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Comparison of porosity and density for $(A384.1)_{1-x}$ $[(Reinforcement)_p]_x$ MMC system using Adaptive Neuro-Fuzzy Inference system

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ABSTRACT

In the present work, the reinforced MMC's of Al/Al alloy-SiC system, with nominal composition $(A384.1)_{1-x}[(SiC)_p]_x$ were fabricated by using A384.1 Al Alloy as matrix and SiC with 0.220, 0.106 and 0.053 µm particle sizes as reinforcement in varying amounts. It is clear that with the change in particle size and %age of doping of reinforcement in Al Alloy matrix, the change in values of density and Porosity is registered. The overall maximum values of density is registered as 2490 gm/cm^3 when the value of x= 0.08 and the particle size is 0.106 as compare to all other values of the MMCs for different values of 'x'. Accordingly, the overall maximum values of porosity is registered as 3.25 when the value of x= 0.10 and the particle size is 0.0.53 as compare to all other values of the MMCs for different values of 'x'. So, the density and porosity of the reinforced MMCs is more as compare to unreinforced Al alloys. Then fuzzy model of the system is developed using adaptive neuro-fuzzy inference system (ANFIS), for carrying out for density and porosity of the MMCs. Performance is evaluated by comparing experimental data with fuzzy model and good correlation is achieved between them.

Keywords: Al Alloys, Metal matrix Composites, Porosity and Density, Fuzzy Logic, ANFIS etc.

INTRODUCTION

Aluminum (Al) is an important engineering materials being used in a number of engineering applications. It is the most abundant metal in nature around 8% by weight of the earth's crust. Al is a good electrical and thermal conductor with Face-Centered Cubic structure. It has good formability and corrosion resistance, etc. and can be readily casted and machined. It is capable of forming alloys with other metals in liquid state, but solid solubility of alloying elements is typically only up to a few percent. In some cases inter-metallic compounds are formed and become a part of the structure of the Al alloy. No element is completely soluble in Al in the solid state[1-2]. The alloy of Al are made to control the physical properties, formability and strengthening of the metal. In order to have a control on aging effect and also to ensure the desired strength ductility balance, a number of reinforcements/inclusions, such as Alumina, Magnesia, Silica, Aluminum Carbide, Silicon Carbide, Aluminum Nitride, fly ash etc. can also be added to Al and Al alloy systems, forming a metal matrix composite microstructure.

The Metal Matrix Composites (MMC), in general, consist of continuous or discontinuous fibers, whiskers or particulates dispersed in a metallic alloy matrix. These reinforcements provide the composite with the properties not achievable in monolithic alloys[3]. Desired improvements in properties including specific strength and modulus, toughness, fatigue, creep, electrical, thermal properties and wear resistance can be achieved by intelligently selecting the reinforcement materials, their size, shape and volume fraction. It is fully established now that MMC's provide a better combination of specific strength and modulus compared to monolithic alloys like aluminum, magnesium, copper, nickel, and steel. There are only a very few materials that are better than reinforced aluminum composites. These include graphite epoxy (along the fiber direction), pure ceramics or diamond but these are much more expensive, anisotropic and very brittle. The specific cost of organic composites is much higher than metal matrix composites for similar specific stiffness. The wear loss of the composite is about 10 times less than that of the matrix alloy. The wear resistance of Aluminum composites is better than that of the Cast Irons that are much heavier[4].

The most commonly used and economically viable techniques for fabrication of MMC's are solidification processing and stir casting. Another important technique used for the purpose, is infiltration of liquid metal through narrow crevices between fibers or particulate reinforcements that are arranged in a perform. In solidification processing liquid metal is combined with the reinforcement phase and solidified in a mold, however in stir casting the molten metal is stirred with the help of either a mechanical stirrer or high intensity ultrasonic waves. This action disperses the reinforcing phase, which is added to the surface of the melt in the molten metal and solidifies the composite melt, containing reinforcements suspended in the melt. Stir mixing and Casting is now used for large-scale production of Metal Matrix Particulate Composites. Various metals such as Al, Mg, Ni, and Cu have been used as the matrix and a wide variety of reinforcements like SiC, graphite, SiO_2, Si_3O_4, Al_2O_3 and $ZrSiO_4$, have been used as reinforcements in available literature using the aforesaid techniques[5-6].

