CHAPTER III

METHODOLOGY

The methodology used in conducting this experimental study will be discussed in this chapter. It will consist materials used, affecting factors, output responses, planning of experiments and material testing.

3.1 Materials used in this study

Aluminum alloy commercially known as LM6 was used as matrix material for this newly developed material. Silicon is the main alloying element which consists of 10 – 13 % composition. Chemical composition of LM6 could be referred to Chapter 2: Table 2.2. Copper powder 4.5 weight percentage with 5 μm in size was added as secondary reinforcement material. Composition of copper was remained constant for all combinations. Silicon carbide particulate was chosen as main reinforcement material and used in 3 different sizes; 40, 59 and 106 μm.

3.2 Controllable factors

In this experimental study, the control factors are those parameters which determined will affect the properties of the Al-Cu-SiC_p MMC. The selected factors for this experimentation are:

(i) Particle sizes of SiC (40, 59 and 106 μm)
(ii) Weight percentage of SiC (5, 10 and 15 %)
(iii) Pouring temperature (675, 700 and 725 ^{0}C)
(iv) Stirring time (5, 10 and 15 minutes)

3.3 Uncontrollable factors

Uncontrollable factors are factors which also may affect the result of testing. These factors are beyond our control and need to upgrade and improve the experimentation facilities in order to reduce or eliminate the factors. The factors are:

(i) Velocity of the molten mixture
(ii) Flow of mixture
(iii) Height of pouring
(iv) Temperature of the mould
(v) Distribution of ceramic reinforcements in the matrix
(vi) Time required for melting the matrix.

Six types of noise factors have been identified. The noise factors will directly influence the properties (mechanical and physical) of Al-Cu-SiC_p MMC. For instance, the solidification process is influenced by the temperature of sand mould. Sand mould with lower temperature encouraged faster cooling process. Rapid cooling of mixture produced finer dendrite. Finer dendrites reduce the chances of isolation of ceramic reinforcement from the dendrites boundaries. This also produced uniform distribution of ceramic reinforcements. However the second factor (height of pouring) is eliminated because the portable electric furnace was placed on the stool. The height of stool is fixed and the molten mixture is poured from the bottom of the furnace.

3.4 Factor – Characteristic Relation Diagram

Figure 3.1 shows the relation between controllable factors, noise factors and the output responses of the experiment.

