IJE TRANSACTIONS A: Basics Vol. 26, No. 4, (April 2013) 365-374

International Journal of Engineering

Journal Homepage: www.ije.ir

Enhancing Wear Resistance of Squeeze Cast AC2A Aluminium Alloy

P. Senthil *[a], K. S. Amirthagadeswaran [b]

[a] *Department of Mechanical Engineering, Coimbatore Institute of Engineering and Technology, Coimbatore-641109, India*
[b] *Department of Mechanical Engineering, Government College of Technology, Coimbatore-641013, India*

PAPER INFO

Paper history:
Received 23 December 2011
Received in revised form 11 May 2012
Accepted 18 October 2012

Keywords:
AC2A Alloy
Squeeze Casting
Wear
Taguchi Method
Genetic Algorithm
XL Solver

ABSTRACT

The effect of squeeze casting process parameters on wear behavior of AC2A aluminium alloy was primarily investigated in this experimental study. Five process parameters, namely squeeze pressure, pouring temperature, die temperature, die material and compression time, each at four levels were chosen and sixteen experimental runs based on L16 orthogonal array were performed. From analysis of variance (ANOVA) and F-test, it was observed that squeeze pressure, die temperature and compression time were the parameters making significant improvement in wear resistance. A mathematical model relating the effect of significant parameters with wear behavior was developed for the process using nonlinear regression analysis with the help of MINITAB software. Taguchi method, Microsoft XL Solver and MATLAB genetic algorithm were employed to optimize the process. The result show that parametric conditions obtained through the optimization tools exhibit about 20% enhancement in wear resistance compared to gravity casting condition.

doi: *10.5829/idosi.ije.2013.26.04a.05*

1. INTRODUCTION

Aluminium alloys are extensively used to produce components for vehicles, locomotives, ship building structures and aircrafts due to their desirable properties such as light weight, excellent strength, good corrosion resistance, good machinability, good fluidity and castability. However, their relatively low melting point and low hardness compared to ferrous alloys limits their applications where high wear resistance is required [1]. Aluminium alloys are generally processed through sand casting, investment casting, continuous casting, centrifugal casting, gravity die casting and pressure die casting [2-5]. Die casting techniques are widely employed for the production of intricate shaped castings in aluminium foundries. Normally, they exhibit several casting defects such as porosities, segregations, hot tears, etc while processing aluminium alloys [6]. Squeeze casting is an emerging metal forming process which has immense potential for the elimination of all defects and drawbacks in the process itself. Reduction or elimination of porosities caused by shrinkage and gas, near net shaping, material savings by eliminating runner and riser, high dimensional exactness and improvement in mechanical properties are the most important advantages of the squeeze casting process.

Squeeze casting of aluminium alloys provides better mechanical properties compared to gravity die casting process [7]. Many research works have been carried out regarding the effects of casting parameters on microstructure and mechanical properties of squeeze cast Al-Si alloys such as Al-13.5% Si, AC8A, LM6, LM13, EN-AB46000 and AlSiMg alloy [8-13]. The squeeze pressure plays an important role in the improvement of mechanical properties of squeeze cast aluminium alloys namely Al-Cu based alloy, Al-10Si-2Cu-0.4Mg alloy, AlZnMgCu alloy, A356, LM24 and LM25 [14-21]. High level squeeze pressure eliminates casting defects such as shrinkage porosity, gas porosity and macro segregation in the Al-7%Si alloy castings [22].

Alireza Hekmat-Ardakan et al. [23] and Rao and Das [24] studied the wear behavior of squeeze cast Al-Si alloys and reported that wear resistance was slightly improved by squeeze casting process. Sukumaran et al. [25] have pointed out the possible defects that could arise from squeeze casting process, if its parameters are not properly controlled and optimized. They have insisted the use of optimization tools for the production of sound castings. The optimum squeeze casting

---

[*] Corresponding Author Email: senth.ksa@gmail.com (P.Senthil)

condition exhibited an appreciable improvement in mechanical properties of LM24 aluminium alloy [26].

Many investigations on squeeze cast aluminium alloys with high silicon content (more than 7%) have been carried out in the recent years. However, further development is still required to process aluminium alloys with low silicon content (less than 7%) in the production of intricate shaped and thin sectioned components through squeeze casting process. Squeeze casting is practicable for processing such aluminium silicon alloys using high pressure for long compression holding time along with certain parametric settings.

AC2A is one of the Al-Si alloys widely used for automotive components such as brake cylinder, master cylinder, engine brackets, cylinder heads, rear axle housings, crank cases, etc. Good fluidity, pressure tightness, hot tear resistance, machinability and corrosion resistance are the desirable properties of this alloy. The chemical composition of this alloy as per Japanese specifications (JIS) is given in Table 1. This alloy is generally processed through gravity and low pressure die casting processes in aluminium foundries. Brake cylinder components produced by these processes normally contain micro pores which results in low hardness andtensile strength and high wear rate. Since an effective braking system is closely connected with the avoidance of accidents, the components used in brake system must be defect-free, strong, wear resistant and durable. In order to produce sound castings of brake cylinder, squeeze casting process was employed for processing AC2A aluminium alloy and optimization tools such as Taguchi method, XL solver and genetic algorithm were employed for the process optimization in this study.

