# Siliconizing of Aluminium Alloys via Silica Sand Bath

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____________________
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MAY 2014

## CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

________________________________________

NAVINDRAN RAJAINDREN

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# ABSTRACT

Aluminium alloy is a material that commonly used in many industries such as automobile and aerospace because of their excellent properties.However their hardness and wear resistance are poor in comparison to steel resistance.This report emphasizes an experiment concerning case hardening process of Aluminium alloy substrate via Silica Sand Bath which is known as Siliconizing. The silica sand was put into the pocket of a ceramic which is brick clay then it was placed into a furnace. The working temperature is 580°C with 1 hour of soaking time.After the siliconizing process is done, the surface of the substrate were evaluated using hardness machine in order to analyze the difference in hardness before and after siliconizing. Based on the results obtained, it was found that the siliconizing process could not be performed on the surface of Aluminium alloy substrate. Hence, mechanical properties evaluation were unable to be performed from the surface of the siliconized sample using Scanning Electron Microscope or optical microscope.As a conclusion, the Aluminium alloy substrate is not a suitable material to be siliconized via silica sand bath.

# CHAPTER 1

# Introduction

## 1.1 Project Background

Siliconizing is basically a case hardening process of coating silica sand onto a material in order to enhance the material surface property. This process is useful particularly for improving resistance to surface indentation, fatigue and wear. Typical applications for case hardening are gear teeth, cams ,shafts ,bearings ,fasteners ,automotive clutch plates, tools and dies. Since the case hardening is a localized heat treatment, case hardened parts have a hardness gradient. Typically the hardness is a maximum at the surface and decreases below the surface of a material. Besides that, by case hardening using siliconizing method the material is not just increased in hardness but also not easily scratch and corrode in the same time.

## 1.2 Problem Statement

Normal heat treatment processes involve micro structural alteration and property changes in the bulk of the material or component by means of through hardening. It is not desirable to through harden parts because a hard part lacks the necessary toughness for these applications: a small surface crack could propagate rapidly through such a part and cause total failure. In many cases, however, alteration of only the surface properties of a part is desirable (case hardening).In this project, new possibilities for making use of the advantage of the aluminum in application that were reserved up to now for harder and more wear-resistant materials have taken into consideration.

## 1.3 Objectives

The objective of this research can be classified into two components which is:

1. To establish an effective siliconizing parameters in producing uniform thin film coating onto aluminium alloy substrate by using the silica sand bath.
2. To characterise and analyse metal's surface properties after the siliconizing process.

## 1.4 Scope of study

Throughout the research, the scope of study that will be focus on is including:

- Literature review on siliconizing.
- Conducting experiment on siliconizing alluminium alloy.
- Conducting microscopic examination on sample after siliconizing process.
- Perform analysis on the siliconized alluminium alloy.

## 1.5 Significant of the Project

Aluminum and its alloys are attractive for many application in chemical, automobile and aerospace industries because of their excellent properties as height strength-to-weight ratio,high electrical and thermal conductivities and good formability.However their hardness, wear resistance and mechanical properties are poor in comparison to steel resistance and continuous efforts are made in the research into new possibilities for making use of the advantage of the aluminum in application that were reserved up to now for harder and more wear-resistant materials.

# CHAPTER 2

## Literature Review

This chapter consists of literature review of various research and publication done on the subject of Siliconizing. The literature review is divided into 3 sections and has been summarized in these paragraphs:

a) Case Hardening

b) Diffusion Coating

c) Siliconizing

  i) Importance of siliconizing

  ii) Experimental Procedures of Siliconization

  iii) Result of siliconizing

  iv) Relevancy of Literature Review to Project

## 2.1 CASE HARDENING

Material failure is the loss of load carrying capacity of a material unit. Failure in engineering material must be avoided because it can risk human life and at the same time reduces economic value of the material. According to Calister (1940) the consequences of failure in materials such as fatigue and creep are often commenced with some sort of cracks or scratches that resulting from machine operation. Hence, they apply surface finishing method to recover the material from getting creep or fatigue and one of them are by applying residual compressive stresses which applied within the material surface outer layer. In limited cases, these process can be used to restore original dimensions to salvage or repair an item.

Case hardening is a method in which the metal or non-metal surface is reinforced by adding of a fine layer at the top of another metal alloy that is generally more durable . There are various methods of case hardening such as carburizing,boronizing,nitriding,flame hardening,induction hardening and laser hardening. This method is basically used to increase the life span of a material.

## 2.2 DIFFUSION COATING

Diffusion coating is a process based on the diffusion saturation of the surface layers of the objects made of metals and alloys of various metals. The process is normally carried out at elevated temperature at control chamber. The coatings widely used where the components subjected to high temperature conditions and highly corrosive environments are coated with non-corrosive material on the surface. The most widely used coatings are chromium, aluminium or silicon material. As a result, the base metal develops extreme resistance to corrosion, oxidation and erosion in its severe working conditions. This makes the process highly reliable, enhancing the manufacture of critical components.

Factors that affecting diffusion coating are diffusion species and temperature.When the process were carried out at elevated temperature then it affects the coefficients and diffusion rate. The description on diffusion coating were clearly discussed in study conducted by Pokhmurskii (1977) "Effect of Diffusion Coatings on the Service Properties of Metal and Alloys". According to him, diffusion impregnation of materials with aluminium, nitrogen, boron, beryllium, vanadium, tungsten, silicon, titanium, chromium, carbon and combination with two other elements will alter the properties of the material surface.

