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Development of the Aluminum Chips Recycling Process for Recovery Rates and Corrosion Resistance of A380 Alloy

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Abstract*— To optimize recycling process, Design of Experiment (DOE) was utilized. In this study, Taguchi orthogonal array were designed based on four factors as flux types, chips/flux ratio, holding times and holding temperatures, and for each factor, three corresponding levels were also chosen. Recovery rate and corrosion resistance were selected as two individual responses to evaluate the effectiveness of the recycling process and the quality of the recycled alloy. Also, S/N ratios for multiple characteristics and analysis of variance (ANOVA) were utilized to analyze experimental data for optimization. Two sets of weighing factors were selected for the responses of recovery rate and corrosion resistance, respectively, for different requirement of the recycled alloy. The optimum combinations led to the highest recovery rate of by using Al-clean 101 as the refining flux, 10:5 as the chips/flux ratio, 60 minutes as the holding time and 760℃ as the holding temperature, while the combination using Al-clean 113 as the refining flux, 10:3 as the chips/flux ratio, 90 minutes as the holding time and 800℃ as the holding temperature made the recycling process effective considering both the recovery rate and corrosion resistance as objective functions.

Index Terms—**Aluminum Alloy, Machining Chips, Recycling, Recovery, Corrosion.**

I. INTRODUCTION

Aluminum alloys have been increasingly used in automotive industry. Among the aluminum usage in each vehicle, almost 35% of automotive aluminum components were manufactured by conventional high pressure die-casting (C-HPDC) processes [1]. C-HPDC components are manufactured along with considerable amount of aluminum waste in the forms of scrap, dross, and machining chips. The casting scrap is easily returned to melting; whereby most of the metal is recovered and re-utilized in production processes. The study by Gronostajski and Matuszak [2] showed that, in the process of melting aluminum and aluminum alloy chips, on average,10% of the metal was burnt and about 10% was lost because dross formed by mixing molten aluminum and slag were removed from the surface of liquid aluminum in the ladle. Also considering 8% loss of casting scraps, 72% aluminum would be recycled after casting. Thus the anticipated recovery rate of conventional recycling processes was around 72%. During the recycling of machining chips and melt dross, large amount of metal is lost as a result of oxidation, and the costs of labor and energy as well as the expenditure on environmental protection increase the general cost of the process. The chips as a by-product not only bring huge waste, but also could produce pollution to the environment. Also, due to high market demand for cost saving on die castings, the recovery of Al chips becomes critical for die casters. However, recovery rates of the chips are often unknown to die casting shops since most chips are presently recycled externally and aluminum content in the chips depends on the practice of molten metal processing. Reducing the aluminum loss is the key to optimize the conventional recycling process. There are several influencing factors during the processes, such as flux types, amount of flux, stirring time, protective gas, holding time and holding temperature during melting, pouring temperature, etc., and for each factor, there are quantities alternative levels. To find the optimum process, many combinations of influencing factors and levels need to be experimented. The Taguchi method uses a special design of orthogonal arrays to study all the designed factors with a minimum of experiments at a relatively low cost. Orthogonality means that factors can be evaluated independently of one another; the effect of one factor does not interfere with the estimation of the influence of another factor [3]. In this study, the Taguchi method for design of experiment (DOE) was used for the optimization of the recycling process for machining chips of high pressure die cast aluminum alloy A380. Since the preliminary results [4] indicates that the recovery rate was primarily determined by several key process parameters such as flux type, chips/flux ratio, holding time and holding temperature during melting, the present design of experiment took into account the influencing extent of each individual process parameter. This consideration led to the selection of those four influencing factors with three different levels. The results of the factor response analysis were used to derive the optimal level combinations. The contribution of each factor was determined by an analysis of variance. The chips collected directly from CNC machines were recycled with refining flux. The recovery rate of the recycled metal was determined based on weight measurements. To ensure the engineering performance of the recycled aluminum, corrosion behavior of the recovered aluminum alloy was analyzed.