2. SQUEEZE CASTING

Squeeze casting process combining the advantages of both casting and forging processes, has been widely used to produce sound castings in aluminium foundries. Because of high pressure applied during solidification of the melt, porosities caused by both gas and shrinkage are minimized or eliminated. Since the contact between casting and surface of die cavity is improved by pressurization, cooling rate of the casting is accelerated, which would result in the formation of fine-grained structures. In recent years, the squeeze casting process has been used for processing various aluminum alloys in the production of near-net shape components requiring high strength, ductility and pressure tightness or high wear resistance.

There are numerous variables that are generally controlled for soundness and quality of the castings. The important variables have been identified as composition of the casting alloy, level of applied pressure, die temperature, pouring temperature, die material, die coat material, melt superheat, duration of pressure application, punch temperature, delay time to achieve maximum pressure, etc. Five important process parameters namely, squeeze pressure, pouring temperature, die temperature, die material and compression time was selected to investigate their effects on wear property of AC2A alloy in this study.

3. MINIMIZATION OF WEAR RATE

Determination of optimum parametric condition through optimization technique is a continuous engineering task with main aim to reduce production cost and achieve desired product quality. There are many optimization techniques/tools used for finding the optimum condition in production fields. Few tools such as Taguchi method, XL solver and genetic algorithm were employed in this study to find the optimum condition for minimization of wear rate (maximization of wear resistance).

3. 1. Taguchi Method This method is a powerful statistical tool for achieving high quality in manufacturing system [27]. It uses a special set of arrays called orthogonal arrays. These arrays stipulate the way of conducting minimal number of experiments which could give complete information of all the parameters that affect the system performance. This method employs the concept of signal to noise (S/N) ratio which is the ratio of variation due to controllable factors (signal) to the deviation due to uncontrollable factors (noise). The S/N ratio depends on quality characteristics of the product/process to be optimized. The standard quality characteristics generally used are nominal-is-best, lower-the-better and higher-the-better.

TABLE 1. Chemical composition of AC2A alloy

Element	Si	Cu	Fe	Mg	Mn	Ti	Pb	Zn	Ni	Sn	Al
JIS standard (wt%)	4-6	3-4.5	<0.75	<0.25	<0.55	<0.2	<0.15	<0.55	<0.3	<0.05	Rest
Ingot analysis (wt%)	4.81	3.69	0.24	0.16	0.11	0.04	0.027	0.02	0.011	0.009	Rest

3. 2. Excel (XL) Solver Solver is a powerful optimization tool, bundled with Microsoft Excel and is widely used for optimizing nonlinear engineering models. Optimization in Microsoft Excel begins with an ordinary spreadsheet. The solver finds a maximum or minimum or specified value of a target cell by varying the values in one or several changing cells. It accomplishes this by means of an iterative process, beginning with trial values of the coefficients. The value of each coefficient is changed by a suitable increment, the new value of the function is calculated and the change in the value of the function is used to calculate improved values for each of the coefficients. The process is repeated until the desired result is obtained. The solver uses gradient methods to find the optimum set of coefficients.

3. 3. Genetic Algorithm (GA) GA is well suited heuristic technique that can find global optimum solution by searching the space with a high probability. The genetic operators such as reproduction, crossover and mutation provide ways of defining new populations from existing populations. The first step in GA is to set up an initial population as defined number of initial individuals (chromosomes) which was created randomly. Evaluation process has a task to evaluate each solution that can be used for creating new individuals (children) and in that way can become part of the next generation. Fitness attributes can serve well for this purpose. The populations can be ranked according to the fitness function (objective function) value. Then, by means of selection procedure from the population, the best individuals can be preferred for reproduction and promotion to the next population. Children are then produced either by making random changes to a single parent (mutation) or by joining the pair of parents (crossover). The current population can be replaced with the children to form the next generation. At each iteration, the genetic algorithm executes a series of computations on the current population to produce a new one. Genetic algorithm runs until it is met with the stopping criteria. Flowchart explaining all the above steps is shown in Figure 1.

4. EXPERIMENTAL PROCEDURE AND TESTING

4. 1. Experimental Set up A universal testing machine of 40 ton capacity was employed for direct squeeze casting. DYCOTE D140 (lubricant on the surface of die cavity), H11 hot die steel (die insert material) and EN8 alloy steel (punch material) were used in these experiments. An electric resistance crucible furnace was used for melting AC2A alloy. The ceramic electric heater was placed around the die assembly for preheating. The experimental set up used in this study is shown in Figure 2.

