INFLUENCE OF REINFORCEMENT PARAMETERS ON THERMAL CONDUCTIVITY OF LM6 ALLOY/SODA LIME GLASS COMPOSITES THROUGH TAGUCHI'S ORTHOGONAL ARRAY APPROACH

M R Shivakumar[1], NVR Naidu[2]

[1]*Assistant Professor, Department of Industrial Engineering and Management*
[2]*Professor and Principal, M S Ramaiah Institute of Technology, Bangalore, India*

Abstract

Metal Matrix Composites (MMCs) are an important class of composite materials which provide as alternate substitute for conventional materials, when desired properties are necessary for the applications. Aluminium alloy composites find applications where high strength to weight ratio is mandated. This work aims to characterize the thermal properties like thermal conductivity of LM6 aluminium alloy/glass powder composite developed by stir casting techniques. The effect of glass powder parameters is aimed at characterization on the developed composites. Taguchi's orthogonal array approach is adopted to reduce the experimentation burden. Parameter levels of glass powder are optimized for the desired thermal conductivity of the composite.

Keywords- *MMC, LM6 alloy, glass powder, Taguchi's orthogonal array, thermal conductivity.*

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1. INTRODUCTION

Automotive industries demand novel materials to improve the efficiency of the product and obtain cost savings so as to gain frequently changing market. The composite development is one of the solutions to meet these requirements. In particular, light weight MMCs are in front line among other categories of composites [1].

Light alloys (viz. aluminium and magnesium) have always been the first choice when weight reduction is mandated. However, these materials suffer from the limitations of low thermal stability, poor thermal and mechanical properties, and wear resistance [2].

Thermal characteristics are mandatory for designing components which are exposed to temperature sensitive environment. The temperature change causes internal stresses in the composite. Thermal conductivity is the heat conduction ability of material. High thermal conductivity is favorable for thermal management equipment [3]. To achieve a desired property in developed composites, other properties of the composite may become slump. To gain the required properties in MMCs, controlled amount of reinforcement is added to the base metal matrix. Selection of the reinforcement and matrix materials is a challenge for the researchers or designers [4].

In the literature, extensive research has been carried out on aluminium based MMCs with ceramics such as silicon carbide, alumina, zirconia, silica and graphite as reinforcement. The literature disclosing that a property of a composite does not solely depend on the material of the composite, but also on the processing and reinforcement parameters. A number of material combinations have been attempted and documented in the literature for the range of applications [5].

To minimize the experimentation efforts (in terms of time, cost and facility), Design Of Experiment (DOE) methodology is highly helpful to the researchers.

2. EXPERIMENTAL DETAILS

2.1 Materials

Among all other aluminium alloys, Al-Si eutectic alloy (LM6) has lower melting temperature. This alloy is easy to cast and has reliable machining characteristics. Most of the automotive components are made by LM6 alloy. LM6 has not been exploited to very great extent. Compared to other reinforcing materials soda lime glass offers several advantages, in particular on the fronts of availability and cost. LM6 alloy was the matrix material and soda lime glass powder was added as the reinforcement. The soda lime glass powder was prepared by crushing the commercially available glass sheets. The glass powder was graded according to its fineness with standard sieves. The chemical compositions of LM6 and soda lime materials are shown in the Tables 1 and 2.

Table 1: Chemical composition of LM6 matrix

element	Si	Cu	Mg	Fe	Mn	Ti	Al
Wt.%	10-13	<0.1	<0.1	<0.6	<0.5	<0.2	balance

Table 2: Chemical composition commercial soda lime glass

element	SiO_2	Na_2O_2	CaO	MgO	Al_2O_3
Wt%	71-73	14-15	8-10	1.5-3.5	0.5-1.5

2.2 Preparation of the Composites

To improve the wettability between glass powder and LM6 alloy, glass powder was treated with alcohol and pre-heated to a particular temperature. About 2 kg of LM6 alloy was melted in a graphite crucible using electric furnace for about 1 hour. When the melt reached $720^{O}C$, which is well above the melting temperature of LM6 alloy, about 25gm of magnesium was added to the melt as a wetting agent. Hexa-chloro-ethene is the degassing agent; about 20gm of hexa-chloro-ethene tablet was added and dross was removed from the melt surface. The melt was stirred with the fixed stirring speed of 400 RPM, which creates a vertex in the melt. Preheated soda lime glass powder was added to the melt at the vertex till the temperature of the melt lowered to $640^{O}C$. To enhance the wettability, melt was re heated at $680^{O}C$ for about 90 minutes. Again the melt was stirred for 10 minutes and poured to the pre-heated steel mould. The composites were prepared by varying the glass reinforcement parameters using the above methodology [6][7].