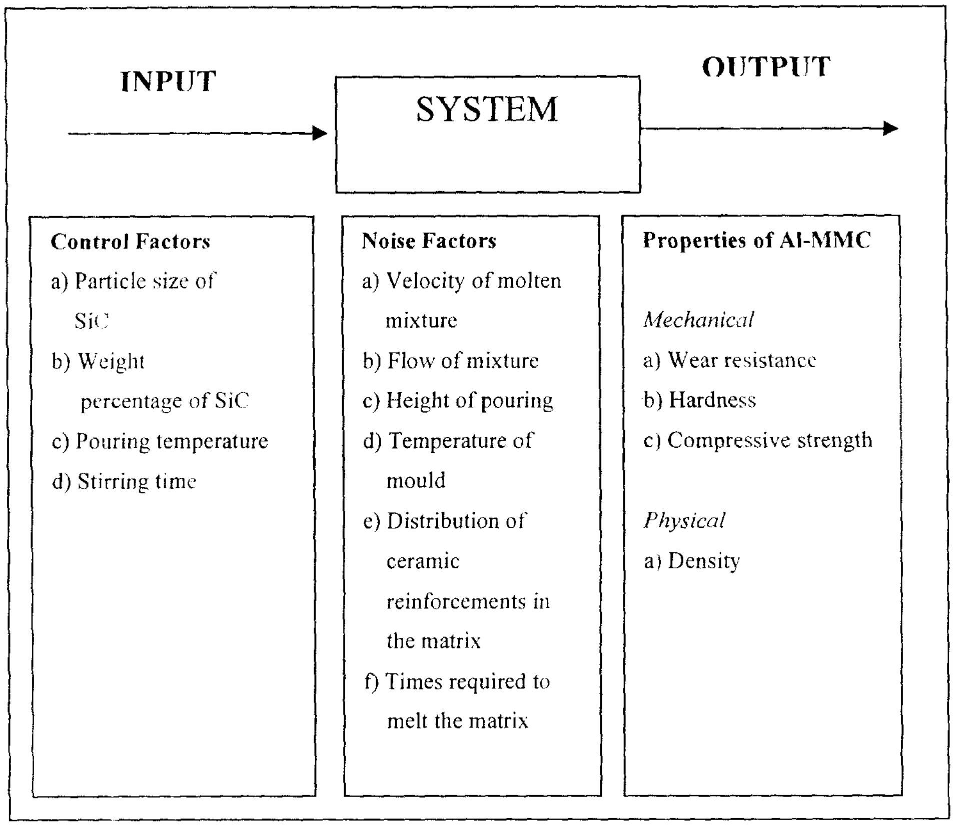

Figure 3.1: Factor – Characteristic Relation Diagram

3.5 Levels of Controllable Factors

Table 3.1: Factors and Level

	Level		
Factors	**0**	**1**	**2**
A: Particle sizes of SiC_p	40 micron	59 micron	106 micron
B: Weight percentage of SiC_p	5%	10%	15%
C: Pouring Temperature	675 °C	700 °C	725 °C
D: Stirring Time	5 minutes	10 minutes	15 minutes

3.6 Planning of Experiment

Taguchi's Robust Parametric Array is used with inner array L_9 3^4 and outer array consuming of 2 replications. The design of experiment is shown in Table 3.2.

Table 3.2: Actual experimental conditions according to Taguchi's Design of Experiment

Exp. Number	Control Factor Assignment				Response		SN
	A Particle Sizes (μm)	B Wt% of SiC	C Pouring Temp. (^{0}C)	D Stirring Time (min.)	1	2	
1	40	5	675	5	y_{11}	y_{12}	SN_1
2	40	10	700	10	Y_{21}	Y_{22}	SN_2
3	40	15	725	15	Y_{31}	Y_{32}	SN_3
4	59	5	700	15	Y_{41}	Y_{42}	SN_4
5	59	10	725	5	Y_{51}	Y_{52}	SN_5
6	59	15	675	10	Y_{61}	Y_{62}	SN_6
7	106	5	725	10	Y_{71}	Y_{72}	SN_7
8	106	10	675	15	Y_{81}	Y_{82}	SN_8
9	106	15	700	5	Y_{91}	Y_{92}	SN_9

Signal – to – noise (SN) ratio suggested by Taguchi is used to eliminate the effect of noise factors. *Larger the better, smaller the better or nominal the best* characteristics are chosen depending upon the output response undergoing.

3.7 Output response parameter signals

3.7.1 Mechanical

(i) Hardness

(ii) Wear rate

(iii) Compressive strength

3.7.2 Physical

(i) Density

3.8 Experimental setup

LM6 alloy ingots were melted in the furnace shown in Figure 3.2. When the molten metal reached the desired temperature, copper powder was added through the upper opening at the top of the furnace, after remaining the stirrer and then SiC particles were added and stirred continuously in the furnace. The set up for this process is shown in Figure 3.3. This process was repeated under different experimental conditions as mentioned in Table 3.2.

When the cold powder was added, temperature of the mixture went down so need to heat up the melt with the powder mixture in it to the desired level of temperature. Then, simultaneous stirring during heating was performed. Mould was made in sand for different sizes and shapes of the specimens required for different tests. The mould was kept under the furnace bottom opening. The bottom was opened and molten mixture was poured into the mould. When the molten mixture was completely solidified, finishing process such as grinding, machining and polishing shall be performed. Additional or large amount of machining is not required because the specimens were cast near to net size.