II. EXPERIMENTAL PROCEDURES

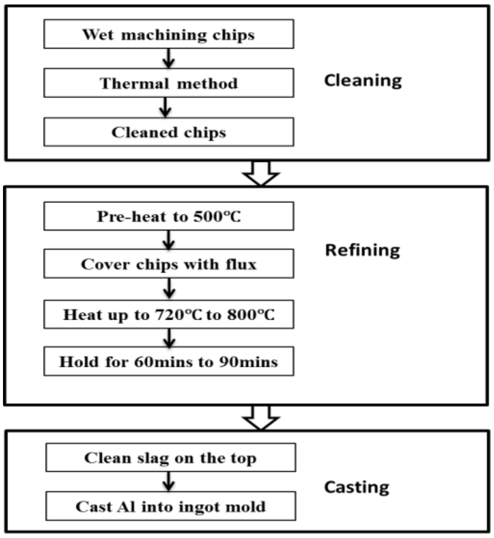
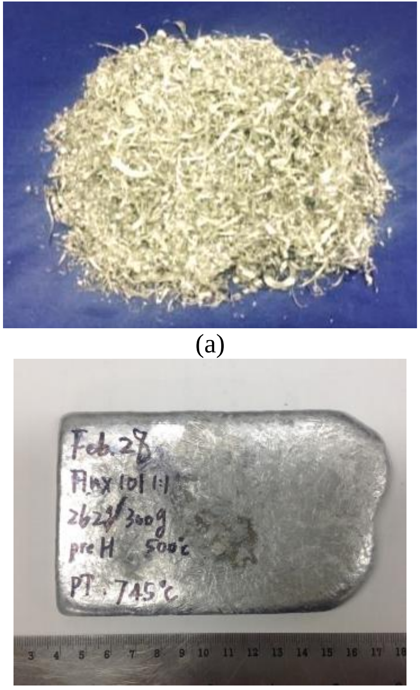


Fig 1 Flowchart of the recycling process

Figure 1 shows the flowchart of the recycling process used in this study. After cleaning, chips were loaded into a crucible and pre-heated to 500°C. Flux types and chips/flux weight ratio were selected as factors A and B in the DOE, respectively. The holding time and holding temperature were chosen as factors C and D.

A. *Materials*

Machining chips of high pressure die-cast aluminum alloy 380 shown in Figure 2-(a) were the raw material to be recycled. The chips were wet and covered with coolants when collected from the CNC machines. Fig.5-2-(b) shows one of the recycled aluminum plate.



(a)

(b)

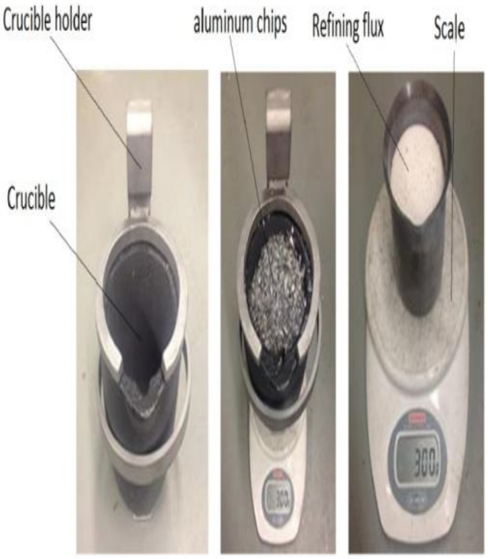
Fig 1 (a) machining chips of aluminum alloy 380, and (b) a cast plate of the recycled alloy.

B. *Cleaning*

For safety and health considerations, wet machining chips were cleaned before refining process. Thermal method was employed in this study. Wet machining chips were loaded into a crucible and then, the crucible was heated up to the temperature of 400°C for 60 minutes in a furnace. With this kind of cleaning method, emulsions and coolant were easily burnt out. Figure 3(a) shows a clay graphite crucible and a crucible holder used during the cleaning and refining process.

