

Optimization of Strengths and Electrical Conductivities of Al-Si-Cu-Ni-Sr Alloys

Yuxian Li, Yintian Fu, Anita Hu, Peilin Ying, Xueyuan Nie, Henry Hu*

Engineering Material Program, University of Windsor, Windsor, Canada

Email: li11115x@uwindsor.ca, fu14@uwindsor.ca, hu14l@uwindsor.ca, yingp@uwindsor.ca, xnie@uwindsor.ca,

*huh@uwindsor.ca

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Abstract

The aim of this study is to develop new cast aluminum alloys for the production of rotor bar in the rotor with high as-cast strength and electrical conductivity. A design of experiment (DOE) technique, Taguchi method, was used to develop high as-cast strength and electrical conductivity alloys with various element addition of Si, Cu, Ni and Sr. The optimal combination of chemical composition for maximizing the ultimate tensile strength (UTS), electrical conductivity (σ) and yield strength (YS) was 6 wt.% Si, 3 wt.% Cu, 0.03 wt.% Sr and 0.5 wt.% Ni. The alloy with the optimal composition had an averaged UTS of 247.58 MPa, an averaged electrical conductivity is 38.01%IACS, and an averaged yield strength is 143.47 Mpa.

Keywords

Squeeze Casting, Aluminum Alloy, Nickle, Strontium, Electrical Conductivity

1. Introduction

With growing market demand for battery-powered electrical vehicles (BEV), development of induction motors with high efficiency has become an urgent and essential task in the automotive industry. A squirrel cage rotor, as one of the popularity types in the industry, plays an important part in the field of electromechanical energy conversion [1]. Traditionally, pure aluminum has been used as the rotor bar material in induction motors due to its high electrical conductivity, light weight and low price. However, the mechanical properties, in particular, ultimate tensile strength (UTS) and yield strength (YS), of the pure aluminum are very low. To satisfy the engineering performance of Al rotor bars, a large cooling system is

usually required in the induction motor, which increases the size and weight of the motor considerably. With the serious energy and environment problems today, energy conservation becomes an important issue for future development. The most benefit for lightweight electric vehicles is low battery energy consumption to achieve the same range, which reduces the total cost [2]. With the high strengths and electrical conductivity of the rotor bar, the size and weight of the motor can be reduced by eliminating the large cooling system.

High strength and high electrical conductivity are mutually exclusive in metals and alloys, and trade-off between strength and conductivity is always encountered in developing conducting materials [3]. Pure aluminum has high electrical conductivity (60%IACS) with very low mechanical strength, and yield strength is about 10 MPa. However, aluminum alloy A319 as a representative of hypoeutectic Al-Si-Cu alloys has good mechanical strength, (UTS: 185 MPa, YS: 125 MPa in sand casting) but low electrical conductivity (27%IACS). In the literature [4]-[7], it has been found that Ni addition combining with Cu improved the strengths of Al-Si-Cu alloys at room and elevated temperatures by forming complex Al-Ni and Al-Cu intermetallic phases. Also, previous studies [8]-[10], indicated that the morphology of primary or eutectic silicon phases affected the mechanical properties of Al-Si alloys. The alkaline earth element, Sr, as a modified element, is capable of effectively modifying the morphology of eutectic silicon from acicular to fibrous form, which enhanced tensile properties of both hypereutectic and hypoeutectic properties significantly.

2. Experimental Procedures

2.1. Materials

Designed Al-Si-Cu-Ni-Sr alloys were prepared by using commercially pure Al, Al-50 wt.% Si, Al-50 wt.% Cu, Al-20 wt.% Ni and Al-10 wt.% Sr. Those alloys were melted and mixed in an electric resistance furnace to achieve the desired compositions which were verified by an Inductively-Coupled Plasma Atomic Emission Spectrometer based on ASTM E1479-99. The melt was kept at $730^{\circ}\text{C} \pm 10^{\circ}\text{C}$ for 30 minutes for the completion of homogenization and modification under the protective gas of nitrogen, and then the melt temperature was decreased to 650°C for squeeze casting.

