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Effect of Flux Application on Aluminium-Silicon Alloy (Al-SiMg) Machining Chips for In-Situ Casting Process

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Abstract: The primary material used in this study is aluminium-silicon alloy (Al-Si7Mg) machining chips and salt flux. The Al-Si7Mg machining chips were gained by cutting the cylindrical of Al-Si7Mg by using the conventional milling machine to get the chips used in this case study. Generally, machining chips are a waste that comes from machining aluminium pieces in the industries or any machining factories. This study is focusing on the effect of on Al-Si7Mg machining chips for in-situ casting process with the application of equimolar mixtures of salt fluxes sodium chloride (NaCl) and potassium chlorides (KCl). The Al-Si7Mg machining chips was mixed with NaCl-KCl flux for in-situ casting experiment at the temperature of 650^{o}C and 700^{o}C for 30mins. Visual evaluation and Scanning Electron Microscope (SEM) with Energy Dispersive Spectroscopy (EDS) were used for analysis of raw and heated samples. The morphology of the heated AlSi7Mg machining chips were wrinkles with oxide nodules scattering on the surface. EDS result revealed amount of aluminium (Al) element of the heated sample reduced from 91.78 wt. % to less than half proving the chips encountered oxidation during in-situ casting experiment. The fluxes promoted partially melting of the machining chips as the agglomeration of the heated machining chips was developed in the ceramic investment casting mould despite of oxidation.

Keywords: Aluminium, Salt Flux, Oxide

1. Introduction

In engineering field, aluminium is the eminent material widely used in manufacturing industries due to its properties and strength. With the attractive silvery white appearance and the weight can be approximately three times lighter than iron's weight. The remarkable physical characteristics that make it universally used because of its light weight, ductile, resilience, durable and high strength. This is a crucial advantage in many products since it can reduce the cost of shipping and handling the product due to it small space used. In developing the aluminium alloy, it tends to raise the strength of the product

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without affects the ductility of it. Some of the elements which are cooper, silicon, magnesium and zinc were added in order to improve the hardness and strength. Aluminium alloys are used in a wide range of electric module packaging, electronic technology, automotive body structure, wind and solar energy management, and other applications due to several advantages of high specific strength, high processability, predominantly anti-erosion, increased conductivity, eco-friendliness, and recoverability.

Other than added any admixtures, there some method can be applied to increase the hardness of aluminium such as degassing agent, heat treatment and grain refinement. It could also be altered using a variety of cold-working, alloying, and heat-treating techniques. In industries, it a common thing in using aluminium and surely while manufacturing product, it will produce a waste namely as chips. It is a waste come from machining aluminium piece. Even though it is a waste but it still can be recycled many times since it can sustain the qualities. The waste or easily called as machining chips will go through some related process to the recycling phase. In addition, it is a good part in using aluminium which the scrap aluminium is recyclable and only requires five percent of the energy used to make new aluminium. In the process of recycling aluminium, it needs to be sorted, cleaned, and remelted to obtain the molten aluminium then it will be formed into ingots to roll, cast, or extruded.

Nowadays, investment casting is extensively studied by researchers to adopt in-situ casting also called as the in-situ melting technique. In-situ melting technique has great potential to be explored further in investment casting of Al alloys. Nevertheless, flux application is essential during in-situ melting or casting due to several reasons such as oxide breaking, degassing and to avoid metal-ceramic mould reaction. Flux application was applied extensively to the metal in casting process as degassing agent to clean the liquid metal.

Investment cast aluminium experiencing porosity defect that can be caused by many factors including the melting process flaws, pouring techniques and its parameters. This porosity affects the mechanical performance of Al castings to function as it is intended to. There are various techniques to reduce the porosity of the Al cast. Controlling the pouring temperature and mould preheat temperature at the lowest possible temperature and the use of low pressure and vacuum assisted method can decrease the porosity in the Al cast [1,2]. However, the temperature control conducted by the operator leads to inconsistent result and the use of low pressure and vacuum assisted method was costly.