MATERIALS AND METHODS

Keeping in view the above mentioned study, the present research work mainly concentrated on the following: We have evaluated a number of methods reported in literature for fabricating Al alloys composites but due to high cost of manufacturing many of them have limited use. Melt stir casting technique is found to be the simplest and most economical fabrication method for these materials. In earlier studies, stirring of the melt has been done in open air or using a furnace having provision to create an inert environment. A simple modification of the conventional technique as proposed by Surappa & Rohatgi [4] [7] leads to remarkable improvement in this method. Besides the other components required in the technique, we have an additional steel cover fitted with glass wool lining to make an inert atmosphere in order to prevent reaction of aluminum with environmental gases. The A384.1 Al alloy is used as the matrix and the reinforcement of SiC with grain sizes of 0.220, 0.106 and 0.053 µm had been used with varying contents (x=0 to x=10). The grain size was determined using Sigma Scanpro Image Analyser^{TM}.

In order to fabricate the MMC samples, base Al alloy A384.1 was melted in an alumina crucible in furnace up to 810^{o}C. The steel cover of the setup was then removed to add the preheated (810^{o}C) reinforced particles of SiC in the melt. A protective atmosphere was maintained during stirring by holding a pipe carrying inert gas over the melt. After the addition and through mixing, the metal matrix composites were fabricated by pouring the melt-mix into a die. The un-reinforced and reinforced casted materials were then subjected to hot extrusion described above. Hot extruded composites of 10 mm diameter bars were then heat treated at 400^{0}C for 3 hours in the furnace. In order to further investigate the effect of aging, the extruded MMC's were then pyroprocessed as per the pre-decided schedule of aging treatment. For structural, micro-structural and mechanical characterization the sample preparation was done first by polishing the sliced samples with emery paper up to 1200 grit size, followed by polishing with SiC suspension on a grinding machine using velvet cloth. Finally, the samples were polished with 0.5 µm diamond paste.

The densities of the samples have been determined by standard Archimede's principle. The porosity has been determined by knowing the difference between the theoretical and measured densities. Mechanical Properties like hardness, tensile strength, compressive strength etc. had also been determined [8-9].

Porosity and density

In the present work, the reinforced MMC's of Al/Al alloy-SiC system, with nominal composition $(A384.1)_{1-x}[(SiC)_p]_x$ were fabricated by using A384.1 Al Alloy as matrix and SiC with 0.220, 0.106 and 0.053 µm particle sizes as reinforcement in varying amounts. The composites reinforced with x=0.10 SiC with an average size of grain sizes of 0.220, 0.106 and 0.053µm had considerably lower porosity contents, good strength and increased ductility in comparison with the as-cast samples.

From Table 1, it is clear that with the change in particle size and %age of doping of reinforcement in Al Alloy matrix, the change in values of density and Porosity is registered. It is clear that change in density (gm/cm^3) for values of 'x' (0.0, 0.05, and 0.10 respectively) are observed as 2380, 2421 and 2460 for SiC 0.220. The 1.0172 %, 1.033% changes in the values of density from unreinforced conditions to reinforced conditions at x= 0.05 and 0.10 is observed. The overall maximum values of density is registered as 2490 gm/cm^3 when the value of x= 0.08 and the particle size is 0.106 as compare to all other values of the MMCs for different values of 'x'. The density of the reinforced MMCs is more as compare to unreinforced Al alloys.

Accordingly, It is also clear that change in porosity for values of 'x' (0.0, 0.05, 0.10 respectively) is observed as 2.01, 3.0 and 3.4 . The 1.492 %, 1.691% changes in the values of porosity from unreinforced conditions to reinforced conditions at x= 0.05 and 0.10 is observed. The density of the reinforced MMCs is more as compare to unreinforced Al alloys. The overall maximum values of porosity is registered as 3.25 when the value of x= 0.10 and the particle size is 0.0.53 as compare to all other values of the MMCs for different values of 'x'. So, the porosity of the reinforced MMCs is more as compare to unreinforced Al alloys.