2.2. Microstructural Analysis

Specimens were sectioned, mounted, and polished from the center of the squeeze disk and prepared following the standard metallographic procedures. A Buehler (Lake Bluff, IL) optical image analyzer 2002 system was used to observe primary characteristics of the specimens. The detailed features of the microstructure were also characterized at high magnifications by a scanning electron microscope (SEM). To maximize composition reading of the energy dispersive spectroscopy (EDS) data, an etchant of 0.5% NaOH solution was applied to polished specimens for microscopic examination.

2.3. Tensile Testing

The mechanical properties of the squeeze cast Al-6Si-3Cu alloys and Al-6Si-3Cu-0.03Sr-0.5Ni alloys were evaluated by tensile testing, which was performed at ambient temperature on an MTS criterion Tensile Test Machine (Model 43) equipped with a data acquisition system. Following ASTM B557, flat tensile specimens (25 mm in gage length, 6 mm in width, and 4 mm in thickness) were machined from the squeeze cast discs. The tensile properties, including ultimate tensile strength (UTS), and 0.2% yield strength (YS) were obtained based on the average of three tests.

2.4. Electrical Conductivity

The electrical conductivity is an important electrical property of the squeeze cast alloys. The handheld device SIGMASCOPE with FS40 probe was employed the electrical conductivity measurements of the squeeze cast alloys based on the phase sensitive eddy current method. This type of signal evaluation enables non-contact measurement. It also minimizes the influence of surface roughness. The measuring range of the device is 0.5% - 108% IACS (% International Annealed Copper Standard), and the accuracy at room temperature is $\pm 0.5\%$ of the measured reading. The electrical conductivity data were obtained based on the average of three tests.

3. Taguchi Design of Experiment

3.1. Design of Orthogonal Array and Signal-to-Noise Analysis

For alloy chemistry design, based on the literature survey, four alloying element, Si, Cu, Ni and Sr, were chosen with three levels and are listed in **Table 1**. The experimental layout for the four factors using L9 orthogonal array is given in **Table 2**. Two sets of the Taguchi experiments were conducted to ensure the reliability of experimental data for signal-to noise analysis.

In the alloy design process, 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 process. The Taguchi method [11] [12] uses the signal-to-noise (S/N) ratio instead of the average value to interpret the trial results data into a value for the characteristic evaluation in the optimum setting analysis. To minimize the influence of the error caused by the variation of

Table 1. Design factors and levels.

Level	Factor			
	A Si [wt.%]	B Cu [wt.%]	C Sr [wt.%]	D Ni [wt.%]
1	6	3	0.01	0.5
2	9	5	0.02	1
3	12	7	0.03	1.5

Table 2. Designed experiment plans.

Experiment	Si [wt.%]	Cu [wt.%]	Sr [wt.%]	Ni [wt.%]
1	6 (A1)	3 (B1)	0.01 (C1)	0.5 (D1)
2	6 (A1)	5 (B2)	0.02 (C2)	1 (D2)
3	6 (A1)	7 (B3)	0.03 (C3)	1.5 (D3)
4	9 (A2)	3 (B1)	0.02 (C2)	1.5 (D3)
5	9 (A2)	5 (B2)	0.03 (C3)	0.5 (D1)
6	9 (A2)	7 (B3)	0.01 (C1)	1 (D2)
7	12 (A3)	3 (B1)	0.03 (C3)	1 (D2)
8	12 (A3)	5 (B2)	0.01 (C1)	1.5 (D3)
9	12 (A3)	7 (B3)	0.02 (C2)	0.5 (D1)

characteristics, the signal-to-noise (S/N) ratio was employed, which converted the trial result data into a value for the response to evaluate the process in the optimum 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. In the present study, the mechanical and electrical properties of the designed alloys were treated as a characteristic value. Since the mechanical and electrical properties of the novel alloys were intended to be maximized, the S/N ratio for higher is best (HB) characteristics was selected and calculated as follows:

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

where n is the repetition number of each experiment under the same condition for design parameters, and η_{pi} is the property of an individual measurement at the i th test. After calculating and plotting the mean S/N ratios at each level for various factors, the optimal level, that was the largest S/N ratio among all levels of the factors, was determined.