Another common method to reduce porosity of the liquid Al is by degassing with inert gas, ultrasonic vibration, salt fluxing and electromagnetic force for removing oxide inclusion were beneficial to clean the liquid Al. All these attempts conducted before pouring of the liquid Al into the mould, however oxidation reoccur due to turbulence and developing the pores in the cast Al during pouring process. Eliminating turbulence during pouring of liquid Al is important, thus turbulence free filling system or a pouring free casting was explored by many researchers. Tilt casting, bottom filling mechanism, low pressure bottom filling and in-situ casting or melting technique were applied to improve the quality of Al cast. In-situ casting and in-situ melting approach had outstanding results. However, the use of graphite split mould and oxidation of the granular alloy became the challenges of it. Thus, fluxing was used for investment casting of pure Al and magnesium (Mg) alloy to facilitate the melting of aluminium alloy during in-situ melting. There are still lack of information on the application of in-situ casting of Al alloy in investment casting especially for recycling of the Al alloy chips would be due to oxidation of the Al alloy during in-situ casting. Therefore, this study aims in exploring the application of flux in investment casting of Al alloy machining chips by in-situ casting.

2. Materials and Methods

2.1 Materials

Aluminium silicon-magnesium alloy (AlSi7Mg) machining chips were used in the study as shown in Figure 1. Flux consists of sodium chloride (NaCl) mixed with potassium chloride (KCl) powder of equimolar mixture were applied as the fluxing medium in the in-situ casting experiment.

Figure 1: AlSi7Mg machining chips

2.2 Methodology

The raw ingot of (Al-Si7Mg) was machined by using conventional milling machine to produce the machining chips. The chips were collected and cleaned before proceeds with in-situ casting experiment. The machining chips were evaluated for the physical properties of the raw state. Ceramic investment casting mould were prepared according to standard operating process for making the ceramic mould. A slurry of zircon ($ZrO_2.SiO_2$) was mixed with the concentration colloidal silica (SiO_2) to produce the ceramic slurry. Then the cylindrical wax pattern was dipped in the ceramic slurry and let it dry for 1 hour for the face coat layer. The process continued with, the pattern was dipped again in the slurry and immediately stuccoed with fine grain (0.3-0.7mm) alumino silicate ($Al2O_3.SiO_2$) sand and left to dry for 1 hour. After that, it was dipped again into the slurry and stuccoed with coarser (0.7-1.0mm) alumino silicate ($Al2O_3.SiO_2$) sand after 1 hour of drying. The step of the process for dipping and stuccoing was repeated for the next 2 consequent coats. For the formation of the final coating, the patterns were dipped into the slurry and let it dry completely for 24 hours. The ceramic mould's wall thickness was measure using vernier caliper to be maintained between 6 to 7 mm thick.

Al-Si7Mg machining chips was then filled into the ceramic investment casting mould till fully occupied. The mould was shaken manually by hand for two minutes to ensure the chips is occupying the empty spaces in the ceramic mould. The flux was mixed with Al-Si7Mg in the ceramic mould before heating in the laboratory furnace. The amount of flux to be applied was divided to two ratios which are 1:0.1 and 1:0.2. The mass of the machining chips used to fill every ceramic mould was 13g. The mass of flux for ratio 1:0.1 was 0.65g for each sodium chloride (NaCl) and potassium chloride (KCl) powder. The mass of flux for ratio 1:0.2 was 1.3g for each NaCl and KCl. The filled ceramic mould was placed at the centre of a laboratory furnace and the experiment for heating was conducted based on the parameters as in Table 1 and Table 2.

The raw and heated Al-Si7Mg alloy machining chips will be evaluated visually for the geometry, colour, and appearance changes. The image from visual evaluation will be captured using Digital Camera and the colour machining chips was observed according to British Standard Colour Code (BS5252).

Table 1: Heating temperature and percentage of flux used in the experiment

Temperature, ºC	650		700	
Percentage of flux, %	0.1	0.2	0.1	0.2

Table 2: Heating temperature and duration

Temperature (ºC)	650	700
Duration (Min)	30	

Oxidation characteristics of the machining chips before and after in-situ casting (after heated) were observed using Optical microscope (OM) for geometry of the machining chips, while Scanning Electron Microscope (SEM) equipped with Energy Dispersive Spectroscopy (EDS) was used for analyzing the oxide morphology and also elemental analysis on the oxide layer.

3. Results and Discussion

3.1 Physical Evaluation

Table 3 shows the outcome of AlSi7Mg chips after being heated at the temperature of 650ºC for 30mins heating duration. Al-Si7Mg machining chips colour before heating is shiny silver to light greyish. The AlSi7Mg machining chips after heated at 650ºC with flux application portrayed grey green mix with grey goose colour for flux amount of 0.1% and xanadu mix with grey goose colour for the flux amount of 0.2% (Table 3). While sample heated at 700ºC with flux used of 0.1% obtained the ash grey mix with dark charcoal and then with flux amount of 0.2% the chips colour became ash grey as depicted in Table 4. Each degree of heat produces a variable depth of oxidation, and each one will reflect a particular wavelength of light while absorbing all others. The colours appeared in multiple colours that are reflected depending on the oxidation of the machining chips at the elevated temperature set up during the experiment.