2.3 Taguchi's Orthogonal Array Approach

The LM6/glass composites were prepared by considering the controllable reinforcement parameters such as quantity, particle size and preheat temperature. The other parameters such as melt temperature, stirring speed, quantity of wetting agent were maintained at same levels in all the composites preparation. The levels of each parameter were fixed based on the processing requirements of composite preparation. The levels of each reinforcement parameter are shown in the Table 3.

Table 3: Levels of the glass parameters

Parameters	Levels		
	1	2	3
A: % weight of glass particles added	1.5	3.0	4.5
B: Glass particle size (micron)	75	125	210
C: Temperature of glass particles (^{O}C)	260	380	500

As per the Taguchi's methodology, L9 orthogonal array was selected for three factors and each at three levels[8][9]. The orthogonal array and physical layout of L9 experimentation is shown in the Tables 4 and 5.

Table 4: L9 Orthogonal array

Test Run	Control factors		
	1	**2**	**3**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 5: Physical layout of experimentation

Test Run	A	B	C
1	1.5	75	260
2	1.5	125	380
3	1.5	210	500
4	3.0	75	380
5	3.0	125	500
6	3.0	210	260
7	4.5	75	500
8	4.5	125	260
9	4.5	210	380

3. TESTING AND RESULTS

Nine samples of LM6 alloy/glass composites were prepared as per the physical layout of experimentation. The distribution and wettability of the reinforcement in the LM6 matrix was confirmed from the micro-structural examination. The microstructure of the LM6/glass composite is shown in the Fig. 1.

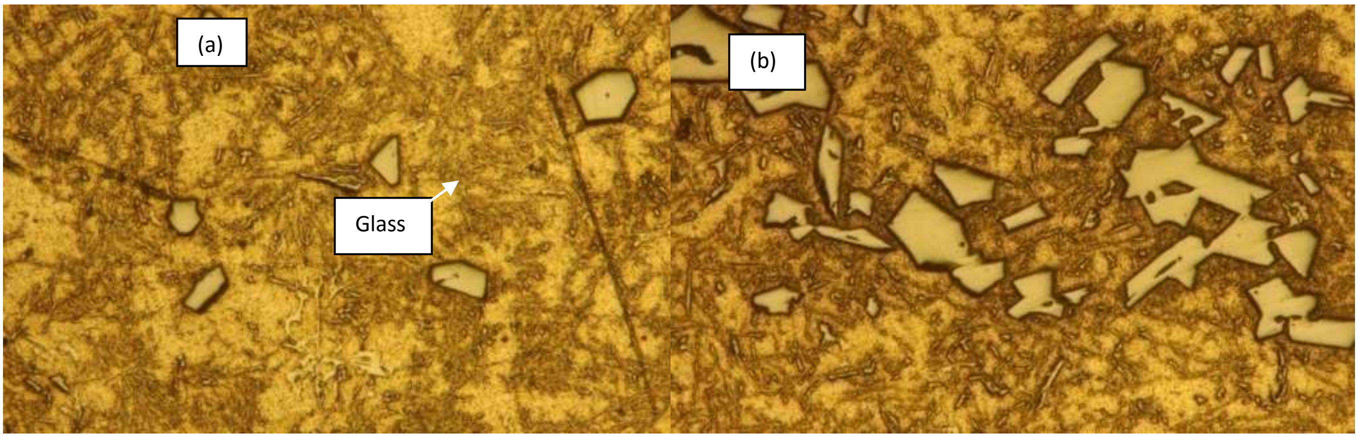

Fig.1: Microstructure of LM6 -glass composites: (a)1.5% (b) 4.5 % glass reinforcement (100X)

Fig. 1 shows the optical micrograph of the transverse cross section of the as-cast composite. These graphs reveal the uniform distribution and wettability of glass particles in LM6 matrix. It is also observed that castings are free from casting defects.

In the present investigation, the thermal conductivity equipment was used to determine the conductivity of LM6 alloy/glass composites, shown in Fig. 2. The principle of comparative cut bar method (ASTM E1225 Test Method) is adopted in the test; this is perhaps the most widely used method for axial thermal conductivity assessment. Three specimens were machined out from each casting and tested [10], the results of which are shown in Table 6.

Fig 2: Test specimen between reference specimens

4. SIGNAL TO NOISE RATIO (S/N RATIO) ANALYSIS

Resulting observations of the experiments were then converted into signal-to-noise ratio. These ratios serve as objective functions for optimization, assist in the analysis of data and lead to prediction of optimum results. S/N ratio represents a quantity of the impact of noise factors on performance. When the S/N ratio is large, the product is more robust against noise. The S/N ratio for maximize thermal conductivity can be expressed as "larger the better" characteristic.