The objective function was formulated according to the proposition for the optimization of mechanical and electrical properties with multiple performance characteristics (three objectives) by a weighting method:

$$\text{Maximize } f(X) = W_1 \cdot \eta_{UTS} + W_2 \cdot \eta_{\sigma} + W_3 \cdot \eta_{YS} \quad (2)$$

where η_{UTS} is the S/N ratio of the ultimate tensile strength, η_{σ} is the S/N ratio of the electrical conductivity, η_{YS} is the S/N ratio of the yield strength, and w_1 , w_2 , and w_3 are the weighting factor of the S/N ratio for the ultimate tensile strength, electrical conductivity and yield strength, respectively.

The above objective function is presented in an analytical form as a function of input parameters since ultimate tensile strength, yield strength and electrical conductivity as three characteristics are important properties for cast components in induction motor. The three characters should be considered as different critical

roles by weighting factors. For induction motor in the electrical vehicle, the strength and electrical conductivity are equally important in engineering applications. For cast components of which strengths have a priority higher than the other mechanical properties, such as ductility, higher weighting factors of ultimate tensile strength and yield strength need to be considered. However, the cast components in the induction motor desired both higher strengths, enhanced electrical conductivity, and improved castability for high-performance applications including automobile parts. As an example, in this study, for high strengths and electrical conductivity application, combination of weighting factor as 0.2:0.6:0.2 is selected to demonstrate the optimization of strength and electrical conductivity. The combinations of weighting factors may vary for various application and engineering requirements.

3.2. Analysis of Variance (ANOVA)

The purpose of the analysis of variance is to investigate the contribution of each factor (chemical element) with multiple characteristics that significantly affect the mechanical properties and electrical conductivity. Following the analysis, it is relatively easy to identify the effect order of factors on strengths and electrical conductivity, and the contribution of factors to strengths and electrical conductivity. In this study, 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 symbol typically used in ANOVA 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_T denotes the total sum of squares.

The total sum of square SS_T from S/N ratio was calculated as:

$$SS_T = \sum_{i=1}^m \eta_i^2 - \frac{1}{m} \left[\sum_{i=1}^m \eta_i \right]^2 \quad (3)$$

where m is the total number of the experiments, and η_i is the factor response at the i_{th} test.

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

$$SS_p = \sum_{i=1}^m \frac{(S_{\eta_{jc}})^2}{t} - \frac{1}{m} \left[\sum_{i=1}^m \eta_i \right]^2 \quad (4)$$

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_{η_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 numbers of the result data points minus one, *i.e.*, the total number of trials times the number of repetitions minus one. 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:

$$V_p(\%) = \frac{SS_p}{D_p} \times 100 \quad (5)$$

4) The Corrected Sum of Squares (SS_p'). SS_p' is defined as the sum of squares of factors minus the error variance times the degree of freedom of each factor:

$$SS_p' = SS_p - D_p V_e \quad (6)$$

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

$$P_p(\%) = \frac{SS_p'}{SS_p} \times 100 \quad (7)$$

4. Results and Discussion

4.1. Multi-Response S/N Ratios

To comprehensively evaluate the engineering performance of lightweight Al alloys for electrically conductive applications, the optimization criteria for rotor bars in electric motors were defined as material capabilities of resisting plastic deformation and fracture effectively, and conducting electric current efficiently. The yield strength (YS) is the stress an alloy can withstand without plastic deformation, while the ultimate tensile strength (UTS) is the maximum stress that an alloy can withstand before fracture [13]. The ability of an alloy to conduct electric current is represented by the electrical conductivity (σ) [14]. Hence, these three characteristics, UTS, YS and σ , were selected as multiple performance objectives for evaluating the designed alloys for the optimization. The experimentally determined UTS, YS and electrical conductivities are listed in **Table 3**.

Table 3. UTS, YS and electrical conductivities of the designed alloys.

Experiment	UTS [MPa]		σ [%IACS]		YS [MPa]	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
1	243.26	247.59	26.8	27.51	213.79	206.59
2	243.93	253.37	24.08	24.45	215.20	213.97
3	228.88	232.69	27.94	28.05	146.71	150.28
4	245.82	246.16	24.80	25.05	170.83	175.86
5	271.81	281.53	24.30	24.80	229.95	241.55
6	291.36	281.93	22.80	22.74	221.29	223.02
7	243.04	249.18	25.47	25.43	153.36	150.41
8	234.00	230.00	21.56	21.42	197.31	183.96
9	239.75	250.48	23.80	23.94	184.55	189.39

