of Cast Al–Si Alloys in Internal Combustion Engine Components. *International Material Reviews*, 59 (3), 132–158.

Ji. S, Wang. Y, Watson. D and Fan. Z. (2013). Microstructural evolution and solidification behaviour of Al–Mg–Si alloy in high-pressure die casting. *Metallurgical and Material Transaction A*, 44 (7), 3185–3197.

Jiang. J, Guanfei. X, Changjie. C and Ying. W. (2018). Microstructure, Mechanical Properties and Wear Behaviour of the Rheoformed 2024 Aluminium Matrix Composite Component Reinforced by Al2O3 Nanoparticles. *Metals*, 8 (6), 460.

Jing. S, Xiaobo. Z, Yijie. Z, Naiheng. M and Haowei. W. (2015). Modification mechanism of primary silicon by TiB2 particles in a TiB2/ZL109 composite. *Journal Material Science*, 50, 1237–1247.

Johny J. S, Venkatesan K, Kuppan. P, Ramanujam. R. (2014). Hybrid Aluminium Metal Matrix Composite Reinforced with SiC and TiB2. *Procedia Engineering,* 97, 1018 – 1026.

Kai-Peng. L, Stachiv. I and Te-Hua. F. (2017). Mechanical properties and deformation mechanism of Al2O3 determined from in situ transmission electron microscopy compression. *Materials Research Express*, 4 (7), 075035. IOP Publishing Series.

Kandpal. B.C., Kumar. J and Singh. H. (2014). Production Technologies of Metal Matrix Composite: A Review. *International Journal of Research in Mechanical Engineering & Technology*, 4 (2), 27-32.

Karakulak. E, Zeren M and Yamanoglu. R. (2013). Effect of heat treatment conditions on microstructure and wear behaviour of Al4Cu2Ni2Mg alloy. *Transaction of Nonferrous Metals Society of China*, 23 (7), 1898–904.

Karvanis. K, Fasnakis. D, Maropoulos. A and Papanikolaou. S. (2016). Production and Mechanical Properties of Al-SiC Metal Matrix Composites. *In: IOP Conference Series: Materials Science and Engineering*, 161 (1). IOP Publishing.

Kenneth. K. A, Adetomilola. V. F and Nthabiseng. B. M. (2019). Development of aluminium-based composites reinforced with steel and graphite particles: structural, mechanical and wear characterization. *Journal of Materials Research Technology*, 8 (1), 670-682.

Kok. M. (2005). Production and Mechanical Properties of Al2O3 Particle-Reinforced 2024 Aluminium Alloy Composites. *Journal of Materials Processing Technology*, 161 (3), 381-387.

Kumar S. and Theatan J.A. (2008). *Production and Characterization of Aluminium Fly Ash Composites using stir Casting Method*. B. Tech Thesis, National Institute of Technology, Pourkela. 2008.

Kumar, K., & Ramesha, C.M. (2018). Tensile and Impact Properties Evaluation of Eutectic, Hypereutectic and Special Eutectic Aluminium Alloys under Various Heat Treated Conditions by Experimental Approach. *International Journal of Scientific Research in Computer Science, Engineering and Information Technology*, 4(5).

Labban H. F. E, Abdelaziz. M and Mahmoud E. R.I. (2014). Preparation and Characterization of Squeeze Cast-Al–Si Piston Alloy Reinforced by Ni and nano-Al2O3 Particles. *Journal of King Saud University– Engineering Sciences*, 28 (2), 230–9.

Lakhvir. S, Baljinder. R and Amandeep. S. (2013). Optimization of process parameter for stir casted aluminium metal matrix composite using Taguchi method. International Journal of Research in Engineering and Technology. Volume: 02 Issue: 08.

Lee. J. A. (2003). *Cast Aluminium Alloy for High Temperature Applications. NASM / Marshall Space Flight Centre (MSFC) Materials*. Processes & Manufacturing Department Mail Code ED33 Huntsville, AL 358 12 USA.

