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Fuzzy Logic Approach for Magnesium Recovery in the Al-Mg Alloys Produced by Modified Stir Casting Method

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Abstract:
Aluminum-magnesium alloys are generally used in automotive and aerospace engineering due to their lightness and strength. The main goal of this research is to achieve an optimal recovery of magnesium during the production process in liquid form. This method involves a modified swirl casting method where piston rods are used to insert magnesium ingots into an aluminum alloy to produce an alloy. Fuzzy logic techniques are used as part of research to determine the yield of Mg in manufactured alloys using temperature, revolutions per minute (RPM) and magnesium addition rate as input parameters to the fuzzy model. The results of the fuzzy models were compared with the experimental results and found to be in good agreement. During the magnesium addition process, at a given furnace maintenance temperature (FMT) and rpm, the percentage recovery of magnesium in the melt is higher and some losses due to evaporation were observed. Keyword: piston rod; Modified Stir Casting Method; Fuzzy logic, Mg recovery; Al-Mg alloys

Introduction

Light and strong materials are widely used in structural applications and in the manufacture of composites. Al-Mg alloys have more advantages due to their low density, high strength, good manufacturability and better mechanical properties. Traditional methods previously used to produce Al-Mg alloy turned out to be low Mg yields. The loss of magnesium during the process makes it uneconomical and environmentally unfriendly. However, the modified stir casting method facilitates the high recovery of magnesium from molten aluminum to achieve the desired mechanical properties [1-8]. Aluminum and its alloys, especially with magnesium, can be used as a possible substitute for steel due to its high corrosion resistance and special strength for special purposes. The presence of magnesium in the aluminum alloy improves strength and reduces the density of the alloy. Magnesium is significantly lost due to its lower density and high volatility when added directly to molten aluminum. However, in a modified alloy casting method, a higher mass of magnesium can be added and retained in the production of an Al-Mg alloy using inexpensive magnesium scrap [9–15].Abdel Kader [16] developed a model for Mg assessment and showed the integration of economic and non-economic factors into these assessments. He also showed that analytic hierarchical process mathematics and fuzzy set theory are conceptually possible. Yadav et al. [17] used the fuzzy inference method to combine and quantify subjective information to map the effect of the fuzzy inference process on the product and the sharp result. It dealt with reliability assessment by integrating failure physics models with classical statistical methods. Daws et al. [18] argued that fuzzy logic (FL) is more suitable for a cast product process selection methodology because the capability of each process varies from foundry and process characteristics also depend on equipment, labor skills, quality management practices, and other company-dependent factors received by the system.

Experimental Procedure for production of Al-Mg alloys

A novel procedure was developed for Al-Mg alloys preparation by using modified stir casting method as shown in Figures 1 and 2. A hollow stirrer pipe imbedded in the machine had been used to accommodate the plunger rod. The one end of the plunger rod shown in Figure 3 was designed to store magnesium turnings and was covered with aluminium foil (Figure 4). The first step was done in the experimental procedure for addition of magnesium turnings into molten aluminium [1,2]. A required quantity of commercially available aluminium was melted in a crucible placed inside a resistance furnace with maintaining different furnace maintenance temperatures of 700 °C, 800 °C and 900 °C. By using a stirrer mechanism, it was rotated at 500 RPM when the stirrer assembly is lowered into the crucible along with the attached plunger rod. The magnesium turnings with varying magnesium percentage were added in a step-by-step manner. Then crucible was removed and the prepared alloy was put into different moulds. The Al-Mg alloys of different compositions were cut into required sizes for analysis. Tables 1–3 show a mass percentage of magnesium added and percentage recovery of magnesium in the Al-Mg alloys at different furnace maintenance temperatures (FMT) at a fixed stirrer RPM.

