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EFFECT OF INPUT PARAMETERS ON THE MECHANICAL PROPERTIES OF A413 ALLOY : COACTIVE NEURO-FUZZY INTERFACE SYSTEM APPROACH

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ABSTRACT

The effects of modification and vibration during solidification of Aluminum-Silicon eutectic alloy (A413) are studied and compared with unmodified alloy. Sodium and Strontium are used as modifiers. Horizontal sinusoidal vibration at different frequencies was imposed using a vibration table. It was found that modification treatment improves properties such as ultimate tensile strength, percentage elongation, hardness, toughness, cutting force, electrical conductivity, thermal conductivity, fluidity, porosity and fatigue strength and optimum values were found for sodium and strontium weight addition of modifier. Neuro fuzzy model (CANFIS) is developed and sensitivity analysis is carried out to measure the relative importance of the inputs of the model and how the model output varies in response to variation of an input.

Keywords: *Modification, Neural Networks, Neuro-Fuzzy, CANFIS and Sensitivity.*

1. Introduction

Among the cast aluminum alloys, Aluminum-Silicon alloy is the first and most important casting alloy primarily because of their excellent casting characteristics. Silicon is one of the few elements that may be added to aluminum, without loss of its weight advantage. Aluminum-Silicon alloys are the most important class of commercial non-ferrous alloys having wide ranging applications in the automotive and aerospace industries because of their casting characteristics, high strength-to-weight ratio, wear and corrosion resistance, pressure tightness, good weldability and good surface finish. Applications of these alloys have included automotive cylinder heads, engine blocks, aircraft components and pipe fittings. This alloy contains 10-13% by weight of silicon. The rapid cooling in pressure die casting causes, a fine structure and reduced grain size. But slower cooling rates encountered in permanent mould and sand casting, the alloy contains silicon phase in the form of large plates with sharp sides and ends, this acicular silicon plates acts as internal stress raisers in the microstructure and provide easy paths for fracture which leads to brittleness.

2. Literature Review

Addition of some elements like sodium or strontium in trace amounts causes a change in the solidification, morphological characteristics of silicon both in eutectic and primary form. This change (specifically the morphological change) is termed as modification. Mechanical vibration is more commonly used than electromagnetic vibration due to its simplicity and low cost. In this work a more simple vibration table is fabricated, which is best suited for small scale foundries.

The beneficial effect of vibration was observed with several types of metals, e.g. zinc, brass, aluminum, etc. The effects include promotion of nucleation and thus reducing as-cast grain size, reducing shrinkage porosities due to improve metal feeding, and producing a more homogenous metal structure[1]. These improved features lead to enhanced mechanical properties and lower susceptibility to cracking [2, 3].

3. Research Methodology

Experiments were conducted by adopting best melting practices and using standard test specimens to find various mechanical properties of A413 alloy. Specimens were prepared using different gating systems viz, direct pouring, single gate and two gate. To find the effect of modification on the properties, modifiers like sodium and strontium were used. A vibration table is fabricated to apply different levels of frequency of vibration. Micro structural analysis in the three stages of experimentation is done using scanning electron beam microscope.

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Best neural network model is found and genetic algorithm is used to optimize the model. Neuro fuzzy hybrid network is developed and results were compared with the neural network models developed. Neuro fuzzy model was trained optimally and graphs were drawn comparing trained data and experimental data for all the output responses. Optimally trained network is tested with production data sets and percentage error is calculated. Sensitivity analysis graphs depict the sensitivity about the mean with different input parameters.