C. *Refining*

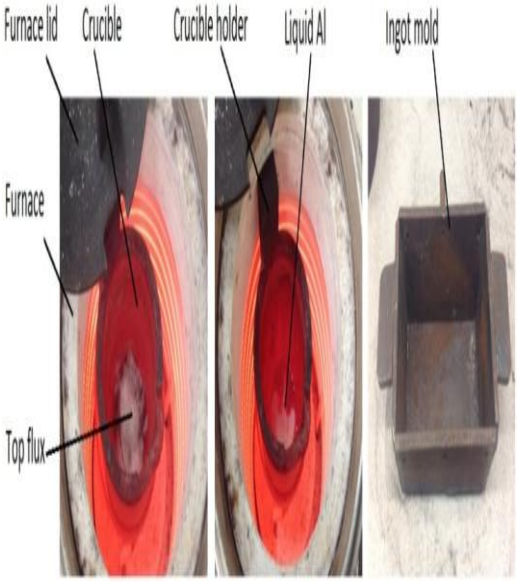
300 grams of cleaned and dried chips were loaded into a clay-graphite crucible inside an electric resistance furnace. The chips inside the crucible was heated to 500℃ for 20 minutes of preheating to remove any entrapped moisture, and then refining flux was added into the crucible to cover the chips. Three different kinds of fluxes made by Basic Resources Inc. were selected for the purpose of comparison. They were Al-clean 101 [5], Al-clean 113 [6]and Al-clean 116[7]. Two of them, Al-clean 101 and Al-clean 116 were fluoride-containing flux, and Al-clean 113 was fluoride-free flux. The chips/flux ratio was selected based on DOE. The crucible with chips and flux was held at 500℃ for 20 minutes. After chips and flux were preheated, the temperature of the furnace was increased to a desired temperature for holding a fixed period of time given by the DOE.



(a) (b) (c)

Fig 2 (a) crucible and its holder used in cleaning and refining process; (b) aluminum chips loaded into crucible; (c) refining flux.

Figure 4(a) showed the melt mixture of the flux and chips in the crucible as the holding temperature reached 800°C, while Figure 4(b) depicted the recovered aluminum alloy after slag removal and before casting the alloy into the ingot mold (Figure 4(c)). The solidified aluminum plates were quenched in water for analysis.



(a) (b) (c)

Fig 3 (a) melt mixture of the flux and chips; (b) recovered Al in the crucible; (c) ingot mold.

D. Recovery rate

Chips were weighed after cleaning and prior to refining experiments, while the recovered aluminum alloy in the form of the cast plate was weighed after refining experiments. The recovery rate of the chips was determined based on the following expression:

$$Recoveryrate(\%) = \frac{weight\ of\ recovered\ Al}{chipsweight} \times 100 \qquad (Er$$

Where the weight of the cleaned and dried aluminum chips was 300grams for each test of all the nine designed recycling experiments.

E. Polarization testing

Specimens for corrosion testing were cut from the tensile bar and prepared following the standard metallographic procedures. Samples were cut into rectangular shape; Polished with emery paper (to 800 grades).

To compare corrosion resistant properties of samples, potentiodynamic polarization tests were carried out at 298 K using a Solartron 1285 corrosion test system (with a Solartron 1285 interface). A three–electrode cell with samples as the working electrode, Ag/AgCl sat KCl as the reference electrode, and a platinum rod as the counter electrode was used in the tests. The ratio of volume of a 0.1 mass % NaCl solution to samples' area is 350 ml/cm^2. After the electrochemical system was stable, scan was conducted at a rate of 1 mV/s from –0.1 V versus open circuit potential (OCP) towards more noble direction until –0.25 V versus the reference electrode for recycled aluminum. The calculation of the corrosion resistance of samples is based on the corrosion potential, the corrosion current density, and the anodic/cathodic Tafel slopes (β_a and β_c) which were derived from the measured polarization curves. Based on the approximately linear polarization at the corrosion potential (Ecorr), the value of corrosion resistance (R_p) was determined from the relationship [8, 9]:

$$Rp = \frac{\beta_a \beta_c}{2.3 i_{corr} (\beta_a + \beta_c)} \qquad (Er$$

Where i_{corr} is the corrosion current density.

III. TAGUCHI DESIGN OF EXPERIMENT

A. Design of orthogonal array

Table 1 gives the parameters selected for specific experimental parameters. Here four factors (flux type, chips/flux ratio, holding temperature and holding time during melting) with three levels were selected shown in Table 2. The factors and levels were used to design an orthogonal array L_9 (3^4) for experimentation. Table 3 presents the experiment plan for this study, and these 9 experiments were conducted twice for consistency. Since each experiment was repeated once for verification, in total, the eighteen (18) tests were conducted base on the DOE given in Table 2 with four factors and three levels. It is noted that the 'Exp" in all tables stands for "Experiment".

