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Modeling of the Impact of Initial Mold Temperature, Al5Ti1B and Al10Sr Additions on the Critical Fraction of Solid in Die Casting of Aluminum Alloys using Fuzzy Expert System

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In the casting of liquid metal, the feeding stops when the mushy zone is clogged and does not allow the transfer of feeding liquid. The growing resistance of the solid dendrites against the fluidity of the feeding liquid is defined as the critical fraction of solid (CFS). CFS value varies depending on many factors such as alloy solidification range, initial mold temperature, and the grain size. Therefore, in many casting simulation applications, it is quite common to get inconsistent results due to insufficient information about the CFS. In this study, a fuzzy expert system (FES) model has been developed in order to determine the value of the CFS in the die casting process, based on the parameters of the alloy type, the initial mold temperature, Al5Ti1B addition and Al10Sr addition. In order to create the rule base for the FES model, 54 die casting experiments have been carried out. The CFS values obtained using the FES model has revealed that the developed model of the FES predicts the CFS value in a high performance.

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1. Introduction

Casting simulation software allows strong casting in one attempt by designing and modeling in the digital environment. Nevertheless, the actual boundary conditions of casting in the foundry environment, which are the inputs of the simulation software, need to be provided accurately to obtain successful results [1–3]. One of the most important boundary conditions that is effective during the solidification of liquid metal is the value of critical fraction of solid and it needs to be accurately defined in the casting simulation program [2–4]. CFS is the stage at which the dendrites growing in the mushy zone reach a certain volume and clogs the flow of the fluid and cause feeding blockage [5]. The feed path is clogged below the CFS value and the flow of liquid metal is blocked. Therefore, the faults occur in the casting parts. It reveals the importance of accurate determination of the CFS for the production of strong and quality parts in the casting process [6].

Considering the literature, there seems a limited number of studies on CFS. In a study by Emadi and Whiting, the CFS value of Al-Si alloys with various Si contents has been examined [7]. The results of a study carried out to examine the CFS values of A319 and A356 alloys using thermocouple method have been determined to be consistent with the values obtained using other thermal methods [8]. Nevertheless, some other studies suggest that the solubility rate of the elements in the alloy have an impact on the thermal analysis method and thus provides inconsistent results [9]. In another study, the importance of CFS modeling in the die casting of the aluminum alloys has been examined by using experimental modeling techniques together with a specially developed permanent mold [10].

Considering the studies in the literature, the lack of a model which ensures that the determination of the proper CFS values for the varying casting conditions in the die casting method draws attention. Therefore, it has been aimed to examine the CFS values determined in the die casting method during the solidification of various commercial aluminum casting alloys and to develop a model that allows determining the CFS value using fuzzy expert system (FES) approach.

2. Experimental procedure

2.1. Materials and experiment parameters

The chemical composition of the aluminum alloys used in die casting experiments is shown in Table I.

The type of the alloy, grain refiner addition, modifier addition, and the initial mold temperature have been determined to be the parameters having an impact on the CFS value in die casting experiments. Al5Ti1B master alloy has been used as a grain refiner to have an effect of 0.2% Ti and Al10Sr master alloy has been used

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TABLE I

Chemical composition of the aluminum alloys used in experiments. (Al balance), (wt%) [11].

Alloy	Fe	Si	Cu	Mn	Mg	Zn	Ti	Sn
A319	0.70	4.00–6.00	2.00–4.00	0.20–0.60	0.15	0.20	0.20	0.05
A413	0.60	11.50–13.50	0.10	0.40	0.10	0.10	0.15	0.05
A380	1.00	7.50–9.00	3.00–4.00	0.50	0.30	1.00	0.20	0.10
A360	0.50	9.00–10.00	0.10	0.40–0.60	0.30–0.45	0.10	0.15	0.05
A356	0.20	6.60–7.40	0.02	0.03	0.30–0.45	0.04	0.08–0.14	0.05
AlCu4Si	0.30	0.35	4.00–5.00	0.10	0.10	0.10	0.05	0.05

TABLE II

Experiment parameters and their levels.

Parameters	Levels					
	I	II	III	IV	V	VI
alloy type	A319	A413	A380	A360	A356	AlCu4Si
grain refiner addition	no add.	TiB	—	—	—	—
modifier addition	no add.	Sr	—	—	—	—
initial mold temp. [°C]	200	300	400	—	—	—

as a modifier to have an effect of 0.1% Sr in the experiments. The experiment parameters and their levels are shown in Table II.

