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# Influence of Sintering Parameters on Density of an Aluminium-Silicon Alloy Processed through Powder Metallurgy Route

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**Abstract—***In recent years aluminium and aluminium alloys are widely used in automotive industries. These are light weight, having good formability, good fluidity, high corrosion resistance and high electrical and thermal conductivity. Within the group of aluminium alloys Silumins play vital role in automobile industries because the silumins enable casting of complicated shapes. In this paper we are going to check the influences of sintering parameters in mechanical properties of Aluminium-Silicon alloy which is processed through powder metallurgy. Powder metallurgy is the Science of producing metal powders and making finished /semi-finished objects from mixed or alloyed powders with or without the addition of nonmetallic constituents. The steps in P/M process are Powder production, Compaction, Sintering, & Secondary operations. This paper mainly involves the study of density variation of the alloy by varying three sintering parameters ie compaction pressure, sintering temperature and sintering time.*

## 1. INTRODUCTION

Aluminium is an element in the boron group having symbol Al and atomic number 13. It is a silvery-white, soft, non-magnetic and ductile metal. Aluminium is the third most abundant element (after Oxygen and Silicon) in the Earth's crust and the most abundant metal there. The chief ore of aluminium is Bauxite [9].

Aluminium alloys are widely used as a main engineering material in various industries such as aerospace, automotive industries where weight is probably the most important factor. By the addition of different alloying element in aluminium we can obtain required properties.

Silicon is the most important single alloying element used in majority of aluminium casting alloys. Silicon is primarily responsible for good castability (ie high fluidity and low shrinkage), low density(2.4 gm/cm$^3$) which has advantage of reducing total weight of cast component and has very low solubility in aluminium therefore precipitates as virtually pure Si which is hard and therefore improve the abrasion resistance. It has high wear resistance, high strength, good temperature resistance [1]. Si reduces thermal expansion coefficient of Al-Si alloys.

The Aluminium-Silicon alloy is also known as Silumin. Silumin is a series of light weight, high strength aluminium alloys with silicon content within range of 3-50 %. Within the Aluminium association designation system silumins are corresponding 4xxx-Binary Aluminium-Silicon alloys [8].

Depending on the Silicon concentration in weight percentage, the Silumin alloy systems are divided into three main categories: Hypoeutectic(<12 wt % Si), Eutectic (12-13 wt % Si), Hypereutectic( 14-25 wt % Si) [2-6]. [fig-1]

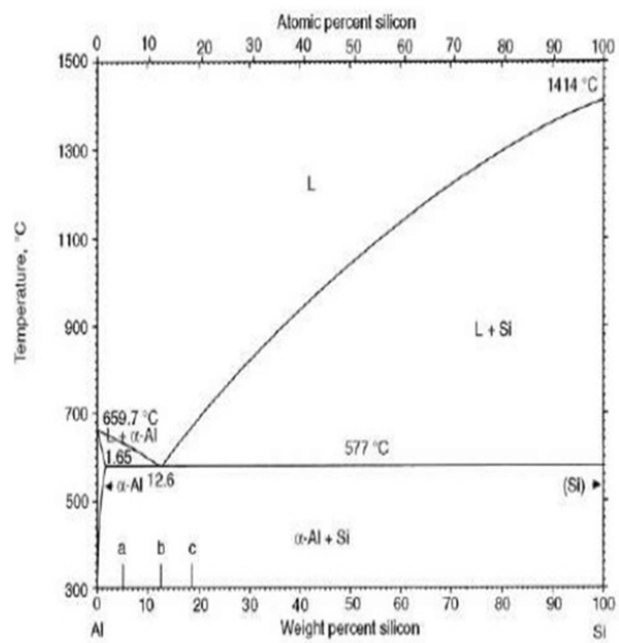


**Fig. 1: Al-Si Phase Diagram**

Powder Metallurgy is the science of producing metal powders and finished/semi-finished objects from mixed or alloyed powders with or without the addition of nonmetallic constituents. Powder metallurgy is the name given to a process in which metallic powders are heated below their melting temperatures to achieve bonding. In reality, the powder metallurgy (PM) process involves metal or alloy powders to be compacted into the desired shape after blending, and then to be heated in a controlled atmosphere at a temperature below their melting points in order to achieve bonding of the particles to get the desired properties. The powder metallurgy process enables to produce parts in their final shape, thus eliminating the need for additional machining. Raw material is not wasted during the processing while unusual materials or mixtures can be utilized [10].

## 2. EXPERIMENTAL PROCEDURE

The raw powder used were commercial Aluminium, silicon and magnesium powder in the composition of 87.5%, 12% and 0.5% respectively. The powders are 99% pure. All the powders were mixed in a mechanical blender. Isopropyl alcohol was used as a binder. The mixed powder was uniaxially pressed in the rigid steel die at the pressure range of 300 – 400 Mpa. The compacts were sintered in a tube furnace under flowing high purity argon gas with the temperature range of 450 – 510 $^oC$ for time range of 30 – 60 min. The density of the samples was calculated before and after the sintering and then both densities were compared.