Li. X, Chen. S, Li. S, Li. X and Wang. Y. (2017). *Preparation method for wear-resistant aluminium alloy and wear-resistant aluminium alloy.* Patent Application No: CN107419117A. https://patents.google.com/patent/CN107419117A/en.

Liu. B, Yu. Z, Tian. Z, Homa. D, Hill. C, Wang. A and Pickrell. G. (2015). Temperature dependence of sapphire fibre Raman scattering. *Optics Letters*, 40 (9), 2041-2044.

Love. K, Ankush. R and Mir. I. U. (2018). Performance Evaluation of Aluminium Alloys for Piston and Cylinder Applications. *Materials Today: Proceedings*, 5, 18170–18175

Ma. P, Jia. Y, Prashanth. K, Yu. Z, Li. C, Zhao. J and Huang. L. (2017). Effect of Si content on the microstructure and properties of Al–Si alloys fabricated using hot extrusion. *Journal of Materials Research*, 32 (11), 2210-2217.

MAHLE GmbH. (2012). *Piston materials. In: MAHLE GmbH (eds) Pistons and engine testing*. ATZ/MTZ-Fachbuch. Vieweg+Teubner Verlag, Wiesbaden

Makarian K, Santhanam. S and Wing. Z. N. (2016). Coefficient of thermal expansion of particulate composites with ceramic inclusions. *Ceramics International*, 42 (15), 17659-17665.

Marek. B. A and Krzysztof. O. (2004). Downsizing – a new direction of automobile engine development. *Silniki Spalinowe*, nr 2/2004 (119).

MatWeb. *International Alloy Designations and Chemical Composition Limits for Wrought Aluminium and Wrought Aluminium Alloys* (Revised 2001). http://www.matweb.com/search/GetReference.aspx?matid=8971. Cite on August, 2020.

Mazahery. A and Shabani. M. O. (2012). Characterization of Cast A356 Alloy Reinforced with Nano SiC Composites. *Transaction of Nonferrous Metal Society of China*, 22 (2), 275–280.

Mazahery. A, Abdizadeh. H, Baharvand.i H. R. (2009). Development of high-performance A356/nano-Al2O3 composites. *Material Science Engineering: A*, 518 (1-2), 61-64.

Meena. K, Manna. A. & Banwait. S. (2013). An Analysis of Mechanical Properties of the Developed Al/SiC-MMC's. *American Journal of Mechanical Engineering*, 1(1), 14-19.

Mehdi. R, Nader. P and Naber. E. (2010). Investigation of particle size and amount of alumina on microstructure and mechanical properties of Al matrix composite made by powder metallurgy. *Materials Science and Engineering: A*, 527(4-5), 1031-1038.

Michael. O. B, Kenneth. K. A and Lesley. H. C. (2015). Aluminium matrix hybrid composites: a review of reinforcement philosophies; mechanical, corrosion and tribological characteristics. *Journal of Material Research and Technology*, 4(4), 434–445.

Mitsuhiro. O, Yuta. M and Kazuma. M. (2015). Material Properties of Various Cast Aluminium Alloys Made Using a Heated Mold Continuous Casting Technique with and without Ultrasonic Vibration. *Metals*, 5 (3)*,* 1440-1453.

Mohammad. M. K and Gajendra. D. (2017). Comparative Study on Erosive Wear Response of SiC Reinforced and Fly Ash Reinforced Aluminium Based Metal Matrix Composite. *Materials Today: Proceedings*, 4 (9), 10093–10098.

Mohanavel. V, Rajan. K, Arul. S and Senthil. P. V. (2017). Production, Microstructure and Mechanical behavior of AA6351/TiB2 composite synthesized by direct melt reaction method. *Materials Today: Proceedings*, 4, 3315–3324.