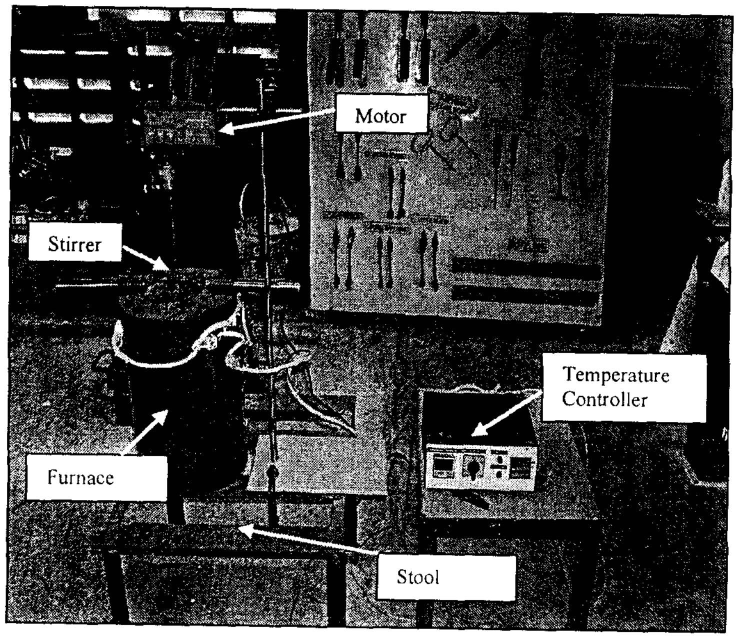

Figure 3.2: Portable Electric Furnace

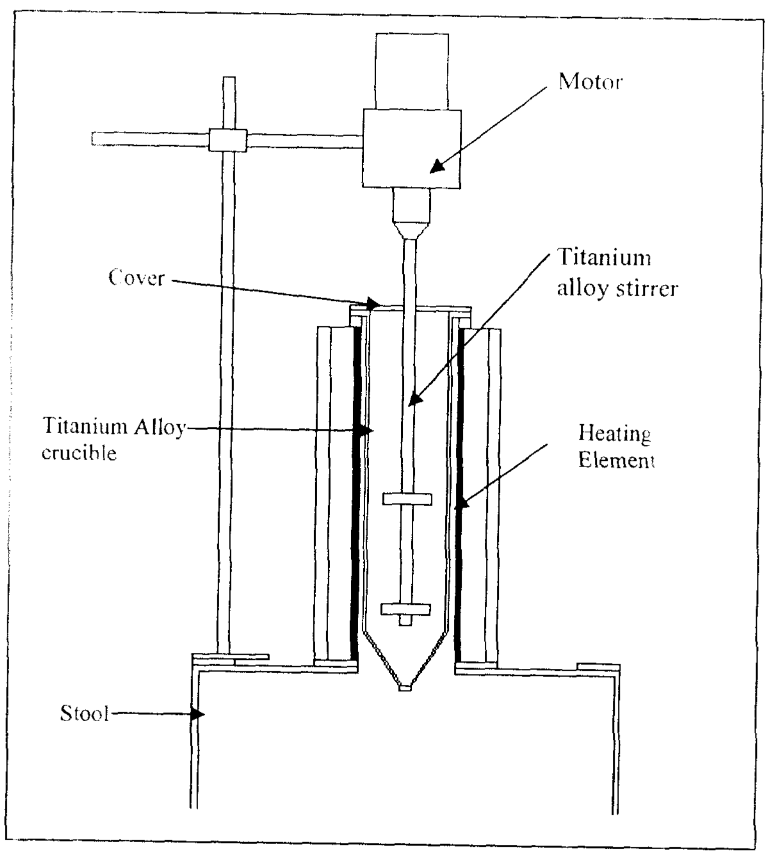

Figure 3.3: Schematic Diagram of Portable Electric Furnace

3.9 Specimen specifications

Table 3.3: Specimen Specifications

Num	Types of Testing	Specimen sizes	Notes
1	Wear	Ø 20 mm and length 28 mm	
2	Hardness (Vickers)	400mm (length) x 250mm (width) x 8mm (thickness).	The specimen's thickness must capable to avoid bulge on the opposite side of specimen after the impression. The test specimen should be placed perpendicular to the axis of indenter. (ASTM E92-82 Reapproved 1997)$^{\varepsilon 3}$
3	Density	No specific size required	Test specimens for wear resistance testing are used
4	Compressive strength	Ø 20 mm and length 60 mm	According to ASTM E9-89a

3.10 Types of Testing

The testing was done in this experimental study can be divided to mechanical and physical testing. Mechanical testing: wear, Vickers hardness test and compression test; and physical testing: density.

