A Study of Taguchi Method Analysis for the Optimization of Factors of Eutectic Al-12Si-xCu Alloy Produced Through Powder Metallurgy Process

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Abstract - *The aim of this present research is to investigate the effects of copper addition on density of eutectic Al-12 Si P/M alloys. Six Al-12Si-xCu alloys with copper content of 0.5%, 1.5%, 2.5%, 3.5%, 4.5%, 5.5% are produced i.e. Alloy A (Al-12Si-0.5 Cu), Alloy B (Al-12Si-1.5Cu), Alloy C(Al-12Si-2.5 Cu), Alloy D (Al-12Si-3.5 Cu), Alloy E(Al-12Si-4.5 Cu) and Alloy F (Al-12Si-5.5 Cu). Alloys are compacted at 400MPa, 500MPa, 600MPa compaction pressure and sintered in vacuum furnace at 570°C, 600°C, and 630°C under vacuum (10^{-2} torr). Taguchi L_{18} mixed design is adopted to get optimum responses where eighteen nos. test specimen of six alloys are produced with different compaction pressure and sintering temperature. It is observed that the green density of alloy samples increases with the increase in copper content in the alloy and sintered density decreases compared to green density after sintering of the samples.*

***Key Words*:** Powder Metallurgy, Eutectic Al-12Si-xCu alloys, Copper content, Taguchi L_{18} mixed design, Optimum responses.

1.INTRODUCTION

Powder metallurgy technique of manufacturing components competes with other manufacturing components such as casting, forging and machining. Over the last decade, several researchers have extensively investigated the effect of various sintering conditions on mechanical properties and micro-structural development of Al-Si-Cu alloys. Subramanian [1] observed that addition of silicon in aluminium improves the wear resistance. He noticed that addition of silicon up to about eutectic composition (12% silicon) increases the wear resistance. Das et al.[16] noticed that Al– Si–Cu alloys with up to 4.5% copper are satisfactory for ordinary conditions of service, addition of just 1% copper in these alloys increases the strength, hardness and stability of protective surface layer. Laska [2] has studied that density is a function of compaction pressure of Alumix (Al-14Si-2.5Cu-0.5Mg)powder. It is seen that green density increases with compaction pressure but sintered density is independent with green density. This study examines the effect of copper content on sintering behaviour, mechanical properties and micro structural observation in Aluminium-silicon Alloys.

2. Composition Selection

In this experiment, six alloys (Al-Si-Cu) with Copper as the varying element i.e. Alloy A (Al-12Si-0.5 Cu), Alloy B (Al-12Si-1.5Cu), Alloy C(Al-12Si-2.5 Cu), Alloy D (Al-12Si-3.5 Cu), Alloy E(Al-12Si-4.5 Cu), Alloy F (Al-12Si-5.5 Cu) is produced by powder metallurgy process, while silicon and some other constituents are being kept fixed. The percentages of the allowing elements such as Mg, Mn, Fe, Zn and Ti are taken approximate lower values to meet desire properties.

Table 1 Chemical Composition of Alloy Used in experiment

Alloy	Wt. % (Cu)	Wt. % (Si)	Wt. % (Mg)	Wt. % (Fe)	Wt. % (Ti)	Wt. % (Al)
A	0.5	12	0.1	0.5	0.08	Bal.
B	1.5	12	0.1	0.5	0.08	Bal.
C	2.5	12	0.1	0.5	0.08	Bal.
D	3.5	12	0.1	0.5	0.08	Bal.
E	4.5	12	0.1	0.5	0.08	Bal.
F	5.5	12	0.1	0.5	0.08	Bal.

3. Design of Experiments (DOE)

Design of experiments (DOE) is a method to determine the relationship between factors that affects the process and output of that process. This technique enables designers to get the optimum output value. A DOE can be analyzed in many software programs; here Taguchi design of experiments is adopted for getting optimum output measures. In Taguchi method, 'optimization' means determination of BEST levels of control parameters. The BEST levels of control factors are those that maximize the Signal-to-Noise ratios. The optimization is achieved by using three signal to noise ratio –smaller the better, larger the better and nominal the best. In any sintering process, the main objective is to maximize density, hardness and strength. So, larger the better type Signal to noise ratio is applied to get best results for sintering process.

$$S/N\ ratio = -10 \log_{10} \left(\frac{1}{j}\right) \sum_{i=1}^{j} \frac{1}{y2}$$

Where, j= number of repetition of experiments

Y_i= observed response value

Taguchi mixed- level L18 (6^1 3^6) factorial design is adopted.