Muhammad. S, Mayumi. O, Anasyida. A. S, Zuhailawati. H and Toshihiko. K. (2016). Mechanical properties of 1.5 wt.% TiB2-added hypoeutectic Al-Mg-Si alloys processed by equal channel angular pressing. *In: 5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) & 2nd International Postgraduate Conference on Materials, Mineral and Polymer (MAMIP), 4-6 August 2015. Procedia Chemistry 19*, 106 – 112.

Mula. S, Padhi. P, Panigrahi. S.C. and Ghosh. S. K. P. (2009). On Structure and Mechanical Properties of Ultrasonically Cast Al–2% Al2O3 Nano Composite. *Materials Research Bulletin*, 44 (5), 1154-1160.

Nai. S. M. L and Gupta. M. (2002). Influence of stirring speed on the synthesis of Al/SiC based functionally gradient materials. *Composite Structures*, 57, 227–233.

Nakata, K., and Ushio, M. (2001). Wear Resistance of Plasma Sprayed Al-Si Binary Alloy Coatings on A6063 Al Alloy Substrate. *Surface Coatings Technology*, 142–144, 277–283.

Neelima D. C, Mahesh. V and Selvaraj. N. (2011). Mechanical characterization of Aluminum silicon carbide composite. *International Journal of Applied Engineering Research, Dindigul*, 1 (4), 793-799.

Nuruzzaman. D. M. and Kamaruzaman, F.F.B. (2016). Processing and mechanical properties of aluminium-silicon carbide metal matrix composites. *In IOP Conference Series: Materials Science and Engineering,* 114 (1), 012123. IOP Publishing.

Okayasu. M, Ohkura. Y, Takeuchi. S, Takasu. S, Ohfuji. H, Shiraishi. T. (2012). A study of the mechanical properties of an Al-Si-Cu alloy (ADC12) produced by various casting processes. *Material Science Engineering: A,* 543, 185–192.

Okumus. S. C, Serdar. A, Ramazan. K, Deniz. G and Hatem. A. (2012). Thermal expansion and thermal conductivity behaviours of Al-Si/SiC/graphite hybrid metal matrix composites (MMCs). *Materials science (medžiagotyra)*, 18 (4), 341-346.

Okayasu. M., Takeuchi. S and Shiraishi. T. (2013). Crystallisation characteristics of primary silicon particles in cast hypereutectic Al–Si alloy. *International Journal of Cast Metals Research,* 26 (2), 105–113.

Olusegun. J, Ilegbusi and Jijin. Y. (2000). Porosity nucleation in metal–matrix composites. *Metallurgy and Materials Transactions A*, 31, 2069–2074.

Ozben. T, Kilickap. E and Cakır. O. (2008). Investigation of Mechanical and Machinability Properties of SiC Particle Reinforced Al-MMC. *Journal of Materials Processing Technology*, 198(1), 220-225.

Palanisamy. P, Murugesan. J and Venkatajalapathy. S. (2019). Study of the microstructures and mechanical properties of aluminium hybrid composites with SiC and Al2O3. *Materials and Technology*, 53 (1), 49–55.

Pankaj. K. G and Srivastava R. K. (2019). Fabrication of Ceramic Reinforcement Aluminium and Its Alloys Metal Matrix Composite Materials: A Review. *Materials Today: Proceedings*, 5, 18761–18775

Pavitra. A, Anjan. B. N, Rajaneesh. N. M, Preetham. K. G. V. (2018). Effect of SiC Reinforcement on Microstructure and Mechanical Properties of Aluminium Metal Matrix Composite. *IOP Conf. Series: Materials Science and Engineering 376*, 012057. Doi:10.1088/1757-899X/376/1/012057.

Pawar. P. B and Abhay A. U. (2014). Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite for Spur Gear. *Procedia Materials Science*, 6, 1150 – 1156.

Perret. D, Leppard. G.G and Mavrocordatos. D. (2005). Microscopy Applications / Environmental*, Encyclopaedia of Analytical Science (Second Edition)*, Elsevier, 65-74.