## 2.3 SILICONIZING

### 2.3.1 Importance of Siliconizing

Nowadays, thermally loaded parts are usually made of heat-resistant steels and nickel super alloys. These materials are expensive and too heavy for some application. Although Fe-Al alloys are promising alternatives for these materials, having lower density and significantly lower price, they are used only sporadically.The reason lies in problematic production and processing in low room-temperature ductility of these alloys. For some application, the corrosion resistance in water – based electrolytes and wear resistance are also insufficient. To improve the high-temperature oxidation resistance and tribological properties of the alloy based material, siliconizing method were used for this purpose.

Siliconizing is basically a simple and inexpensive method to modify the surface of a material (Xiong, Mao, Xie, Cheng, & Li, 2005). In a recent research they have conducted on TiAl alloy,it was found that TiAl which has insufficient ductility and poor oxidation resistance can be improved by liquid-phase siliconizing. Through the microstructural examination, they found that the element Si diffused strongly from the brazing alloy to the surface of the TiAl presented in figure 1.

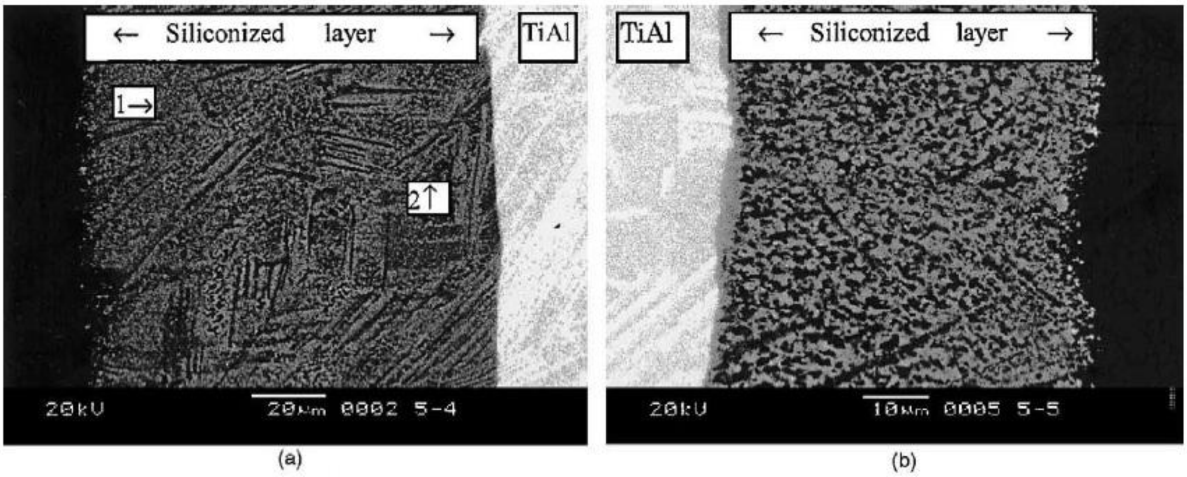


Figure 1. Back scattered electron images of the siliconized layers of the TiAl based alloys. Retrieved from Xiong, Mao, Xie, Cheng, & Li (2005).

Hardening during siliconizing depends on redistribution of the carbon, which with diffusion saturation, can be combined with the carbide forming elements that are present in the steel or that are introduced together with the silicon. However, the carbon is basically driven back into the core components, this lead to an increase and its maximum hardening and in the bearing capacity of the surface.

Siliconized layers on materials exhibit high resistance to various chemical effects. Moreover, the ferrite of the siliconized layers which can be hardened to a greater degree by silicon than the other alloying element is distinguished by good stability. According to Markos (2009), he states that siliconized surface gives high resistance to chemical effects. The statements have similar agreement with Pokhmurskii (1977) who mentioned that siliconizing of materials give high resistance from mineral, organic acids and also salt for a broad temperature range.

Apart from that, the beneficial effects of Si on the high temperature oxidation resistance are two folds. First, with sufficient concentration, it can form a continuous vitreous silica layer between the metal and scale interface. This silica layer has a low concentration of defects, which becomes a good diffusion barrier and provides excellent oxidation resistance.Secondly,the preferentially formed silica acts as the nucleation site for the subsequent formation of chromia which renders oxidation protection.

In a research carried out by Hsu & Tsai (2000) they found that siliconization treatment provides better high temperature corrosion resistance for 310 Stainless Steel both in air and in reducing gas environment. In this investigation, the high temperature corrosion behaviour of AISI 310 SS with or without siliconization treatment was explored. Another findings from Motojima, Kohno, & Hattori (1987) also agreed that diffusion coating using silica on the metal resulted in a layer that protect against hot corrosion and oxidation as their physical and chemical properties improved.

In other studies by Broide & Udovitskii (1981) have discussed laterally on prospects for the commercial use of diffusion siliconizing coatings. Based on their findings, siliconizing techniques can be used for food and chemical industries as rubbing components since the siliconized layer were saturated with polymer. When the silicon layer were platted with chromium on carbon then it is ready to use as transmission components in agricultural industries. As for the siliconized layer saturated with lubricants, the variety uses can be implemented in molds, bearings, machinery and also components subjected under corrosion and high temperature.

### 2.3.2 Experimentation of Siliconization

In order to improve the high-temperature oxidation resistance and tribological properties of a material Novak, Filip, & Michalcova (2012) have conducted an experiment on Siliconizing of FeAl based alloy. Siliconizing of this alloy was completed by annealing in silicon powder (powder fraction < 50 µm) at 1000 and 1150°C for 2 to 7 hours. Microstructure of the layers was observed in cross-section by optical and scanning electron microscope. High temperature oxidation resistance of siliconized layers was tested at 800 °C in air. The abrasive wear resistance was evaluated by using the “pin-on-disc” method were “pin” was the tested material and “disc” was a P1200 grinding paper.