Since the objectives, *i.e.*, UTS, YS and σ , were intended to be maximized, the S/N ratio for HB (higher-is-best) characteristics was used [11]. The S/N ratios of these tensile properties and electrical conductivity were given in **Table 4**. The multi-responses of the S/N ratios using three weighting factor combinations were also concluded in **Table 4**. The three-weighting factors were $w_1 = 0.2$, $w_2 = 0.6$ and $w_3 = 0.2$ for UTS, σ and YS, respectively. The response of each factor to its individual level was calculated by averaging the S/N ratios of all the experiments at each level for each factor. With three combinations of three weighting factors, the mean multi-response S/N ratios of the factors for each level were calculated and summarized in **Table 5**, respectively. For instance, the mean S/N ratio (35.33) for Sr addition at level 2 in **Table 5** with the weighting factors of $w_1 = 0.2$, $w_2 = 0.6$ and $w_3 = 0.2$ was the average value of the S/N ratios of experiment No.2 (35.55), No.4 (35.27) and No.9 (35.18) which were listed in **Table 4**.

Table 4. S/N ratios of objectives and multi-response S/N ratio with three weighting factors.

Experiment	S/N ratio (UTS)	S/N ratio (σ)	S/N ratio (YS)	Multi-response of S/N ratio $w_1 = 0.2, w_2 = 0.6$ and $w_3 = 0.2$
1	47.80	28.67	46.45	36.05
2	48.02	27.70	46.63	35.55
3	47.26	28.94	43.43	35.50
4	47.82	27.93	44.78	35.27
5	48.84	27.80	47.44	35.93
6	49.14	27.15	46.93	35.50
7	47.82	28.11	43.63	35.16
8	47.31	26.65	45.59	34.56
9	47.78	27.56	45.43	35.18

Table 5. Mean multi-response S/N ratios of the factors for each level with three weighting factors.

Level	Mean S/N ratio for case: $w_1 = 0.2, w_2 = 0.6$ and $w_3 = 0.2$			
	A Si	B Cu	C Sr	D Ni
1	35.70	35.49	35.37	35.72
2	35.57	35.35	35.33	35.40
3	34.97	35.39	35.53	35.11

4.2. Optimal Chemical Composition for Strengths and Electrical Conductivity Performance

As high strength and high electrical conductivity are mutually exclusive for metallic materials, the balance between strength and conductivity is essential to the

design optimization of as-cast Al alloys for electrically conductive applications [15]. To optimize the strengths and electrical conductivities of the designed alloys for the rotor bars in the electric motors, the order of the performance characteristics was given as electrical conductivity ($w_2 = 0.6$), ultimate tensile strength ($w_1 = 0.2$), and yield strength ($w_3 = 0.2$). **Figure 1** depicts the multi-response S/N ratios for the certain case of strength and electrical conductivity optimization.

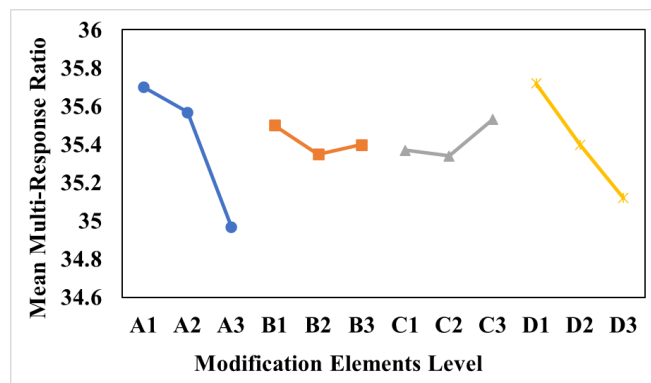


Figure 1. Multi-response signal-to-noise graph for the case: $w_1 = 0.2$, $w_2 = 0.6$ and $w_3 = 0.2$.