Table 1 Experimental parameters

Flux type	Chips/ flux ratio	Holding **time** (mins)	Holding temperature (°C)
101	10:3	60	720
113	10:4	75	760
116	10:5	90	800

Table 2 Design factors and levels

	Factors			
Level	A Flux type	B Chips/flux ratio	C Holding time (mins)	D Holding temperature (°C)
1	101	10:3	60	800
2	113	10:4	75	760
3	116	10:5	90	720

Exp	A Flux Type	B Chips/Flux Ratio	C Holding Time (mins)	D Holding Temperature (℃)
1	(1) 101	(1) 10:3	(3) 90	(2) 760
2	(2) 113	(1) 10:3	(1) 60	(1) 800
3	(3) 116	(1) 10:3	(2) 75	(3) 720
4	(1) 101	(2) 10:4	(2) 75	(1) 800
5	(2) 113	(2) 10:4	(3) 90	(3) 720
6	(3) 116	(2) 10:4	(1) 60	(2) 760
7	(1) 101	(3) 10:5	(1) 60	(3) 720
8	(2) 113	(3) 10:5	(2) 75	(2) 760
9	(3) 116	(3) 10:5	(3) 90	(1) 800

Table 3 Designed experiment plan

B. Signal-to-noise analysis with multiple characteristics

In process design, it is almost impossible to eliminate all errors caused by the variation of characteristics. An increase in the variance of multiple characteristics lowers the quality reliability of the recycling process. The Taguchi method uses signal-to-noise (S/N) ratio instead of the average value to interpret the trial results data into a value for the evaluation characteristic in the optimum setting analysis. To minimize the influence of the recovery rate and corrosion resistance variation on the analysis of experimental data, the signal-to-noise(S/N) ratio was employed, which converted the trial result data into a value for the response to evaluate the recycling process in the optimal setting analysis. The S/N ratio consolidated several repetitions into one value which reflected the amount of variation present. This is because the S/N ratio can reflect both the average and the variation of the quality characteristics. There are several S/N ratios available depending on the types of characteristics [10]: lower is best (LB), nominal is best (NB), and higher is best(HB). In the present study, recovery rates were treated as a characteristic value. Since the recovery rates of the recycling process were intended to be maximized, the S/N ratio for HB characteristics was selected, which was be calculated as follows:

$$S/N_{HB} = -10\ log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{\eta_{pi}^{2}}\right) \qquad \text{(Er}$$

Where n is the repetition number of each experiment under the same condition for design parameters, andη_{pi} is recovery rate or corrosion resistance of an individual measurement at the ith test.

The proposition for the optimization of recycling process with multiple performance characteristics (two objectives) using a weighting method is defined as the Eqs. (4)–(6):

$$Y_{SUM} = Y_p \times w \qquad \text{(Er}$$

Where

$$Y_{SUM} = \begin{bmatrix}\eta_{1c}\\ \eta_{2c}\\ \vdots\\ \eta_{9c}\end{bmatrix};\ Y_p = \begin{bmatrix}\eta_{11}\eta_{12}\\ \eta_{21}\eta_{22}\\ \vdots\ \ \vdots\\ \eta_{91}\eta_{92}\end{bmatrix};\ w = \begin{bmatrix}w_1\\ \\ w_2\end{bmatrix} \qquad \text{(Er}$$

$$\sum_{i=1}^{2} w_i = 1 \qquad \text{(Er}$$

Where $w_1$and $w_2$are the weighting factor of recovery rate and corrosion resistance, respectively. $\eta_{jc}$is the multi S/N ratio in the jth test, η_{ji} is the ith single response S/N ratio for the jth test; w_i is the weighting factor in the i th performance characteristics.

The objective function was formulated according to the previous optimization criteria:

$$Maximize\ f(X) = w_1 \cdot \eta_{recovery} + w_2 \cdot \eta_{corrosion} \qquad \text{(Er}$$

The above objective function is presented in an analytical form as function of input parameters since increased productivity and corrosion resistance play the important roles during recycling of machining chips. However, in the actual manufacturing process, for different metal specifications, the two characters should be considered as different critical roles by weighting factors. When quality demand becomes critical, high weighting factors of corrosion resistance needs to be considered. For metal yield requirement, high recoveries require due to the consideration of cost saving. In this study, case 1 (1.0, 0), and case 2 (0.5, 0.5) with two different combinations of weighting factors were selected for demonstrating recycling requirements