Quality characteristic of 'Larger-the-better': S/N ratio $= -10 \log_{10}(1/n)\, \Sigma(1/y_i^2)$

Where 'n' is the number of observations and 'y' is the observed data.

Table 6: Results on thermal conductivity test

Run	Physical layout			Thermal conductivity (W/m ^{o}C)		
	A	B	C			
1	1.5	75	260	109.4	119.9	110.5
2	1.5	125	380	109.8	112.9	111.3
3	1.5	210	500	109.2	107.8	107.1
4	3	75	380	107.5	106.2	100.1
5	3	125	500	106.7	102.2	100.5
6	3	210	260	100.3	98.5	98.3
7	4.5	75	500	95.3	96.1	95.2
8	4.5	125	260	92.9	94.5	92.4
9	4.5	210	380	88.7	87.8	88.3

Table 7: Mean thermal conductivity and S/N ratios

Run	Mean Thermal conductivity (W/m ^{o}C)	S/N ratio (dB)
1	113.267	41.0603
2	111.333	40.9308
3	108.033	40.6703
4	104.600	40.3779
5	103.133	40.2597
6	99.033	39.9146
7	95.533	39.6029
8	93.267	39.3933
9	88.267	38.9157

S/N ratio has been calculated for every experimental run and is shown in Table 7. The S/N ratio for every factor level is summarized in the Table 8. The main effect plot is shown in the Fig.3. This has been done by using the MINITAB 14 statistical software package that is specifically meant for DOE applications. Results distinctly reveal that soda lime glass particles reinforcement reduces the thermal conductivity significantly. The '***larger-the- better'*** quality characteristic of S/N ratio is used to maximize thermal conductivity. The maximum thermal conductivity for factor A is at level 1 compared to that of levels 2 and 3 (based on maximum S/N ratio, for factors B and C, thermal conductivity at levels 1 and 3. The analysis of the results based on S/N ratio concludes that the factor combination A_1 B_1 C_3 results in maximum thermal conductivity. The optimal levels of factors is shown in Table 9. The confirmation test has been conducted at the optimal factor levels and the result of this test is presented in Table 10. The mean thermal conductivity obtained from the confirmation experiment is 113.9 W/m °C.

Table 8: Response table for S/N ratios

A		B		C	
Level	**S/N ratio**	**Level**	**S/N ratio**	**Level**	**S/N ratio**
1	**40.89**	**1**	**40.35**	**1**	40.12
2	40.18	**2**	40.19	**2**	40.07
3	39.30	**3**	39.83	**3**	**40.18**
Delta	1.58		0.51		0.10
Rank	**1**		**2**		**3**

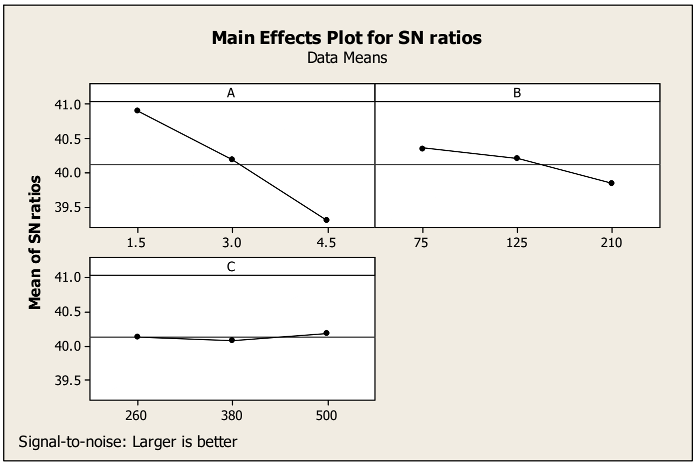

Fig. 3: Main effects plots for S/N ratio

Table 9: Optimal level of factors based on S/N ratio

Factor	**A**	**B**	**C**
Level	1	1	3
Value	1.5 wt.%	75 micron	500 °C

Table 10: Results of confirmation experiment

Factor	A	B	C	Observed Thermal conductivity (W/m °C)			Mean Thermal conductivity (W/m °C)
Value	1.5	75	500	113.5	112.5	115.7	113.9

5. CONCLUSION

Fabrication of LM6 alloy/glass particulate composite is possible by stir-casting technique. Use of Taguchi's orthogonal array approach reduces the experimental runs from 27 to 9. The glass powder parameters namely weight % and particle size of glass of the composite reduces the thermal conductivity of the composites. It is observed that preheat temperature of the glass particles has no effect on thermal conductivity. Weight % of 1.5 and particle size of 75 microns yields better thermal conductivity compared to other combinations of glass parameters. Thermal conductivity is 113.9 W/m °C at weight % of 1.5 and particle size of 75 microns.

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