CHAPTER IV

DATA ANALYSIS AND DISCUSSION

In this study, specimens with various combinations of factors are subjected to mechanical and physical properties. The factors include particle size of SiC, weight percentage of SiC, pouring temperature and time of stirring. Four types of testing were conducted. There are hardness, wear, compression and density test. This chapter will review the findings and data analysis obtained from experimental study.

4.1 Results and data analysis

This section reviews and discusses the findings and analysis of data using Pareto-ANOVA analysis.

4.1.1 Hardness test

Table 4.1 depicts results obtained from Vickers hardness test. Signal to noise ratio values also are shown in this table. Pareto-ANOVA is applied on the findings in order to determine the significant factors which affect the hardness of Al-Cu-SiC_p MMC. Optimum combination factor also can be identified by this method.

Table 4.1: Results For Vickers Hardness Test

Experiment Number	Control Factor Assignment				Replications (HV)		Signal to Noise, SN*	Average Hardness (HV)
	A	B	C	D	1st	2nd		
1	0	0	0	0	75.6	76.3	37.61	75.95
2	0	1	1	1	64.5	65.2	36.24	64.85
3	0	2	2	2	80.4	73.7	37.71	77.05
4	1	0	1	2	75.2	71.2	37.28	73.20
5	1	1	2	0	79.3	79.9	38.02	79.6
6	1	2	0	1	80.6	84.4	38.32	82.5
7	2	0	2	1	70.7	71.5	37.04	71.1
8	2	1	0	2	72.5	70.7	37.10	71.6
9	2	2	1	0	83.4	80.8	38.28	82.1

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

* Larger-the better characteristic is used for hardness test.

$$SN_i = -10\log\left(\frac{1}{n}\sum_{j=1}^{n}\frac{1}{y_{ij}^2}\right) \qquad \text{(Equation 4.1)}$$

Where; SN = Signal to Noise Ratio

n = number of observation in each row

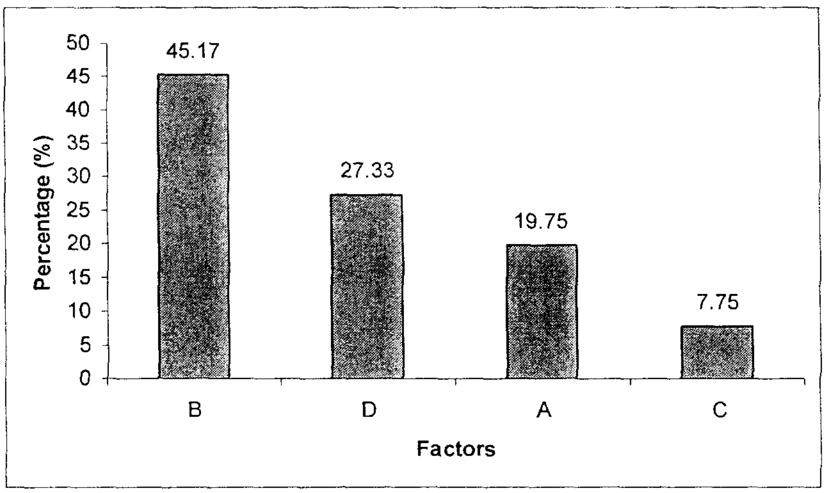
y = value of data from observations in each row *i*

Table 4.2 depicts Pareto ANOVA for hardness.

Table 4.2: Pareto ANOVA for Hardness

Factors and interaction		A Particle Sizes of SiC	B Weight Percentage of SiC	C Pouring Temperature	D Stirring Time	Total
Sum at factor level	0	111.56	111.93	113.03	113.91	337.60
	1	113.62	111.36	111.80	111.60	
	2	112.42	114.31	112.77	112.09	
Sum of squares of differences (S)		6.4232	14.6918	2.5214	8.8886	32.525
Contribution ratio (%)		19.75	45.17	7.75	27.33	100%

Pareto Diagram



Factor and interaction	B	D	A	C
Cumulative contribution ratio (%)	45.17	72.5	92.25	100
Optimum condition	$A_1B_2C_0D_0$			
Overall optimum conditions for all factors	A_1 = 59μm (Particle size of SiC) B_2 = 15% (Weight percentage of SiC) C_0 = 675°C of pouring temperature D_0 = 5 minutes (Stirring time)			
Estimate of error variance	$V_e = (S_e/ 8)/2 = 0.1576$			

Results of Confirmation Test for Hardness

Hardness for Al-Cu-SiC$_p$ MMC at optimum conditions is 82.5 HV.

From Table 4.1, it may indicate that the SiC particles and copper have distributed uniformly in the matrix because the hardness values for the first and second replications for same combination show very slight differences. This statement could be supported by Figure 4.1; shows the SEM photograph for the distribution of SiC particles and copper under 100 magnifications (100 µm). SiC particles in black colour dispersed almost uniform as shown in this figure. Mechanical properties of the composites will be affected significantly by the non-uniformity in the reinforcement arrangement (Ganguly, 2001). J. Hashim (1999) stressed the distribution of the reinforcement material in the matrix alloy must be uniform in order to achieve the optimum properties of the MMC. Even though results in the Table 4.1 and SEM photograph (Figure 4.1) could not taken as very strong evidence to witness the uniformity of the reinforcement distribution, but continuous stirring the composition by using mechanical stirrer with constant speed, it hoped that SiC particles and copper powder dispersed uniformly

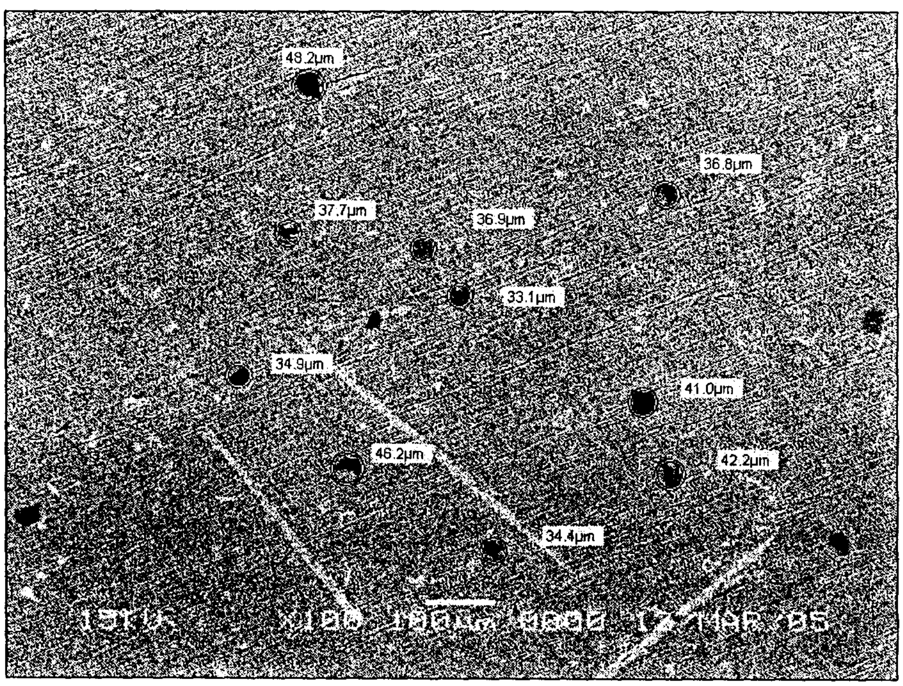


Figure 4.1: Distribution of SiC particles in the matrix

For further research, technique of quantification of the reinforcement distribution may be applied to correlate the microstructure with the properties of the materials (J. Hashim, 1999).