The die set was so designed that can withstand maximum pressure of 125 MPa. Porosities and segregations were observed in the castings for squeeze pressures below 50 MPa. A pouring temperature of 675°C was required for effective filling of molten metal alloy (melt) into the die cavity. It was observed that the properties of alloy were adversely affected beyond 750°C. Die temperature below 150°C caused prematurity in castings. If the die was preheated above 300°C, solidification time of the melt would get prolonged, leading to loss in production and reduction in life of the die. The die material was considered as a process parameter and materials such as stainless steel, brass, spheroidal graphite (SG) iron and copper were used for making dies in this study. The minimum time for complete solidification of the melt was noted to be 15 seconds and compression time above 60 seconds did not show any appreciable improvement in mechanical properties. The bounds for each process parameter were fixed as follows:

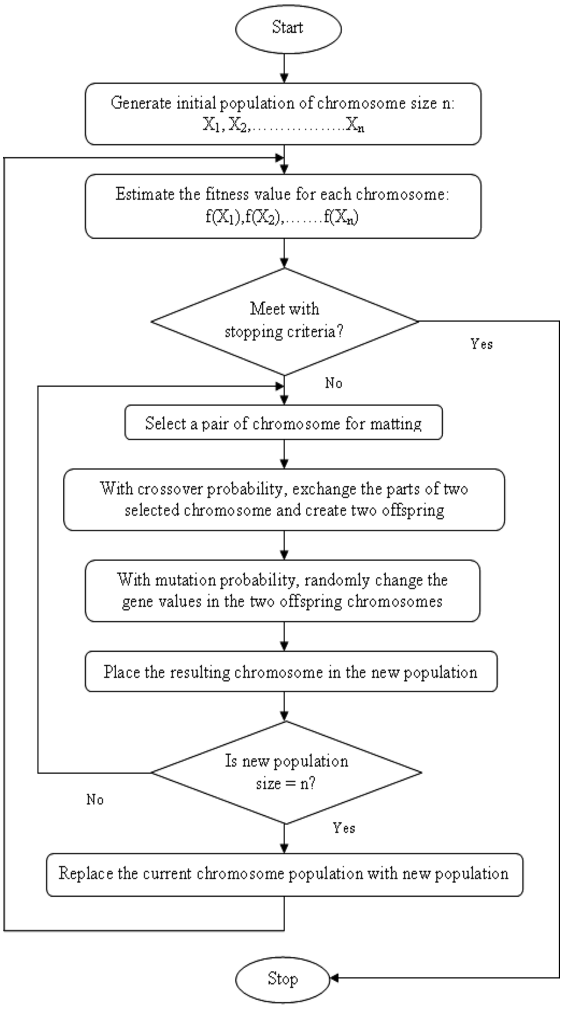

Figure 1. GA steps

Figure 2. Experimental set up

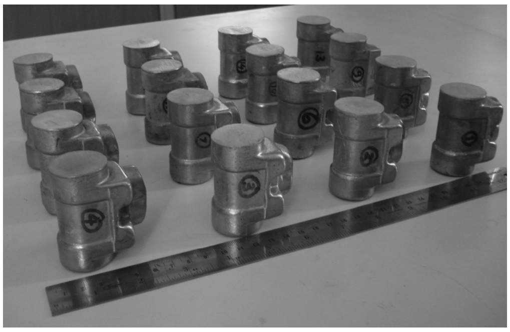

Figure 3. Squeeze cast samples

TABLE 2. Levels for process control parameters

Process control parameter	**Notation**	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Squeeze pressure (MPa)	A	50	75	100	125
Pouring temperature (°C)	B	675	700	725	750
Die temperature (°C)	C	150	200	250	300
Die material	D	Stainless steel	brass	SG iron	copper
Compression time (s)	E	15	30	45	60

Squeeze pressure, A (MPa) : $50 \leq A \leq 125$
Pouring temperature, B(°C) : $675 \leq B \leq 750$
Die temperature, C (°C) : $150 \leq C \leq 300$
Die material, D : stainless steel, brass, SG iron, copper
Compression time, E (s) : $15 \leq E \leq 60$

A suitable orthogonal array should be selected for the conduct of experiments. For the five process parameters (factors), the possible orthogonal arrays suggested in Taguchi's offline quality control concept are $L_8(2^7)$, $L_{16}(4^5)$ and $L_{25}(5^6)$. Since number of levels for factor D are four, $L_8(2^7)$ is not suitable in this study. With respect to levels, either $L_{16}(4^5)$ or $L_{25}(5^6)$ is suitable. $L_{25}(5^6)$ necessitates more number of experiments, leading to cost prohibitive one. So, $L_{16}(4^5)$ orthogonal array was selected and all process parameters were set at four levels within the above bounds to conduct experiments. The levels for all parameters are given in Table 2.