3.10.1 Mechanical Testing

The mechanical testing was done in this experimental study are wear, hardness, compression and flexural test. The following section discusses all of the testing.

3.10.1.1 Wear Resistance

Dry sliding wear test was conducted in this experimental study. The wear resistance of Al-Cu-SiC_p MMC was tested by wear tester. Wear resistance of the specimen was determined based on the wear rate which was weight of loss per unit time. Weight loss of the specimen was calculated from Equation 3.1

$$W_l = W_b - W_a \qquad \text{(Equation 3.1)}$$

Where

W_l = Weight loss

W_b = Weight of specimen before experiment

W_a = Weight of specimen after the experiment

So, wear rate of the specimens was calculated from Equation 3.2

$$\text{Wear rate} = \frac{\text{weight loss of specimen}}{\text{unit time (sec.)}} \qquad \text{(Equation 3.2)}$$

Specimen with better wear resistance exhibits lower wear rate compared to low wear resistance's specimen. The experiment conditions were:

a) Linear velocity = 0.84 m/s

b) Sliding time = 10 minutes

c) Sliding distance = 502.65 m

d) Loading force = 32.7N

e) Counterface material = mild steel

The loading force is exerted from the spring located inside the loading load holder. The generated force can be determined by Equation 3.3

$$F = kx \qquad \text{(Equation 3.3)}$$

where, F = exerted force (N)

k = Spring stiffness (3.27 KN/m)

x = Displacement (m)

Figure 3.4 illustrates the wear tester used in this experiment.

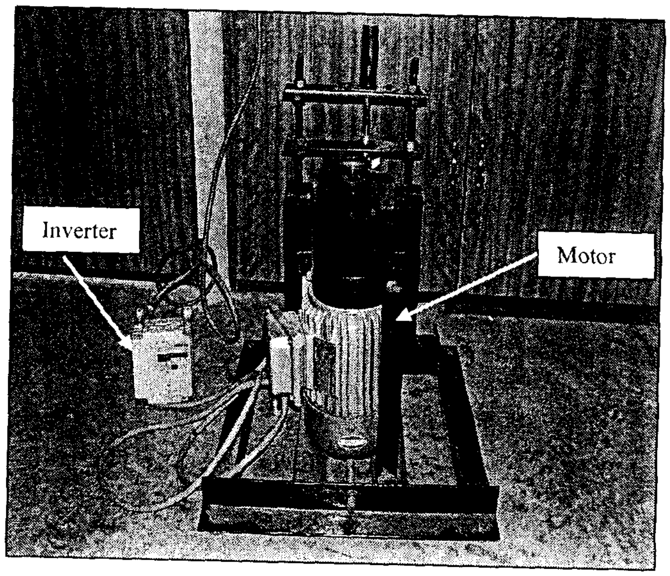

Figure 3.4: Wear Tester

The procedure of wear testing can be understood from Figure 3.5 and for further explanation could refer to Appendix D.

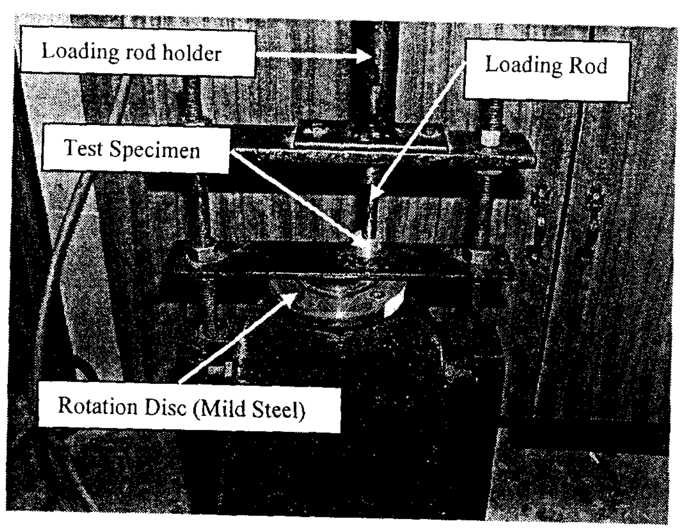

Figure 3.5: Tester of Wear

3.10.1.2 Vickers Hardness Test

Vickers hardness test was used in this experimental study.

