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A STUDY ON MACHINING CHARACTERISTICS OF STRONTIUM MODIFIED LM-6 ALLOY

BY

SAMI SALAMA HAJJAJ

INTERNATIONAL ISLAMIC UNIVERSITY
MALAYSIA

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SAMI SALAMA HAJJAJ

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requirements for the degree of Master of Science
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ABSTRACT

The eutectic aluminium silicon alloy (LM-6) is known to have poor machinability. This work explains the effect of strontium modification on increasing machinability of LM-6 alloy. Samples of LM-6 alloy were prepared; sand cast, die cast, heat treated, and non-heat treated samples were created in pairs, strontium modified and un-modified, resulting in eight different combinations of LM-6 alloy samples. These samples were put to identical physical and machining tests, their microstructures were photographed using Scanning Electron Microscope (SEM) photography. To remove statistical error, each test was conducted three times. Results showed that strontium addition to LM-6 alloy resulted in refining its microstructure; large silicon flakes in the un-modified LM-6 alloy were transformed into fine and well dispersed globular grains. Also, strontium modified samples produced a 4% reduction in hardness, a 7% increase in ductility and a 36% reduction in average flank wear, thus Strontium addition resulted in improving its machinability. Strontium addition improved machinability of LM-6 alloy by primarily refining its microstructure; reduced grain size of the hard silicon particles resulted in reduction of the abrasive effect on the tool face. Evidence of this can be shown in the fact that dramatic reductions in flank tool wear rate were observed only when the microstructure was refined, furthermore, SEM figures of cutting tools that cut modified samples showed great reduction in abrasive wear.

ملخص البحث

مركب ل-م-6 معروف عنه انه لديه معدل وزن- قوة جيد، بالإضافة إلى مقاومة عالية للصدء و موافقة عالية للصبّات. ولكن هذا المركب لا يمكن قطعه بسهولة. هذا العمل يعرض قدرة عنصر السترونشيوم على تحسين هذا الوضع، أيضا هذا العمل يعرض تأثير زيادة معدل التبريد و معالجة التسخين المعادِلة، و يبحث إذا ما كانا يؤثران على القدرة التحسينية لعنصر السترونشيوم. ثماني قطع من مركب ل-م-6 تم تحضيرهم، كل واحدة معدلة بطريقة خاصة لكي يتم بحث تأثير التعديل. كل هذه القطع تم وضعهم تحت اختبارات جسمية واختبارات قطع ، و تم تصوير تركيباتهم وكل عذه المعلومات تم تخزينها. كل القطع التي تم تعديلها بإضافة عنصر السترونشيوم سجّلت انخفاضا في معدلات الاهتراء مما يعتبر تحسنا في قدرة ل-م-6 للقطع. ولكن هذا التراجع لم يكن بنفس المعدل لكل القطع. تم أيضا تسجيل انخفاضا في الصلابة بدرجة 6% و انخفاض قيمة الضغط القصوى بدرجة 13% ولكن تم أيضا تسجيل زيادة الليونة بقيمة 9%. المعلومات تؤكد أن إضافة عنصر السترونشيوم تؤدي إلى تحسين القدرة القطعية لمركب ل-م-6 عن طريق تصغير حجم نويات السيليكون في مركب ل-م-6 ، و ذلك يؤدي بدوره إلى تقليل اثر السيليكون على معدل الاهتراء. وبما ان عنصر السترونشيوم يؤدي إلى تقليل الصلابة فهذا يؤدي الى تقليل القوة اللازمة للقطع مما يحسن القدرة القطعية لمركب ل-م-6 و ذلك أيضا يؤدي الي تقليل معدلات الإهتراء بصورة مباشرة. وكما تخبرنا المعلومات، فإن تأثير عنصر السترونشيوم على زيادة و أثرها العكسى القدرة القطعية تم التغطية عليه بتصغير حجم نوايات السيليكون و تقليل الصلابة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Manufacturing Engineering)

....
Ahsan Ali Khan
Supervisor

....
Md Mohafizul Haque
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Manufacturing Engineering).

....
Shahjahan Mridha
Internal Examiner

....
Che Hassan Che Haron
External Examiner

This dissertation was submitted to the Department of Electrical and Computer Engineering and is accepted as a partial fulfillment of the requirements for the degree of Master of Science (Manufacturing Engineering).