C. Analysis of variance (ANOVA)

The analysis of variance (ANOVA) on the experimental results was performed to evaluate the source of variation during the recycling process. Following the analysis, it was relatively easy to identify the effect order of factors on recovery rate and corrosion resistance of the recycled alloys as well as the contribution of factors to corresponding characteristics. In this study, the variation due to both the four factors and the possible error was taken into consideration. The ANOVA was established based on the sum of the square (SS), the degree of freedom (D), the variance (V), and the percentage of the contribution to the total variation (P). The five parameters symbols typically used in ANOVA [10] are described below:

1. Sum of squares (SS). SS_P denotes the sum of squares of factors A, B, C, and D; SS_e denotes the error sum of squares; SS_Tdenotes the total sum of squares. The total sum of square SS_T from S/N ratio was calculated as:

$$SS_T = \sum_{i=1}^{m}\eta_i^{\,2} - \frac{1}{m}\left[\sum_{i=1}^{m}\eta_i\right]^2 \qquad \text{(Er}$$

Where m is the total number of the experiments, and η_i is the factor response at the ith test.

The sum of squares from the tested factors, SS_p, was calculated as:

$$SS_p = \sum_{i=1}^{m} \frac{\left(S_{\eta_{jc}}\right)^2}{t} - \frac{1}{m}\left[\sum_{i=1}^{m} \eta_i\right]^2 \qquad \text{(Er}$$

where m is the number of the tests (m= 9), j the level number of this specific factor p, t is the repetition of each level of the factor p, and $S_{\eta j}$ the sum of the multi-response S/N ratio involving this factor p and level j.

2. Degree of freedom (D). D denotes the number of independent variables. The degree of freedom for each factor (D_P) is the number of its levels minus one. The total degrees of freedom (D_T) are the number of total number of the result data points minus one, i.e. the total number of trials times the number of repetition minus one. And the degree of freedom for the error (D_e) is the number of the total degrees of freedom minus the total of degree of freedom for each factor.

3. Variance (V). Variance is defined as the sum of squares of each trial sum result involved the factor, divided by the degrees of freedom of the factor:

$$Vp\ (\%) = \frac{SS_p}{D_p} \times 100 \qquad \text{(Err}$$

4. The corrected sum of squares (SSp). SSp is defined as thesum of squares of factors minus the error variance times thedegree of freedom of each factor:

$$SS_p{}' = SS_p - D_p V_e \qquad \text{(Err}$$

5. Percentage of the contribution to the total variation (P). P_p denotes the percentage of the total variance of each individual factor:

$$Pp\ (\%) = \frac{SS_p{}'}{SS_p} \times 100 \qquad \text{(Err}$$

IV. RESULTS AND DISCUSSION

A. Multi-response of S/N ratios

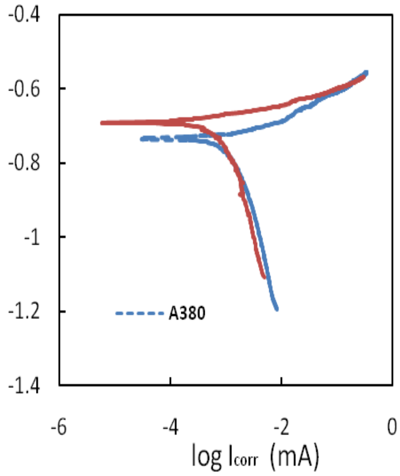


Fig 5 Typical potentiodynamic polarization curve of experiment No.6.

The recovery rate and corrosion resistance were selected as two original responses. Two combinations of weighting factors selected in this study for the multi-response S/N ratio were calculated from Eqs. (4) to (7) to evaluate the effectiveness and efficiency of the recycling process and the quality of the recycled plates for different engineering requirements. Figure 5 showed typical corrosion curve of recycled aluminum and die-cast A380 alloy.

Tables 4 and 5 give the original data of recovery rate and corrosion testing results. The recovery rate was calculated with Eq. (1) using the weight of recycled aluminum. The corrosion resistances of the recovered Al alloy were calculated with Eq. (2), and are given in Table 6.

B. Optimal recycling factors

With combinations of weighting factors, the factor's mean multi-response S/N ratios for each level are summarized in Tables 8 and 9 for cases 1 and 2, respectively. For instance, the mean S/N ratio (38.93) for flux type and level 1 was the average value of the S/N ratios of experiment No.1 (38.70), No.4 (39.05) and No.7 (39.05) listed in Table 7. The mean S/N ratios of the recovery rate and corrosion resistance were influenced by four factors, the flux type, chips/flux ratio, holding time and holding temperature. For each factor, the mean S/N ratios of case 1 (w_1=1.0, w_2=0) and case 2 (w_1=0.5, w_2=0.5) were plotted in Figures 6 and 7 based on the results given in Tables 8 and 9.