A measured quantity of the melt was poured into the preheated die cavity. Pressure was directly applied on the melt through the punch and was maintained until the solidification of the melt was complete. Then, the pressure was stopped by withdrawing the punch and the casting was separated from the die set. Samples were cast for each experimental condition based on L16.The photograph of brake cylinder samples is shown in Figure 3.

4. 2. Wear Test

Wear test specimens were machined from the functional volume of brake cylinder samples as shown in Figure 4. Four specimens (pins), each of 6 mm diameter and 15 mm height were prepared from each sample. Wear test was conducted in a pin on disc type apparatus under dry sliding conditions at room temperature. An EN24 steel disc of 250 mm diameter in size and 57 HRC in hardness was used. The test specimen was tightly clamped in the specimen holder and held against the rotating steel disc. Tests were carried out under the following conditions: Load of 10 N, sliding speed of 7 cm/s and sliding distance of 100 m. A fresh disc was used and cleaned each time with acetone for the removal of oil, grease and other surface contaminants. The specimen was cleaned with ethanol and weighed before and after the test using an electronic balance accurate to 0.0001 g. The dry sliding wear loss (Δw) was computed using the weight loss of the specimen. Wear rate (W) in terms of volume loss was calculated using Equation (1).

$$W = \frac{\Delta w}{\rho t} \tag{1}$$

where ρ and t are density and sliding time respectively.

5. RESULTS AND DISCUSSION

5. 1. Optimum Condition via Taguchi Method

Wear rate was considered as quality characteristic with the concept of "smaller the better". The S/N ratio used for this type is given by:

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

where i=1, 2,…, n (here n=4) and R_i is the response value for an experimental condition. S/N ratio was computed for each experimental condition and their values are given in Table 3. Average S/N ratio response values were calculated for determining the optimum level of parameters and the details are listed in Table 4. Based on the response values, response graph was depicted to show variations of each parameter on the process performance. This is shown in Figure 5. From the response graph, the optimum level for all parameters was noted (A_3, B_3, C_2, D_3 and E_4).

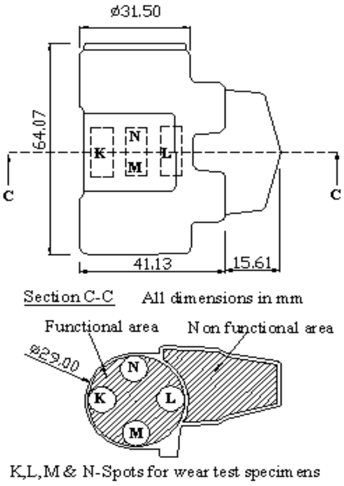

Figure 4. Functional and non functional areas

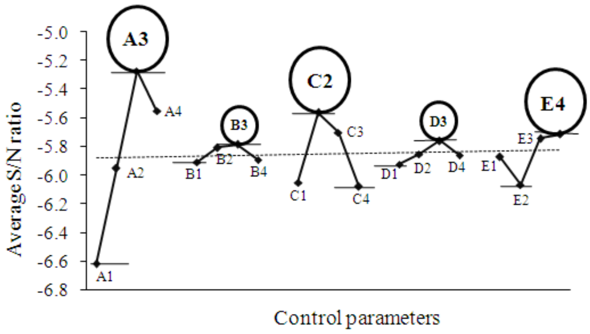

Figure 5. Response graph of wear rate

TABLE 4. Average S/N ratio response table

	A	B	C	D	E
Level1	-6.61602	-5.90636	-6.04952	-5.92141	-5.8693
Level2	-5.95033	-5.80535	-5.56207	-5.84972	-6.0638
level3	-5.27192	-5.78469	-5.69871	-5.75731	-5.7407
level4	-5.54771	-5.88957	-6.07566	-5.85752	-5.7121
Max-Min	1.3441	0.12167	0.51359	0.1641	0.35171
Rank	1	4	2	5	3
Optimum level	A3	B3	C2	D3	E4