4. Experimentation

The experiment has been carried out in three stages by controlling the operating parameters like A413 alloy composition, melting and pouring temperatures. Stage I: In this stage, molten metal is poured into the mould boxes with direct pouring gating system (no gate).Various tests were conducted by varying sodium percentage by weight modifier and frequency of vibration. Tests were repeated with permanent modifier strontium and frequency of vibration. Percentage of modifier is added at various levels 0, 0.5, 1, 1.5, 2 and 2.5. Frequency of vibration is carried out on the mould box by bolted over the vibrating table as shown in Fig.1 and forced to vibrate during solidification of the molten metal in the mould box. By varying the speed of the motor the frequency of vibration has been varied. Vibration is given for 2 minutes to each casting at 0, 5, 10, 15, 20 and 25 Hz.
Stage II: In this stage, molten metal is poured into the mould box using parting gate or single gating system. Experimentation is carried as discussed in stage I.
Stage III: In this stage, molten metal is poured into the mould box using step gate or two gating system. Experimentation is carried as discussed in stage I

The values like UTS, elongation, BHN, toughness, cutting force, electrical resistivity, thermal conductivity, porosity, fatigue strength and fluidity were found in the three stages above and results were tabulated.

5. Predictions of Strontium Modified Alloy

There are 3 input parameters (no. of gates, % modifier and frequency of vibration) and 10 output parameters (UTS, % elongation, BHN, toughness, fatigue strength, cutting force, electrical resistivity, thermal conductivity, porosity and fluidity). For finding fluidity, fluidity spiral is used directly. Hence no. of gates is not an input parameter to study the Fluidity. Hence a separate model is required to develop a model to predict fluidity of the alloy. Hence for the remaining 9 output responses a single model can be developed.

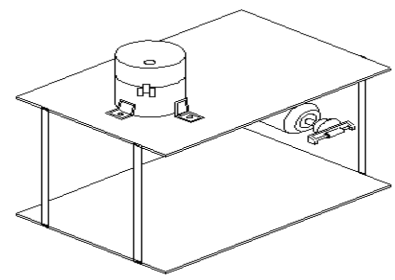

Fig.1 Line Diagram of Vibration Table

Architecture is selected based on the lowest Mean Square Error (MSE) value. Once the network architecture is selected, parameters such as the number of hidden layers, the number of epochs and the learning algorithm can be customized. Details of CANFIS neuro-fuzzy model data sets are given in table 1 and various parameters selected for predicting accurate results using neuro-fuzzy network are given in table 2. Complete error analysis of the model and best network values are given in table 3. Percentage error of CANFIS predicted values and experimental values considered for production is calculated and shown in table 4. MSE of the network (Training) w.r.t no. of epochs is shown in Fig. 2.

Table 1: CANFIS Model Data Sets

Training data sets	Cross validation data sets	Testing data sets	Production data sets
99	3	3	3

Table2- Parameters Selected for CANFIS Neuro-Fuzzy Model

Processing Elements (PEs)	3	Transfer function	Axon
Output PEs	8	Learning rule	Momentum
Exemplars	99	Step size	1
Hidden layers	0	Momentum	0.7
Membership function(MF)	Bell	Maximum epochs	30244
MFs per unit	3	Threshold	0.01
Fuzzy model	TSK	Weight update	Batch

Sensitivity values of various properties with respect to the three input process variables are given in table 5.

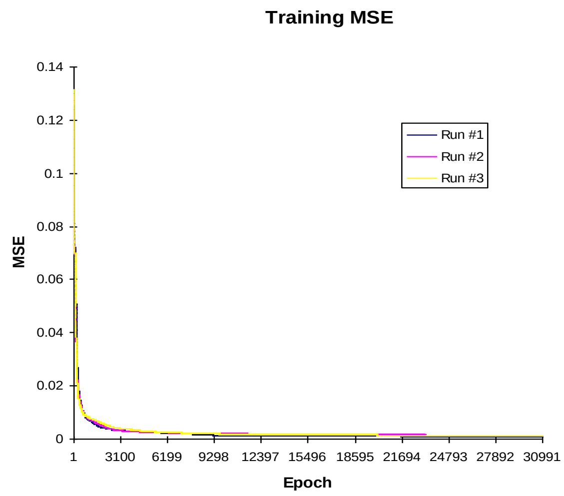

Fig.2 Mean Square Error of the Network

Table 3: Error Analysis of the Model-Strontium Modified Alloy

(a) MSE & Std. deviation of training and cross validation network

All runs	Training minimum	Training standard deviation	Cross validation minimum	Cross validation standard deviation
Average of Minimum MSEs	0.001087476	0.000461126	0.003865431	0.00112645
Average of Final MSEs	0.010460847	0.008837798	0.011532547	0.00838212