Table 1 Data of original results of recovery rate

Exp	Recycled Al (g)		Recovery Rate (%)	
	Test 1	Test 2	Test 1	Test 2
1	260.68	255.71	86.89	85.24
2	230.80	256.18	76.93	85.39
3	228.27	262.66	76.09	87.55
4	267.53	270.31	89.18	90.10
5	235.23	247.15	78.41	82.38
6	259.36	274.32	86.45	91.44
7	270.63	267.40	90.21	89.13
8	246.14	265.50	82.05	88.50
9	257.85	252.31	85.95	84.10

Table 2 Data of original results of corrosion testing

Exp	[illegible] (mV)		[illegible](mV)		i_{cc} (μA)	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
1	0.050	0.041	0.327	0.352	0.383	0.425
2	0.033	0.038	0.389	0.397	0.267	0.356
3	0.040	0.036	0.506	0.456	0.593	0.692
4	0.030	0.039	0.495	0.521	0.442	0.705
5	0.052	0.048	0.557	0.595	0.439	0.651
6	0.030	0.032	0.575	0.410	0.914	0.675
7	0.027	0.030	0.523	0.478	0.629	0.484
8	0.041	0.030	0.489	0.502	0.784	0.663
9	0.037	0.039	0.600	0.589	0.652	0.771

Table 6 Corrosion resistance

Exp	*Corrosion resistance (Ω)*	
	Test 1	Test 2
1	49.232	37.531
2	49.535	42.312
3	27.179	20.961
4	27.824	22.361
5	47.103	29.650
6	13.563	19.126
7	17.747	25.362
8	20.974	18.562
9	23.240	20.623

Exp	*S/N ratio of Recovery rate*	*S/N ratio of Corrosion resistance*	*S/N ratio of Multi-response*	
			case 1 (w_1=1.0, w_2=0)	case 2 (w_1=0.5, w_2=0.5)
1	38.70	32.51	38.70	35.60
2	38.15	33.16	38.15	35.66
3	38.19	27.41	38.19	32.80
4	39.05	27.84	39.05	33.44
5	38.10	31.00	38.10	34.55
6	38.97	23.89	38.97	31.43
7	39.05	26.26	39.05	32.66
8	38.60	25.87	38.60	32.23
9	38.59	26.77	38.59	32.68

Table 7 S/N ratio of multi-response objectives

Table 8 case 1:The factor's Mean multi-response S/N ratio for each level with two weighting factors

level	Mean S/N ratio for case 1 (w_1=1.0,w_2=0)			
	A Flux type	B Chips /flux ratio	C Holding time	D Holding temperature
1	38.93	38.35	38.73	38.60
2	38.28	38.71	38.61	38.76
3	38.59	38.75	38.46	38.45

Table 9 Case 2: The factor's Mean multi-response S/N ratio for each level with two weighting factors

level	Mean S/N ratio for case 2 (w_1=0.5, w_2=0.5)			
	A Flux type	B Chips/ flux ratio	C Holding time	D Holding temperature
1	31.13	32.10	30.55	31.13
2	31.65	30.46	30.12	30.41
3	29.58	29.80	31.69	30.82