TABLE 3. Experimental observations and S/N ratio

Ex. no	**A**	**B**	**C**	**D**	**E**	**Wear rate, W (10^{-12} m^3/s)**				**Average wear rate, $\overline{W}$ (10^{-12} m^3/s)**	**S/N Ratio, Y_j (dB)**
						R_1	**R_2**	**R_3**	**R_4**		
1	1	1	1	1	1	2.1573	2.3232	2.2099	2.2372	2.2319	-6.97663
2	1	2	2	2	2	2.0361	2.2099	2.0829	2.1319	2.1152	-6.51104
3	1	3	3	3	3	1.9697	2.1319	2.0134	2.0592	2.0435	-6.21145
4	1	4	4	4	4	2.1071	2.2651	2.1573	2.1833	2.1782	-6.76494
5	2	1	2	3	4	1.8304	1.9485	1.8681	1.8876	1.8836	-5.50224
6	2	2	1	4	3	1.9278	2.0829	1.9697	2.0134	1.9984	-6.01745
7	2	3	4	1	2	2.0134	2.1833	2.0592	2.1071	2.0907	-6.40997
8	2	4	3	2	1	1.9075	2.0361	1.9485	1.9697	1.9654	-5.87167
9	3	1	3	4	2	1.8121	1.9278	1.8491	1.8681	1.8642	-5.41239
10	3	2	4	3	1	1.7942	1.9278	1.8304	1.8876	1.8600	-5.39357
11	3	3	1	2	4	1.7766	1.9075	1.8121	1.8491	1.8363	-5.28201
12	3	4	2	1	3	1.7095	1.8304	1.7766	1.7942	1.7776	-4.99969
13	4	1	4	2	3	1.8681	2.0134	1.9075	1.9485	1.9343	-5.73417
14	4	2	3	1	4	1.7942	1.8876	1.8304	1.8491	1.8403	-5.29935
15	4	3	2	4	1	1.7766	1.8876	1.8121	1.8304	1.8266	-5.23532
16	4	4	1	3	2	1.9075	2.0592	1.9485	1.9913	1.9766	-5.92199

$\bar{Y} = -5.84649$

TABLE 5. ANOVA

Source	Pool	Sq	DOF	Mq	F ratio	Sq'	%
A		4.08946	3	1.36315	82.9505	4.04	76.49
B	Yes	0.04381	3	0.01460			
C		0.78589	3	0.26196	15.9409	0.737	13.95
D	Yes	0.05479	3	0.01826			
E		0.30804	3	0.10268	6.24821	0.259	4.898
Pooled error		0.09860	6	0.01643		0.247	4.667
St		5.28198				5.282	

Analysis of variance (ANOVA) was performed on signal to noise ratios to predict significant parameters [28]. The following terms were used for ANOVA and computed using Equations (3-10).

(i) Mean, $\overline{Y} = \frac{1}{N}\left(\sum_{j=1}^{N} Y_j\right)$ (3)

Where, j=1, 2,..N (here N=16) and Y_j is S/N ratio for the j^{th} experiment.

(ii) Sum of squares due to mean,

$S_m = N\overline{Y}^2$ (4)

(iii) Sum of squares due to factor A,

$$S_q(A) = n_{A1} \times \overline{A_1}^2 + n_{A2} \times \overline{A_2}^2 + n_{A3} \times \overline{A_3}^2 + n_{A4} \times \overline{A_4}^2 - S_m \quad (5)$$

Similarly, sum of squares due to parameters B, C, D and E were calculated. Sum of squares due to parameters B and D were found to be much less in this study. Therefore, their effects on the output response were assumed to be negligible and treated as an error (pooled error).

(iv) Total sum of squares,

$S_t = \sum S_q\,(\text{all factors})$ (6)

(v) Mean sum of squares due to factor A,

$M_q(A) = \frac{S_q(A)}{DOF_A}$ (7)

where DOF_A is degree of freedom associated with factor A (here DOF_A= number of levels of factor A – 1= 4-1=3).

(vi) F ratio for factor A,

$\text{F ratio} = \frac{M_q(A)}{M_q(\text{pooled error})}$ (8)

(vii) Pure sum of squares due to factor A,

$S'_q(A) = M_q(A) - DOF_A \times M_q(\text{pooled error})$ (9)

(viii)Percentage contribution of factor A,

$\% = \frac{S'_q(A)}{S_t} \times 100$ (10)

Similarly, all terms were calculated for all factors and their values are given in Table 5. At 5% level of significance ($F_{1,6}$ =5.9874), the parameters such as squeeze pressure (A), die temperature (C) and compression time (E) were identified as significant process parameters controlling the wear rate. From the percentage contribution of pooled error (less than 5%), it was confirmed that the effect of pooled variables B and D on wear rate was insignificant. The overall optimum parametric setting (A_3: 100 MPa; C_2: 200°C; E_4: 60 seconds) was obtained after eliminating the effect of insignificant parameters on wear rate. Taguchi method was used to find better level of process parameters within the set levels. In order to tune the parameter setting between the set levels, XL solver and genetic algorithm were employed in the following sections.

5. 2. Optimum Condition via XL Solver

By using non-linear regression analysis with the help of MINITAB 14 software, the effect of significant control parameters on average wear rate ($\overline{W}$) was modeled as follows:

$$\overline{W} = 3.70709 - 0.00985A - 0.00920C - 0.01079E + 0.00004A^2 + 0.00002C^2 - 0.00005E^2 - 0.00001AC + 0.00005AE + 0.00004CE \quad (11)$$

For this model, it was found that r^2 = 0.96 where r is correlation coefficient. The value of r^2 indicates the closeness of the model representing the process. Since r^2 is nearing unity, this model can be taken as an objective function for the application of optimization algorithms through which better parameter settings can be found.

