Experimental Investigations on Squeeze Casting of Metal Matrix Composites (A356 Al Alloy+ Sic)

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Abstract - Squeeze casting is a hybrid metal forming process combining features of both casting and forging in one operation. An attempt was made to prepare solid cylindrical components of MMC (A356 Al alloy + SiC) using squeeze casting. The quality of castings from squeeze casting process mainly depends on various process parameters such as turn depend on squeeze pressure, pouring temperature, die-preheating temperature and duration of pressure applied. The objective is to investigate the effect of process parameters on the mechanical and metallurgical properties exhibited by the castings produced by squeeze casting process. Experiments are conducted based on L9 orthogonal array (OA) using taguchi technique. Tensile strength and micro hardness are considered as quality characteristics from the experimental results, it is found that the squeeze pressure and die preheating temperature are having more influence on the quality of the squeeze castings. The Mechanical properties of squeeze castings are better than the gravity die castings due to the grain refinement and uniform distribution of SiC practical in soft aluminum matrix. It is also revealed from the microstructure study.

Keywords: Squeeze casting .Taguchi method. Tensile strength, micro hardness

I. INTRODUCTION

Metal Matrix Composites are composed of a metallic matrix (Al,Mg,Fe,Cu etc) and a dispersed ceramic (oxide, carbides) or metallic phase(Pb,Mo,W etc). Ceramic reinforcement may be silicon carbide, boron, alumina, silicon nitride, boron carbide, boron nitride etc. The major advantages of MMCs compared to unreinforced materials are Greater strength, improved stiffness, reduced density, improved high temperature properties, controlled thermal expansion coefficient, Enhanced and tailored electrical performance and improved abrasion and wear resistance. Aluminum matrix composites one of the constituent is Aluminum or Aluminum alloy, which forms per locating network and is termed as matrix phase. The constituent is embedded in this Aluminum alloy matrix, which is usually non metallic and commonly ceramic such as Sic and Al_2O_3. AMCs have been successfully used as components in automotive, aerospace and opto-mechanical assemblies. It is also used as rotating blade sleeves in helicopters. The most notable large size and high volume use of AMCs is in braking systems of trains and cars.(1)

This study investigated the effects of squeeze parameters on the properties of squeeze castings and the optimum parameters for producing squeeze castings from Al-Si alloy. Squeeze casting is a very important manufacturing process that combines the advantages of forging and casting and is used for the production of a wide range of products from monolithic alloys and metal-matrix composites parts.(2) The use of reinforcement among others a good understanding of the effects of process parameters is essential as the structure and properties of alloys can be optimized without the use of expensive alloying elements or nucleating agents It was found that the SiC particles acted as substrates for heterogeneous nucleation of Si crystals in one of the cast composites(3).

The physical and mechanical properties of the composite were measured. The effects of the composition on the physical and mechanical properties have also been investigated. In addition, the microstructure and fracture behavior of the composites were examined The Taguchi approach enables a comprehensive understanding of the individual and combined from a minimum number of simulation trials. (4)This technique is multi – step process which follow a certain sequence for the experiments to yield an improved understanding of product or process performance(5).Though several works applying Taguchi methods on die cast components have been reported in literature, it appears that very limited works have been carried out for squeeze cast components. On considering the importance of aluminum alloys, the main objective of the research was to apply Taguchi method to find the optimal set of control parameters for squeeze casting of (A356+ sic) aluminum alloy.

II. EXPERIMENTAL WORK

2.1 Composite Preparations

A356aluminum alloy with a composition (in %) of: Si 6.87 %, Cu 0.04%, Fe 0.20%,mg 0.54%, Mn 0.03%, Zi 0.02%, Ti 0.06 and Al as the balance; a prepared lubricant consisting of 10% graphite in lubricating oil of the type 20W/50; A Stir Casting furnace and a 25T hydraulic press were the main equipment used for the study**.**

The method involved melting the matrix by heating to a temperature of 800°c in a Stir Casting furnace. After the aluminum was melted, it was degassed with dry nitrogen gas to minimize the oxidation of the molten metals. A simple steel stirrer attached to a variable speed motor was used to stir the melt. The stirring speed was 750 rpm and the stirring time was about 10-15 minutes. Before introducing the sic to the melt. After the stirring process was completed, the crucible was taken from the furnace and the composite was poured into a metallic mold. The alloy was then heated to the required pouring temperatures of 800^{o}, 850^{o} or 900^{o}C and the metal poured into the already prepared die or mould on the die so that the casted component can be removed very easily.