It is shown in Figure 6 that the mean S/N ratio of the factor flux type (factor A) reaches maximum using flux Al-clean 101 (level 1), and has the minimum using flux Al-clean 113 (level 2). As the flux Al-clean 101 has a melting temperature around 500℃ and Al-clean 113 has a melting temperature between 690℃ and 705℃. The flux Al-clean 101 is more easily softened to have larger contact area with aluminum chips to achieve higher effectiveness. The effect of the chips/flux ratio (factor B) on the mean S/N ratio of the recovery rate also plotted in Figure 6. The mean S/N ratio of recovery rate grows when additional flux was introduced. It can be seen that the additional flux enhances the recovery rate as the ratio 10:3 (level 1) changes to the ratio 10:4 (level 2). This might be because sufficient flux can greatly protect the aluminum chips from being oxidized during melting process. The curve seems to reach a plateau from the ratio 10:4(level 2) to 10:5 (level 3). This observation implies that the excessive amount of flux would result in minor effect on recovery rates. In the viewpoint of cost saving, the ratio 10:4 might be considered for recycling production. While the ratio 10:5 was employed, the recovery rate becomes the highest. The lines plotted from C1 to C3 are the effect of holding time (factor C) on the mean S/N ratio of the recovery rate. The curve is much smoother without sharp fluctuations comparing to other plots, which means holding time has minor effect on the recovery rate. The mean S/N ratio decreases when extended holding times are employed. However, aluminum chips are more likely to be oxidized when being kept at elevated temperatures for a prolonged period of time. Thus, level 1 (60 minutes) is selected for its higher S/N ratio response. The plot points D1 to D3 shows the holding temperature (factor D) on the mean S/N ratio of the recovery rate. The mean S/N ratio reaches the peak at 760℃, and then drops to 720℃. The working temperature of the three fluxes is within the temperature range of 700℃ to 800℃. Since the energy consumption for recycling is high and chips are more likely to be oxidized at high temperatures, the medium temperature is preferred.

Factor	Degree of freedom (D)	Sum of squares (SS_p)	Variance (V)	Corrected sums of squares (SS_p')	Contribution	Rank
A	2	0.64	0.32	0.64	54.13%	1
B	2	0.29	0.15	0.29	24.75%	2
C	2	0.11	0.06	0.11	9.04%	4
D	2	0.14	0.07	0.14	12.08%	3
error		0.00	0.00		0	
Total		1.17			100%	

Table 10 Results of the ANOVA for case 1 (w1=1.0, w2=0)

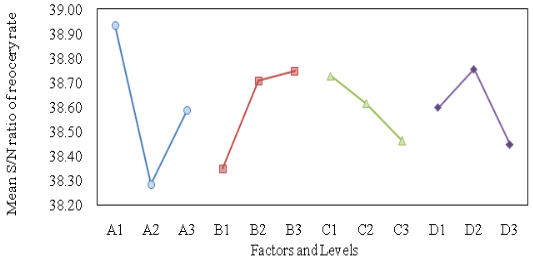


Fig 6 Multi-response signal-to-noise graph for case 1 (w_1 = 1.0, w_2=0)

By selecting the highest value of the mean S/N ratio for each factor, the optimal level can be determined. On this basis, the optimum combination of levels in terms of maximizing the recovery rate for this recycling process is A1, B3, C1 and D2; i.e. Al-clean 101 as the refining flux; 10:5 as the chips/flux ratio; 60mins as the holding time and 760℃ as the holding temperature.

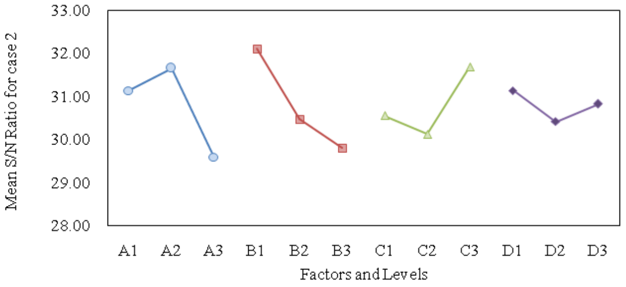


Fig B Multi-response signal-to-noise graph for case 2 (w1 = 0.5, w2=0.5)

For case 2, the recovery rate and corrosion resistance are taken into consideration simultaneously. Figure 7 shows the mean signal-to-noise ratio for case 2. By selecting the highest value of the mean S/N ratio for each factor, the optimal level can be determined. Hence, the optimum combination of the levels in terms of minimizing the corrosion resistance for the present recycling process is A2, B1, C3, D1; i.e., Al-clean 113 as the refining flux; 10:3 as the chips/flux ratio; 90 minutes as the holding time and 800℃ as the holding temperature.

C. Factor contributions

The contribution of each factor to the recovery rate can be determined by performing analysis of variance based on Equations 8–12. The results of analysis of variance (ANOVA) for case 1 (w_1=1.0, w_2=0) and case 2 (w_1=0.5, w_2=0.5) are summarized in Table 10 and 11, respectively.