Based on Table 4.2, it is found that weight percentage of SiC is the most significant factor for hardness of Al-Cu-SiC_p MMC. It consists of 45.17 percent from total contribution ratio and follow by stirring time; 27.33 percent. Other factors which significantly influence the hardness include particle size of SiC and pouring temperature which accumulate 19.75 percent and 7.75 percent respectively.

Pareto ANOVA provides valuable information in determining optimum condition for each desired properties, in this discussion is hardness. According to analyzed value in Table 4.2 at '*Sum at factor level*' column, optimum level of particle size of SiC is A_1 which is 59 μm while for weight percentage of SiC is B_2; 15 percent. Pouring temperature at optimum is C_0; 675^0C and stirring time, D_0 for 5 minutes of stirring. The optimum condition for maximum hardness value of newly developed Al-Cu-SiC_p MMC is $A_1B_2C_0D_0$.

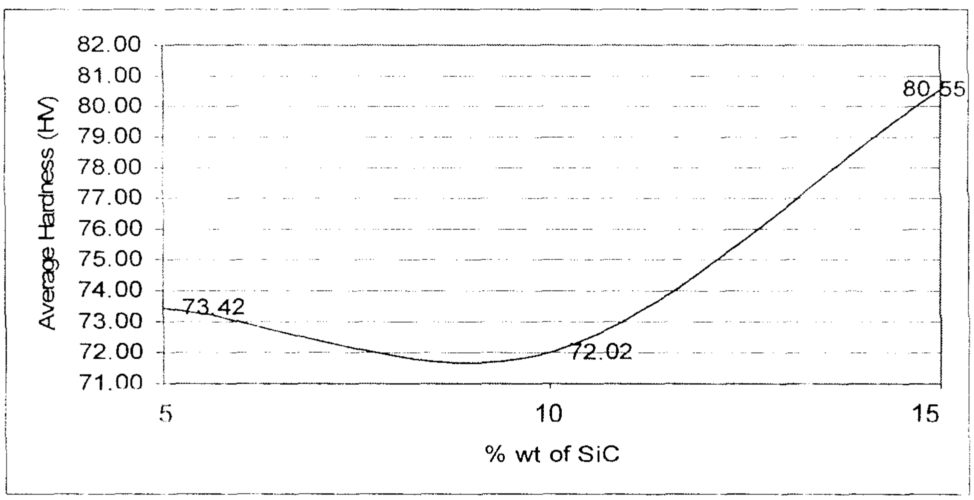


Figure 4.2: Effect of weight percentage of SiC on average hardness

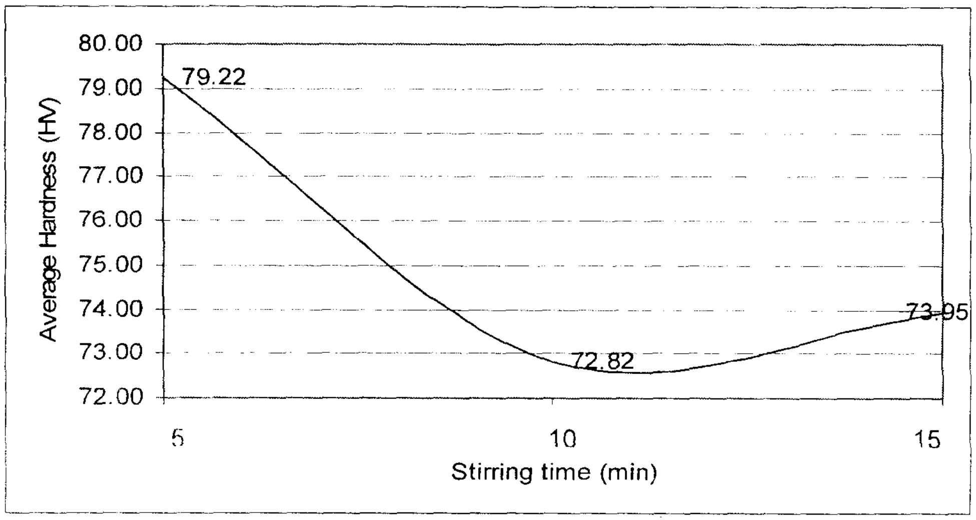


Figure 4.3: Effect of stirring time on average hardness

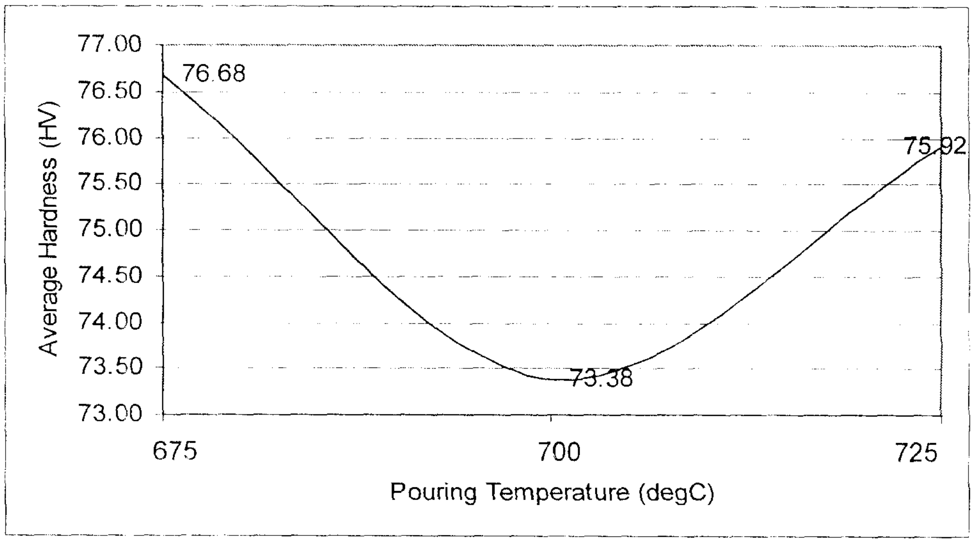


Figure 4.4: Effect of pouring temperature on average hardness

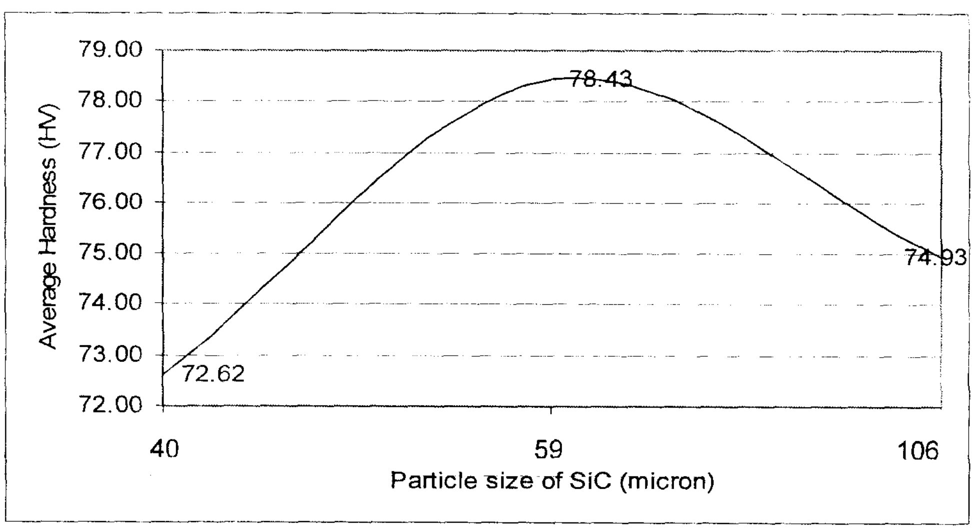


Figure 4.5: Effect of particle size of SiC on average hardness

This optimum condition is confirmed from the graphs plotted for hardness properties. Only average of each level was taken for each factor. Other 3 controllable factors were ignored in this case. Highest peak of the graph represent the optimum level of the respective factor.

Weight percentage of SiC was found the most significant factor influencing hardness of Al-Cu-SiC_p MMC. Graph in Figure 4.2 shows the increasing of SiC percentage of weight in the matrix alloy, will increase the hardness. Silicon carbide (SiC) is a very hard abrasive with hardness range of 2000 HV. By adding it into the aluminum alloy, hardness of the composites dramatically increased from 15 HV (http://www.matweb.com) to 70 – 80 HV. It was great achievement. Hardness of the composites increased more or less linearly with the volume fraction of particles in the alloy matrix due to the increase of the ceramic phase and hardness also influenced by porosity. Volume fraction here could be considered as weight percentage of SiC. Increasing of volume fraction of SiC decreased the porosity of the composite. So, lower porosity associated with higher hardness (Sahin, 2003). Fareed (2002) also reported hardness increased with increasing of weight percentage of SiC. Fabrication of Al-MMC through powder metallurgy also shown similar trend. Purohit et. al. (2001) found hardness of Al-SiC cam increase in range of 72.65 to 107.0 HV for 10 to 30 percent of weight of SiC.

Stirring time contribute 27 percent of influencing hardness. The optimum average hardness is 79.22 HV for 5 minutes of stirring. Hardness of composites decreased as stirring time increased. Stirring process is important to ensure the uniform distribution of reinforcement particles during casting. But, increasing time of stirring will increase chances of air bubbles and other impurities entering the slurry results the porosity of the composite (Ghosh, 1984 and Bindumadhavan et. al, 2001). As previously mentioned, decreasing on hardness results from increasing of porosity. This is the possible reason explained why hardness of the composite decrease on increasing of stirring time as shown in Figure 4.3.