Fig. 1 Stirring Process

2.2 Squeeze casting – process outline

Squeeze casting process, is based on the pressurized Solidification of the molten metal in re-usable dies, and involves the following steps:
Preparation of metal matrix composites using stir casting furnace. Squeeze casting process, is based on the pressurized solidification of the molten metal in re-usable dies. Preheating of the die and the punch Pouring molten metal into the die cavity. The pressure applied by the punch keeps the entrapped gases in solution, and the contact under high pressure at the die-metal interface promotes rapid heat transfer, resulting in a fine microstructure with good mechanical properties. Ejection of solidified casting.

This project aims to measure the squeeze pressure, pouring temperature; die-preheating temperature and duration of pressure applied of Aluminum metal matrix composites (A356+SiC) with the help of optimize the process parameters of castings in squeeze casting. The

Table 1 Control factors and levels

Factor notation	Control factor	Level 1	Level 2	Level 3
A	Squeeze pressure(Mpa)	40	80	120
B	Pouring temperature(°c)	800	850	900
C	Duration of pressure application (s)	20	40	60
D	Die preheating temperature (°C)	80	160	250

objective is to investigate the effect of process parameters on the mechanical and metallurgical properties exhibited by the castings produced though squeeze casting process. A set of trials are conducted based on parameters settings suggested in Taguchi's offline quality control concept. A three level L_9 orthogonal array with nine experimental runs is selected (degrees of freedom = 9-1 = 8).

2.3 Experimental procedure

A 25tonne hydraulic press was modified to apply pressure during solidification of the aluminum alloy.
The A356 aluminum alloy was melted in an Stir Casting furnace and the die was preheated using a
Ceramic electric heater. The experimental set-up is shown in Fig. 1. Two trial castings were made as per the data sheet of L9 (34) orthogonal array. Tensile strength and hardness specimens were machined from these castings and the obtained values are tabulated in Table 2.

Fig. 2.Experimental set-up

III. TAGUCHI METHOD

Taguchi method is an efficient problem-solving tool, which can upgrade/improve the performance of the product, process, design, and system with a significant slash in experimental time and cost this method combining the experimental design theory and quality loss function. Concept has been applied for carrying out robust design of processes and products and solving several complex problems in manufacturing industry. Further, this technique determines the most influential parameter on the output response for the significant improvement in the overall performance. In order to observe the influencing degree of process parameters in squeeze casting, four parameters namely squeeze pressure (A), pouring temperature (B), die-preheating temperature(C) Duration of pressure applied (D), each at three levels were considered

Maintaining these processing parameters as constants enabled us to study the effect of squeeze pressure, pouring temperature, die Preheating temperature, Duration of pressure applied, the degrees of freedom for four parameters in each of three levels were and it is calculated as follows
Degree Of Freedom (DOF) = number of levels -1 ………… (1)

For each factor, DOF equal to:

For (A); DOF = 3 – 1 = 2, For (B); DOF = 3 – 1 = 2
For (C); DOF = 3 – 1 = 2, For (D); DOF = 3 – 1 = 2

Experiments were conducted based L_9 Orthogonal Array and the tensile strength and Microhardness was measured as said in the previous chapter. The readings of two trials are tabulated in Table 2

Table 2 Experimental observations

EX P NO	A	B	C	D	Tensile strength MPa		Microhardness HV	
					R1	R2	R1	R2
1	40	800	80	20	173	180	70	77
2	40	850	160	40	178	174	75	71
3	40	900	250	60	170	166	69	65
4	80	800	160	60	166	172	65	70
5	80	850	250	20	200	196	85	81
6	80	900	80	40	184	179	80	76
7	120	800	250	40	220	214	97	93
8	120	850	80	60	198	188	94	90
9	120	900	160	20	180	186	78	84