In a research carried out by Li, Taniguchi, Matsunaga, Nakagawa, & Fujita (2003) found that the oxidation resistance of a TiAl can be improved through siliconizing process. The experiment was conducted by burying the TiAl in Silica powder and heating at different temperature of 1073K,1123K,1173K and 1273K for 5 hours in vacuum. The results indicated that the TiAl alloy siliconized above 1173 K shows excellent isothermal and cyclic oxidation resistance in air presented in figure 2.This means the thickness of the above constituent layers which is Si increases with rising siliconizing temperature.

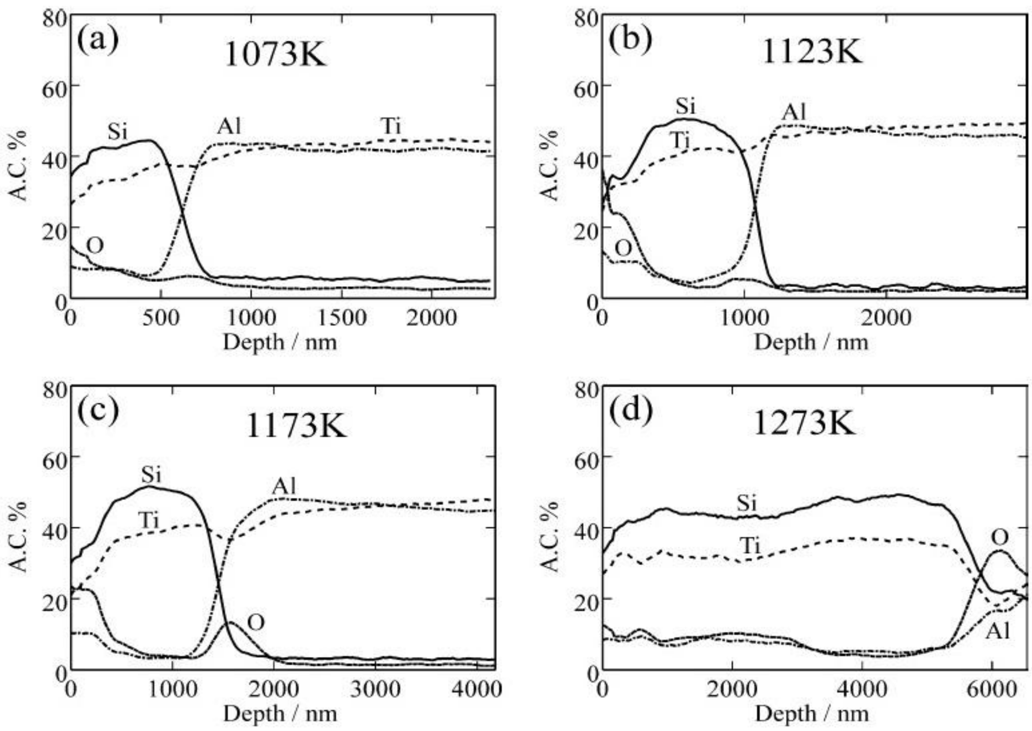


Figure 2. AES profiles of the element distribution in the modified layers siliconized at: a)1073K, b)1123K ,c) 1173K d) 1273 K. Retrieved from Li, Taniguchi, Matsunaga, Nakagawa, & Fujita (2003) .

A studies on powder siliconizing using different experimental procedures were conducted by Motojima, Kohno, & Hattori (1987). Based on their experiment, nickel alloy plates were put in quartz boat before kept at central part of diffusion reaction tube. Hydrogen saturated with hexachlorodisilane was released inside the reaction tube as it can dissolve in the steel lattice effuses to avoid embrittlement.X-ray microanalysis was carried out on a polished cross-section of the siliconized plate using an X-ray dispersive microanalyser.Using $Si_2Cl_6$ as a silicone source, a noticeable weight gain of the nickel base alloy plates were observed at a temperature about 500°C and the weight increased was measured. The relationship between the reaction (siliconizing) temperature and the weight gain obtained was is shown in Figure 4.

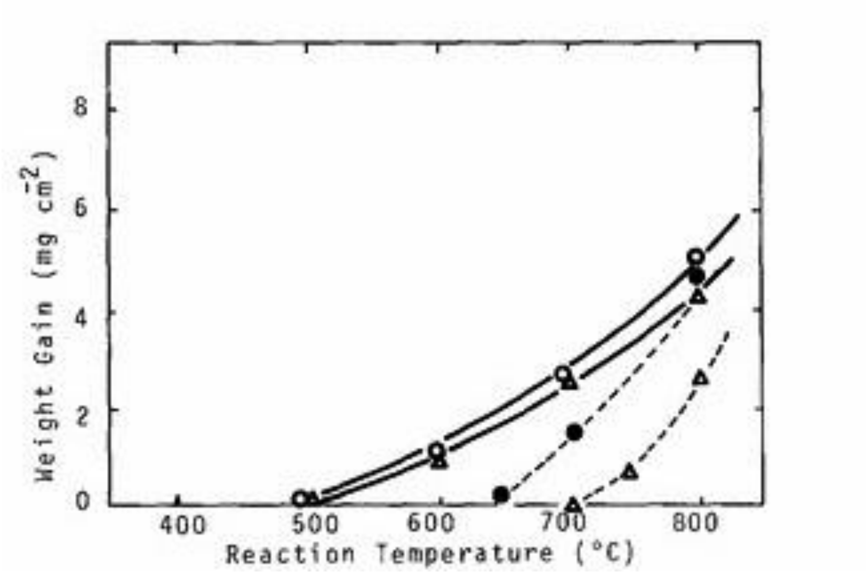


Figure 3. Effect of the reaction (siliconizing) temperature on the weight gain of nickel – base alloys. Retrieved from Motojima, Kohno, & Hattori (1987).