Figure 4.4 shows the effect of particle size on hardness of Al-Cu-SiC_p MMC. Highest peak of the graph is 78.43 HV for 59 μm of particle size. Particle size give significant effect to the hardness properties of this material with almost 20 percent contribution to the hardness increment. Graph of particle size of SiC versus average hardness as in Figure 4.4 shows hardness increased as particle size increased but optimum at 59 μm. Previously, mentioned that hardness influenced by porosity of the material. Sahin (2003) revealed that increasing amount of porosity is observed with increasing the percentage of weight of SiC, especially for low particle size of SiC, because the decrease in the inner-particles spacing. Others also reported same conditions in their work (Zamzam et. al., 1993; Mortensen et. al., 1993 and Cooke et. al., 1991). Graph in Figure 4.4 does not show increment trend as hardness value drop to 74.93 HV for 106 μm particle size. This may due to the poor distribution of larger particle because it may deposit at the bottom of the channel during solidification. Particles raging from 100 to 1000 μm in size show this behavior (J. Hashim et. al., 2002).

Pouring temperature observed as least significant effect to the hardness of the composite; which less than 10 percent effect ratio. Maximum hardness of 76.68 HV results from minimum pouring temperature, 675 ^{0}C. Minimum hardness exhibits when pouring temperature was 700 ^{0}C. This may because of more gas entrap when higher temperature applied during pouring process, leads to porosity which reduce the hardness of newly developed composite. Increasing of pouring temperature also increase the temperature gradient between sand mould and molten composite, caused formation of air envelopes between the particles, altering the properties of the composites. Jananee (2004) concluded the increase in pouring temperature will reduce hardness of Al-MMC.

Porosity is the major factor influencing hardness of the developed material. It caused by existence of air bubbles during casting process results from stirring, temperature gradient, introduction of reinforcement particles during melting and size of the particles. Higher level of porosity indicates lower hardness value for the composite.

4.1.2 Wear Resistance Test

Wear resistance is determined based on the weight loss per unit time of the specimen after undergo sliding wear process. Specimen which has low wear resistance will exhibits higher weight loss. Lower weight loss indicates that, the specimen has better wear resistance. The results for wear resistance test are depicted by Table 4.3. Pareto-ANOVA is applied on the findings in order to determine the significant factors which affect the wear resistance of Al-MMC. Optimum combination factor also can be identified by this method.