A – Squeeze pressure, MPa
B – pouring temperature, °C
C – Duration of pressure application, sec
D- die-preheating temperature°C
R1 and R2, – Replication 1 and 2 of trail casting

In this research nine experiments were conducted at different parameters, and then the specimens were machined and tested by micro hardness and tensile test. The hardness of each specimen is measured by using micro hardness apparatus while the tensile tests were done by using the tensor meter. Fig shows the dimensions of the tensile specimen**.**

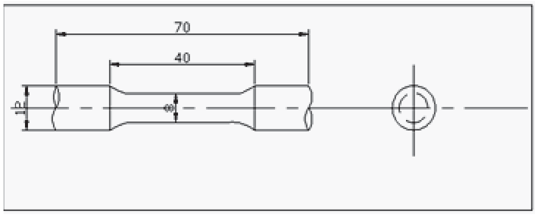


Fig. 3 Tensile Test Specimen

A three level L9 34 orthogonal array with nine experimental runs was selected. The total degree of freedom is calculated from the following:

Total DOF = no. of experiments – 1 ………… (2)

The total DOF for the experiment is:

Total DOF = 9 – 1 = 8

Signal to Noise Ratio (S/N):

Taguchi contributions are the signal to noise ratio it was developed as a proactive equivalent to the reactive loss function. The tensile strength and hardness were Considered the quality characteristic with the concept of "the larger the better". The S/N ratio used for this type response is given by:

$$S/N\ (dB) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Yi^{2}}\right)$$

………… (3)

Where dB means decibel and Yi is the response value for a trial condition repeated n times.

The process parameters namely squeeze pressure (A), pouring temperature (B) and die preheating temperature (C) duration of pressure applied (D) and were assigned to the 1st, 2nd, 3nd and 4th columns of L9 3^4 array, respectively. The S/N ratios were computed for tensile strength and hardness in each of the nine trial conditions and their values are given in Table3

Table 3 S/N ratio for tensile strength and hardness

EXP NO	A	B	C	D	S/N Ratio Tensile strength	S/N Ratio (Microhardness Hv)
1	1	1	1	1	44.9298	37.2962
2	1	2	2	2	44.9086	37.2567
3	1	3	3	3	44.5043	36.5099
4	2	1	3	2	44.5536	36.5682
5	2	2	1	3	45.9320	38.3740
6	2	3	2	1	45.1751	37.8333
7	3	1	2	3	46.7267	39.5487
8	3	2	3	1	45.7024	39.2696
9	3	3	1	2	45.2455	38.1518

Exp. no: Experiment number
A: squeeze pressure (MPa.);
B: pouring temperature ((°C);
C: Duration of pressure application (sec);
D- die-preheating temperature.

Computation scheme of Pareto ANOVA for three level factors is shown in Table.4 In order to study the contribution ratio of the process parameters; Pareto ANOVA was performed for tensile strength and hardness.

Table 4 Pareto ANOVA for three level factors

Factors	**A**		**B**	**C**	**D**	Total
Sum at factor level	**1**	ΣA_1	ΣB_1	ΣC_1	ΣD_1	**T**
	2	ΣA_2	ΣB_2	ΣC_2	ΣD_2	
	3	ΣA_3	ΣB_3	ΣC_3	ΣD_3	
Sum of squares of differences	S_A		S_B	S_C	S_D	S_T
Degrees of freedom	**2**		**2**	**2**	**2**	**8**
(contribution ratio)/100	S_A/S_T		S_B/S_T	S_C/S_T	S_D/S_T	**1**