Testing conditions were:

(i) Load = 30kg

(ii) Load time = 10 sec

(iii) Loading speed = 55μm/sec.

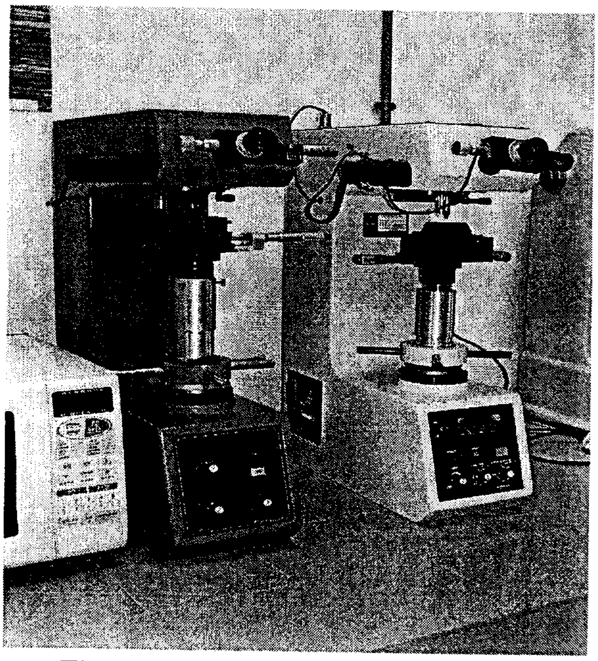

Figure 3.6: Vickers Hardness Tester

3.10.1.3 Compression Test

Compression test was used to determine the compressive strength of metal and alloys. Mechanical properties of metal and alloys which is important for structural design; could be obtained from the engineering tensile are: modulus of elasticity, yield strength at 0.2 percent offset, ultimate compressive strength, percent elongation at fracture and percent reduction in area at fracture. The Universal Testing Machine (floor-type) was used for this test. Testing was conducted according to ASTM E9-89a, Standard Test Method of Compression Testing of Metallic Materials at Room Temperature. The ultimate compressive strength was the maximum strength reached in the engineering stress-strain curve while the yield strength was important value for use in engineering structural design since it is the strength at which a metal or alloy shows significant plastic deformation.

The specimen was placed between upper and lower plate, and need to ensure the specimen was located at the centre of the plate. Force (load) shall be applied on the specimen. From this test, several data could be obtained such as ultimate tensile strength, Young modulus, yield strength at 0.2 percent offset and yield point.

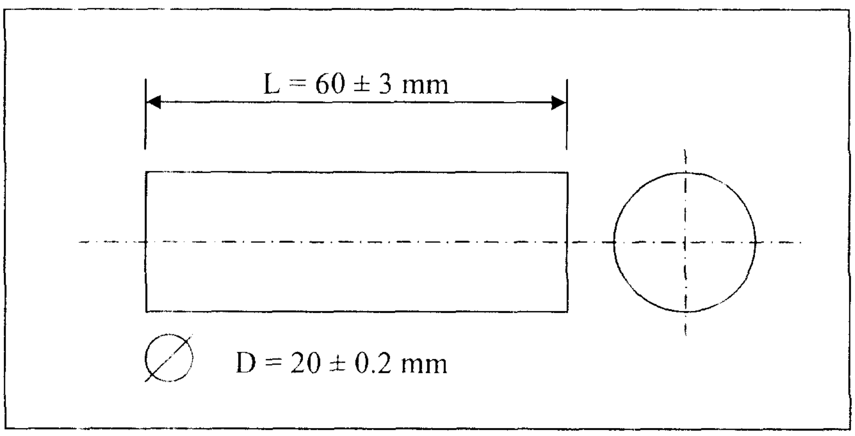

Figure 3.7: Standard round compression test specimen.