Table 4.3: Results For Wear Rate

Experiment Number	Control Factor Assignment				Replications (Wear rate) g/sec ($x10^{-5}$)		Signal to Noise, SN*	Average Wear Rate g/sec ($x10^{-5}$)
	A	B	C	D	1^{st}	2^{nd}		
1	0	0	0	0	9.17	6.17	82.14	7.67
2	0	1	1	1	5.17	7.83	83.56	6.50
3	0	2	2	2	1.83	5.33	87.99	3.58
4	1	0	1	2	9.33	9.83	80.37	9.58
5	1	1	2	0	5.50	5.83	84.93	5.67
6	1	2	0	1	6.67	5.67	84.17	6.17
7	2	0	2	1	6.83	4.83	84.56	5.83
8	2	1	0	2	4.00	8.17	83.84	6.08
9	2	2	1	0	6.83	2.00	85.96	4.42

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

* Smaller-the better characteristic is used for hardness test.

$$SNi = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} y_{ij}^2\right) \qquad \text{(Equation 4.2)}$$

Where; SN = Signal to Noise Ratio

n = number of observation in each row

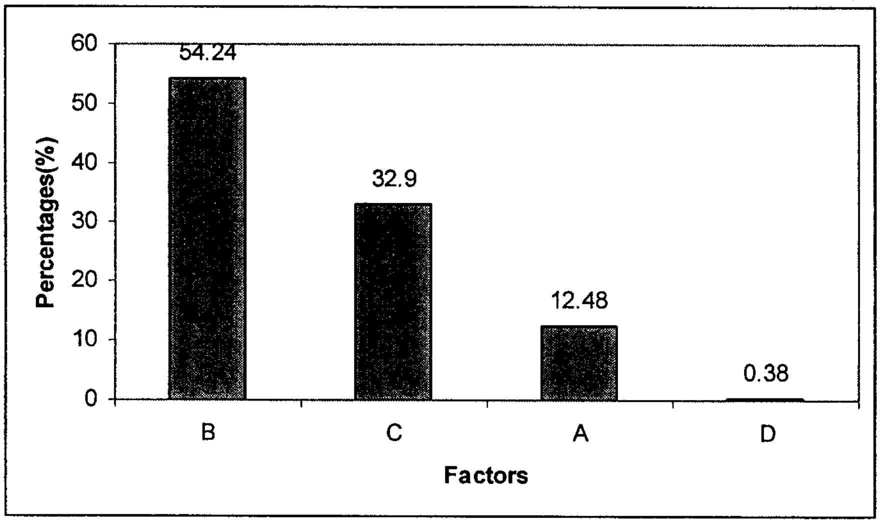
y = value of data from observations in each row *i*

Table 4.5 depicts Pareto ANOVA for Wear Rate.

Table 4.4: Pareto ANOVA for Wear Rate

Factors and interaction		A Particle Size of SiC	B Weight Percentage of SiC	C Pouring Temperature	D Stirring Time	Total
Sum at factor level	0	253.69	247.07	250.15	253.04	730.42
	1	249.47	252.33	249.89	252.29	
	2	254.35	258.12	257.47	252.19	
Sum of squares of differences (S)		42.16	183.27	111.12	1.29	337.83
Contribution ratio (%)		12.48	54.24	32.90	0.38	100

Pareto Diagram



Factor and interaction	B	C	A	D
Cumulative contribution ratio (%)	54.24	87.14	99.62	100
Optimum condition	$A_2B_2C_2D_0$			
Overall optimum conditions for all factors	A_2 = 106μm (Particle size of SiC) B_2 = 15% (Weight percentage of SiC) C_2 = 725°C (Pouring temperature) D_0 = 5 minutes (Stirring time)			
Estimate of error variance	V_e= (S_d/ 8)2 = (1.283 / 8)/2= 0.0802			

Results of Confirmation Test for wear rate

Wear rate at optimum conditions is 1.585 x 10^{-5} g/sec.

Figure 4.6 shows the effect of weight percentage of SiC on wear rate. Linear graph shows higher insertion of SiC particles reduced wear rate of composite. Minimum wear rate, 4.72 x 10^{-5} g/sec recorded for 15 percent of SiC particles addition. It may predict wear rate will reduce as the weight percentage of SiC particles increase based on linear graph trend. Weight loss during friction between 2 surfaces has inter relation with hardness of the material. Higher hardness results lower wear rate. In this study, for maximum weight percentage of SiC, minimum wear rate and maximum hardness were determined. Archard equation (Equation 2.1; Clyne and Whither, 1995) also supports this finding. The equation correlates the relationship between wear loss and hardness which could be concluded as the wear rate increases as the contact load is raised and hardness value falls. Miyajima and Iwai (2003) concluded when volume fraction of SiC particles increased, wear loss will be decreased. They also found that the worn surface of MMCs with higher volume of SiC_p exhibits smooth flat surface without large groove. Particles of SiC with some clusters and lead to porosity, are loosely bonded to the matrix. They are easily pulled out of the matrix during friction of two surfaces (Bindumadhavan et. al., 2001). Increasing of volume fraction (weight percentage of reinforced material) of particles may reduce the area of matrix which comparatively softer. Higher content of particles were 'hide' the softer part of the composite and reduce the chances of the particles from pulled out during friction. Lower content of particles may exhibit the softer area and the particles will greatly exposed to the rubbing material.

Wear rate maximum (6.83 x 10^{-5} g/sec) when pouring temperature was 700 ^{0}C while minimum wear rate (5.03 x10^{-5} g/sec) at 725 ^{0}C. Pouring temperature influenced wear resistance properties for 32 percent, which was very significant. Jananee (2004) concluded interaction of pouring temperature with other factor exhibit significant effect on wear resistance of Al-MMC. By referring back to Figure 4.5, at 725 ^{0}C hardness of composite also found significantly high, 75.92 HV. Higher hardness results lower wear rate. So, at 725 ^{0}C; maximum hardness and minimum wear rate were recorded. During casting process, better blending between matrix and reinforced particles might happen and results matrix and particles tightly bonded until at this temperature. Higher temperature provide better environment to the composition process where particles and matrix may embed tightly. This might direct to lower wear rate as hard particles bonded and exhibits its hard properties without pulled out when rubbing with other materials.

Figure 4.7 shows the effect of particle size of SiC on wear rate. Lowest wear rate is 5.44 x 10^{-5} g/sec at 106 micron and highest wear rate is 7.14 x 10^{-5} g/sec for 59 micron of SiC. Larger surface area might be provided and more space for SiC particles to bind with Al during mixing process when size of particles increased. Wear rate might correlate with wear resistance. Lower wear rate means higher wear resistance. Song et. al., concluded that the wear resistance of MMCs containing small SiC_p is considerably lower than that of MMCs with larger SiC_p. smaller reinforcing particles more easily pulled out from the matrix by the ploughing action of the abrasive particles during wear. Smaller size of particles embedded loosely in the matrix as range between them comparatively far. Particles around the weaker surface tend to get debonded and pulled out, leading to an increase in wear (Bindumadhavan et. al., 2001).