### 2.1 Weight measurement of powder

3 samples of Al-Si alloy are prepared. The following table shows weight of elemental compositions taken in grams:

**Table 1: Composition of Al-Si Alloy**

| | **Sample 1** | **Sample 2** | **Sample 3** |
|---|---|---|---|
| Composition | Wt. (gms) | Wt. (gms) | Wt. (gms) |
| Al | 87.5 | 87.5 | 87.5 |
| Si | 12 | 12 | 12 |
| Mg | 0.5 | 0.5 | 0.5 |
| Total | 100 | 100 | 100 |

### 2.2 Mixing of the powders

Here ball milling type mixing method is adopted for proper mixing. The powder of each sample is kept in a cylindrical steel container. In the container containing powder mix, some spherical steel balls are put. Then the closed container is rotated at 160 rpm in both clockwise and anti-clockwise direction for 30 minutes each. Steel balls are removed and the powder is weighed in the digital weighing machine. The balls were rotated by holding it in a lathe chuck.

### 2.3 Die preparation

10 mm diameter circular cross section die and punch set is made for compacting circular pin. Another die of 30 mm dia is made for holding the 10 mm dia die. The length of both the dies are 50 mm. Lower punch and upper punch are 20 mm and 40 long respectively. The die sets are made of high strength steel with a highly polished die cavity. The clearance between die and punch is maintained as 0.1 mm.

### 2.4 Compaction of powder

Compaction of different powder is done in the hydraulic press at different compaction pressures with the help of prepared die and punch. The corresponding pressures of compaction for Al-Si alloys are mentioned below.

**Table 2: Compaction Pressures for different alloy samples**

| **Alloy Samples** | **Alloy Composition** | **Compaction Pressure (MPa)** |
|---|---|---|
| Sample 1 | Al-12%Si-0.5%Mg | 300 |
| Sample 2 | Al-12%Si-0.5%Mg | 350 |
| Sample 3 | Al-12%Si-0.5%Mg | 400 |

### 2.5 Theoretical Density Calculation

Mixture rule formula was used to calculate the theoretical density (TD).

$$\frac{1}{TD} = \frac{wt\%\ Al}{\rho Al} + \frac{wt\%\ Si}{\rho Si} + \frac{wt\%\ Mg}{\rho Mg}$$

$$\frac{1}{TD} = \frac{0.875}{2.7} + \frac{0.12}{2.329} + \frac{0.005}{1.738}$$

TD = 2.6434 $gm/cm^3$

### 2.6 Green Density Calculation

After cold compaction, the green densities were obtained. It can be seen from Table 3 that high densities were obtained, suggesting good bonding between the powders during cold compaction. However, using high pressure did not play a major role in increasing the green density.

**Table 3: Green densities of the samples**

| **Alloy Samples** | **Mass of the samples (gms)** | **Volume of the samples ($cm^3$)** | **Green Density ($gm/cm^3$)** | **% TD** |
|---|---|---|---|---|
| Sample 1 | 1.8244 | 0.85 | 2.146 | 81 |
| Sample 2 | 1.7130 | 0.80 | 2.141 | 80 |
| Sample 3 | 1.8599 | 0.85 | 2.188 | 83 |

### 2.7 Sintering of Green compact

Sintering of the green compact of the 3 alloys is done in the tube furnace under flowing argon gas.

**Table 4: Sintering of the samples**

| **Alloy Samples** | **Compaction Pressure (MPa)** | **Sintering Temperature ($^oC$)** | **Sintering Time (min)** |
|---|---|---|---|
| Sample 1 | 300 | 450 | 30 |
| Sample 2 | 350 | 480 | 60 |
| Sample 3 | 400 | 510 | 45 |

### 2.8 Sintered Density Calculation

After sintering again dimension and weight of the samples were measured and sintered density was calculated. Sample 3 sintered to the highest density, suggesting a greater contribution of sintering temperature during sintering.

**Table 5: Sintered Density of the samples**

| Alloy Samples | Mass of the samples (gms) | Volume of the samples ($cm^3$) | Sintered Density ($gm/cm^3$) | % TD |
|---|---|---|---|---|
| Sample 1 | 1.6758 | 0.7225 | 2.3194 | 88 |
| Sample 2 | 1.4150 | 0.6454 | 2.192 | 83 |
| Sample 3 | 1.8570 | 0.7500 | 2.476 | 94 |

## 3. RESULT AND DISCUSSION

Green density and Sintered density of the all three samples was measured. Acquired data are listed below in the table:

**Table 6: Comparision of Densities**

| Alloy Samples | Green Density (%) | Sintered Density (%) |
|---|---|---|
| Sample 1 | 81 | 88 |
| Sample 2 | 80 | 83 |
| Sample 3 | 83 | 94 |

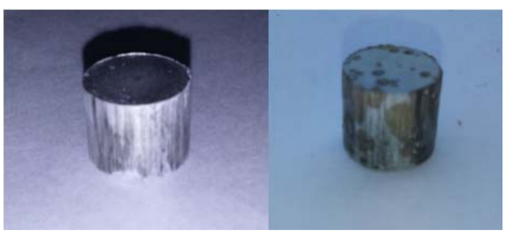

**Fig. 2: Sample before and after sintering**

## 4. CONCLUSION

Al-12Si-0.5Mg alloy powder was successfully sintered under flowing argon gas at the sintering temperature range of 450 – 510 $^oC$ and with the compaction pressure range of 300 – 400 MPa. The Green density was around 80 % of TD and after sintering it was around 90 % of TD. Best alloy was obtained as sample 3 (ie 400 MPa, 510 $^oC$, 45 min). So from above experiment we can finally conclude that sintering temperature has a far more effect on the final density of the alloy than the cold compaction pressure.

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