(b) Best fit values

Best networks	Training	Cross validation
Run #	2	3
Epoch #	30244	22083
Minimum MSE	0.000795124	0.002959439
Final MSE	0.000813704	0.006708017

Table 4: % Error of CANFIS Predicted Values of Production Data

S.No	Property	Experimental	CANFIS Predicted	% error
1	Ultimate Tensile Strength	73	73.12	0.16
2	Percent elongation	5	5.02	0.4
3	Brinell Hardness Number	44	43.61	0.88
4	Toughness	6	5.86	2.33
5	Cutting force	33	32.65	1.06
6	Electrical resistivity	0.061	0.06	1.63
7	Thermal conductivity	109	108.58	0.38
8	Porosity	1.8512	1.7872	3.45

Table 5: Sensitivity Values of Sr Modified Alloy

S.No	Sensitivity	No. of gates	% modifier	Frequency
1	Ultimate Tensile Strength	1.0512	7.4399	0.6115
2	Percent elongation	0.122	1.1742	0.1504
3	Brinell Hardness Number	0.1162	0.8321	0.435
4	Toughness	0.0695	1.3222	0.3306
5	Cutting force	0.669	8.2953	1.5799
6	Electrical resistivity	0.0007	0.0035	0.0011
7	Thermal conductivity	0.8541	8.6216	1.174
8	Porosity	0.2426	0.3068	0.057

6. Results & Discussion

Surface plots for various properties with respect to % modifier and frequency of vibration of sodium modified A413 alloy specimens with single gating system are drawn. It has been found that optimum values were obtained at 1.5% by weight of modifier and vibration at 15 Hz frequency except for electrical resistance, porosity, thermal conductivity and fluidity as shown in Fig. 3 to 6. SEM photographs of the unmodified, modified, modified-vibrated A413 alloy is shown in Fig. 7. Unmodified alloy contains silicon in large flake types as shown in Fig. 7a. As reported by many investigators, modification breaks up the silicon into fibrous form, which is seen in Fig. 7b. The change in silicon morphology by the use of modification and vibration during solidification is shown in the SEM micrograph of Fig. 7c, and is considered to be responsible for the enhanced strength of the modified-vibrated alloy. The observed smaller fatigue striation spacing may be linked to the smaller silicon particles in the modified and modified-vibrated alloys. The refinement of silicon may be due to the increased number of nuclei present, when solidification is taking place under vibration 4.