T = ΣA1 + ΣA2 +ΣA3
SA = (ΣA1 - ΣA2)2 + (ΣA1 - ΣA3)2 + (ΣA2 - ΣA3)2
SB = (ΣB1 - ΣB2)2 + (ΣB1 - ΣB3)2 + (ΣB2 - ΣB3)2
SC = (ΣC1 - ΣC2)2 + (ΣC1 - ΣC3)2 + (ΣC2 - ΣC3)2
SD = (ΣD1 - ΣD2)2 + (ΣD1 - ΣD3)2 + (ΣD2 - ΣD3)2
ST = SA + AB + SC + SD

IV. RESULTS AND DISCUSSION

4.1 Pareto ANOVA

The squeeze cast process parameters, namely squeeze pressure (A), pouring temperature (B) and duration of pressure application (C) and die preheating temperature (d) were assigned to the 1st, 2nd, 3nd and 4th columns of L9 3^4 array, respectively. The S/N ratios were computed for tensile strength and hardness in each of the nine trial conditions and their values are given in Table3.

To study the contribution ratio of the process parameters, Pareto ANOVA was performed for tensile strength and Microhardness. The details are given in Tables 5and 6 respectively

Table 5 Pareto ANOVA for tensile strength

Factors		A	B	C	D	Total
Sum at factor level	1	134.3427	136.2101	135.8073	136.1073	407.678
	2	135.6607	136.543	134.7077	136.8104	
	3	137.6746	134.9249	137.163	135.7603	
Sum of squares of differences		10.8247	4.3808	9.0755	6.6601	30.9411
Degrees of freedom		2	2	2	2	8
Contribution ratio		34.9849	14.1585	29.3315	21.5251	100
Optimum level		A_3	B_2	C_3	D_2	

Table 6 Pareto ANOVA for Microhardness

Factors		A	B	C	D	Total
Sum at factor level	1	111.0628	113.4131	114.3991	113.822	340.8084
	2	112.7751	114.9003	111.9767	114.6387	
	3	116.9701	112.495	114.4326	112.3477	
Sum of squares of differences		55.4242	8.8401	11.9006	8.0892	84.2541
Degrees of freedom		2	2	2	2	8
Contribution ratio		65.7822	10.4921	14.1247	9.6010	100
Optimum level		A_3	B_2	C_3	D_2	

From Table(6), it can be seen that the third level of factor (A) give the highest summation squeeze pressure of 120 MPa (A_3). The highest summation for factor (B) is at the second level pouring temperature of 850°c (B_2) and the highest summation for factor (B) is at the third level die preheating temperature of 250°C (C_3) and the highest summation for factor (D) is at the second level duration of pressure applied 40 s (D_2).

Further, Pareto ANOVA was used to determine the optimum level of process parameters. We conducted an experiment at the predicted parameters (A = 120 MPa, B = 850°c and C =250°C, D=40), and tested the resulted specimen by tensile. These levels were found to improve tensile strength and hardness. It must be noted that the above combination of factor levels A3, B2, C2, D3 are not among the nine combinations tested for the experimentation. This was expected because of the multifactor nature of the experimental design employed. (L^9 from 3^4=81 possible combinations). The resulted tensile strength was 256 MPa which is greater than the tensile strength values in table (5). These results have proved the success of Taguchi method in the prediction of the optimum parameters for higher tensile strength and microhardness In table (8.7) it can be seen that the highest summation is at A_3 (squeeze pressure of 120 MPa e), B_2 (pouring temperature of 850°c), and C_2 (die preheating temperature of 250°C), and D_4 (duration of pressure applied 40 sec)The predicted parameters for giving the highest microhardness by Taguchi method is already used in our experiments and it gave the highest microhardness. This also proves the success of Taguchi method

4.2 Optimizing tensile strength and Microhardness

Analysis of mean for each of experiments gives better combination of parameter levels mean response refers to average value of performance characteristics for each parameter at different levels. Means for one level was calculated as average of all responses that were obtained with that level.S/N ratio of tensile strength and Microhardness for each parameter of level 1,2and 3 were calculated table (8.5and8.6). it is observed that a larger s/n ratio corresponds to better quality characteristics. Therefore optimal level of process parameter is the level of highest S/N ratio. s/n ratio for tensile strength and microhardness (fig 8.1 and 8.2) calculated by statistical software indicated that tensile strength and microhardness was at maximum. When: A = 120 MPa, B = 850°c and C = 250°c, D=40sec