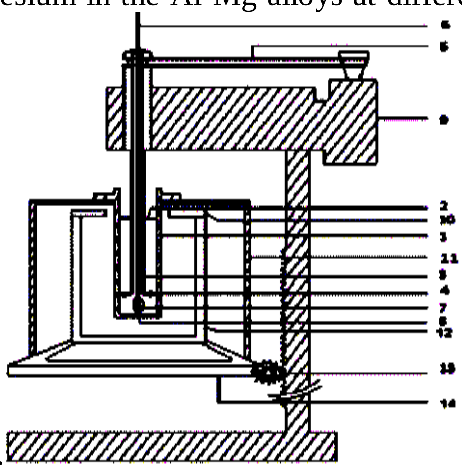

Figure 1: Schematic diagram of modified stir Casting apparatus

Figure 2: Plunger rod for magnesium

Figure 3: Experimental setup for Al-Mg alloy preparation

Figure 4: Plunger rod containing magnesium wrapped with aluminium foil

1. Application of fuzzy approach for evaluation of percentage of magnesium recovery

For the proposed fuzzy model, the percentage of magnesium addition were considered as input parameters at different furnace maintenance temperatures with a fixed RPM and the percentage of magnesium recovery as output parameters. The fuzzy inference system changes the crisp inputs to output crisp values by mapping. The input and output fuzzy operators i.e., fuzzifier and defuzzifier indicated the membership functions. The fuzzification process converts the input crisp values into input fuzzy sets through its input membership functions. In the present analysis, trapezoidal membership function shown in Figure 5 has been used for the analysis. The fuzzy inference engine was mapped for each element in the fuzzy input sets with each base rule to evaluate its degree of association. The fuzzy inference system in Figure 6 was formulated the output set by aggregating the output from base rule of fuzzy output sets through its output membership functions. The defuzzification process was converted to output fuzzy set into crisps output as percentage of magnesium recovery (Figure 7).

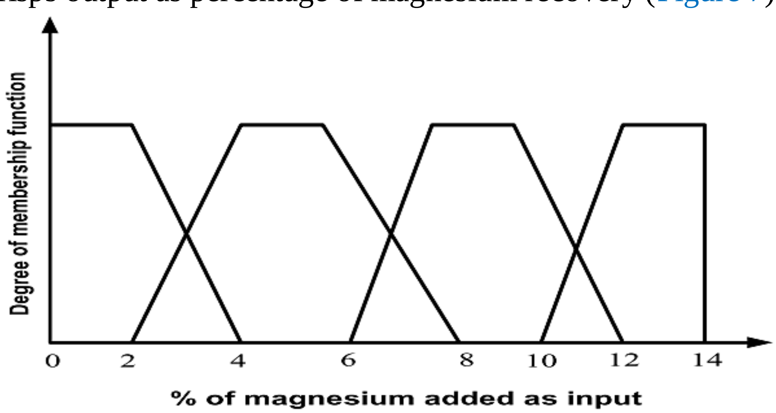

Figure 5: Trapezoidal membership functions with input as percentage of magnesium

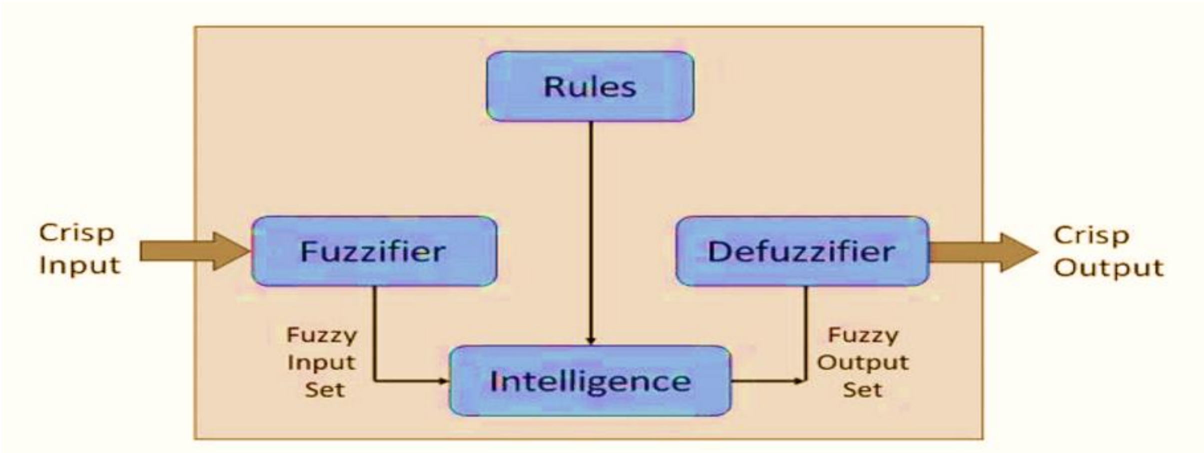

Figure 6: Fuzzy inference system

2. Comparative results of experimental and fuzzy analysis

Experiments are conducted with variation of magnesium addition and magnesium recovery Table 1-3 and Figure 7 shows the variation of magnesium recovery with magnesium addition.