Ponnusamy. P., Feng. B, Martin. H.-P and Groen. P. (2018). Effect of TiB2 nano-inclusions on the thermoelectric properties of boron rich boron carbide. *Materials Today: Proceedings*, 5(4), 10306–10315.

Pooja. V, Prabha. K, Joyjeet. G and Vijay. P. (2019). Investigation of Mechanical Properties and Microstructure of Pure Al-SiC-Nanocomposite Casted by Stir-Squeeze Casting Process. *Innovation in Materials Science and Engineering. Proceedings of ICEMIT 2017,* 2.

Prabu S. B, Karunamoorthy. L, Kathiresan. S, and Mohan. B. (2006). Influence of Stirring Speed and Stirring Time on Distribution of Particles in Cast Metal Matrix Composite. *Journal of Material Processing Technology*, 171 (2), 268–273.

Pramod. S. L, Srinivasa R and Murty. B. S. (2015). Aluminium-Based Cast in Situ Composites: A Review. *Journal of Materials Engineering and Performance*, 24, 2185–2207.

Rafsanjani. F.E and Rezaeezadeh. M. (2016). Mechanical Properties of Piston for Engine of Terex Dump Truck and Assessment of their Impact on the Ultimate Performance of Piston, *Scinzer Journal of* Engineering, 2, 21-24.

Rahman, M. H. & Al Rashed, H. M. (2014). Characterization of Silicon Carbide Reinforced Aluminium Matrix Composites. *Procedia Engineering*, 90, 103-109.

Raju. G. B, Basu. B and Suri. A. K. (2010). Thermal and electrical properties of TiB2–MoSi2. *International Journal of Refractory Metals and Hard Materials*, 28 (2), 174–179.

Ramnath. B.V, Elanchezhian. C, Annamalai. R. M, Aravind. S, Atreya. S. T. S. A, Vignesh. V and Subramanian. C (2014). Aluminium Metal Matrix Composites- A Review. *Revision of Advance Material Science*, 38 (5), 55-60.

Ravi. K. R, Sreekumar. V. M, Pillai. R.M, Mahato. C, Amaranathan. K.R and Arul. K. R. (2007). Optimization of mixing parameters through a water model for metal matrix composites synthesis. *Materials Design*, 28 (3), 871–881.

Robles. F. C. H and Sokolowski. J. H. (2006). Thermal analysis and microscopical characterization of Al–Si hypereutectic alloys. *Journal of Alloys and Compounds*, 419, 180–190.

Saaminathan. R and Antony R. D. (2017). Design and Analysis of Piston by amc225xe Alloy. *International Journal for Innovative Research in Science & Technology,* 3 (9), 147-153.

Sahoo. S. K, Majhi. J, Patnaik. S. C, Behera. A, Sahoo. J. K and Sahoo. B. P. (2017). Characterization of Al-Si-TiB2 In-situ Composite Synthesized by Stir Casting Method. *Elixir Materials Science*, 113, 49066-49069.

Sajjadi S. A, Ezatpour H. R, Parizi M. T. (2012). Comparison of Microstructure and Mechanical Properties of A356 Aluminium Alloy/Al2O3 Composites Fabricated by Stir and Compo-Casting Processes. *Materials and Design*, 34:106–111.

Sajjadi S. A, Torabi. P. M, Ezatpour. H. R and Sedghi. A. (2011). Fabrication of A356 composites reinforced with micro and nano Al2O3 particles by a developed compo-casting method and study of their properties. *Journal of Alloys and Compounds*, 511 (1), 226-231.

Sajjadi, S. A., Ezatpour, H. R, Beygi N. H. (2011). Microstructure and Mechanical Properties of Al/Al2O3 Micro and Nano Composites Fabricated by Novel Stir Casting. *Materials Science and Engineering: A*, 528 (29-30), 8765-8771.