Windows XL solver tool was used in order to find the optimum parametric condition for minimizing wear rate. The mathematical model given in Equation (11) was given as a target function with a condition of minimization. The constraints were set for all significant control parameters. An optimized wear rate ($1.8301\text{x}\ 10^{-12}\ m^3/s$) was found at optimum parametric condition (A: 110 MPa; C: 197.5°C; E: 60 seconds).

5. 3. Optimum Condition via Genetic Algorithm (GA)

MATLAB genetic algorithm tool was used to find the optimum parametric condition for minimization of wear rate in this study. The mathematical model given in Equation (11) was used as fitness function. The bound for all significant control parameters (A, C and E) were inputted. Genetic algorithm was run with setting values for the evolutionary parameters such as number of iterations

TABLE 6. Confirmation test results

S. no	Optimization tool	Parametric condition		Average wear rate, $\overline{W}$ (x10^{-12} m^3/s)		% error
				Model value	Tested value	
1	Taguchi method	Squeeze pressure Die temperature Compression time	: 100 MPa : 200°C : 60 s	1.8347	1.7544	4.58
2	XL solver	Squeeze pressure Die temperature Compression time	: 110 MPa : 197.5°C : 60 s	1.8301	1.7453	4.86
3	Genetic algorithm	Squeeze pressure Die temperature Compression time	: 125 MPa : 246°C : 15 s	1.8088	1.7301	4.55
4		Gravity casting Atm. pressure Die temperature Compression time	 : 0.1 MPa : 200°C : 60 s	2.3188	2.2143	4.71

(50), population type (double vector), population size (20), crossover probability (0.8), fitness selection function (stochastic) and mutation probability (0.03). It was observed that the fitness value decreased through generations as shown in Figure 6 and an optimized wear rate (1.8088x10^{-12} m^3/s) was obtained in the final generation. The optimum parametric condition in the final generation was noted (A: 125 MPa; C: 246°C; E: 15 seconds).

5. 4. Confirmation Tests

Brake cylinder samples were cast by squeeze casting for all optimum parametric settings obtained via Taguchi method, XL solver and genetic algorithm. From wear test results, wear rate values obtained for the optimum settings were found to be smaller compared with the values obtained for all experimental conditions based on L$_{16}$(4^5). The optimum condition obtained through GA technique exhibited a slight improvement in wear resistance compared to the other optimum parametric settings.The details are given in Table 6. For comparison purposes, a sample was also cast by gravity casting (A: 0.1 MPa; C: 200°C; E: 60 seconds) using the same experimental set up.

The percentage improvement in wear resistance of samples made for the optimum conditions compared to the gravity condition is shown in Figure 7. It was noted that all optimum parametric conditions showed around 20% improvement in wear resistance compared to gravity casting condition. Pouring temperature of 725°C and die material of SG iron were taken during the confirmation tests.

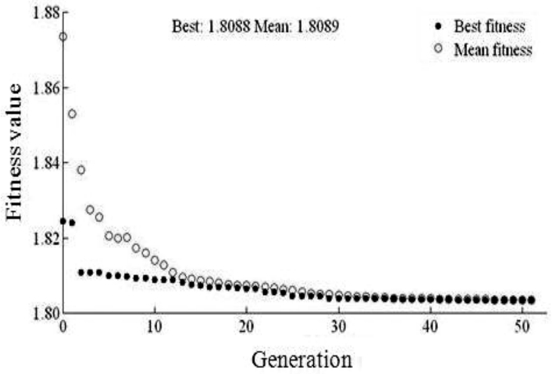

Figure 6. Fitness function values through generations

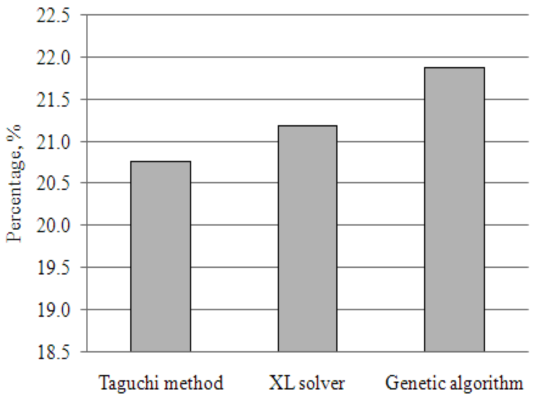

Figure 7. Enhancement in wear resistance of squeeze castings than gravity castings

5. 5. Discussion on Optimum Conditions The optimum setting for C and E was noted to be almost the same in gravity casting, Taguchi method and XL solver. From this, it is clearly understood that increased pressure resulted in decrease of wear rate or increase in wear resistance. When pressure was raised from 110 MPa (XL setting) to 125 MPa (GA setting), it was noted that there was a significant slash in compression time. This was mainly due to rapid cooling of the melt with the application of pressure. Actually, high pressure would result in high heat transfer rate i.e. cooling rate due to elimination of air gap between the melt and the die cavity surface, leading to more effective contact area. In the aspect of energy savings, it seems that the optimum conditions of XL solver and Taguchi method are better than GA optimum condition. In the aspects of production time and quality, GA optimum setting seems to be better than all other conditions.