Table 1: Percentage of magnesium recovery in the aluminium alloy for different percentage of magnesium added at FMT = 700 °C, RPM = 500

No. of Observations	Percentage of Magnesium added	Percentage of magnesium recovery in the aluminium alloy Experimental
1	1	0.98
2	2	1.93
3	3	2.88
4	4	3.76
5	5	4.62
6	6	5.46
7	7	6.34

Table 2: Percentage of magnesium recovery in the aluminium alloy for different percentage of magnesium added at FMT = 800 °C, RPM = 500

No. of Observations	Percentage of Magnesium added	Percentage of magnesium recovery in the aluminium alloy Experimental
1	1	0.99
2	2	1.94
3	3	2.89
4	4	3.79
5	5	4.71
6	6	5.52
7	7	6.42

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Table 3: Percentage of magnesium recovery in the aluminium alloy for different percentage of magnesium added at FMT = 900 °C, RPM = 500

No. of Observations	Percentage of Magnesium added	Percentage of magnesium recovery in the aluminium alloy Experimental
1	1	0.97
2	2	1.92
3	3	2.86
4	4	3.74
5	5	4.59
6	6	5.38
7	7	6.28

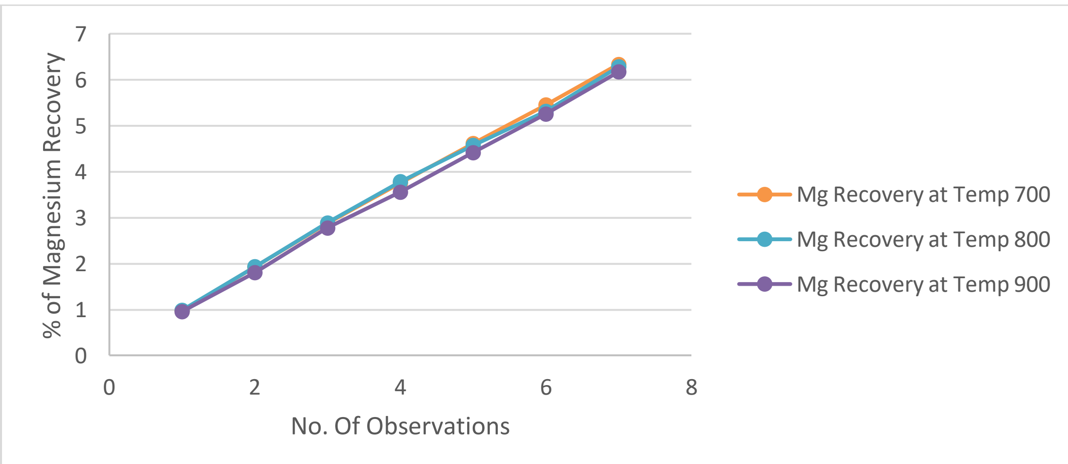

Figure 7: Percentage of magnesium recovery vs Percentage of magnesium addition

Fuzzy logic is used to assess the Mg recovery in the Al-Mg alloys. The fuzzy inference engine maps each element of the fuzzy input set to each rule-based rule to produce the fuzzy output set.

Here MR = Magnesium Recovery, N= RPM, FMT= Furnace Maintenance Temperature, Mg_a=% of Mg added.

Table 4: Fuzzy Rules

Sl. No	Rule Box	
1.	If Mg_a= 1, N=500, FMT=700^0C	Then 0.97<MR<0.99
2.	If Mg_a= 2, N=500, FMT=700^0C	Then 1.92<MR<1.94
3.	If Mg_a= 3, N=500, FMT=700^0C	Then 2.87<MR<2.89
4.	If Mg_a= 4, N=500, FMT=700^0C	Then 3.78<MR<3.80
5.	If Mg_a= 5, N=500, FMT=700^0C	Then 4.61<MR<4.63
6.	If Mg_a= 6, N=500, FMT=700^0C	Then 5.45<MR<5.47
7.	If Mg_a= 7, N=500, FMT=700^0C	Then 6.33<MR<6.35