Furthermore, Bianco & Rapp (1996) have carried out the study on pack cementation for siliconizing. The vital components in pack cementation are the parts to be coated.The parts which ready to be coated must be immersed into the mixture of the other components. In their experiment, for the retort they use a cylinder for pure alumina with one end closed. The retort is then closed with lid from alumina before it sealed with alumina base cement. The retort were kept at furnace and heated at 800˚C to 1100˚C for 4 to 12 hours. At elevated temperature, the coating powder tent to react with energizer which resulting the volatile metal halides that will diffuse in gas form before deposited and mix with the specimen.

In another experiment conducted by Hsu & Tsai (2000) found that the addition of Si into 310 stainless steel improved its high temperature corrosion resistance. Both the authors have attempted this experiment by employing pack cementation process to increase the corrosion resistance of 310 SS.The dimension of 310SS used for siliconization treatment was 10 x 10 x 2 mm.The mixed powders consisted of silicone source,activator and inert filler materials. After siliconization treatment ,high temperature corrosion tests were performed in a tube furnace in air or in $CO/CO_2$ gas mixtures at the temperature range of 700 - 800°C shown in figure 4 and figure 5.

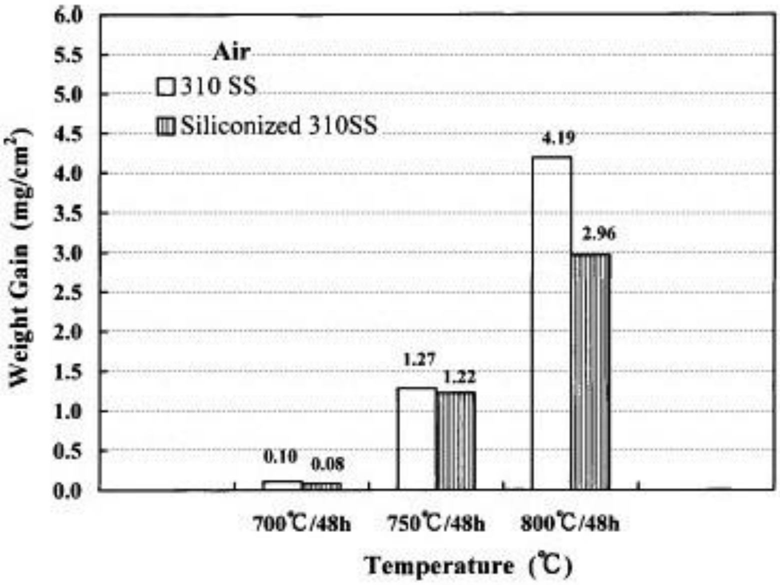


Figure 4. Weight gains of 310 SS and siliconized SS exposed in air at various temperature for 48 hours.Retrieved from Hsu & Tsai (2000).

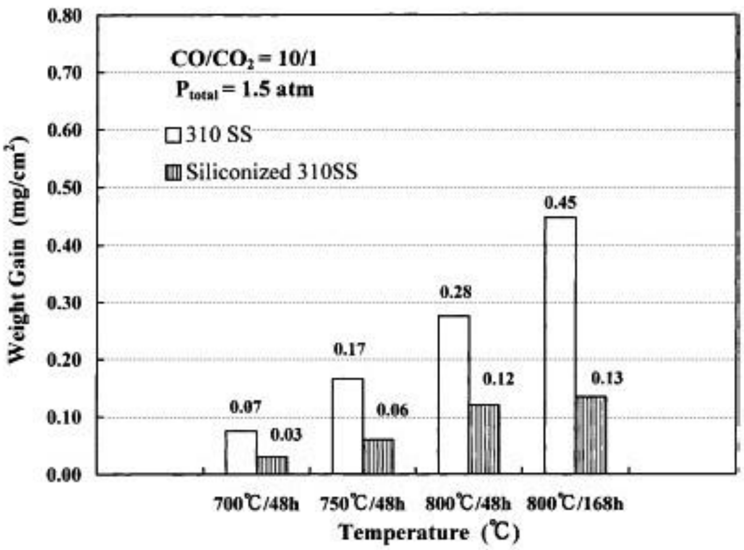


Figure 5. Weight gains of 310 SS and siliconized SS exposed in mixed gas of $CO/CO_2$ at different temperature with various time. Retrieved from Hsu & Tsai (2000).

Apart from pack cementation, Markos (2009) have carried a different method of siliconizing by thermochemical treatment.According to him, the siliconizing process conducted using a sealed boxes in a pulverous environment with powdery medium paste. The experiment test were done at different temperature , namely 600˚C,650˚C and 700˚C for 4 hours.The electron probe microanalysis results for every analyzed point for the siliconized samples are presented in Table 1.