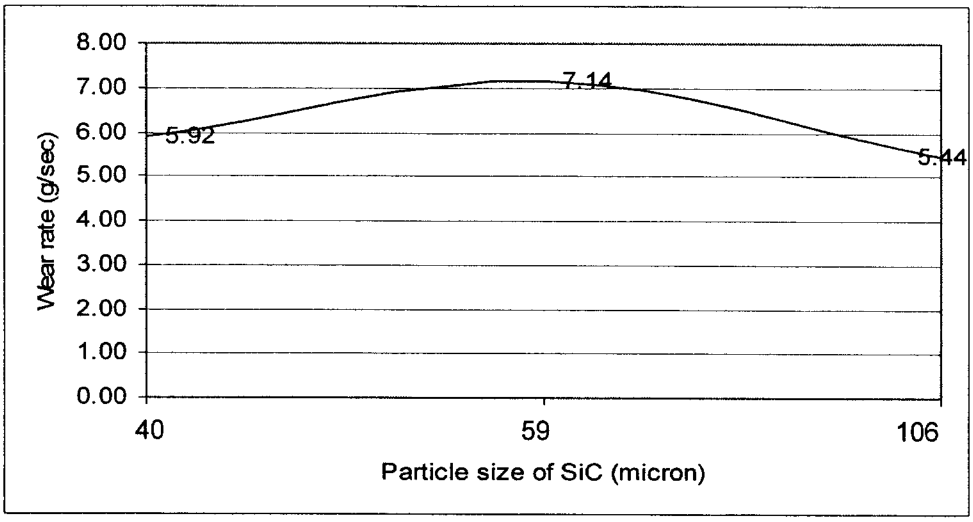


Figure 4.6: Effect of particle size of SiC on wear rate

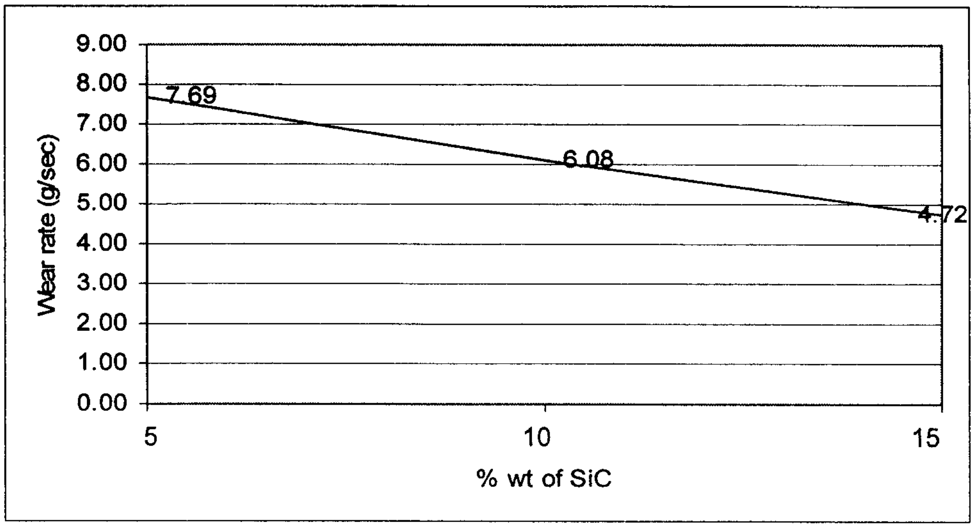


Figure 4.7: Effect of weight percentage of SiC on wear rate

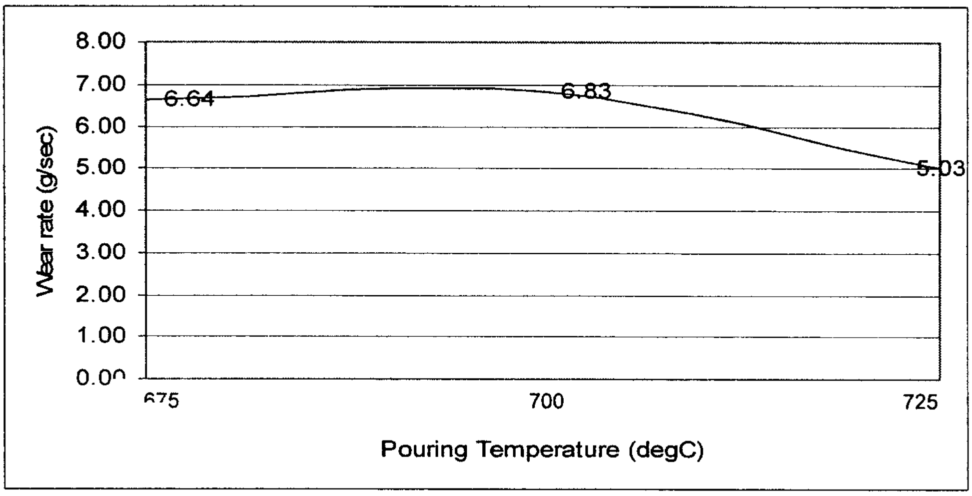


Figure 4.8: Effect of pouring temperature on wear rate

4.1.3 Compression Test

Table 4.5 shows results of compression test for the newly developed material. From the test, average compressive strength was collected for the analysis. Pareto-ANOVA is applied on the findings for determining the significant factors which affect the compressive strength of Al-Cu-SiC_p MMC. Optimum combination factor also can be identified by this method.

Table 4.5: Results For Compression Test

Experiment Number	Control Factor Assignment				Replications (MPa)		Signal to Noise, SN*	Average (MPa)
	A	B	C	D	1st	2nd		
1	0	0	0	0	8712.03	4161.86	74.50	6436.95
2	0	1	1	1	6134.20	5852.93	75.55	5998.57
3	0	2	2	2	10695.37	5777.51	77.13	8236.44
4	1	0	1	2	6768.55	6746.33	76.60	6757.44
5	1	1	2	0	8608.06	8608.06	78.70	8608.06
6	1	2	0	1	9410.06	9410.06	79.47	9410.06
7	2	0	2	1	6154.43	7431.14	76.53	6792.79
8	2	1	0	2	6863.60	6948.66	76.78	6906.13
9	2	2	1	0	4228.53	8073.09	75.44	6150.81

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

* Larger-the better characteristic is used for compression test.

$$SN_i = -10\log\left(\frac{1}{n}\sum_{j=1}^{n}\frac{1}{y_{ij}^2}\right) \qquad \text{(Equation 4.1)}$$

Where; SN = Signal to Noise Ratio

n = number of observation in each row

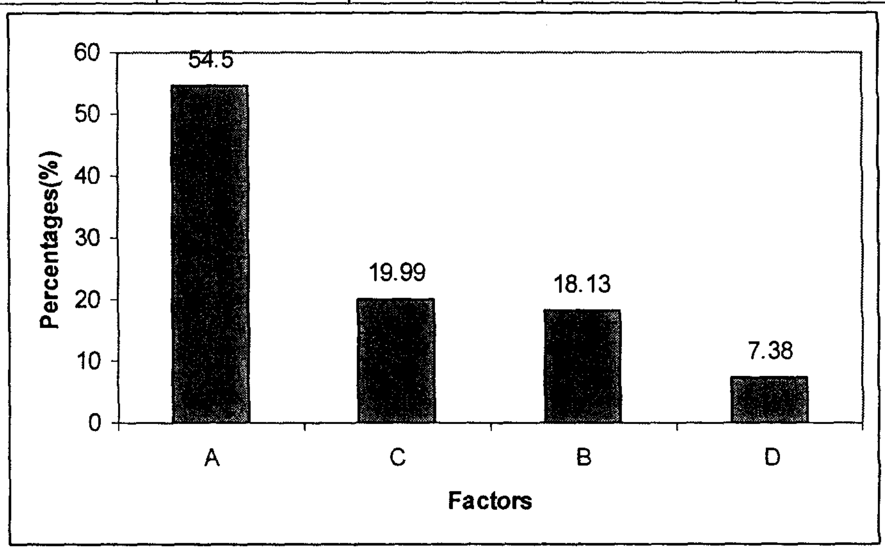
y = value of data from observations in each row *i*

Table 4.6 depicts Pareto ANOVA for Compression Test.