2.2. Die casting experiments

Die casting experiments have been carried out in a commercial company. The mold has been attached to a hydraulic opening-closing press and the processes of pouring of the liquid metal at the specified temperature, filling the mold, and the opening of the molds after solidification have been carried out by using this system. The surfaces of the molds have been cleaned using dry ice before casting and they have been painted with the wash. After mold painting process, the mold, which has been brought to the initial mold temperature conforming with the experiment parameter conditions, has been closed by placing 20 ppi (pore per inch) ceramic foam filter and made ready for the next casting. After the process of slagging and degassing by nitrogen, the liquid metal prepared in conformance with the experiment parameters has been taken from the furnace and poured into the sprue by using a primary ingot for each alloy using a hand casting ladle. The mold opening time has been set to 5 minutes and the surface of the mold, which has been opened after 5 minutes, has been cleaned and then the other casting process has been carried out. A mold after the die casting process is shown in Fig. 1.

54 die casting experiments have been conducted. Obtained experimental CFS values have been cross-checked with the CFS values based on casting simulation software. After the crosscheck stage, results of the experiments have been used for rule base of the FES model. A sample set of the experiments is given in Table III.

Fig. 1. A mold after the die casting process.

TABLE III

A sample set of the experiments.

Exp. No.	Alloy type	Grain refiner addition	Modifier addition	Initial mold temp. [°C]	CFS [%]
1	A319	—	—	200	36
13	A413	—	—	300	35
24	A380	Al5Ti1B	Al10Sr	300	57
32	A360	Al5Ti1B	—	300	52
39	A356	Al5Ti1B	Al10Sr	200	53
...	...	...	...	...	...
54	AlCu4Si	Al5Ti1B	Al10Sr	400	53

2.3. Fuzzy expert system model

Being an artificial intelligence technology, the FES allows processing uncertainties, contradictions, and the linguistic expressions in the digital environment. Therefore, a new FES model has been developed for predicting the CFS value in die casting process. While developing the model, Fuzzy Logic Designer tool of MATLAB®R2017a

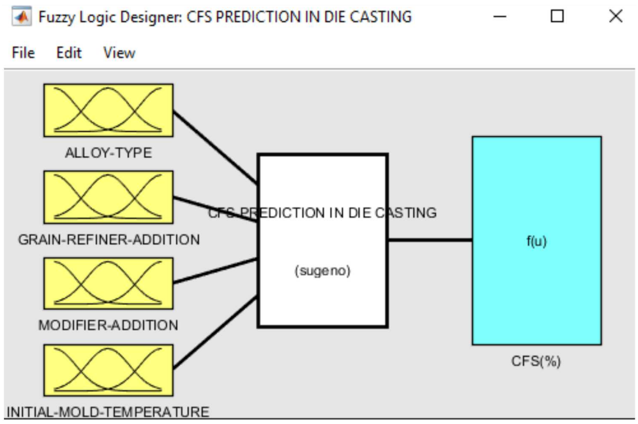

Fig. 2. Developed FES model.

software has been used. Developed model consists of four inputs and one output. Inputs are alloy type, grain refiner addition, modifier addition and initial mold temperature. Output is CFS value. Developed FES model is shown in Fig. 2.

3. Results and discussion

12 new die casting experiments have been determined randomly for testing the prediction performance of developed FES model. These experiments have been carried out and CFS values have been obtained. Obtained experimental CFS values have been crosschecked with the CFS values based on casting simulation software. In addition, developed FES model has given CFS values for these experiments. A sample set of test experiments is shown in Table IV.

TABLE IV

A sample set of test experiments.

Test exp. No.	Alloy type	Grain refiner addition	Modifier addition	Initial mold temp.	CFS [%]	Predict. of CFS [%]
1	A319	Al5Ti1B	—	250 °C	52	53
2	A319	Al5Ti1B	Al10Sr	350 °C	60	60
...	...	...	...	...	...	...
12	AlCu4Si	Al5Ti1B	—	340 °C	52	52

Mean square error (MSE) have been used in order to evaluate the prediction performance of the FES model. MSE are defined as:

$$\mathrm{MSE} = \frac{1}{n}\sum_{t=1}^{n}(A_t - F_t)^2, \tag{1}$$

where A_t is actual data, F_t is forecast at time t and n is the number of samples.

MSE value has been calculated as 0.083. This shows that there is a good agreement between experimental CFS value and estimated CFS value based on FES model.

4. Conclusion

In this study, a FES model have been developed in order to predict the CFS value in die casting process. While predicting the CFS value using developed model, alloy type, grain refiner addition, modifier addition and initial mold temperature parameters have been taken into account. Prediction performance of the FES model has been evaluated by using MSE error type. MSE value of the FES model is 0.083. This value shows that developed FES model predicts CFS value with a performance of 91.67%.

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