Table 1. The electron probe microanalysis results. Retrieved from Markos (2009).

| Temperature | El. At % | Distance from margin to core [mm] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 0.05 | 0.1 | 0.15 | 0.2 | 0.25 | 0.3 | 0.35 | 0.4 | 0.45 | 0.5 |
| 600 °C | Si K | 10.54 | 9.57 | 6.68 | 1.37 | 0.77 | - | - | - | - | - | - |
| | Sn L | 0.92 | 1.26 | 4.94 | 7.10 | 7.40 | - | - | - | - | - | - |
| | Cu K | 88.54 | 89.17 | 88.38 | 91.53 | 91.83 | - | - | - | - | - | - |
| 650 °C | Si K | 8.50 | 7.90 | 7.79 | 8.04 | 6.60 | 5.93 | 4.87 | 4.67 | 4.12 | 2.30 | - |
| | Sn L | 1.94 | 1.98 | 1.99 | 2.41 | 2.77 | 2.73 | 3.46 | 3.92 | 4.17 | 8.14 | - |
| | Cu K | 89.56 | 90.12 | 90.22 | 89.55 | 90.63 | 91.3 | 91.6 | 91.4 | 91.7 | 89.5 | - |
| 700 °C | Si K | 4.67 | 4.61 | 4.56 | 4.91 | 4.35 | 4.22 | 4.50 | 4.16 | 3.65 | 2.87 | 1.42 |
| | Sn L | 3.66 | 3.50 | 3.80 | 3.83 | 4.07 | 4.45 | 5.09 | 5.52 | 6.41 | 7.09 | 7.56 |
| | Cu K | 91.69 | 91.89 | 91.64 | 91.26 | 91.56 | 91.3 | 90.4 | 90.3 | 89.9 | 90.0 | 91.0 |

Within the 600 ˚C (Table 1), it is possible to obtain a diffusion layer of which content of Si should approach the silicon solubility limit in a copper. At 700˚C the thickness of diffusion layer growth, but the Si concentration decreases.

In the light of preceding discussions, when energy is given to a substance and the substance is not performing any work, it results into increase in temperature of the substance (A.Cengel & A.Boles, 2007). Amount of heat, required to raise the temperature of a substance by a certain amount, depends on the properties of the substance and this amount of heat varies from substance to substance. For example, the amount of energy or heat required to increase the temperature of 1 kg of water by 1°C is 4.186 J, but the amount of heat required to increase the temperature of 1 kg of copper by 1°C is only 387 J. Therefore, if energy Q is given to the substance having mass m, and it results in the change in the temperature of the substance by difference in temperature, ΔT.

$$\boldsymbol{Q = mc\Delta T} \qquad \text{Equation 1}$$

### 2.3.3 Result of Siliconizing

Markos (2009) emphasizes that the treatment parameters have great influence on properties of diffusion layers. The higher the concentration of Si ,the higher the hardness which improves the wear resistance of siliconized material. This statement was agreed by another author Hsu & Tsai (2000) who have conducted studies on High Temperature Corrosion

Behavior of Siliconized 310 stainless steel. According to them, the siliconization treatment provides high temperature corrosion resistance when sufficient concentration of silica is provided in order to form better silica layer between the metal and scale interface.

From the study by Li, Taniguchi, Matsunaga, Nakagawa, & Fujita (2003) regarding influence of siliconizing on the oxidation behaviour ; they found that the thickness of the constituent layers depends on the siliconizing temperature. This statement was agreed by another authors Xiong, Mao, Xie, Cheng, & Li (2005) who have carried out a research on formation of silicide coatings on the surface of material and improvement in the oxidation resistance. According to them, the thickness of the silicide coatings increases with siliconizing temperature (T) and siliconizing time (t).

### 2.3.4 Relevancy of Literature Review to Project

Based on the literature reviews studied by the author,it was found that siliconizing method helps to improve the mechanical properties of a particular material.In this case,the author realize that the siliconizing method would become handy in producing uniform thin film coating onto aluminium alloys in order to improve the resistance to surface indentation, fatigue and wear. Even though the author finds various ways of siliconizing a material such as pack cementation process,siliconizing using thermochemical treatment and burying Silica powder based on the literature review, the author believes that siliconizing of aluminium alloys via silica sand bath would be successful and meet the objective of the research.

Apart from that, the author finds the literature review is very helpful in terms of determining an optimum siliconizing parameters in producing uniform thin film coating onto aluminium alloy. One of the useful parameter that the author discovered is the optimum temperature of silica which is above 560˚C and form a Silica rich layer onto aluminium alloy. The second useful parameters is the time of conducting the siliconizing process. It was found that,heating the silica in a heat resistant container (brick) for more than 1 hour would results an effective uniform thin film coating onto aluminium alloy substrate.

# CHAPTER 3

# Methodology

## 3.1 Research Methodology

As per the research done before based on the literature review, the surface of material properties can be enhanced by using case hardening techniques which involves immersing the metal substrate in silica sand bath. Before commencing to the procedure, a clear understanding on research and the vital objectives must be known. As per the previous discussion, the main aim of the project is to improve and enhance the microstructure as well the surface properties of the metal. The next step is to analyse the related case and research studies on case hardening method, siliconizing and various other techniques. Previously, there are some authors have done the experiment in order to match their relevant theories. Hence, the next step will be extracting the procedures to carry out experiments and manipulate the experiment parameters according to the author's expectation.

When all the vital parameters have been noted, the following steps will be conducting an experiment. Firstly, the Aluminium specimen were cut into pieces of square plates according to a specified dimensions.Next,the prepared brick were milled to form slots in order to place the specimen in the brick.Furthermore,to obtain good siliconizing result the sand have been sieved until 150µm using sieving machine. After the required materials is prepared ,the sieved sand is filled up into the slotted brick and the sample is immersed in the middle of the sand lump. Next, the brick container is kept in the furnace and heated at 580ºC for 1 hour. Later, the Aluminium alloy specimen is left cool at room temperature and hardness test were carried out to get the results of the experiment. As for the analysis, results before and after the experiment is compared based on the surface properties. Eventually, the last procedure is to identify the constraint evolves during carry out the experiments and analyze the experimental data obtained.