3.10.2 Physical Test

There are many types of physical test such as density and porosity. However, only density test was conducted in this experimental study.

3.10.2.1 Density Test

Density is defined as ratio of mass to volume. In a simpler word, it is described as how 'heavy' something is. The common unit for density is kilogram per cubic meter (kgm^{-3}). Lighter products shall have lower value of density while heavier products have higher value of density.

Ultrapycnometer 1000 was used to measure the density of the casted specimen. This equipment uses Archimedes principle in determining the specimen's density. Illustration of Ultrapycnometer 1000 is shown in Figure 3.8.

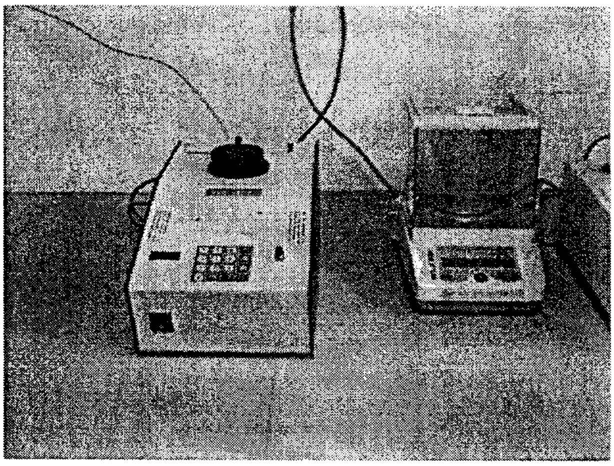

Figure 3.8: Ultrapycnometer 1000 (left) and Digital Weighing Unit

3.11 Data Analysis

Data analysis was done by using Pareto analysis of variance (Pareto-ANOVA) manually. Pareto-ANOVA is a powerful tool to determine the factors which affect the mechanical and physical properties of Al-Cu-SiC_p MMC significantly.

After completing the testing, the value of signal to noise ratio (SN) for each level of control factor was calculated by using the formulas below. SN ratio represents the averages response and amount of variation presents in the experiment. Equation 3.4 and 3.5 are used to calculate the signal to noise ratio

a) Smaller-the better characteristic

$$SNi = -10\log(\frac{1}{n}\sum y^2) \quad \text{(Equation 3.4)}$$

b) Larger-the better characteristic

$$SN_i = -10\log(\frac{1}{n}\sum \frac{1}{y^2}) \quad \text{(Equation 3.5)}$$

The following step is calculating and fills in Table 3.7.

Table 3.4: Pareto ANOVA for Three-Level Factors

Factors and interaction		A	B	C	D	Total
Sum at factor level	0	A_0	B_0	C_0	D_0	$T= A_0+A_1+A_2$
	1	A_1	B_1	C_1	D_1	
	2	A_2	B_2	C_2	D_2	
Sum of squares of differences (S)		$(A_0-A_1)^2+(A_0-A_2)^2+(A_1-A_2)^2=S_A$	$(B_0-B_1)^2+(B_0-B_2)^2+(B_1-B_2)^2=S_B$	$(C_0-C_1)^2+(C_0-C_2)^2+(C_1-C_2)^2=S_C$	$(D_0-D_1)^2+(D_0-D_2)^2+(D_1-D_2)^2=S_D$	$S_T= S_A+S_B+S_C+S_D$
Contribution ratio (%)		(S_A/S_T) x 100	(S_B/S_T) x 100	(S_C/S_T) x 100	(S_D/S_T) x 100	100%
Pareto Diagram						
Factor and interaction						
Cumulative contribution ratio (%)						
Remarks on Optimum Condition						
Optimum combination of significant factor level						
Overall optimum conditions for all factors						
Estimate of error variance						