Table 2 Selection of parameters and their levels

Parameters	Level					
	1	2	3	4	5	6
Composition (Wt% of Cu)	0.5	1.5	2.5	3.5	4.5	5.5
Compaction pressure (MPa)	400	500	600			
Sintering temperature (°C)	570	600	630			

Table: 3 Taguchi L-18 mixed factorial designs

Coded			Un-coded		
C	P	T	Composition (Wt% of Cu)	Compaction pressure (MPa)	Sintering temperature(°C)
1	1	1	0.5	400	570
1	2	2	0.5	500	600
1	3	3	0.5	600	630
2	1	1	1.5	400	570
2	2	2	1.5	500	600
2	3	3	1.5	600	630
3	1	2	2.5	400	600
3	2	3	2.5	500	630
3	3	1	2.5	600	570
4	1	3	3.5	400	630
4	2	1	3.5	500	570
4	3	2	3.5	600	600
5	1	2	4.5	400	600
5	2	3	4.5	500	630
5	3	1	4.5	600	570
6	1	3	5.5	400	630
6	2	1	5.5	500	570
6	3	2	5.5	600	600

4. Compaction of Powders and Sintering of Green Compact

The powder mixture is pressed unidirectionally in Universal Tensing Machine by the help of die and punch. Circular cross section die is used for compacting circular pins. Compactions are done at three different compaction pressures (400MPa, 500MPa,) for each alloy. Sintering of green compact is done in Vacuum furnace at different temperature i.e. 570° C, 600° C and 630° C respectively. Each alloy is sintered with three different sintering temperatures under vacuum (10^{-2} torr) to get optimum result.

Table 4 Test samples preparation at different compaction pressure and temperature

Alloy	Alloy designation(Test Samples)	Compaction pressure (MPa)	Sintering temperature (°C)
A(0.5 %Cu)	A_1	400	570
	A_2	500	600
	A_3	600	630
B(1.5 %Cu)	B_1	400	570
	B_2	500	600
	B_3	600	630
C(2.5 %Cu)	C_1	400	600
	C_2	500	630
	C_3	600	570
D(3.5	D_1	400	630
	D_2	500	570

%Cu)	D_3	600	600
E(4.5 % Cu)	E_1	400	600
	E_2	500	630
	E_3	600	570
F(5.5 %Cu)	F_1	400	630
	F_2	500	570
	F_3	600	600

5. RESULTS AND DISCUSSION

The effect of various process parameter like copper percentage, compaction pressure and sintering temperature on various properties like green density, sintered density, porosity.