Table 4.6: Pareto ANOVA for Compression Test.

Factors and interaction		A Particle Size of SiC	B Weight Percentage of SiC	C Pouring Temperature	D Stirring Time	Total
Sum at factor level	0	227.18	227.63	230.75	228.64	690.7
	1	234.77	231.03	227.59	231.55	
	2	228.75	232.04	232.36	230.51	
Sum of squares of differences (S)		96.31	32.03	35.33	13.05	176.72
Contribution ratio (%)		54.5	18.13	19.99	7.38	100.0

Pareto Diagram



Factor and interaction	A	C	B	D
Cumulative contribution ratio (%)	54.5	74.49	92.62	100
Optimum condition	$A_1B_2C_2D_1$			
Overall optimum conditions for all factors	A_1 = 59µm (Particle size of SiC) B_2 = 15% (Weight percentage of SiC) C_2= 700°C (Pouring temperature) D_1 = 10 minutes (Stirring time)			
Estimate of error variance	V_e= (S_D/ 8)2 = (7.38 / 8)/2= 0.46			

Results of Confirmation Test for compression test.

Confirmation test for compression was unable to conduct due to break down of testing machine.

Table 4.5 shows the value of compressive strength for Al-Cu-SiC_p MMC during compression test in the range of 6000 MPa to 16000 MPa and Pareto ANOVA depicted on Table 4.6. From the Pareto ANOVA, particle sizes of SiC were determined as the most significant factor for compressive properties, 54.5 percent from total contribution ratio. With more than 50 percent of contribution ratio, particle sizes of SiC play important effect to the mechanical properties of the mixture. Z. Gnjidic *et al* (2001) revealed that sizes of reinforcement particles give an effect to the elastic modulus of MMC.

Secondly, pouring temperature became one of most significant factor which 19.99 percent. Pouring temperature has effects on mechanical properties (wear, toughness and hardness) as discovered by Fareed (2002). Temperature also may effect the grain growth of the mixture during melting and solidification. This follow by weight percentage of SiC with 18.13 percent. As mentioned before, the properties of Al-MMCs not only depended on particle sizes but also the volume fraction (weight percentage) as discussed by Sahin (2003).

Stirring time was found least significant effect for this mechanical property. It only consists of 7.37 percent. These results the optimum combination for optimum compressive properties for Al-Cu-SiC_p MMC is $A_1B_2C_2D_1$ which are 15 weight percentage of 59 μm size of SiC at pouring temperature of 725^0C and 10 minutes stirring time. So, the optimum combination is $A_1B_2C_2D_1$.

Graphs plotted (Figure 4.9 to 4.12) from data collected in Table 4.5 are shown below. All graphs are inline with the results on determining optimum condition for compressive strength. Peak or highest values of compressive strength indicate the optimum level of each factor. The values confirmed analysis in Pareto ANOVA, where optimum condition for compressive strength of Al-Cu-SiC_p MMC is $A_1B_2C_2D_1$. But unfortunately, conformity test was not be able to conduct due to break down of testing equipments. From the control factor condition designed through Taguchi's Robust

Parametric Array, there is the nearest condition to the optimum condition defined from the design of experiment (DOE). It is condition number 6 ($A_1B_2C_0D_1$). The difference is only at C factor where optimum condition require C_2 (750^0C) but the nearest is C_0 (675^0C). This condition shows the highest average compressive strength, 9410.06 MPa. Most probably, the optimum condition may reach higher than this value with C_2 condition.

Particle size of SiC was determined as the most significant factor on influencing compressive strength of the newly developed composite. The highest compressive strength values was obtained for the composite reinforced with 59 μm SiC particles. It is 8258.52 MPa. Pouring temperature and weight percentage of SiC were almost equal effect on influencing this property. Pouring temperature with 19.99 percent effect while 18.13 percent for weight percentage of reinforcement particles as shown in graphs depicted in Figure 4.10 and 4.11.

Trend in particle size of SiC's graph is expected in that normally decreasing particle sizes of particles are associated with improved mechanical characteristics of the particulate-reinforced MMCs. The probability of the reinforcement cracking increases with increasing particle size (Gnjidic et. al., 2001). This explained why bigger particle had lower value of compressive strength. The presence of SiC particles can be detrimental to the ultimate compressive strength of the composite materials because of the addition to the failure mechanisms of unreinforced aluminum alloy of particle cracking, particle matrix debonding and particle agglomerate decohesion (Majumdar et. al., 1984).

Stronger matrix alloy tend to produce stronger composites, but comparatively weak matrix such as aluminum should get additional benefits gained from the reinforcement particles. Reinforcement with harder material changed the aluminum alloy to become less ductile. As mentioned previously, bigger particles lower the strength of the composite to the compression load and provide more space for crack to occur. It is believed that the damage will occur first by particle fracture because the interface between SiC particles and aluminum is very strong. The bonding between particles grain is weak and lead to microcrack then fracture. Higher pouring temperature might slower the solidification of molten composite and increased the grain size. During casting, the molten composite should heat up until reached the desired pouring temperature.

Higher percentage of SiC particles added into the composites results the composite become tougher. The presence of SiC particles improved the ability of material withstand to compression load. Other researchers have previously reported that the reinforcement can support more applied load to the matrix (Doel et. al., 1996). The SiC particles can support stress until it become sufficiently large to cause damage by failure either at or near the interface, or by fracture of the particles.