Sajjadi. S. A, Ezatpour. H. R, Beygi. H. (2010). Microstructure and mechanical properties of Al–Al2O3 micro and nano composites fabricated by stir casting. *In: Proceedings of 14th national conference on Materials Science and Engineering, Tehran, Iran*, 325–32.

Sanjeev K. Y, Surendra K. P and Raman. N. (2015). Microstructure, Micro hardness and compressive behaviour of dual reinforced particles Aluminium alloy composites. *International Journal of Innovative Science Engineering & Technology,* 2 (4), 1154-1163.

Sharma. S.K, Saini. P. K, and Samria. N. K. (2013). Modelling and analysis of radial thermal stresses and temperature field in diesel engine valves with and without air cavity. *International Journal of Engineering, Science and Technology*, 5 (3), 111–123.

Shavi. A, Ghose. A. K, Chakraborty. I. (2017). Effect of Rotary Electromagnetic Stirring during Solidification of In- Situ Al-TiB2 Composites. *Materials and Design*, 113, 195-206.

Sheelam. M and Ankush. A. (2018). Design and analysis of piston by Al-GHS 1300, Al-GHY 1250, Al-Si-C, A6061 and A4032 composite material: A review. *AIP Conference Proceedings 1953, 130004*; https://doi.org/10.1063/1.5033148

Shirasu. K, Nakamura. A, Yamamoto. G, Ogasawara. T, Shimamura. Y, Inoue. Y and Hashida. T. (2017). Potential use of CNTs for production of zero thermal expansion coefficient composite materials: An experimental evaluation of axial thermal expansion coefficient of CNTs using a combination of thermal expansion and uniaxial tensile tests. *Composites Part A: Applied Science and Manufacturing*, 95, 152-160.

Shorowordi. K. M, Laoui. T, Haseeb. A. S. M. A, Celis. J. P and Froyen. L. (2003). Microstructure and interface characteristics of B4C, SiC and Al2O3 reinforced Al matrix composites: a comparative study. *Journal of Material Processing Technology*, 142 (3), 738–743.

Sijo. M. T and Jayadevan. K. R. (2016). Analysis of Stir Cast Aluminium Silicon Carbide Metal Matrix Composite: A Comprehensive Review. *Procedia Technology*, 24, 379 – 385.

Singh. L. Ram. B. and Singh. A. (2013). Optimization of Process Parameter for Stir Casted Aluminium Metal Matrix Composite Using Taguchi Method. *International Journal of Research in Engineering and Technology*, 2(08), 375-383.

Singh. N, Mir. I. U. H, Raina. A, Anand. A, Kumar. V and Sharma. S. M. (2017). Synthesis and tribological investigation of Al-SiC based nano hybrid composite. *Alexandria Engineering Journal*, 57 (3), 1323-1330.

Singla. M, Dwivedi. D. D, Singh. L and Chawla. V. (2009). Development of aluminium based silicon carbide particulate metal matrix composite. *Journal of Minerals and Materials Characterization and Engineering*, 8(6), 455-467.

Sjolander. E and Seifeddine. S. (2010). The heat treatment of Al–Si–Cu–Mg casting alloys: Review. *Journal of Materials Processing Technology*, 210 (10), 1249–59.

Soltani. S, Azari. K. R, Mousavian. R, Taherzadeh., Jiang. Z, Fadavi. B A. and Brabazon. D. (2017). Stir Casting Process for Manufacture of Al–SiC Composites. *Rare Metals*, 36 (7), 581-590.

Soo. J, Park. M and Kang. S. (2011). Interface Science and Technology. *Chapter 6 - Element and Processing*, 18, 431-499.

Sroka. Z. J and Dziedzioch. D (2015). Mechanical load of piston applied in downsized engine. *Archives of Civil and Mechanical Engineering,* 15, 663 – 667.

Subodh. K. S, Saini. P. K, and Samria. N. K. (2015). Experimental Thermal Analysis of Diesel Engine Piston and Cylinder Wall. *Journal of Engineering*, vol. 2015, 10 pages, 2015. https://doi.org/10.1155/2015/178652.