8.	If Mg_a= 1, N=500, FMT=800^{0}C	Then 0.98<MR<1.00
9.	If Mg_a= 2, N=500, FMT=800^{0}C	Then 1.93<MR<1.95
10.	If Mg_a= 3, N=500, FMT=800^{0}C	Then 2.88<MR<2.90
11.	If Mg_a= 4, N=500, FMT=800^{0}C	Then 3.78<MR<3.80
12.	If Mg_a= 5, N=500, FMT=800^{0}C	Then 4.70<MR<4.72
13.	If Mg_a= 6, N=500, FMT=800^{0}C	Then 5.51<MR<5.53
14.	If Mg_a= 7, N=500, FMT=800^{0}C	Then 6.41<MR<6.43
15.	If Mg_a= 1, N=500, FMT=900^{0}C	Then 0.96<MR<0.98
16.	If Mg_a= 2, N=500, FMT=900^{0}C	Then 1.91<MR<1.93
17.	If Mg_a= 3, N=500, FMT=900^{0}C	Then 2.85<MR<2.87
18.	If Mg_a= 4, N=500, FMT=900^{0}C	Then 3.73<MR<3.75
19.	If Mg_a= 5, N=500, FMT=900^{0}C	Then 4.58<MR<4.60
20.	If Mg_a= 6, N=500, FMT=900^{0}C	Then 5.37<MR<5.39
21.	If Mg_a= 7, N=500, FMT=900^{0}C	Then 6.27<MR<6.29

In the following Tables 5-7, the percentages of magnesium recovery in the aluminium-magnesium alloy were presented both in experimental and fuzzy analysis. Using Fuzzy rules, the percentage deviation of fuzzy results from experimental results were calculated (Figure 8-10).

Table 5: Percentage deviation of fuzzy results from experimental results; Here N=500, FMT=700^{0}C

Experiment No.	% of Mg added	Magnesium Recovery		Deviation $\delta = \frac{E\_F}{E} \times 100$
		Experimental (E)	Fuzzy (F)	
1	1.5	1.47	1.412	3.946
2	2.5	2.38	2.285	3.992
3	3.5	2.82	2.686	4.752
4	4.5	4.12	3.96	3.883
5	5.5	4.94	4.742	4.008
6	6.5	5.96	5.723	3.977

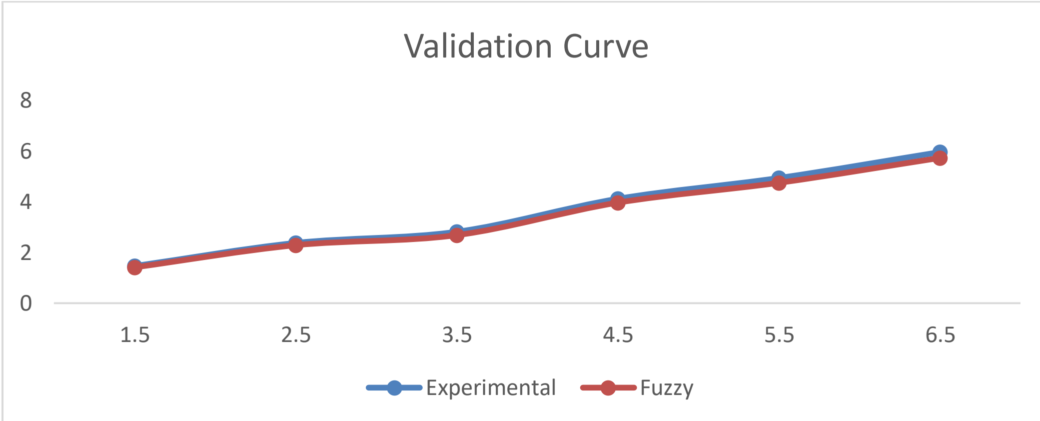

Figure 8: Percentage deviation of fuzzy results from experimental results at FMT=700^{0}C, RPM=500

Table 6: Percentage deviation of fuzzy results from experimental results; Here N=500, FMT=800^{0}C

Experiment No.	% Of Mg added	Magnesium Recovery		Deviation $\delta = \frac{E\_F}{E} \times 100$
		Experimental (E)	Fuzzy (F)	
1	1.5	1.492	1.432	4.021
2	2.5	2.39	2.294	4.017
3	3.5	3.31	3.178	3.988
4	4.5	3.87	3.691	4.625
5	5.5	4.96	4.762	3.992
6	6.5	5.77	5.541	3.969