## 3.2 Project Activities

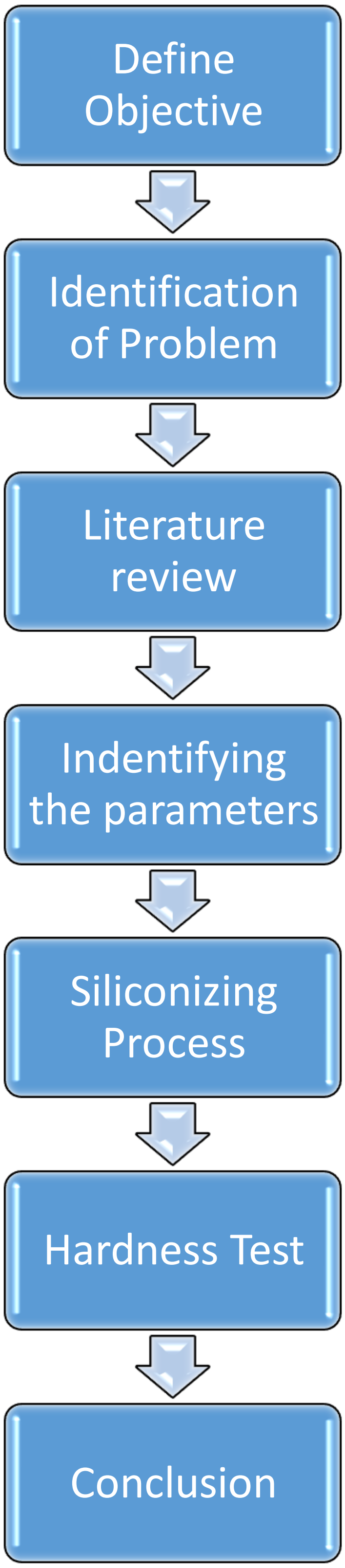


Figure 6. Research methodology of the study

### 3.3 Materials and Testing

The materials that are used in the siliconizing experiments are listed as below:

1.Silica sand (150µm)

2.Brick as the ceramic container.

3.Sample : Aluminium Alloy 6061 (2.3 x 2.7 x 0.3 cm).

The testing that were conducted for this study:

1.Hardness Test

#### 3.3.1 Sample Preparation

Aluminium Alloy will be used to conduct the siliconizing experiment as have been discussed before in the project activities. The Aluminium alloy was cut into small pieces of square plates according to specified dimensions as shown in figure 7 and figure 8. Next the Aluminium alloy sample is weighed and its height is measured in order to be compared with the data after experiment. Since the surface of Aluminium alloy has a good finishes naturally there is no need to be ground and polish.

Figure 7. Process of cutting Aluminium alloy plate (Al 6061)

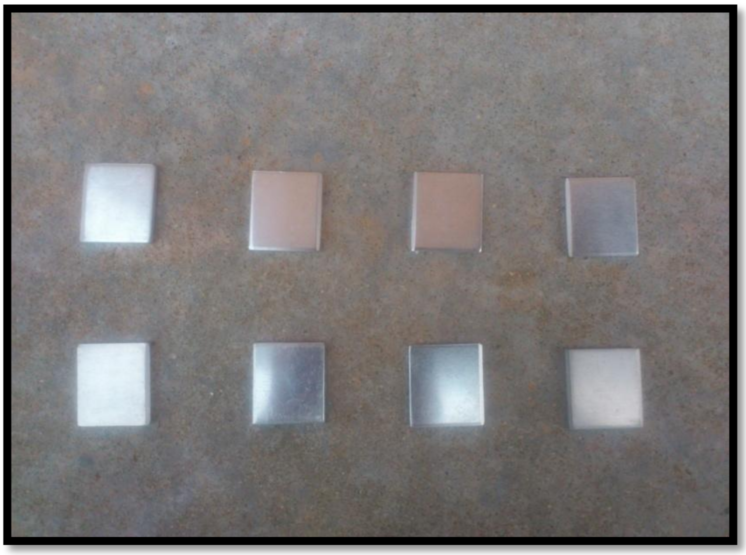

Figure 8. Aluminium alloy sample that will be used in experiment

### 3.3.2 Siliconizing Preparation

For this experiment, brick has been choose to be used as the container of Aluminium alloy as it is easily available and able to withstand high temperature .Besides that, brick is also a good insulator where heat can be trapped inside and will not escape easily. In order place the specimen in the brick, the brick was milled to form slots on the surface as shown in figure 9 and 10 .

Figure 9. The brick is milled to form slots

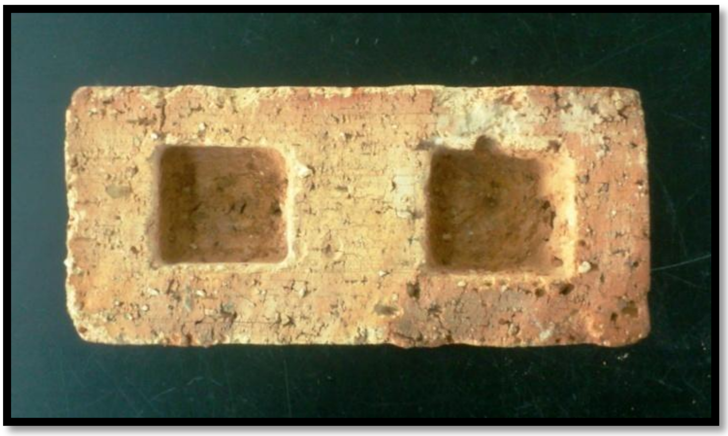

Figure 10. Slotted Brick

Furthermore, to perform siliconizing process the author used slica sand for coating.Based on the literature review it was found that in order to obtain good siliconizing result the sand must be in very fine size for easy diffusion coating. Thus, the author spent at least 3 hours in a week to sieve the sand into finer particle size distribution.Before proceed to the sieving process the author has dried a tray of sand under the sun for one whole day as presented in figure 11. The sand was successfully sieved until 150 µm using sieve shaker machine which have been a challenged for the author as shown in figure 12 and figure 13.