Sujan. D, Oo. Z, Rahman. M. E, Maleque. M. A and Tan. C. K. (2012). Physio-Mechanical Properties of Aluminium Metal Matrix Composites Reinforced with Al2O3 and SiC. *International Journal of Engineering and Applied Sciences*, 6, 228-291.

Surappa. M. K. (2003). Aluminium matrix composites: Challenges and opportunities. Sadhana 28, 319–334.

Suresh. S and Moorthi. N. S. V. (2013). Process development in stir casting and investigation on microstructures and wear behavior of TiB2 on Al6061 MMC. *In: International Conference on Design and Manufacturing, IConDM 2013. Procedia Engineering*, 64, 1183 – 1190.

Suresh. S, Shenbag. N and Navaneethakrishnan. S. V. M. (2012). Aluminium-Titanium Diboride (Al-TiB2) Metal Matrix Composites: Challenges and Opportunities. *Procedia Engineering*, 38, 89 – 97.

Suresh. S, Shenbaga. N, Moorthi N. S. V, Vettivel. S. C, Kumar. N. S. (2014). Mechanical Behavior and Wear Prediction of Stir Cast Al6061-Ti2B Composites Using Response Surface Methodology. *Materials and Design*, 59, 383-396.

Tan. E, Tarakcilar. A. and Dispinar. D. (2015). The Effect of Melt Quality and Quenching Temperature on the Weibull Distribution of Tensile Properties in Aluminium Alloys. *Materials Science and Technology*, 46 (10), 1005-1013.

Taylor. J. A. (2012). Iron-Containing Intermetallic Phases in Al-Si Based Casting Alloys. *Procedia Material Science*, 1, 19–33.

Tian. S. (2004). *The Physical Properties of Materials*. Beijing: Beijing University of Aeronautics and Astronautics Press.

Tomasz. A and Piotr. L. (2015). Selected failures of internal combustion engine pistons. *Logistyka,* 3, 48–55.

Tongmin. W, Yu-fei. Z, Zongning. C, Yuanping. Z and Huijun K. (2015). Combining effects of TiB2 and La on the aging behaviour of A356 alloy. *Materials Science & Engineering: A*, 644, 425–430.

Tsai. F.Y and Kao P. W. (2012). Improvement of Mechanical Properties of a Cast Al–Si Base Alloy by Friction Stir Processing. *Materials Letters*, 80, 40–42.

Ünlü. B. S, Durmuş. H, and Akgün. S. (2009). Tribological and Mechanical Properties of Al Alloyed Bearings. *Journal of Alloys and Compound*, 487(1–2), 225–230.

Uthayakumar. M, Prabhaharan. G, Aravindan. S and Sivaprasadad. J. V. (2008). Study on Aluminum alloy piston reinforced with cast iron insert. *International Journal of Material Science*, 3 (1), 1–10.

Vaucher. S and Beffort. O. (2001). Bonding and interface formation in metal matrix composites. *MMC-Assess Thematic Network, EMPA Thun*, 9.

Vencl. A, Bobi. I, and Mi¡skovi. Z. (2008). Effect of thixocasting and heat treatment on the tribological properties of hypoeutectic Al–Si alloy. *Wear*, 264, 616–623.

Vencl. A, Bobic. I, Arostegui. S and Bobic. B. (2010). Structural, mechanical and tribological properties of A356 aluminium alloy reinforced with Al2O3, SiC and SiC + graphite particles. *Journal of Alloys and Compounds*, 506, 631–639.

Vijaya. B. R. R, Elanchezhian. C, Naveen, P. E, Nagarajakrishnan, T. C, Saleem. A, and Srivalsan. M. (2018). Mechanical and Wear Behaviour of Aluminium Zircon Sand-Fly Ash Metal Matrix Composite. *IOP Conference Series: Materials Science and Engineering 390*, 012018 doi:10.1088/1757-899X/390/1/012018.