6. CONCLUSION

Squeeze casting process plays an important role in the quality enhancement of cast components. From ANOVA, significant parameters affecting wear rate were predicted. Among all significant parameters such as squeeze pressure, die temperature and compression time, squeeze pressure was noted to be a prime parameter in controlling wear rate. A mathematical model was developed for the process. Taguchi method, XL solver and GA were applied to determine the optimum parametric condition which minimizes the wear rate of squeeze cast AC2A castings. The optimum conditions were determined and confirmed by experiments. It was confirmed that GA optimum condition for squeeze casting exhibited a slight improvement in wear resistance as compared to the optimum squeeze casting conditions of Taguchi method and XL solver, and a noticeable improvement over gravity casting condition.

7. REFERENCES

1. Ghomashchi, M. and Vikhrov, A., "Squeeze casting: an overview", ***Journal of Materials Processing Technology***, Vol. 101, No. 1, (2000), 1-9.
2. Jenabali Jahromi, S. and Eslami, M., "Fatigue behavior of advanced spray casting 7075 aluminum alloy", ***International Journal of Engineering***, Vol. 14, No. 4, (2001), 361.
3. Shahmiri, M. and Kharrazi, Y., "The effects of gating systems on the soundness of lost foam casting (LFC) process of al-si alloy (A. 413.0)", ***International Journal of Engineering-Transactions B: Applications***, Vol. 20, No. 2, (2007), 157.
4. Ebrahimzadeh, I. and Akbari, G., "Comparison of mechanical behavior and microstructure of continuous cast and hot worked CUZN40AL1 alloy (Technical Note)", ***International Journal of Engineering-Transactions B: Applications***, Vol. 20, No. 3, (2007), 249.
5. Ghazvinizadeh, H., Meratian, M., Kermanpur, A., Fathi, M. and Minouei, H., "Effect of mold preheating on the microstructure of the investment cast ASTM F-75 implant alloy", ***International Journal of Engineering***, (2011).
6. Abou El-khair, M., "Microstructure characterization and tensile properties of squeeze-cast AlSiMg alloys", ***Materials Letters***, Vol. 59, No. 8, (2005), 894-900.
7. Maleki, A., Niroumand, B. and Shafyei, A., "Effects of squeeze casting parameters on density, macrostructure and hardness of LM13 alloy", ***Materials Science and Engineering: A***, Vol. 428, No. 1, (2006), 135-140.
8. Yang, L., "The effect of casting temperature on the properties of squeeze cast aluminium and zinc alloys", ***Journal of Materials Processing Technology***, Vol. 140, No. 1, (2003), 391-396.
9. Lee, J., Won, C., Cho, S., Chun, B. and Kim, S., "Effects of melt flow and temperature on the macro and microstructure of scroll compressor in direct squeeze casting", ***Materials Science and Engineering: A***, Vol. 281, No. 1, (2000), 8-16.
10. Vijian, P. and Arunachalam, V., "Optimization of squeeze cast parameters of LM6 aluminium alloy for surface roughness using Taguchi method", ***Journal of Materials Processing Technology***, Vol. 180, No. 1, (2006), 161-166.
11. Ashiri, R., Niroumand, B., Karimzadeh, F., Hamani, M. and Pouranvari, M., "Effect of casting process on microstructure and tribological behavior of LM13 alloy", ***Journal of Alloys and Compounds***, Vol. 475, No. 1, (2009), 321-327.
12. Boschetto, A., Costanza, G., Quadrini, F. and Tata, M., "Cooling rate inference in aluminum alloy squeeze casting", ***Materials Letters***, Vol. 61, No. 14, (2007), 2969-2972.
13. Jiang, X.-S., He, G.-Q., Liu, B., Fan, S.-J. and Zhu, M.-H., "Microstructure-based analysis of fatigue behaviour of Al-Si-Mg alloy", ***Transactions of Nonferrous Metals Society of China***, Vol. 21, No. 3, (2011), 443-448.
14. Zhang, M., Zhang, W.-w., Zhao, H.-d., Zhang, D.-T. and Li, Y.-Y., "Effect of pressure on microstructures and mechanical properties of Al-Cu-based alloy prepared by squeeze casting", ***Transactions of Nonferrous Metals Society of China***, Vol. 17, No. 3, (2007), 496-501.
15. Zhao, H., Yao, D., Qiu, F., Xia, Y. and Jiang, Q., "High strength and good ductility of casting Al–Cu alloy modified by Pr $_xO_y$ and La_xO_y", ***Journal of Alloys and Compounds***, Vol. 509, No. 5, (2011), 43-46.
16. Lee, C. D., "Effect of damage evolution of Si particles on the variability of the tensile ductility of squeeze-cast Al–10% Si–2% Cu–0.4% Mg alloy", ***Materials Science and Engineering: A***, Vol. 527, No. 13, (2010), 3144-3150.
17. Fan, C., Chen, Z., He, W., Chen, J. and Chen, D., "Effects of the casting temperature on microstructure and mechanical properties of the squeeze-cast Al–Zn–Mg–Cu alloy", ***Journal of Alloys and Compounds***, Vol. 504, No. 2, (2010), 42-45.
18. Gokhale, A. and Patel, G., "Quantitative fractographic analysis of variability in tensile ductility of a squeeze cast Al–Si–Mg base alloy", ***Materials Characterization***, Vol. 54, No. 1, (2005), 13-20.
19. Vijian, P. and Arunachalam, V., "Modelling and multi objective optimization of LM24 aluminium alloy squeeze cast process parameters using genetic algorithm", ***Journal of Materials Processing Technology***, Vol. 186, No. 1, (2007), 82-86.
20. Britnell, D. and Neailey, K., "Macrosegregation in thin walled castings produced via the direct squeeze casting process", ***Journal of Materials Processing Technology***, Vol. 138, No. 1, (2003), 306-310.
21. Postek, E., Lewis, R., Gethin, D. and Ransing, R., "Influence of initial stresses on the cast behaviour during squeeze forming processes", ***Journal of Materials Processing Technology***, Vol. 159, No. 3, (2005), 338-346.