A. Effect of Composition on Green Density

B. Effect of Composition on Sintered Density

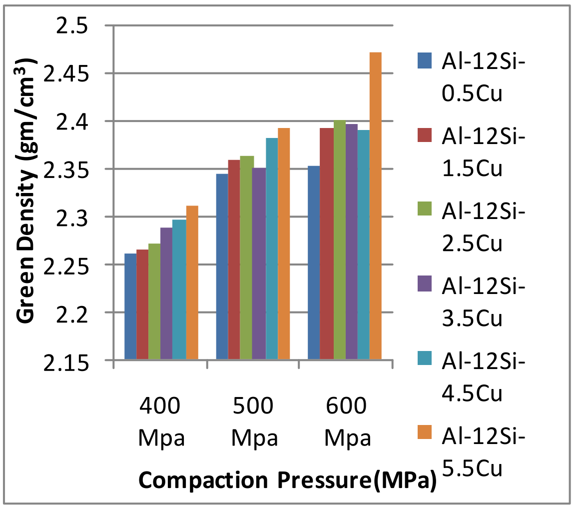

Figure 2 Green Density of alloy samples at different compaction pressure

It has been observed from the above graph that green density increases with the increase of copper content in Al-Si-xCu alloy. It may be due to the higher density of Copper alloy (8.83 gm/cm³) than Aluminium (2.699 gm/cm³) and silicon (2.3296 gm/cm³). It also observed from the graph that compaction pressure largely effects on green density. As the compaction pressure increases, green density also increases. At 400MPa compaction pressure, alloy sample having 0.5 % copper shows least value of density, but density increases with the increase of copper content and maximize with 5.5% Cu at the same compaction pressure. Again, density of corresponding alloy samples increases at 500MPa and 600MPa respectively. Alloy sample having 5.5% Cu results in maximum density at compaction pressure 600MPa.

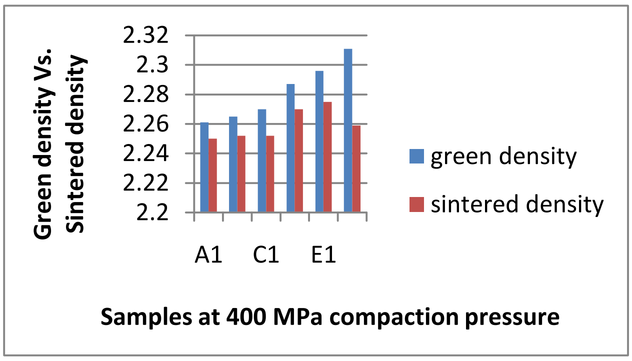

Figure:3 Green dens. vs. sintered dens. at 400MPa compaction pressure

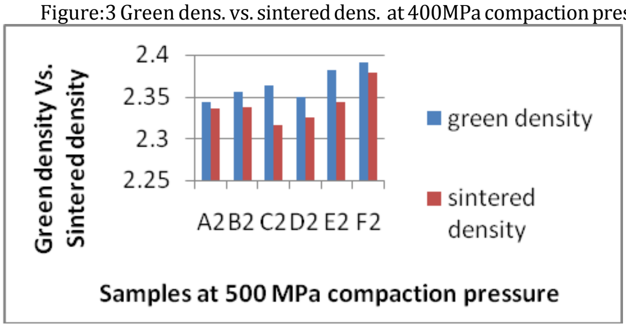

Figure 4 Green density vs. sintered density at 500 MPa compaction pressure

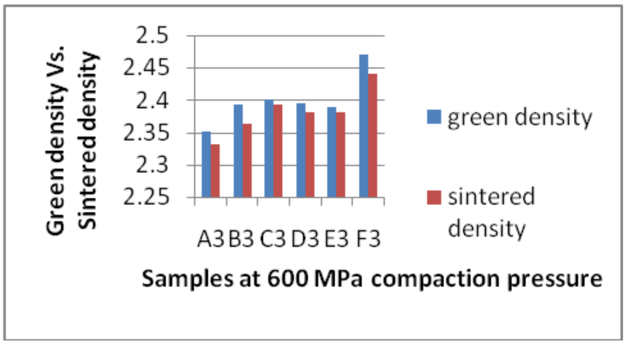

Figure 5 Green density vs. sintered density at 600MPa compaction pressure

It is observed from the above charts that sintered density decreases as compared to green density of Al-12Si-xCu alloy. It is due to the expansion in volume of each sample after sintering of silicon based Aluminium alloy. Sintered density largely falls at higher sintering temperature (630° C). It may be due to the porosity forms, phase change etc after sintering in silicon based aluminium alloy. Further investigations are necessary for a better understanding of all the dimensional changes (volume) and density changes in silicon based aluminium alloy.

6. CONCLUSION

In this paper shows that the Taguchi analysis of Eutectic Al-12Si-xCu alloys to get the optimum responses where eighteen nos. test specimen of six alloys are produced with different compaction pressure and sintering temperature. The Verification experiments are performed to compare with the Taguchi results and also have a good agreement with the experimental data .It can be conclude that the green density increases with the increase of copper content in Al-12Si-xCu alloy and compaction pressure largely effects on green density. As the compaction pressure increases, green density also increases. The sintered density decreases as compared to green density of Al-12Si-xCu alloy after sintering of the alloy samples.

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