Vikas. V, Prakash. K, Kamal. K. M, Sandeep. C and Tewari. P.C. (2016). Microstructure and mechanical behaviour characterization of Al-Al2O3 MMC processed by DIMOX and Al-Al2O3/MnO2 MMC processed via stir casting route. *International Journal of Materials Engineering Innovation*, 7 (3/4), 219.

Wang. J. H, Du. M. H, Han. F. Z and Yang. J. (2014). Effects of the Ratio of Anodic and Cathodic Currents on the Characteristics of Micro-Arc Oxidation Ceramic Coatings on Al Alloys. *Applied Surface Science*, 292, 658–664.

William. D. C Jr., (2007). *Materials Science and Engineering an Introduction*, seventh ed., John Wiley & Sons Inc., New York.

Yang. H, Ji. S and Fan. Z. (2015). Effect of heat treatment and Fe content on the microstructure and mechanical properties of die-cast Al–Si–Cu alloys. *Materials and Design*, 85, 823–32.

Yang. L. J. (2003). The Effect of Casting Temperature on the Properties of Squeeze Cast Aluminium and Zinc Alloys. *Proceedings of the 6th Asia Pacific Conference on Materials Processing. Journal of Materials Processing Technology, Singapore*, 140 (1-3), 391–6.

Yang. Y, Li. Y, Wu. W, Zhao. D and Liu. X. (2011). Effect of Existing Form of Alloying Elements on the Micro Hardness of Al–Si–Cu–Ni–Mg Piston Alloy. *Materials Science and Engineering: A*, 528 (18), 5723–8.

Yu. N, D, Enikeev. R. D and Ivanov. V. Y. (2017). Thermal Protection of Internal Combustion Engines Pistons. In: *International Conference on Industrial Engineering, ICIE 2017. Procedia Engineering 206*, 1382–1387.

Yuan. Z, Li. F, Zhang. P, Chen. B and Xue. F. (2014). Mechanical properties study of particles reinforced aluminium matrix composites by micro-indentation experiments. *Chinese Journal of Aeronautics*, 27 (2), 397-406.

Yuksel. C, Tamer. O, Erzi. E, Aybarc. U, Cubuklusu. E, Topcuoglu. O, Cigdem. M, and Dispinar. D. (2016). Quality Evaluation of Re-melted A356 Scraps. *Archives of Foundry Engineering*, 16 (3), 151-156.

Yun-liang. Q, Zhi. W, Jianxin. W. X. H. (2015). Effects of thermodynamic conditions on the end gas combustion mode associated with engine knock. *Combustion and Flame,* 162, 4119–4128.

Yoon-Seok. L, Yuya. M, Jun. N and Eunkyung. L. (2020). Influence of Continuous Casting Speeds on Cast Microstructure and Mechanical Properties of an ADC14 Alloy. *Metals*, 10, 625; 1-9, doi:10.3390/met10050625.

Zainon. M.F, Ahmad. K.R and Daud. R. (2015). Effect of Heat Treatment on Microstructure, Hardness and Wear of Aluminium Alloy 332. *Applied Mechanics and Materials*, 786, 18-22, 2015.

Zeren. M. (2007). The effect of heat-treatment on aluminium-based piston alloys. *Materials and Design*, 28 (9), 2511–2517.

Zhu. D. Z, Li. F. Z, Chen. G Q, Zhang. Q and Wu G. H. (2005). Study on thermal expansion property of SiCp/Cu composite. *Journal of Harbin University of Science and Technology*, 10 (2) 125-128.

Zou. Q. C, Jie. J. C, Sun. J. L, Wang. T. M, Cao. Z.Q, Li. T. et al., (2015). Effect of Si Content on Separation and Purification of the Primary Si Phase from Hypereutectic Al–Si Alloy Using Rotating Magnetic Field. Separation and Purification Technology, 142, 101–107.