....
A.K.M Nurul Amin
Head, Department of
Manufacturing and Materials
Engineering

This dissertation was submitted to the Kulliyyah of Engineering and is accepted as partial fulfillment of the requirements for the degree of Master of Science (Manufacturing Engineering).

....
Ahmad Faris Ismail
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Sami Salama Hajjaj

Signature: ……………………………… Date:………………………

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To my love and driving force to complete this work, who had to endure a lot while I was away completing this work,

My Children,
Faris Sami Hajjaj,
Nabeil Sami Hajjaj

My lovely wife,
Ella Karim

My parents,

Salama Hussain Hajjaj and Wajeeha Muhaisen Hajjaj

And,

siblings, and the rest of the Hajjaj family

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

For the last three decades, the automotive industry saw a steady increase in the demand for improved fuel economy, enhanced safety performance, and reduced exhaust emission. This was coupled with a substantial increase in the use of newer and lighter materials, to achieve weight reduction in high volume passenger vehicles. During the same period, the amount of aluminum, and its alloys, used on each vehicle produced worldwide has seen a steady increase (Sherman, 2000).

Aluminum applications in the automotive industry cover a wide range of components, from powertrain components, aluminium wheels, radiators and heat exchanger, chassis, suspension parts, closure panels, pistons and other engine components, as well as primary body structures (Sherman, 2000).

Concerns about global warming and fossil fuel shortages only increased the demand for fuel economy improvement. Indeed reducing vehicle weight is a key requirement for more efficient and reduced emission powertrain systems, such as hybrids and fuel cells. With production of these new vehicles, aluminium is poised to continue to the path of development as one the key components of these vehicles.

Technical developments in material science and manufacturing of current materials, such as steel, challenged some of the advantages aluminium might bring about. Therefore, winning new application and keeping existing ones will require extensive and sustained research and development. The target of such research should be to reduce costs, while improving benefits (Sherman, 2000).

High specific strength, excellent corrosion resistance, sound castability, and good thermal and electrical conductivity characterize aluminium alloys. In addition to the automotive industry, they are replacing traditional materials in the areas of packaging, construction, electrical conductors, and machinery (Sherman, 2000).

Aluminum–silicon alloys have the potential for excellent castability, good weldability, good thermal conductivity, high strength at elevated temperatures and excellent corrosion resistance. They are therefore well suited to aerospace structural applications, the automobile industry, military applications, etc.

The near-eutectic group of aluminium silicon alloys enjoys common features; low thermal expansion, excellent castability, high corrosion resistance, and high abrasive wear resistance, this has led to their use in automotive piston components. This group of alloys is sometimes referred to as “piston alloys”.

The eutectic aluminum silicon alloy - or LM-6 alloy - is a member of this group. Just like all piston alloys, LM-6 alloy is difficult to machine. Therefore, LM-6 and the rest of the piston alloys are generally cast into shape; however, with more and more automotive technology advances, and complicated component shapes, lean manufacturing, and constant changes in design, the need for machining LM-6 alloy has increased.

This brings about the need to investigate possible methods to improve machinability of LM-6 alloy, with the aim of reducing machining time and cost, while improving quality.

1.2 HYPOTHESES

Machinability of an alloy depends two major factors, the first factor is the “status of the work material”, which is its microstructure, physical and mechanical properties, etc. This factor has a direct impact on machinability. The second factor is the machining environment, i.e. the cutting parameters, tooling settings, miscellaneous and other settings, etc. This factor has an indirect effect on machinability.

In the present work, it is expected that modification of LM-6 alloy results in altering its “status of work material”, which is expected to improve its machinability. This modification is brought by adding Strontium. In this work, it is expected that strontium modification can bring favorable changes in microstructure, and physical properties of LM-6 alloy, thus improving its machinability

In this work, the effect of strontium addition on microstructure, physical properties, machinability, and castability of LM-6 alloy is investigated. Also, the effect of solution heat treatment and cooling rate (separately and in combination) on the effectiveness of strontium addition is also investigated.

1.3 OBJECTIVES

The main objectives of this work are:

1. To demonstrate the effect of strontium addition on the microstructure and physical properties of LM-6 alloy.
2. To demonstrate and explain the effect of strontium addition on the machinability of LM-6 alloy.
3. To investigate the effects of cooling rate and solution heat treatment on the effect of strontium modification to LM-6 alloy.