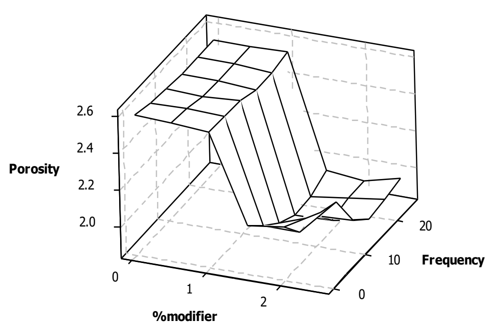

Fig. 3 Porosity

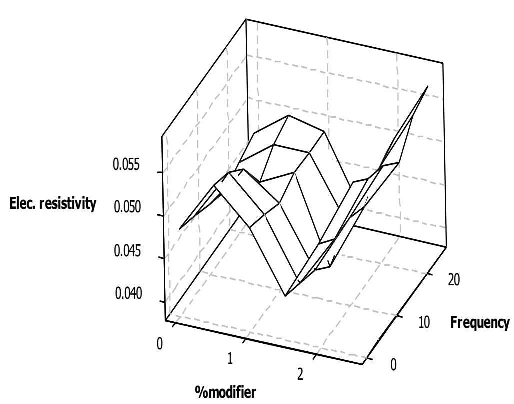

Fig. 4 Electrical Resistivity

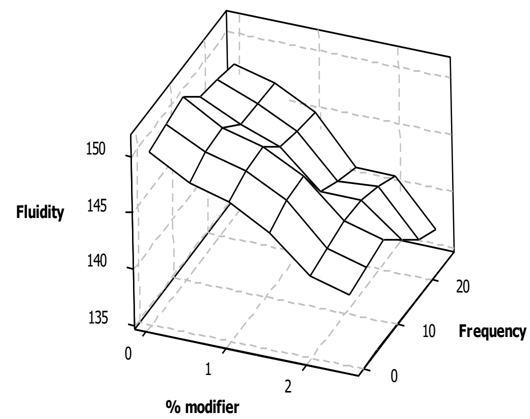

Fig. 5 Fluidity

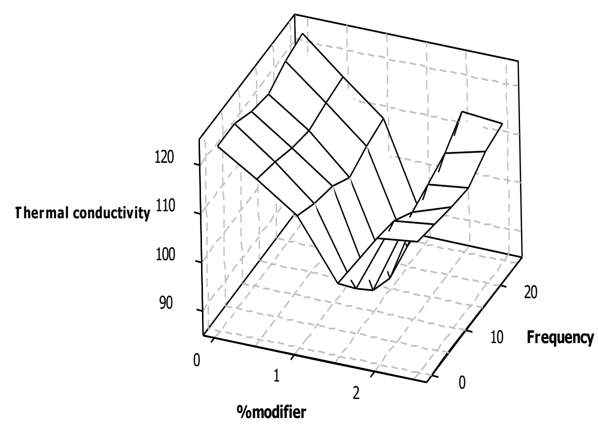

Fig. 6 Thermal conductivity

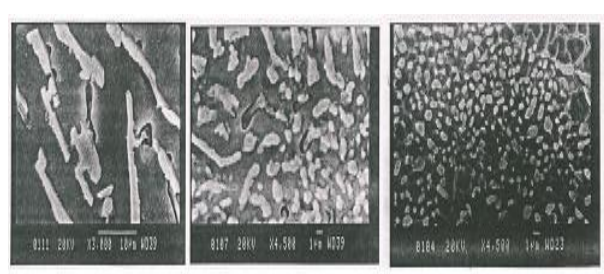

Fig.7 (a-c) SEM micrographs in three stages (X4500)

7. Conclusions

Modification treatment on A413 alloy using Sodium/ Strontium modifiers, improves the properties such as ultimate tensile strength, percentage elongation, hardness, toughness, cutting force, electrical conductivity and thermal conductivity. Optimum values are obtained at 1.5% by weight addition of Strontium/Sodium modifier. Modification with vibration further improves the mechanical properties of A413 alloy. At 15 Hz frequency optimum values are obtained. Modified-vibrated alloy has changed the silicon morphology better compared to the modified alloy. It is found that fatigue strength of modified-vibrated Al-Si eutectic alloy is higher than that of the unmodified and modified alloys. It is also found that vibration during solidification reduces the porosity in modified Al12Si alloy. Fluidity decreases with increasing the weight percent of strontium modifier. Modification with vibration increases the fluidity slightly.

From neuro-fuzzy network model, it is found that fatigue strength is more sensitive to number of gates and fatigue strength and thermal conductivity are more sensitive to % modifier and electrical resistivity is least sensitive to %modifier. Sensitivity values of thermal conductivity and fluidity are next to fatigue strength than all other properties with respect to frequency of vibration. Porosity and electrical resistivity are least sensitive to frequency of vibration.

Porosity decreases with increase in % modifier up to 1.8% by weight of sodium. Porosity is maximum at 0.5 % by weight of sodium as per neuro fuzzy hybrid model predictions.

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