Table 10 gives the contribution of the four factors in case 1, i.e. the flux type, chips/flux ratio, holding time and holding temperature is 54.13%, 24.75%, 9.04% and 12.08%, respectively. The flux type makes a contribution of 54.13%, higher than the sum of the rest three factors, which has the major influence on the corrosion resistance of the recycled alloy. The chips/flux ratio takes the second place with a contribution of 24.75%. The holding time and holding temperature has minor influence on recovery rate for both of their contributions are around 10%.

Factor	Degree of freedom (D)	Sum of squares (SS_p)	Variance (V)	Corrected sums of squares (SS_p')	Contribution	Rank
A	2	6.94	0.40	3.47	34.58%	2
B	2	8.39	1.80	4.19	41.80%	1
C	2	3.95	1.45	1.98	19.67%	3
D	2	0.79	3.87	0.39	3.94%	4
error		0.00	0.00		0.00	
Total		20.08			100%	

Table 11 Results of the ANOVA for case 2 (w1=0.5, w2=0.5)

Table 11 shows the contribution of the four factors in case 2, i.e. the flux type, chips/flux ratio, holding time and holding temperature is 34.58%, 41.80%, 19.67% and 3.94%, respectively. Chips/flux ratio has a contribution of 41.80% and flux type has a contribution of 34.58%, which are the two major influencing factors. The holding time makes medium contribution while holding temperatures during the refining process has little effect on case 2 for its contribution percentages are below 5%.

D. Confirmation run

As the last step of verifying the optimal combinations drawn from the DOE and the above discussion, two individual confirmation experiments were conducted focusing on the single optimization response, the recovery rate and the multi-response combining recovery rate and corrosion resistance. As discussed above, the designed factors A1B3C1D2 are selected as the optimal combination for case 1 (w_1=1.0, w_2=0), experimental conditions are set as: Al-clean 101 for the refining flux; 10:5 for the chips/flux ratio; 60 minutes for the holding time and 760℃ for the holding temperature. The results from the confirmation experiment show that 276.09 grams of aluminum alloy 380 recovered from 300 grams aluminum chips. Its recovery rate reaches as high as 92.03% with porosity content of 0.87%. The S/N ratio of multi-response of case 1 is calculated as 39.28 using Eqs. (4) - (9). Which is the highest value comparing with the S/N ratio of multi-response for case 1 in Table 4, it verifies the most effective combination of experimental factors and levels as predicted when the metal yield is a major concern. For case 2 (w_1=0.5, w_2=0.5), A2, B1, C3, D1are selected as the optimized combination, i.e., Al-clean 113 as the refining flux; 10:3 as the chips/flux ratio; 90 minutes as the holding time and 800℃ as the holding temperature. The results show that 272 grams of aluminum are recovered with a recovery rate of 90.67% and the corrosion resistance is 15.23. The S/N ratio of multi-response for the confirmation run is calculated as 31.40 with Eqs. (4) - (9). It verifies A2B1C3D1 is the optimal combination when both the metal yield and the corrosion resistance of the recovered aluminum were both required.

V. CONCLUSION

The Taguchi method for the design of experiment has been used for optimizing the recycling process for the machining chips of high pressure die cast aluminum alloy A380. Four factors, three levels for each factor were designed based on Taguchi method. To achieve the maximum recovery rate and corrosion resistance, the signal-to-noise ratio of HB characteristics was employed to calculate the S/N ratio of recovery rate and corrosion resistance. The optimum combinations were worked out based on the S/N ratio of each factor. For the multi-response objective case 1, the metal yield was the only requirement for the recycling process. The optimum combination (A1B3C1D2) was Al-clean 101 as the refining flux, 10:5 as the chips/flux ratio, and 60 minutes as the holding time and 760℃ as the holding temperature. The flux type made the major contribution to recovery rate with the percentage of 54.13%, which was higher than the sum of the rest three factors. The chips/flux ratio made medium contribution while both the holding time and holding temperature during refining process had minor effect on the recovery rate for their low contribution percentages. For the multi-response objective case 2, weighing factors were selected as w_1= 0.5, w_2=0.5. The optimum combination (A2B1C3D1) was Al-clean 113 as the refining flux, 10:3 as the chips/flux ratio, and 90 mins as the holding time and 800℃ as the holding temperature. The chips/flux ratio made the major contribution with the percentage of 41.80% and followed by flux type. Holding time made medium contribution while temperature during refining process had minor effect for its low contribution percentages.

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