1.4 ORGANIZATION OF THESIS

This thesis is divided into five chapters. The first chapter, which is the introduction chapter, includes the hypothesis, objectives, organization of thesis, as well as the significance of this work. It is aimed at building a scenario for its readers.

The second chapter provides the literature review; this chapter is divided into three main sections. The first section discusses aluminium alloys, aluminium silicon alloys, and LM-6 alloy. It reviews their classifications, properties and features. The second section discusses machinability and the effect of work material. It focuses on the effect of microstructure, hardness, ultimate tensile stress (UTS), and ductility.

Finally, this section ends with an in depth review of machinability of LM-6 alloy. The third section reviews modification and its effect on altering “the status of the work material”. This section reviews effect of microstructure modification, methods of modification, strontium, solution heat treatment, and cooling rate.

Experimental procedure is presented in the third chapter. This chapter reviews the research methodology, the experimental setup for all experiments performed in this work, including preparation and testing steps, such as sand casting, die casting, heat treatment, hardness tests, tensile tests, machinability tests, and microstructure analysis.

Chapter four reviews the results and discussion of the data recorded from experiment conducted in chapter three. The final chapter, chapter five, lists down conclusions and recommendations for future research, which is followed by appendices I through IV.

1.5 SIGNIFICANCE OF THIS WORK

This work is of research value because previous work on the effect of strontium addition on LM-6 never investigated its effect on machinability.

Traditionally, LM-6 alloy has poor machinability. Therefore most researchers focused strontium effect on physical properties and casting characteristics. Others investigated the mechanism of modification. But little work has been conducted on the strontium refining effect on machinability.

The effect of solution heat treatment and cooling rate on LM-6 alloy has been investigated. However, their effects, separately and in combination, on the effect of strontium addition have never been studied; whether they further improve the effect of strontium addition or impede it.

Also, this work may help researchers investigating the mechanism of strontium modification. Up to date, there is no conclusive and widely accepted theory on how strontium brings about its modifying effect. Analysing the effect of heat treatment and the effect of cooling rate on the effect of strontium addition may shed some light on this phenomena and lead researches to gain a better understanding of the mechanism of strontium addition.

Lastly, no other work has included the wide variety of LM-6 samples. This is coupled with a wide range of tests and experiments. With such a vast source of information, there is always room for researchers.

CHAPTER TWO

LITERATURE REVIEW

2.1 ALUMINUM AND ALUMINUM ALLOYS

High-purity aluminum is soft and ductile; it is unsuitable for most commercial and industrial applications that require greater strength. Alloying or heat treatment can increase strength in aluminum (The Aluminum Association [AA], 1998).

Nevertheless, aluminum is a very versatile metal and can be cast in any form known. It can be rolled, stamped, drawn, spun, roll-formed, hammered and forged. For most applications, aluminum needs no protective coating as it can be finished to look good; however it is often anodized to improve colour and strength (AA, 1998).

Aluminum and its alloys offer an extremely wide range of capability and applicability, with a unique combination of advantages that make it the material of choice for numerous products and markets (AA, 1998).

Aluminum castings have played an integral role in the growth of the aluminum industry since its inception in the late 19th century. Those early applications rapidly expanded to address the requirements of a wide range of specifications (AA, 1998).

2.1.1 Aluminum alloys designation system

Aluminum alloys have a strong resistance to corrosion, which is a result of an oxide skin that forms as a result of reactions with the atmosphere. This corrosive skin protects aluminum from most chemicals, weathering conditions, and even many acids; however alkaline substances are known to penetrate the metal (AA, 1998).

Aluminum also has a rather high electrical conductivity, making it useful as a conductor. Copper is the more widely used conductor, having a conductivity of approximately 161% that of aluminum (AA, 1998).