Figure 11. Sand is dried under the sun before sieving process

Figure 12. Sieving process

Figure 13. Sieve Shaker (150 µm)

### 3.3.3 Siliconizing ( Heating Process)

At this stage, the author filled up the slotted brick with sieved sand and the sample is immersed in the middle of the sand lump in order to run the experiment at high temperature as presented in figure 14. Based on the literature review, the author have decided to set the working temperature at 580ºC for 1 hours of heating process as shown in figure 15.

Figure 14. Filled brick with sand and the sample


Figure 15. Heating Process (Siliconization)

### 3.4 Gantt Chart and Key Milestone

Table 2 shows the key stages of the project undertaken for the past eight months.

Table 2. Gantt Chart and Key Milestone of the project

| Activity / Monthly(weekly) | FYP 1 ( Jan - April 2014) | | | | | | | | | | | | | | FYP 2 ( Mei - August 2014) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Selection of FYP Topic | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1st Discussion with SV | | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Literature Review | | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | |
| Extended Proposal First Draft | | | | | ■ | | | | | | | | | | | | | | | | | | | | | | | | |
| Extended Proposal Submission | | | | | | ▲ | | | | | | | | | | | | | | | | | | | | | | | |
| Proposal Defence | | | | | | | | ■ | ■ | | | | | | | | | | | | | | | | | | | | |
| Study on experiment parameters | | | | | | | | | | ■ | ■ | ■ | | | | | | | | | | | | | | | | | |
| Interim Report Draft Submission | | | | | | | | | | | | | ■ | | | | | | | | | | | | | | | | |
| Submission interim report | | | | | | | | | | | | | | ▲ | | | | | | | | | | | | | | | |
| Conducting the experiment | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| Prepare report | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | |
| Progress report submission | | | | | | | | | | | | | | | | | | | | | ■ | | | | | | | | |
| Submission of draft final report | | | | | | | | | | | | | | | | | | | | | | | | | ■ | | | | |
| Submission of Dissertation (Soft Copy) | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | | | |
| Submission of technical paper | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | | | |
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| Submission of Dissertation (Hard Copy) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ |

▲ Key Milestone

■ Process

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 Estimation of Time to Reach Working Temperature

In order to perform the siliconizing process of Aluminium alloy via Silica sand bath, the time taken to reach working temperature needs to be obtained. The calculation to estimate time taken is performed based on equation 1.

$$Q_T = mc\Delta T_{\text{Brick}} + mc\Delta T_{\text{Silica Sand}} + mc\Delta T_{\text{Aluminium}} \qquad \text{Equation 1}$$

**Parameters:**

Mass of Silica Sand : 0.030kg

Mass of Aluminium specimen : 0.055kg

Mass of Brick : 2.43kg

Required Temperature: 580$^o$C

Initial Temperature: 24$^o$C

Specific Heat Capacity of:

- Silica Sand : 0.83kJ/kg.K
- Aluminium : 0.91 kJ/kg.K
- Brick : 0.79 kJ/kg.K

Ein = (2.43kg) (0.79kJ/kg.K)(580-24)°C + (0.030kg)(0.85kJ/kg.K)(580-24)°C + (0.055kg)(0.91kJ/kg.K)(580-24)°C

= 1067.4kJ + 13.84 kJ + 27.9kJ

= **1109.14 kJ**

Therefore,the time needed for this furnace to supply 1109.14 kJ of heat to increase the temperature of silica sand,brick and Aluminium alloy specimen from 24ºC to 580ºC is determined based on the equation below:

$$\Delta t = \frac{\text{Total energy transfered}}{\text{Rate of energy transfer}} = \frac{1109.14 \text{ kJ}}{0.91 \text{ kJ}} = 1218.84\text{s} = \mathbf{20\ min}$$

Therefore,the experiment period of 1 hour is sufficient enough since it only takes 20 minutes for the Aluminium alloy specimen to obtain working temperature before siliconizing process occurs.

## 4.2 The Sample Before And After Siliconizing

The melting temperature of Aluminium alloy is between 650°C to 660°C. Therefore, the experiments were conducted to observe the effect on the Aluminium alloy in silica sand bath for the temperature below melting point of Aluminium alloy.

Since the surface of Aluminium alloy has a good finishes naturally there is no need to be ground and polish.The sample before siliconizing process takes place shown in figure 16. After the siliconizing process is completed, it was found that coating layer is not produced on the Aluminium alloy sample as shown in the Figure 17.

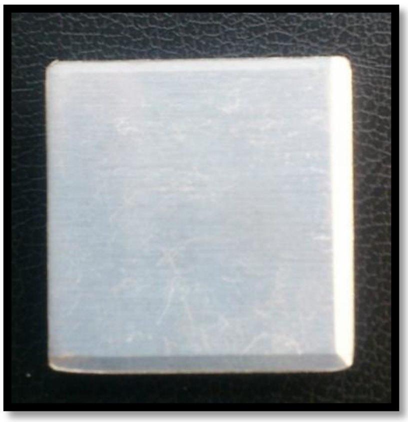

Figure 16. Sample Before Siliconizing

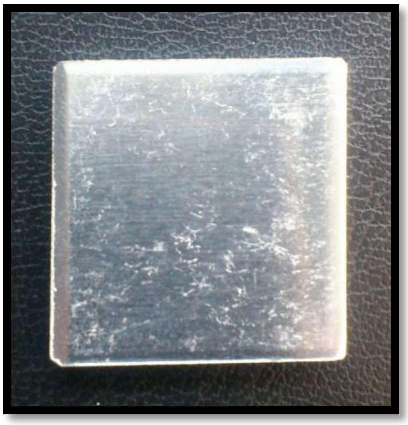

Figure 17. Sample After Siliconizing

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## 4.3 Hardness Test

After performing siliconizing process, the author decided to measure the hardness of the specimen before and after siliconizing process.Since there is no any coating formed on the specimen, Vickers Hardness Test has been used to find any changes occurred on the surface of the aluminium alloy substrate and the results are shown in figure 18 (a) and (b).