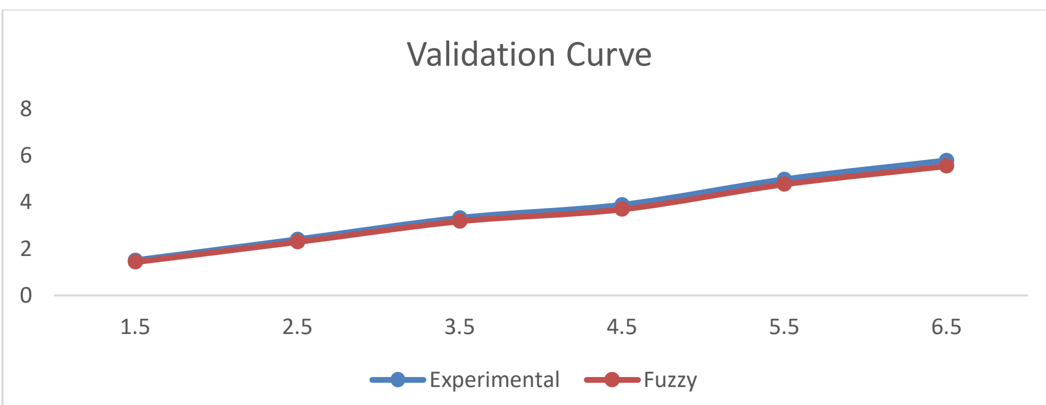

Figure 9: Percentage deviation of fuzzy results from experimental results at FMT=800^{0}C, RPM=500

Table 7: Percentage deviation of fuzzy results from experimental results; Here N=500, FMT=900^{0}C

Experiment No.	% Of Mg added	Magnesium Recovery		Deviation $\delta = \frac{E\_F}{E} \times 100$
		Experimental (E)	Fuzzy (F)	
1	1.5	1.44	1.382	4.028

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2	2.5	2.38	2.285	3.992
3	3.5	2.98	2.851	4.329
4	4.5	4.12	3.956	3.981
5	5.5	4.95	4.752	4.000
6	6.5	5.78	5.549	3.997

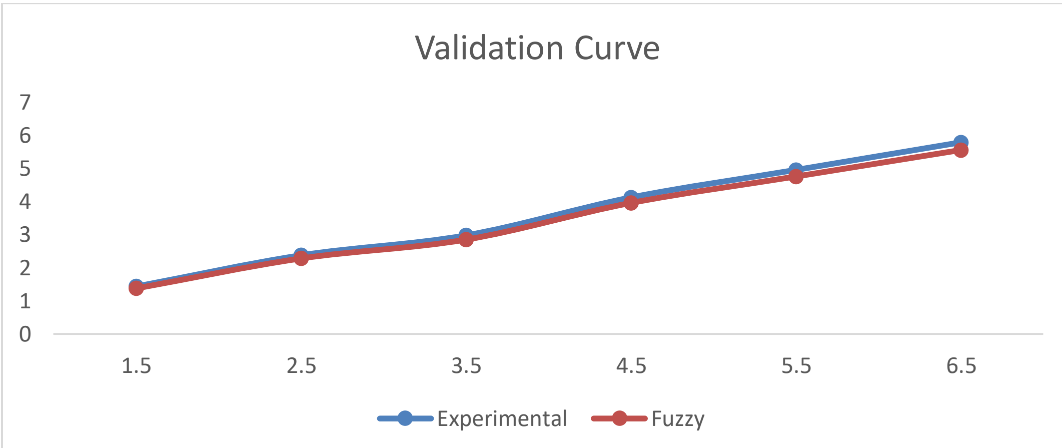

Figure 10: Percentage deviation of fuzzy results from experimental results at FMT=900^{0}C, RPM=500

3. Conclusions

A systematic experimental analysis has been carried out to investigate the percentage of magnesium recovery in aluminium-magnesium alloys. The alloys are produced by considering the different input parameters like furnace temperature, rpm and percentage of magnesium added. The study reveals that the maximum magnesium percentage recovery in the alloy is observed in 800 °C at 500 RPM. This is due to the higher furnace maintenance temperature and given RPM. The percentage Mg recovery in the alloy falls due to evaporation of magnesium during the magnesium addition process. Further, a fuzzy logic model has been developed to investigate the robustness of experimental investigations. It has been concluded that the result obtained using fuzzy model is in good agreement with that of experimental results and percentage deviation falls within 5%.

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