The breadth of individual aluminum alloys and their applications is so broad that a system has been establish to classify aluminum alloys. The Aluminum Association uses a four digit numerical system to identify aluminum alloys. The system used for wrought alloys is slightly different from that used for cast alloys. This system is shown in table 2.1

Table 2.1
Aluminium alloys designation system (AA, 2006)

Wrought Alloys		**Cast Alloys**	
Alloying element	**Designation**	**Alloying element**	**Designation**
None (99% Al)	1XXX	None (99% Al)	1XX.X
Cu	2XXX	Cu	2XX.X
Mn	3XXX	Si + Cu and/or Mg	3XX.X
Si	4XXX	Si	4XX.X
Mg	5XXX	Mg	5XX.X
Mg + Si	6XXX	Unused series	6XX.X
Zn	7XXX	Zn	7XX.X
Others	8XXX	Sn	8XX.X
Unused series	9XXX	Others	9XX.X

2.1.2 Machinability of aluminum and aluminum alloys

Pure aluminum has poor machinability due to its extremely high ductility. Aluminum alloys, however, rank high in the machinability tables by most of the criteria. Good tool life can be attained up to speeds of 600 m/min when using carbide tools, and 300 m/min when using high speed steel tools. Cutting speeds as high as 4,500 m/min have been used in special purposes such as high speed machining (Pollack, 1988).

Aluminum silicon alloys are the exception, due to the high hardness and abrasive effect of silicon. This is especially true for hypereutectic Al-Si alloys, with its larger silicon grains (Trent, 1991)

2.1.3 Aluminum silicon alloys

As the name implies, silicon is the main alloying element in Al-Si alloys. Silicon imparts high fluidity and low shrinkage on the alloy, which results in good castability and weldability. Silicon's low thermal expansion coefficient is exploited for pistons.

The maximum amount of silicon in cast alloys is of the order of 22-24% Si, but alloys made by powder metallurgy may go as high as 40-50% Si. Increasing silicon increases strength at the expense of ductility (Key-to-Metal Database [KMD], 2006). Figure 2.1 shows the equilibrium diagram of Al-Si alloys (redrawn from the University of Manchester Institute of Science and Technology [UMIST], 2006).

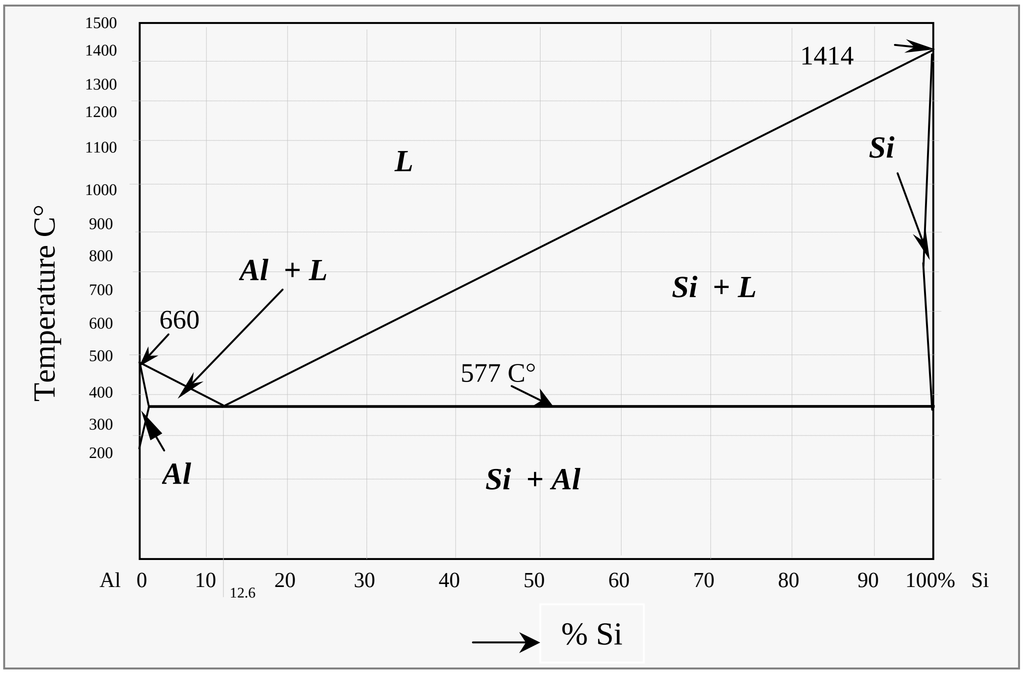

Figure 2.1. Equilibrium diagram of aluminium-silicon alloys. (UMIST, 2006)

The eutectic point for this alloy is at 12.6% Silicon. Hypereutectic aluminum silicon alloys are those with silicon content more than 12.6% Si, whereas alloys containing less than 12.6% Si are hypoeutectic aluminum silicon alloys. Figure 2.2 shows microstructures of hypereutectic, hypoeutectic and eutectic aluminum silicon alloys (Warmuzek, 2004a).