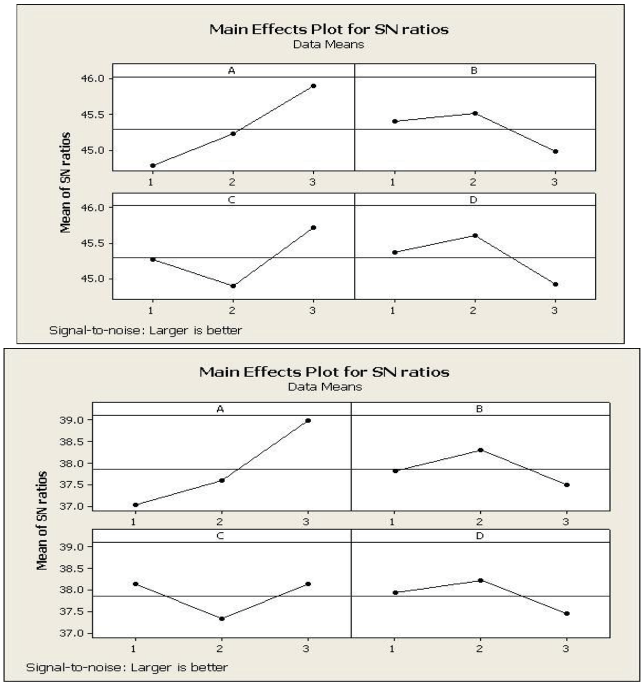


Fig 4. S/N ratios for tensile strength and Microhardness

4.3 Percentage of contribution (P %)

Percentage of contribution is the portion of total variation observed in the experiment attributed to each significant factor and /or reflected In traction (fig 8.3). P% a function of sum of squares for each signicant item indicates relative power of a factor to reduce then variation. If factor levels were controlled precisely then total variation could be reduced by the amount indicated by P%.

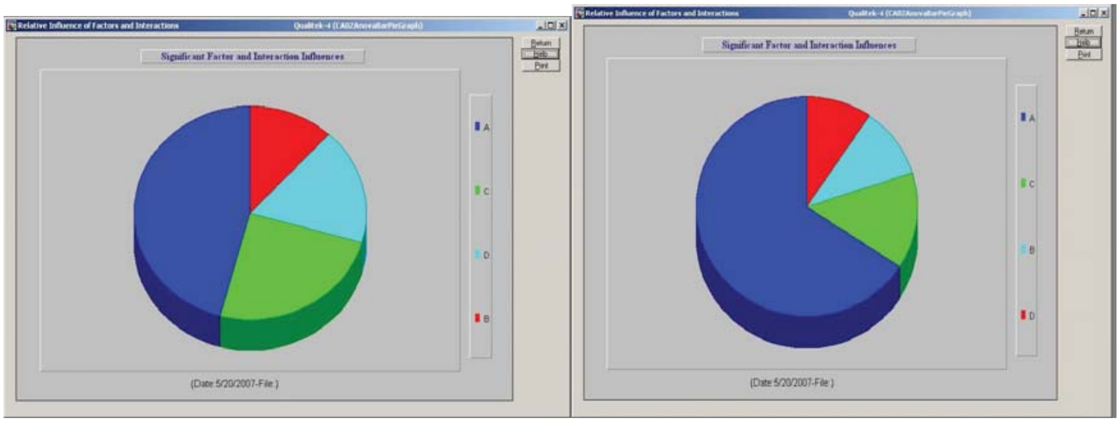


Fig 5 Percentage contribution of factors and their interaction

4.4. Confirmation Test

The optical micrographs of MMC using squeeze casting and gravity die casting are shown in fig 8.4. When compared to its gravity die-cast counterpart, microstructure of the squeeze-cast A356 Al alloy reveals an overall refinement in grain size coupled with absence of porosity. These features are attributed to the high applied pressure. Used in the squeeze-casting process. Under the influence of an applied pressure, there is no air gap formation between the solidifying metal and die-wall interface. This aids in dramatically enhancing the local heat transfer rate across the die surface, resulting in rapid solidification of the liquid metal