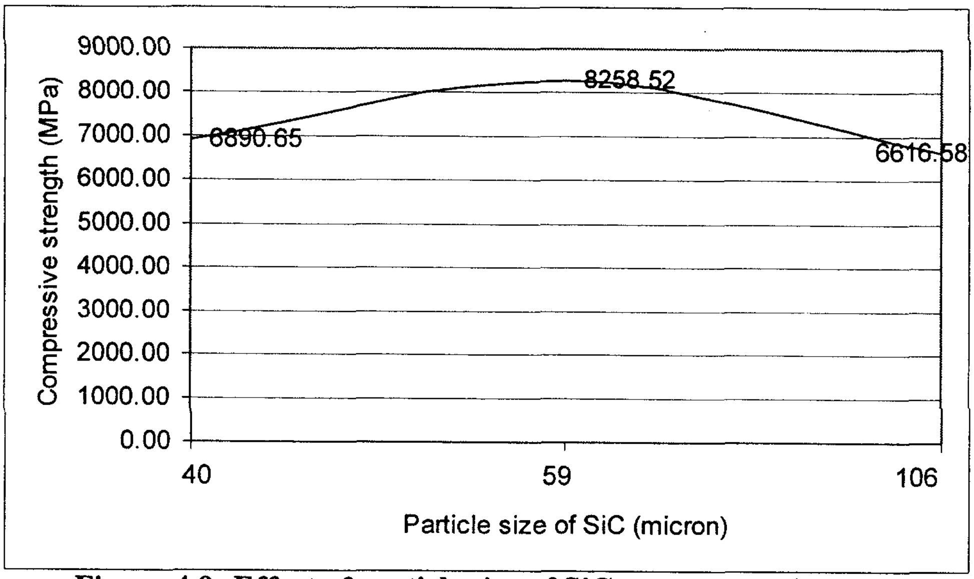


Figure 4.9: Effect of particle size of SiC on compressive strength

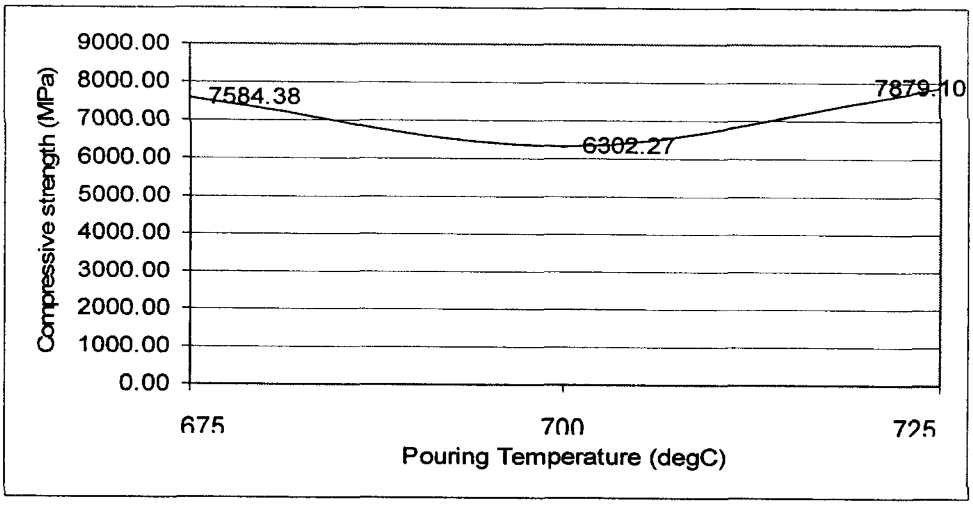


Figure 4.10: Effect of pouring temperature on compressive strength

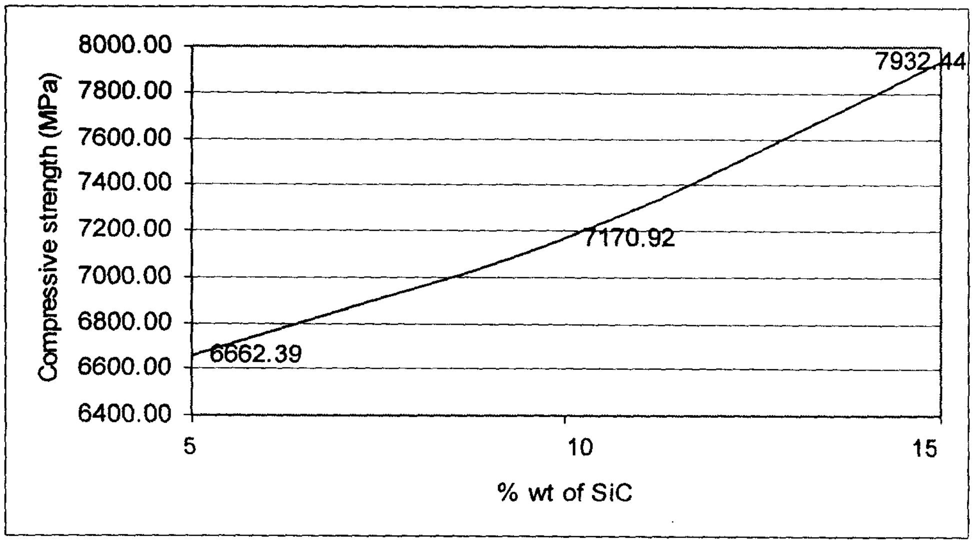


Figure 4.11: Effect of weight percentage of SiC on compressive strength

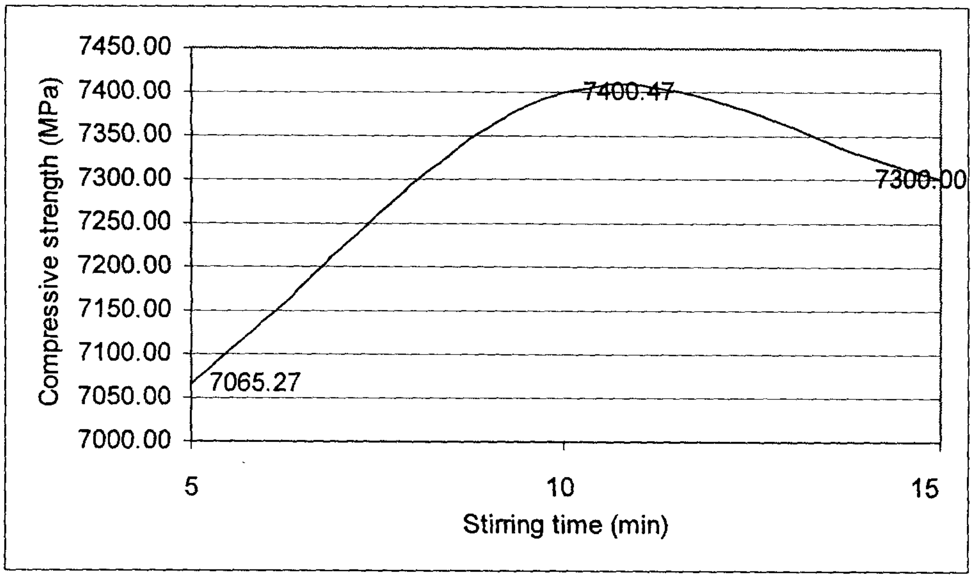


Figure 4.12: Effect of stirring time on compressive strength

4.1.4 Density Test

Value of density for each specimen was determined by using Ultrapynometer 1000. Pareto-ANOVA is applied on the findings in order to determine the significant factors which affect the wear resistance of Al-Cu-SiC_p MMC. Optimum combination factor also can be identified by this method. Results from this testing are shown in Table 4.9.