Table 3: Result of machining chips after heating in temperature 650ºC

TEMPERATURE (ºC)	**650**	
PERCENTAGE OF FLUX (%)	**0.1**	**0.2**
TOP VIEW		
COLOUR CHANGE	Grey Green and Grey Goose	Xanadu and Grey Goose

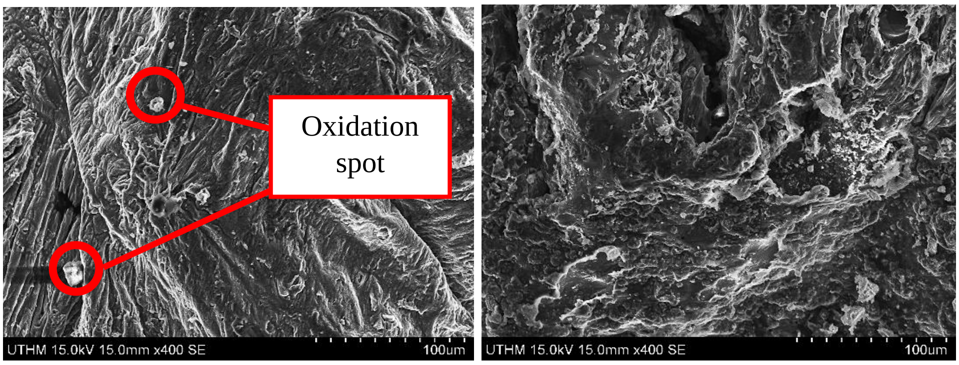
Table 4: Result of machining chips after heating in temperature 700ºC

TEMPERATURE (ºC)	**700**

PERCENTAGE OF FLUX (%)	**0.1**	**0.2**
TOP VIEW		
FRAGMENTS		
COLOUR CHANSGE	Ash Grey and Dark Charcoal	Ash Grey

The result of formation for all samples after heating showed that at the heating temperature at 650ºC revealed the Al-Si7Mg machining chips mixed with flux 0.1% and 0.2% were agglomerated in in the ceramic mould. In contrast to the sample which heated at temperature 700ºC, there were some fragments separated from the agglomerated machining chips as shown in Table 4. It can be suggested that the increased in temperature during in-situ casting experiment allowing the oxidation of the AlSi7Mg machining chips to become greater thus prohibiting the melting of aluminium element. Therefore, some machining chips were oxidised severely preventing the complete agglomeration [3].

Figures 2 depicts SEM images of AlSi7Mg machining chips morphology after being heated at the temperatures of 650ºC. Oxidation was observed during SEM analysis as shown in Figure 2(a) at the sample heated with 0.1% flux amount while the sample heated with 0.2% flux showed scattered oxide nodules on the machining chips surface (Figure 2(a)).



(a) (b)

Figure 2: SEM images of the aluminium silicon alloy after heating at temperature 650ºC with different percentage of flux used (a) 0.1% and (b) 0.2%

The sample of AlSi7Mg machining chips heated at the temperature of a and 700ºC with 0.1% flux applied shown in Figure 3 indicating that the oxidation had taken place during the in-situ casting experiment. The layer of oxide can be clearly seen in the SEM image (Figure 3(a)) while other oxide nodules were observed to be scattered on the surface of the chips. Similar observation was found to the sample of AlSi7Mg machining chips that was heated at the temperature of 700ºC with 0.2% flux used during heating. The machining chips were oxidized which can be seen by the existence scattered oxide nodules all over the chips surface as shown in Figure 3(b).

(a) (b)