22. Hong, C., Lee, S. and Shen, H., "Prevention of macrodefects in squeeze casting of an Al-7 wt pct Si alloy", ***Metallurgical and Materials Transactions B***, Vol. 31, No. 2, (2000), 297-305.
23. Hekmat-Ardakan, A., Liu, X., Ajersch, F. and Chen, X., "Wear behaviour of hypereutectic Al–Si–Cu–Mg casting alloys with variable Mg contents", ***Wear***, Vol. 269, No. 9, (2010), 684-692.
24. Rao, R. and Das, S., "Wear coefficient and reliability of sliding wear test procedure for high strength aluminium alloy and composite", ***Materials & Design***, Vol. 31, No. 7, (2010), 3227-3233.
25. Sukumaran, K., Ravikumar, K., Pillai, S., Rajan, T., Ravi, M., Pillai, R., and Pai, B., "Studies on squeeze casting of Al 2124 alloy and 2124-10% SiCp metal matrix composite", ***Materials Science and Engineering: A***, Vol. 490, No. 1, (2008), 235-241.
26. Vijian, P. and Arunachalam, V., "Optimization of squeeze casting process parameters using Taguchi analysis", ***The International Journal of Advanced Manufacturing Technology***, Vol. 33, No. 11, (2007), 1122-1127.
27. Ross, P. J., "Taguchi Techniques for Quality Engineering", Singapore, McGraw-Hill, (1996).
28. Belavendram, N., "Quality by Design", Prentice Hall New York, (1995).

Enhancing Wear Resistance of Squeeze Cast AC2A Aluminum Alloy

P. Senthil [a], K. S. Amirthagadeswaran [b]

[a] *Department of Mechanical Engineering, Coimbatore Institute of Engineering and Technology, Coimbatore-641109, India*
[b] *Department of Mechanical Engineering, Government College of Technology, Coimbatore-641013, India*

PAPER INFO

Paper history:
Received 23 December 2011
Received in revised form 11 May 2012
Accepted 18 October 2012

Keywords:
AC2A Alloy
Squeeze Casting
Wear
Taguchi Method
Genetic Algorithm
XL Solver

چکیده

در این تحقیق تجربی تاثیر پارامترهای فرایند ریخته‌گری فشاریبر رفتار سایشی الیاژ AC2A آلومینیوم بررسی شده است. ۵ پارامتر فشار ، دمای ریخته گری، دمای قالب گیری، مواد قالب گیری و زمان وارد کردن فشار در ٤ سطح انتخاب و ١٦ آزمایش بر اساس ردیف متعامد L16 انجام شده است. بر اساس تحلیل واریانس (ANOVA) و تست-F مشاهده می‌شود که فشار ، دمای قالب گیری و زمان وارد کردن فشار پارامترهایی بودند که در مقاومت سایشی بهبود قابل توجهی ایجاد کردند. با استفاده از رگرسیون یا برگشت غیر خطی نرم افزار MINITAB، مدل ریاضی برای ارتباط بین این پارامترهای مهم بر رفتار سایشی در این فرایند ارائه داده شده است. به منظور بهینه سازی فرایند روش تاگوچی، Microsoft XL Solver و الگوریتم ژنتیک matlab به کار گرفته شده‌اند. نتایج نشان می‌دهند که شرایط پارامتری که از ابزارهای بهینه سازی به دست امده‌اند مقاومت سایشی را در حدود ۲۰ درصد در مقایسه با شرایط ریخته گری ثقلی افزایش داده‌اند

doi: *10.5829/idosi.ije.2013.26.04a.05*