As shown in **Figure 1**, the mean S/N ratio for factor A of Si addition continuously decreased with the amount of Si from 6 wt.% (level 1) to 12 wt.% (level 3). Since Si is a semiconductor, when a high amount of Si was introduced to the alloy, the electrical conductivity of the alloy decreased. The effect of the Cu addition (factor B) on the mean S/N ratio of the mechanical properties and electrical conductivity was also plotted in **Figure 1**. When Cu increased from 3 wt.% (level 1) to 5 wt.% (level 2), the mean multi-response S/N ratio of tensile properties and electrical conductivity decreased from 35.49 to 35.35. The ratio showed almost no increase to 35.39 (+0.11%), as Cu rose to 7 wt.% (level 3). This might be because sufficient Cu addition could form a large amount of the strengthening Al-Cu intermetallic phase and fine grain structure, which increased ultimate tensile strengths and yield strengths [16]. For Sr addition, as increasing from levels 1 to 2, the S/N ratio decreased slightly. Further addition of Sr led to an increase in the S/N ratio. This observation suggested that the presence of a high level of Sr benefited both the strengths and conductivity of the designed alloys. This is because Sr is a good modifier for silicon in Al alloys. An appreciable amount of Sr changed the morphology of eutectic silicon to spherical appearance in the microstructure, which increased the strengths of the alloys [17]. Examination of the effect of Ni addition (factor D) revealed that the multi-response S/N ratios including the electrical conductivity and tensile properties decreased, as the amount of Ni addition increased. As the maximum solubility of Ni in Al is very low (0.24 wt.%) [18], the introduction of relatively high Ni levels over 0.5 wt.% led to form massive Ni-containing intermetallics present not only at the boundaries of the primary α -Al dendrites but also inside them. Although the Al-Ni intermetallics in the microstructure enhanced the strengths of the Al-Si-Cu alloys, their presence in the

primary α -Al phase impeded the electron movement and reduced the electrical conductivity [15] [19]. It revealed that the low level of Ni was desired for the designed alloys. By selecting the highest value of the mean S/N ratio for each factor, the optimal levels were determined, which were A1B1C3D1; *i.e.* 6 wt.% Si, 3 wt.% Cu, 0.03 wt.% Sr and 0.5 wt.% Ni.

4.3. Factor Contributions

The contribution of each factor to the tensile properties and electrical conductivity was determined by performing the analysis of variance (ANOVA) based on Equations (3)-(7). The results of analysis of variance for case: $w_1 = 0.2$, $w_2 = 0.6$ and $w_3 = 0.2$, are summarized in **Table 6**.

Table 6. Results of the ANOVA for case: $w_1 = 0.2$, $w_2 = 0.6$ and $w_3 = 0.2$.

Factors	Degree of freedom (D)	Sum of squares (SSp)	Variance (V)	Corrected sums of squares (SSp')	Contribution	Rank
Si (%)	2	2.046	1.023	2.046	40.58%	1
Cu (%)	2	1.562	0.781	1.562	22.84%	2
Sr (%)	2	1.28	0.64	1.28	19.52%	3
Ni (%)	2	1.398	0.699	1.398	17.05%	4
Error		0.00	0.00		0	
Total		6.286			100%	

Table 6 lists the contribution of the four factors (Si, Cu, Sr and Ni addition) in case: $w_1 = 0.2$, $w_2 = 0.6$ and $w_3 = 0.2$, in which the electrical conductivity has a priority, was 40.58%, 22.84%, 19.52%, and 17.05%, respectively. The addition of Si had the highest contribution of 40.58%, which indicated that Si had the major influence on the electrical conductivity of the designed alloys. Cu (22.84%) and Sr (19.52%) were ranked as the second and third highest contributors which had a very close contribution to each other. The Ni had the lowest contribution of 17.05%.

4.4. Confirmation Experiment

As discussed above, the designed factors and levels of A1B1C3D1 were selected as the optimal combination for maximizing the ultimate tensile strength, electrical conductivity and yield strength ($w_1 = 0.2$, $w_2 = 0.6$ and $w_3 = 0.2$). The optimal alloy composition was 6 wt.% Si, 3 wt.% Cu, 0.03 wt.% Sr and 0.5 wt.% Ni. To confirm the optimal combination from the DOE based on the Taguchi method, a confirmation experiment of squeeze casting of the optimal alloy was conducted. Two individual tests were performed to obtain the objectives, UTS, σ and YS, are listed in **Table 7**. The results from the confirmation experiment given in **Table 8** showed that the confirmed alloy had an averaged UTS of 247.58 MPa, an averaged

electrical conductivity is 38.01%IACS, and an averaged yield strength of 143.47 MPa.