Table 1, Doping of reinforcement with SiC with varying particle size and varying %age (for porosity and density)

	SiC 0.220		SiC 0.106		SiC 0.053	
	Density *gm/cm^3*	porosity	Density *gm/cm^3*	Porosity	Density *gm/cm^3*	porosity
0.0	2380	2.01	2380	2.01	2380	2.01
0.05	2421	3.0	2440	3.19	2453	3.15
0.06	2424	2.99	2433	3.1	2424	3.16
0.07	2451	3.2	2455	2.80	2460	3.2
0.08	2462	3.1	2490	3.4	2467	3.22
0.09	2466	3.15	2467	3.1	2473	3.30
0.10	2460	3.4	2484	3.12	2473	3.25

FUZZY MODELING

The modeling of the system has been done using adaptive neuro fuzzy inference system (ANFIS) [10-12] by considering the input parameters; varying particle size & percentage of doping and output as Porosity as shown in Table 2. This technique provides procedure to learn information about a data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data. Figure 1, shows fuzzy model of the generator. ANFIS without sub cluster is shown in figure 2. Figures 3 & 4, show various membership functions of 'Varying particle size' and 'percentage of doping' for the model. Figure 5, indicates the output membership function of 'Porosity'.

Table 2, values of porosity, density with respect to variation in particle size and percentage of doping for developing different ANFIS models with and without clustering

Particle Size of reinforcement	% age of Doping	Density	Porosity
0.53	0.05	2453	3.15
0.53	0.06	2424	3.16
0.53	0.07	2460	3.2
0.53	0.08	2467	3.22
0.53	0.09	2473	3.3
0.53	0.10	2473	3.25
0.106	0.05	2440	3.19
0.106	0.06	2433	3.1
0.106	0.07	2455	2.8
0.106	0.08	2490	3.4
0.106	0.09	2467	3.1
0.106	0.10	2484	3.12
0.220	0.05	2421	3
0.220	0.06	2424	2.99
0.220	0.07	2451	3.2
0.220	0.08	2462	3.1
0.220	0.09	2466	3.15
0.220	0.10	2460	3.4

Here the model makes use of eighteen rules. Set of linguistic rules for fuzzy model without sub clustering are given below in Table 3:

Table 3, Set of linguistic rules	
1.	If (input1 is in1mf1) and (input2 is in2mf1) then (output is outmf1)(1)
2.	If (input1 is in1mf1) and (input2 is in2mf2) then (output is outmf2)(1)
3.	If (input1 is in1mf1) and (input2 is in2mf3) then (output is outmf3)(1)
4.	If (input1 is in1mf1) and (input2 is in2mf4) then (output is outmf4)(1)
5.	If (input1 is in1mf1) and (input2 is in2mf5) then (output is outmf5)(1)
6.	If (input1 is in1mf1) and (input2 is in2mf6) then (output is outmf6)(1)
7.	If (input1 is in1mf2) and (input2 is in2mf1) then (output is outmf7)(1)
8.	If (input1 is in1mf2) and (input2 is in2mf2) then (output is outmf8)(1)
9.	If (input1 is in1mf2) and (input2 is in2mf3) then (output is outmf9)(1)
10.	If (input1 is in1mf2) and (input2 is in2mf4) then (output is outmf10)(1)
11.	If (input1 is in1mf2) and (input2 is in2mf5)then (output is outmf11)(1)
12.	If (input1 is in1mf2) and (input2 is in2mf6) then (output is outmf12)(1)
13.	If (input1 is in1mf3) and (input2 is in2mf1) then (output is outmf13)(1)
14.	If (input1 is in1mf3) and (input2 is in2mf2) then (output is outmf14)(1)
15.	If (input1 is in1mf3) and (input2 is in2mf3) then (output is outmf15)(1)
16.	If (input1 is in1mf3) and (input2 is in2mf4) then (output is outmf16)(1)
17.	If (input1 is in1mf3) and (input2 is in2mf5) then (output is outmf17)(1)
18.	If (input1 is in1mf3) and (input2 is in2mf6) then (output is outmf18)(1)