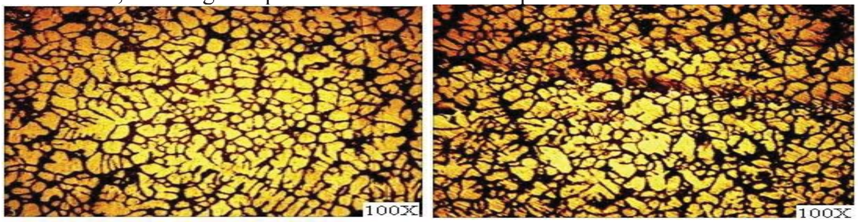
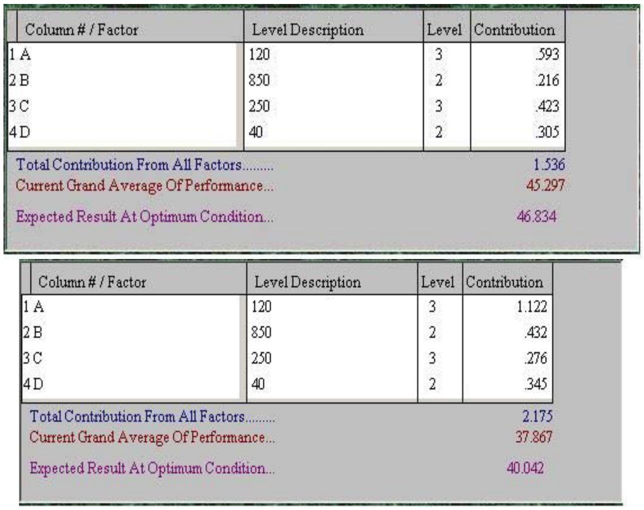


Fig 6 Optical micrographs of MMC (A356+SiC) using **(a)** Gravity die cast sample and **(b)**.squeeze cast sample

4.5 Squeeze Casting process parameters for MMC castings

This work focused on multi response variables in tensile strength and hardness, it became essential to construct the overall summary Table 8.7 and 8.8 to arrive at optimum condition. Based on the highest values of the S/N ratio levels for the significant factors A and B, C, D the overall optimum condition thus obtained wereA3 and B2.C3, D4 (squeeze pressure of 120 MPa and pouring temperature of 850°C and die preheating temperature of 250°C, duration of pressure application 40 sec).



Column # / Factor	Level Description	Level	Contribution
1 A	120	3	.593
2 B	850	2	.216
3 C	250	3	.423
4 D	40	2	.305

Total Contribution From All Factors......... 1.536
Current Grand Average Of Performance... 45.297
Expected Result At Optimum Condition... 46.834

Column # / Factor	Level Description	Level	Contribution
1 A	120	3	1.122
2 B	850	2	.432
3 C	250	3	.276
4 D	40	2	.345

Total Contribution From All Factors......... 2.175
Current Grand Average Of Performance... 37.867
Expected Result At Optimum Condition... 40.042

Table 7 optimum condition and performance for tensile strength& Microhardness

V. CONCLUSIONS

Experimental investigations were made to find the influence of process parameters of squeeze casting on MMC (A356+ SiC) castings using Taguchi technique the following conditions are draw from the investigation. 1. Among the process parameter considered for the studying, squeeze pressure and die preheating temperature are having more influence on the quality of the MMC castings.2. The optimum process parameters for Material MMC 5% SiC are squeeze pressure of 120 MPa and pouring temperature of 850°C and die preheating temperature of 250°C, duration of pressure applied 40 sec.3. The Mechanical properties of squeeze castings are better than the gravity die castings due to the grain refinement and uniform distribution of SiC Partial in soft Aluminum matrix. It is also revealed from the microstructure study

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