Table 7. Tensile properties and electrical conductivity of the confirmed alloy with optimal combinations.

Experiment	UTS [MPa]		σ [%IACS]		YS [MPa]	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Confirmation	248.43	246.73	38.79	37.23	145.63	141.31

Table 8. The S/N ratio of objectives and Multi-Response S/N ratio of confirmation experiments.

Experiment	S/N ratio	S/N ratio	S/N ratio	Multi-response of S/N ratio
	(UTS)	(σ)	(YS)	$w_1 = 0.2, w_2 = 0.6$ and $w_3 = 0.2$
Confirmation	47.87	31.59	43.13	37.154

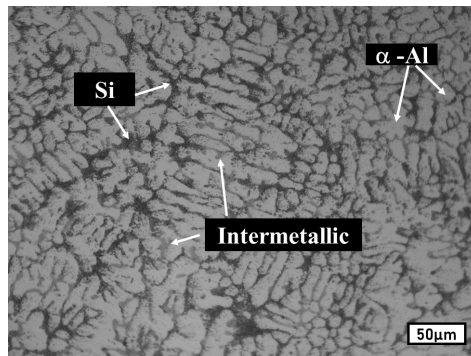


Figure 2. Multi-response signal-to-noise graph for the case: $w_1 = 0.2, w_2 = 0.6$ and $w_3 = 0.2$. Optical micrograph showing the microstructure of the optimal alloy at low magnification.

Figure 2 presents the microstructure of the optimized alloy obtained from the confirmation experiment. The analysis by the optical microscopy (**Figure 2**) showed that the microstructure consisted of the primary α -Al dendrite, eutectic silicon phase and intermetallic phases surrounding the α -Al phase. The element analysis indicates that the microstructure of the etched optimal alloy consists of primary α -Al, eutectic Si, the Al-Cu intermetallic phase and Al-Cu-Ni intermetallic phase. **Figure 3** and **Figure 4** present the SEM micrograph and EDS spectra of the optimal alloy squeezed cast in the confirmation experiment. Examination of the detailed features of the microstructure characterized by SEM and EDS analyses on the etched specimen revealed the intermetallic containing Cu and Ni. The addition of Ni facilitated the formation of the Ni-containing intermetallic phase. Also, it can be seen from **Figure 3(a)** that the addition of Sr refined the morphology of eutectic silicon, which was in a fibrous and globular shape. At high magnification, the SEM and EDS analyses identified the nano-sized particles of eutectic silicon, primary α -Al, the Al-Cu intermetallic phase and Al-Cu-Ni intermetallic phase in the optimal alloy, as illustrated in **Figure 3(b)** and 4. The significant

improvement of the tensile properties and electrical conductivity should be attributed to the modification of eutectic silicon phase by addition of Sr and the presence of increased intermetallic content by the introduction of Ni. Fang [20] observed the similar strengthening effect in the squeeze cast Al-Si-Cu-Ni alloys.

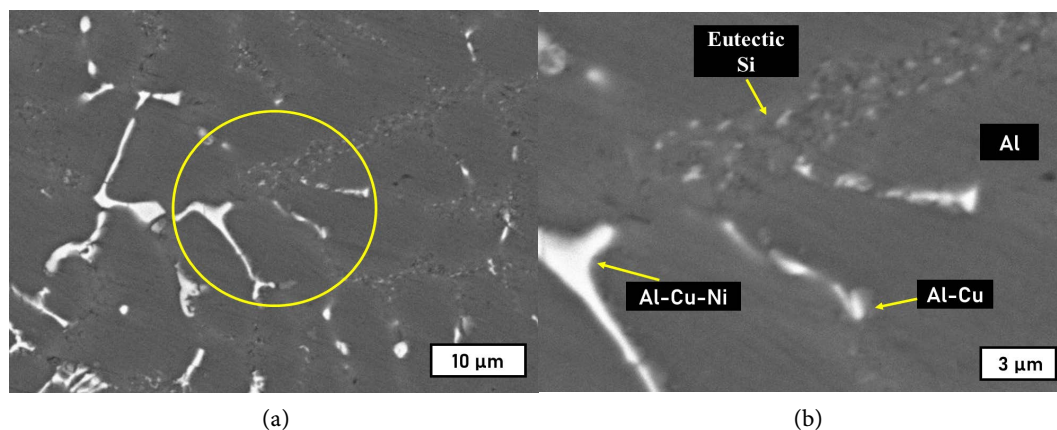


Figure 3. SEM micrograph showing microstructure of the optimal alloy obtained from the confirmation experiment in (a) high magnification, and (b) low magnification.