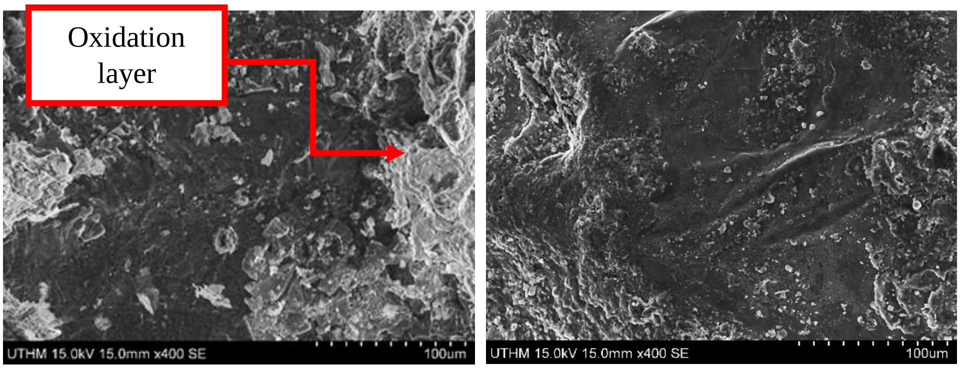
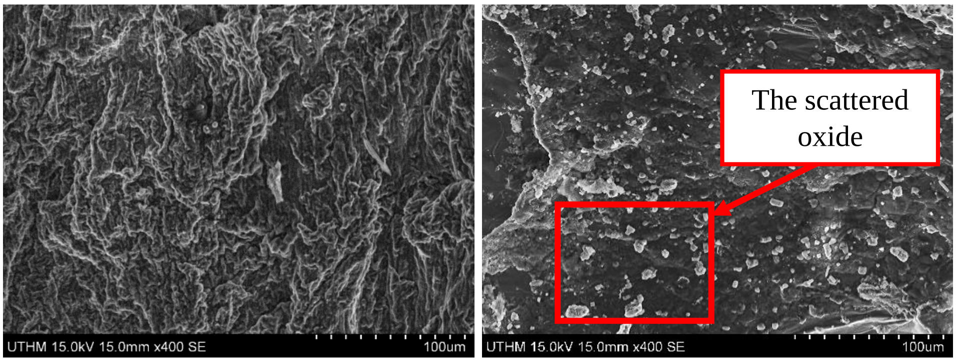


Figure 3: SEM images of the aluminium silicon alloy after heating at temperature 700ºC with different percentage of flux used (a) 0.1% and (b) 0.2%

Figure 4, oxidation of the fragments machining chips was found to be similar with the sample of machining chips that was agglomerated. The surface of the heated chips was wrinkles with whitish color indicating the fragmented chips experienced oxidation. The machining chips heated with 0.2% flux prove that the chips oxidized with individual oxide nodules scattering on the surface as shown in Figure 4(b).



(a) (b)

Figure 4: SEM images of the fragments of aluminium silicon alloy after heating at temperature 700ºC with different percentage of flux used (a) 0.1% and (b) 0.2%

Table 5 shows the summary of elemental analysis by EDS containing the percentage in weight of the oxygen and aluminium in the Al-Si7Mg machining chips in raw state and after heated with NaCl and KCl flux mixture. The machining chips before heating have a higher value for aluminium (Al) was the predominant metal in Al-Si7Mg with 91.78 wt. % compared to the oxygen (O) element in the alloy which was 0.92 wt. % only.

All samples of AlSi7Mg after being heated at the temperature of 650ºC and 700ºC mixed with flux at 0.1% and 0.2% indicated the reduction of Al elements percentage during EDS analysis as shown in Table 5. Generally, the amount of Al element detected during EDS analysis was less than 30 wt. % of every sample. It proved that the machining chips were experiencing oxidation during in-situ casting experiment instead of melting into a liquid metal to develop castings [4]. While the amount of oxygen in every sample was greater than the raw machining chips sample which is about 50 wt. %. Higher amount of oxygen element in the EDS spectrum analysis showed that the machining chips was severely oxidized during the experiment.

Table 5: Weight (%) of elements found on the AlSi7Mg chips sample

Sample	Weight (%) of elements	
	Oxygen	Aluminium
Before heating	0.92	91.78
650ºC (0.1 flux used)	51.84	4.09
650ºC (0.2 flux used)	56.65	1.11
700ºC (0.1 flux used)	46.42	19.97
700ºC (0.1 flux used) (Fragments)	48.06	18.32
700ºC (0.2 flux used)	49.60	26.73
700ºC (0.2 flux used) (Fragments)	48.85	26.45

4.0 Conclusion

It can be concluded that the AlSi7Mg machining chips were not affected by the amount of flux used in the experiment for formation of the castings. Both flux percentage used able to promote the agglomeration of the machining chips during in-situ casting, however oxidation that taken place during heating hindering the complete melting of the AlSi7Mg to produce castings. The used of flux changed the color of the raw machining chips from shiny silver greyish to grey goose at the temperature of 650ºC and finally to ash grey at the temperature of 700ºC.

Oxidation characteristics which is the oxide morphology on the surface of heated machining chips were individually oxide nodules that scattered all over the chips surface after heated at both temperatures of 650ºC and 700ºC with flux application. It is recommended that the application of flux shall be using mixing and cover on top method for more flux coverage during in-situ casting experiment to promote the complete melting of AlSi7Mg machining chips.

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