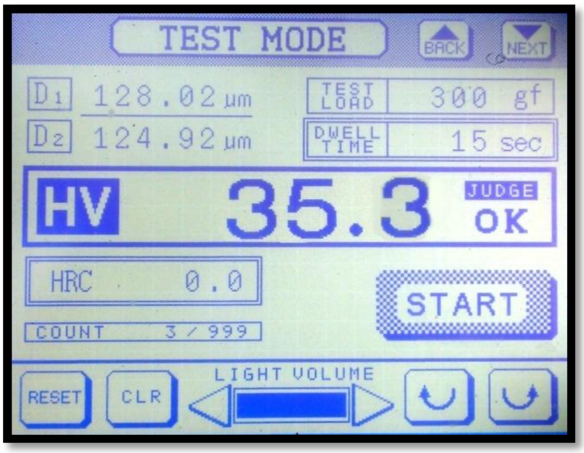


Figure 18 (a).   Sample before siliconizing,VHN =  35.3

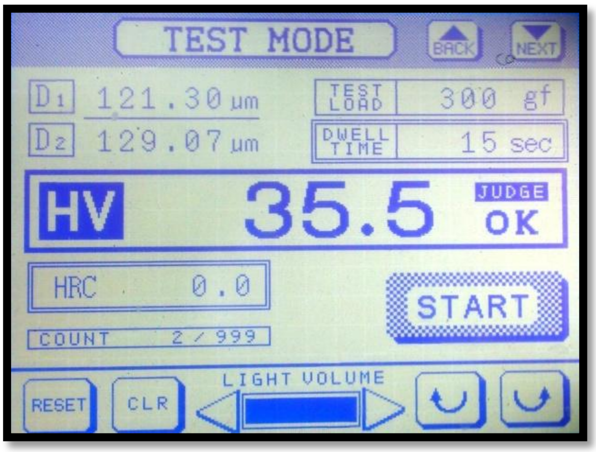


Figure 18 (b).   Sample before siliconizing,VHN =  35.5

Based on the results obtained, it was found that the hardness value for both the samples are almost the same which means siliconizing process could not produce an uniform silica coating on the surface of Aluminium alloy substrate. Hence, mechanical properties evaluation were unable to be performed from the  surface of the siliconized sample using Scanning Electron Microscope or optical microscope.

## 4.4 Factors Influence The Siliconization Process

Since there is no any changes discovered after siliconization process, the author believes that there must be some factors that influence this siliconization process for not producing silica coating on the specimen. The factors are discussed as follows:

i. **Heat transfer in the brick**

   It was found that heat produced in the furnace could not transfer effectively to the slotted compartment where the specimen is placed in sand bath. This is because, the clay brick which has been used in this experiment was naturally build up with porous. The heat produced in the furnace is not fully transmitted to the slotted compartment so that the silica sand could be coated onto the specimen.

ii. **Working Temperature**

   The working temperature used in this experiment was 580 ºC which is below the melting point of Aluminium. The author believes that if the working temperature of the experiment is increased more than 600 ºC the siliconization process could be done effectively by forming an uniform silica coating.

iii. **Siliconization time**

   The time used to run the siliconization process was 1 hour. The author believes that the working time used in this experiment was not enough to diffuse the silica sand onto the sample. Thus, the siliconization time should be increased at least 4 hours so that it would results an effective uniform thin film coating onto aluminium alloy surface.

# CHAPTER 5

## 5.1 Conclusion

Siliconizing is basically a simple and inexpensive method to harden the surface of Aluminium alloy as compared to other methods such as carburizing, boronizing,induction hardening and laser hardening. This is because, the siliconization method which the author has used only requires a high temperature furnace, Silica from sand and a brittle container (brick).However, the siliconizing process in this experiment could not produce an uniform silica coating onto the surface of Aluminium alloy substrate.

After performing hardness test, it was proven that there is no much changes occurred in the hardness of the material since the value for the sample before siliconizing is VHN 35.3 and after siliconizing is VHN 35.5 which are almost the same.Hence, mechanical properties evaluation were unable to be performed from the  surface of the siliconized substrate. For the study, it was concluded that Aluminium alloy is not a suitable material to be siliconized via silica sand bath in order to enhance the hardness, wear resistance and corrosion resistance of the substrate surface.

## 5.2 Recommendations

Determining the heat transfer rate and the temperature of Aluminium alloy inside the furnace always been a limitation of this research. As a recommendation, simulation analysis may be used in determining the parameters for siliconizing process. Besides that, it is recommended to apply higher temperature during siliconization process to increase the coating layer thickness of Aluminium alloy substrate.

Apart from that, the author found that heat produced in the furnace could not transfer effectively to the slotted brick compartment where the specimen is placed in sand bath. This is because, the clay brick which has been used in this experiment was naturally build up with porous. Hence, a better container must be used in order focus the amount of heat produced to the desired area.

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