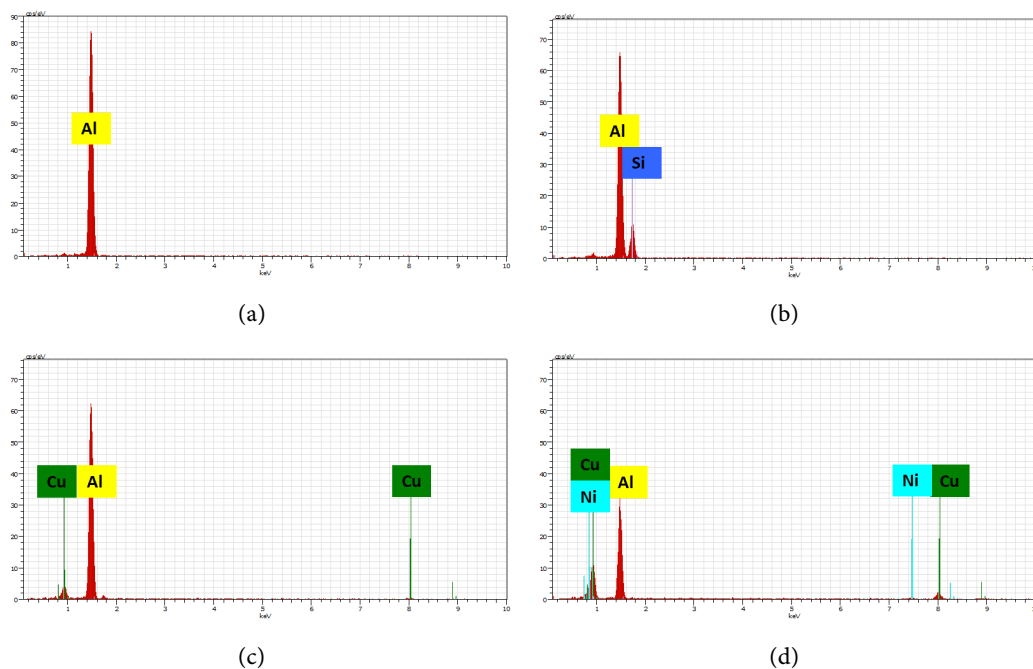


Figure 4. EDS spectra (a), (b), (c) and (d) for the primary α -Al dendrite, the eutectic silicon, the Al-Cu intermetallic phase and Al-Cu-Ni intermetallic phase as shown in **Figure 3**(b), respectively.

5. Summary

The aim of this study is to develop new casting aluminum alloys for production of rotor bar in the rotor with as cast high strength and electrical conductivity. In developing novel aluminum alloys, the Taguchi method with multiple performance characteristics has been demonstrated for optimizing the addition levels of one

metalloid element (Si), two transient elements (Cu and Ni), and one alkaline earth element (Sr) based on defined objectives (UTS, YS and σ) for the development of novel aluminum alloys. For each element, three different levels of weight percentages were selected (Si: 6, 9, 12 wt.%, Cu: 3, 5, 7 wt.%, Ni: 0.5, 1, 1.5 wt.% and Sr: 0.01, 0.02, 0.03 wt.%). The main conclusions from this work could be drawn as follows:

1) The multiple performance characteristics such as mechanical properties including ultimate tensile strength and yield strength as well as the electrical property such as electrical conductivity can be simultaneously considered and improved through this optimization technique.

2) The maximum multi-response S/N ratio (37.154) was achieved by the confirmed experiment with the optimum levels of A1B1C3D1 (6 wt.% Si, 3 wt.% Cu, 0.03 wt.% Sr and 0.5 wt.% Ni). This confirms that Taguchi method is reliable to design high strength and electrical conductivity aluminum alloy.

3) The optimum alloy with the optimal composition had an averaged UTS of 247.58 MPa, an averaged electrical conductivity is 38.01%IACS, and an averaged yield strength is 143.47 MPa under the as-cast condition for a squeeze casting.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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