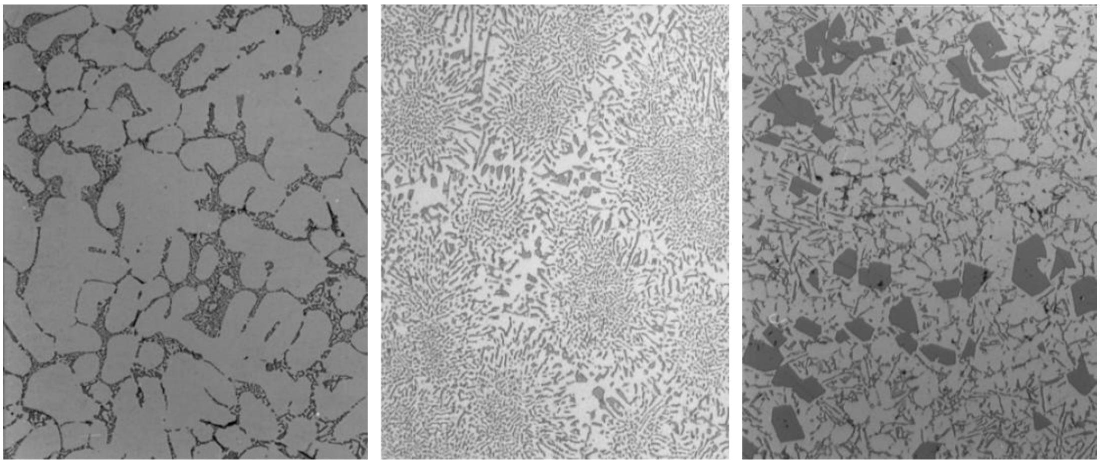
(a) (b) (c)

Figure 2.2. Microstructure of Al-Si alloys, (a) Hypoeutectic (1.65-12.6 wt% Si) 150x. (b) Eutectic (12.6% Si). 400x, (d) Hypereutectic (>12.6% Si). 150x. (Warmuzek, 2004a).

2.1.3.1 Properties of aluminum silicon alloys

Castings are the main use of aluminum-silicon alloys, although some sheet or wire is made for welding and brazing, and some of the piston alloys are extruded for forging stock. Often the brazing sheet has only a cladding of aluminum-silicon alloy and the core consists of some other high melting alloy. Below is a review of other features (KMD, 2006).

- The lattice parameter is decreased slightly by silicon in solution; none of the other elements affects it appreciably. Thus, the parameter of the alloys is between a = 4.045 x 10^{-10} m and a = 4.05 x 10^{-10} m, depending on composition and treatment.

- Thermal expansion is reduced substantially by addition of silicon. Expansion coefficients at subzero temperatures also are some 10-20% lower than those for pure aluminium. Alloys produced by powder metallurgy containing up to 50% Si have even lower expansion coefficients. Permanent expansion accompanies precipitation out of solution of silicon, magnesium and copper; the amount varies but may be as high as 0.15%.
- Thermal conductivity is of the order of 1.2-1.6 x 10-2 W/m/K, the lower values being for the alloys cast in metallic dies or heat treated to retain silicon, copper or magnesium in solution.
- Electric conductivity depends mostly on the amount of silicon in solution. Values of the order of 35-40% IACS for annealed materials and of 22-35% IACS for solution treated alloys are reported. In the liquid state resistivity is some 10-15 times the resistivity at room temperature.
- Magnetic susceptibility is only slightly decreased by silicon, copper and magnesium, but depends mostly on manganese content.
- Compressive strength is higher than tensile strength by some 10-15%. Shear strength is approximately 70% of the tensile strength.
- Impact resistance is low, but so is notch sensitivity, as is to be expected in alloys that contain a large amount of hard, brittle second phase, often with sharp angles. Impact resistance is improved by spheroidising the silicon.
- Creep resistance is not particularly good. Silicon increases the creep resistance of aluminium much less than do most other alloying elements.