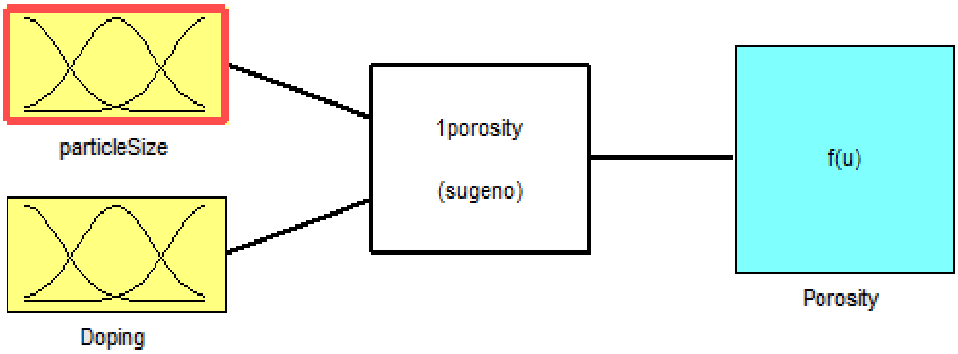

Figure 1, Fuzzy model of the generator for porosity

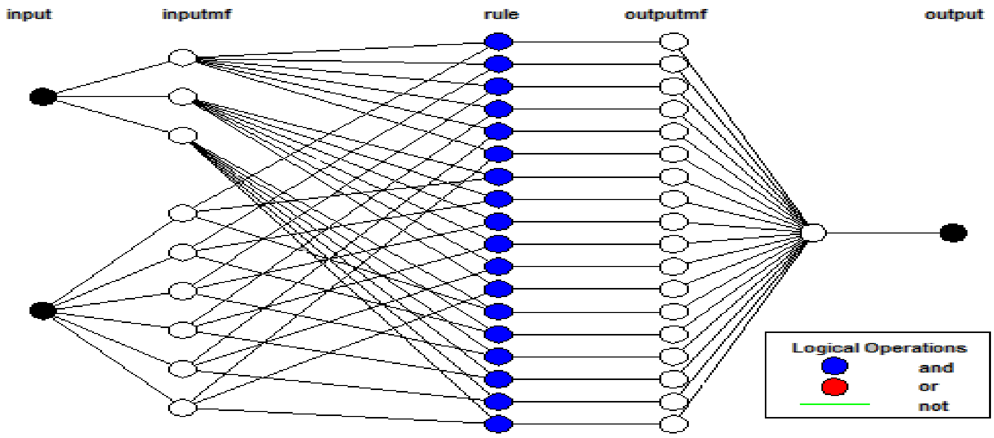

Figure 2, Anfis Model Structure without sub-clustering for Porosity

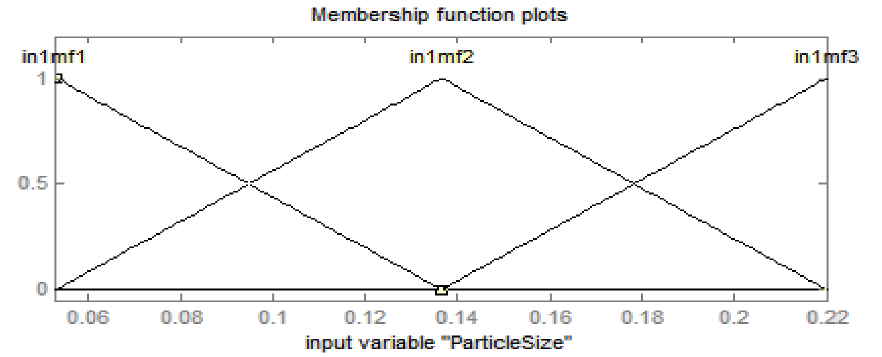

Figure 3, Input variables Particle Size vary from 0.06-0.220 for Porosity

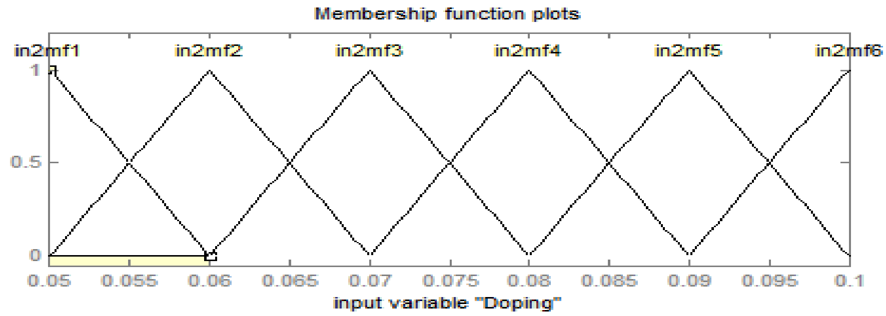

Figure 4, Input variables i.e. change in doping for 'x' for Porosity

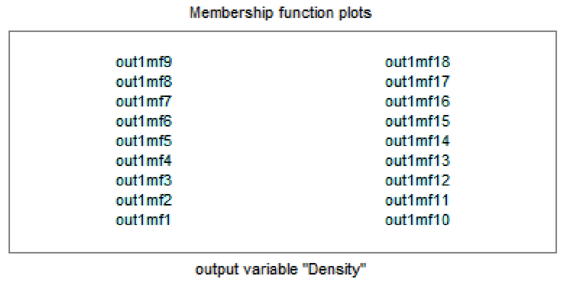

Figure 5, Output variables for Porosity

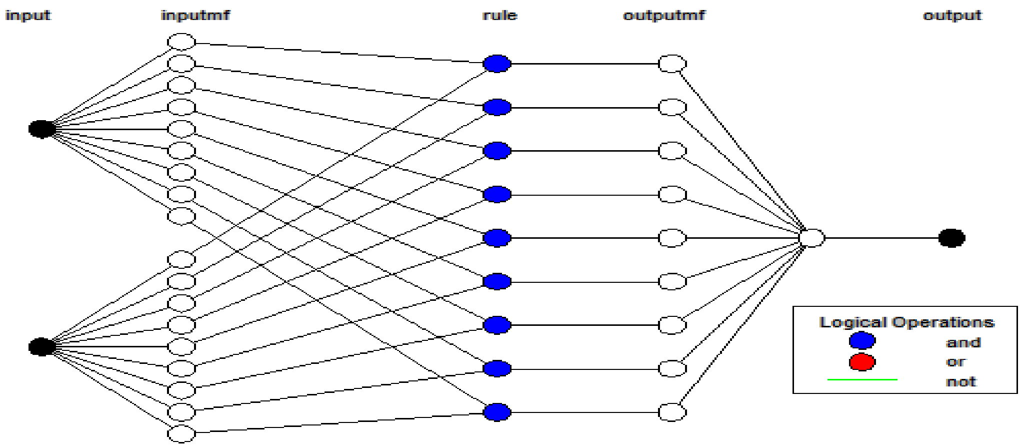

Figure 6, Anfis Model Structure with sub-clustering for Porosity

Figure 6, shows the ANFIS with sub-clustering for the values of porosity corresponding to the values of particle size and doping. Set of linguistic rules for fuzzy model with sub-clustering are given below in Table 4.

Table 4, Set of linguistic rules

1.	If (In1 is in1cluster1) and (In2 is in2cluster1) then (0ut1 is out1cluster1)(1)
2.	If (In1 is in1cluster2) and (In2 is in2cluster2) then (0ut1 is out1cluster2)(1)
3.	If (In1 is in1cluster3) and (In2 is in2cluster3) then (0ut1 is out1cluster3)(1)
4.	If (In1 is in1cluster4) and (In2 is in2cluster4) then (0ut1 is out1cluster4)(1)
5.	If (In1 is in1cluster5) and (In2 is in2cluster5) then (0ut1 is out1cluster5)(1)
6.	If (In1 is in1cluster6) and (In2 is in2cluster6) then (0ut1 is out1cluster6)(1)
7.	If (In1 is in1cluster7) and (In2 is in2cluster7) then (0ut1 is out1cluster7)(1)
8.	If (In1 is in1cluster8) and (In2 is in2cluster8) then (0ut1 is out1cluster8)(1)
9.	If (In1 is in1cluster9) and (In2 is in2cluster9) then (0ut1 is out1cluster9)(1)

To study variation of density for various positions with respect to particle size and doping as input variables were chosen and output as Density. Figures7 & 8, show various membership functions of ‘particle size’ and ‘percentage doping’. Percentage of the doping and variation in particle size will simultaneously used to know the value of density as membership function output in Figure 9. Here the model makes use of nine rules. Set of linguistic rules for fuzzy model without sub clustering are given below:

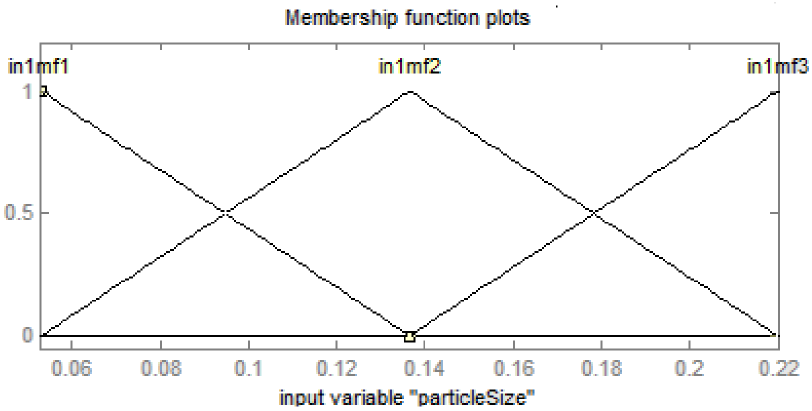

Figure 7, input variables for membership functions

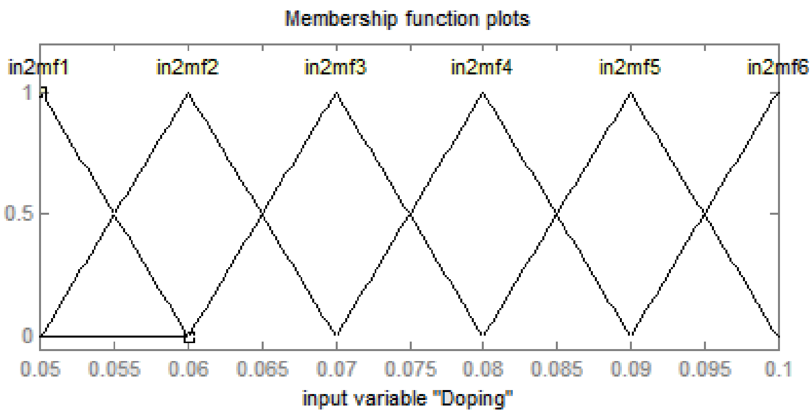

Figure 8, input variables for membership function of doping

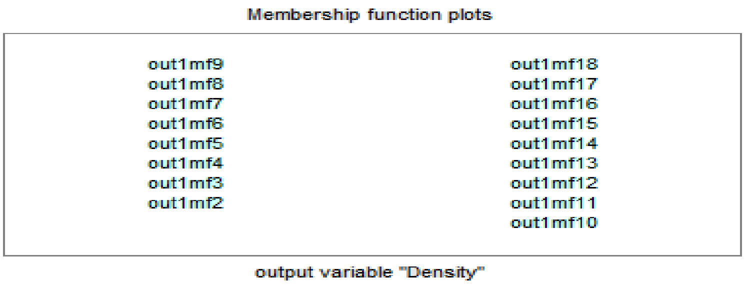

Figure 9, output membership function for Density

RESULTS AND DISCUSSION

The computed values of density and porosity for various particle sizes and doping percentages are shown in Table1 and their plot is shown in figure 10a & 10b. From the Figure 10a, it is shown that for x= 0.05, the values of density are maximum for SiC 0.053 composite because of bigger particle size, nasalization growth was fast and the values of all the composites were drastically have a sharp fall for x=0.06 because of small clusters were developed, due to which weak bond in between the particles of the reinforcement and the matrix registered. But for x=0.08, the density has maximum value as compare to other composites. The plot shows that the value of density increases with increased value of doping and change in particle size. It is observed from the graph that SiC 0.106 based reinforced MMC has better density as compare to other MMCs of its category i.e. SiC0.53 and SiC 0.220.

From the Figure 10b, it is observed that for x= 0.05, the values of porosity are maximum for SiC 0.106 composite because of fast nasalization growth. A steady increase in values of porosity is observed in SiC0.53 MMC, while there is a sharp fall in the value of porosity in the case of SiC0.106. the MMCs with the value of x=0.10 for SiC 0.220 registered more porosity as compare to other MMCs. The reason is, when the particle size decreases, the possibility of cluster formation is more and this may be because of escape of gases present in the solution during solidification. The plot shows that the value of porosity increases with decrease in particle size and increase in doping. It is observed from the graph that SiC 0.220 based reinforced MMC is more porous as compare to other MMCs of its category i.e. SiC0.53 and SiC 0.106.

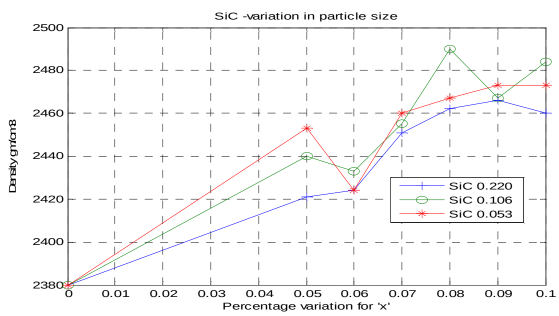

Figure 10.a

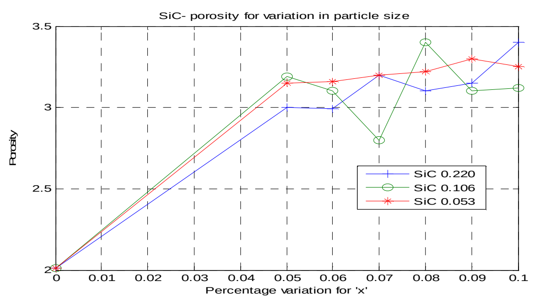

Figure 10.b.

Figure 11a, shows the rule viewer for the generator without sub-clustering for a particular case when particle size is 0.137, doping = 0.075 for which output i.e. density is 2480 gm/cm^3, which is very near to the value 2484 gm/cm^3(for SiC0.106 , x=0.10) obtained by experimental results, given in Table1. Figure 12a, shows the control surface representation for density without clustering.

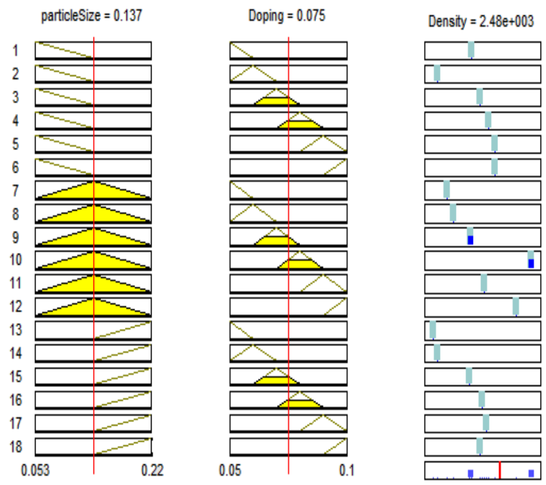

Figure 11a, rules viewer for density without sub-clustering

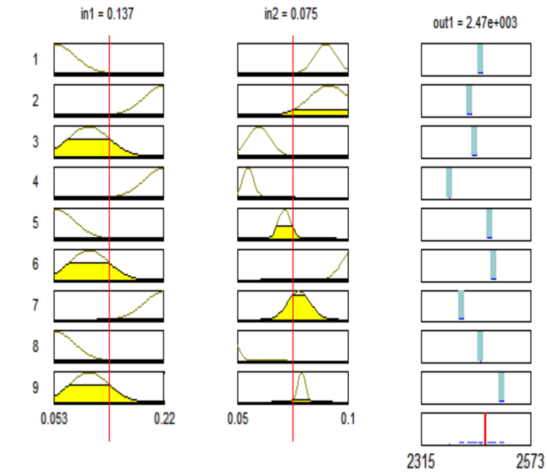

Figure 11b, rules viewer for density with sub-clustering

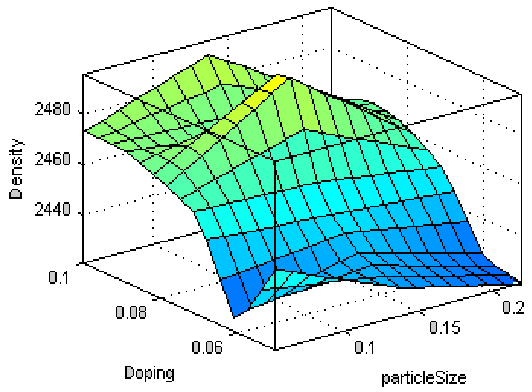

Figure 12a, surface representation for density without clustering

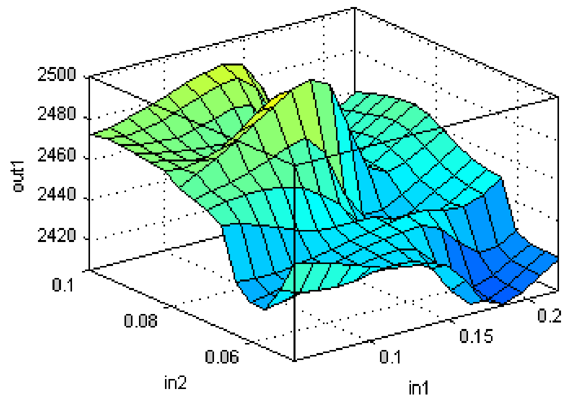

Figure 12b, surface representation for density with clustering

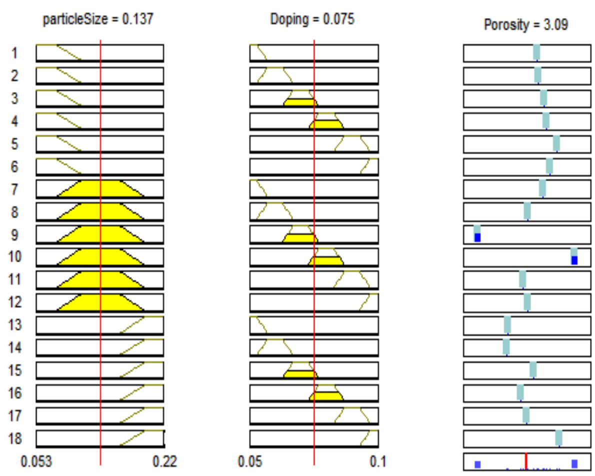

Figure 13a, Rules viewer with sub clustering for Porosity

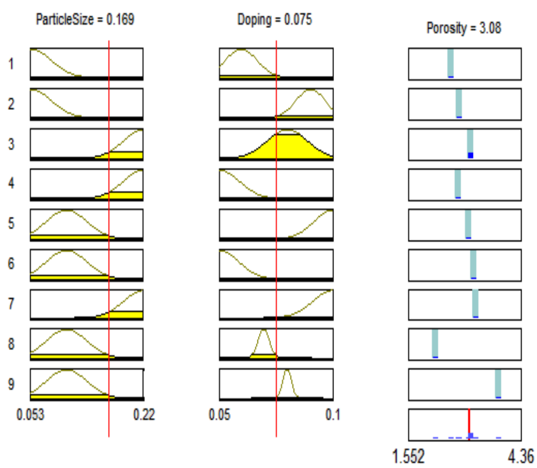

Figure 13b, Rules viewer with sub clustering for Porosity

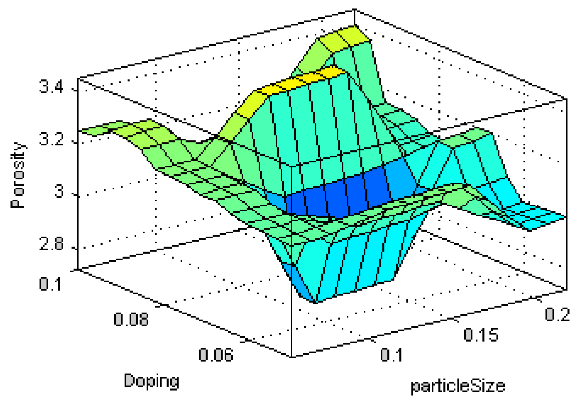

Figure14a, Surface representation for Porosity without sub clustering

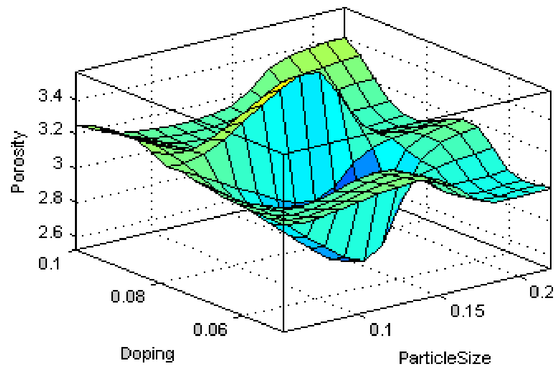

Figure14b, Surface representation for Porosity with sub clustering

Rule viewers for the generator with sub-clustering for a particular case when particle size 0.137, value of x= 0.075 is shown in figure 11b. The output density for this case is 2470, which is very near to the value of 2473 obtained by experiments (for particle size 0.54, x= 0.09 & 0.10), given in Table1. Figure 12b, shows control surface of density for various positions with sub-clustering.

CONCLUSION

1. The computed values of density and porosity for various particle sizes and doping percentages were obtained.
2. It is observed that SiC 0.106 based reinforced MMC has better density as compare to other MMCs of its category i.e. SiC0.53 and SiC 0.220.
3. It is also observed that SiC 0.220 based reinforced MMC is more porous as compare to other MMCs of its category i.e. SiC0.53 and SiC 0.106.
4. This paper presents a comparison in the experimental data with the results obtained from ANFIS fuzzy model. The experimental results obtained are quite comparable with the well established fuzzy models.

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