Table 4.7: Results For Density Test

Experiment Number	Control Factor Assignment				Replications (Density) g/cm^3		Signal to Noise, SN	Average Density (g/cm^3)
	A	B	C	D	1st	2nd		
1	0	0	0	0	2.6870	2.6780	-8.57	2.6825
2	0	1	1	1	2.6852	2.6332	-8.50	2.6592
3	0	2	2	2	2.7143	2.6506	-8.57	2.6825
4	1	0	1	2	2.6918	2.6919	-8.60	2.6919
5	1	1	2	0	2.7021	2.7112	-8.65	2.7067
6	1	2	0	1	2.6947	2.6996	-8.62	2.6972
7	2	0	2	1	2.6997	2.7077	-8.64	2.7037
8	2	1	0	2	2.6956	2.6940	-8.61	2.6948
9	2	2	1	0	2.7082	2.7139	-8.66	2.711

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

* Smaller-the better characteristic is used for density test.

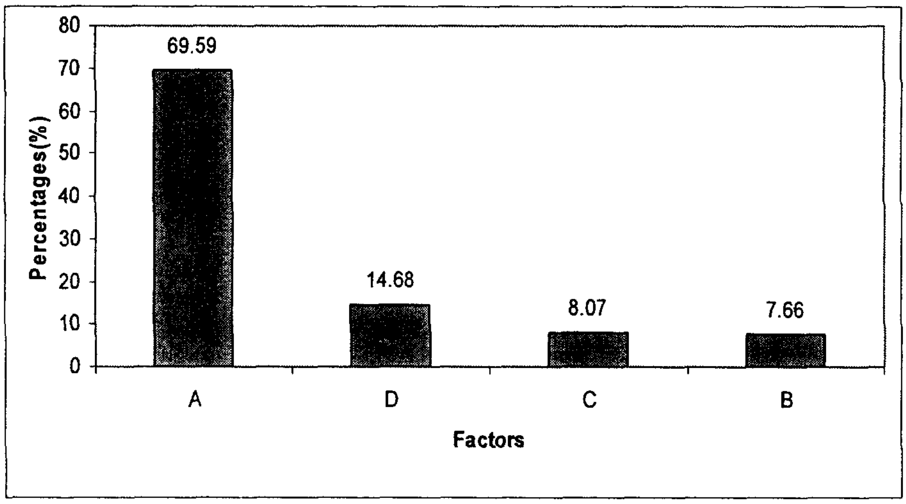
$$SNi = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} y_{ij}^{2}\right) \quad \text{(Equation 4.2)}$$

Where;
SN = Signal to Noise Ratio
n = number of observation in each row
y = value of data from observations in each row *i*

Table 4.10 depicts Pareto ANOVA for density test.

Table 4.10: Pareto ANOVA for Density Test

Factors and interaction		A Particle Size of SiC	B Weight Percentage of SiC	C Pouring Temperature	D Stirring Time	Total
Sum at factor level	0	-25.64	-25.81	-25.80	-25.88	-77.42
	1	-25.87	-25.76	-25.76	-25.76	
	2	-25.91	-25.85	-25.86	-25.78	
Sum of squares of differences (S)		0.1274	0.0122	0.0152	0.0248	0.1796
Contribution ratio (%)		69.59	7.66	8.07	14.68	100%

Pareto Diagram				
Factor and interaction	A	D	C	B
Cumulative contribution ratio (%)	69.59	84.27	92.34	100
Optimum condition	$\mathbf{A_0B_1C_1D_1}$			
Overall optimum conditions for all factors	A_0 = 40 µm (Particle size of SiC) B_1 = 10% (Weight percentage of SiC) C_1 = 700°C (Pouring Temperature) D_1 = 10 minutes (Stirring Time)			
Estimate of error variance	V_e= (S_b/ 8)2 = (0.0122/ 8)/2= 0.00076			

Results of Confirmation Test for density test.

Density at optimum conditions for lowest wear rate is 2.6592 g/cm^3

Density is the most important property of composite in this study. As density is proportionate with mass, lower density means lower mass of the material. Weight of material is directly proportional to its mass. It means by lowering density of a composite, we could have lighter material. Density is very meaningful to this study.

From Pareto-ANOVA method, the most significant factor that influences the density of Al-Cu-SiC$_p$ MMC can be determined. Based on this method, it is found that particle sizes of SiC are the most significant factor in density of Al-Cu-SiC$_p$ MMC. This factor contributes 69.59%. Other significant factors include stirring time, pouring temperature and weight percentage of SiC which recorded 14.68%, 8.07% and 7.66% respectively. The optimum combination that derived from Pareto ANOVA is $A_0B_1C_1D_1$. A_0 represents 40μm of SiC particles, B_1 for 10 percent of weight of SiC, C_1 for 700°C pouring temperature while D_1 represents 10 minutes stirring time.

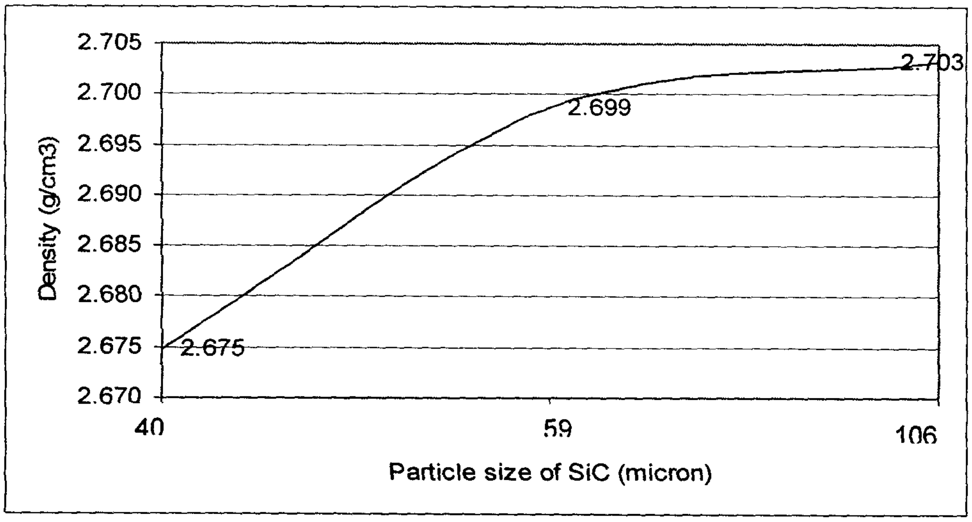


Figure 4.13: Effect of particle size of SiC on density

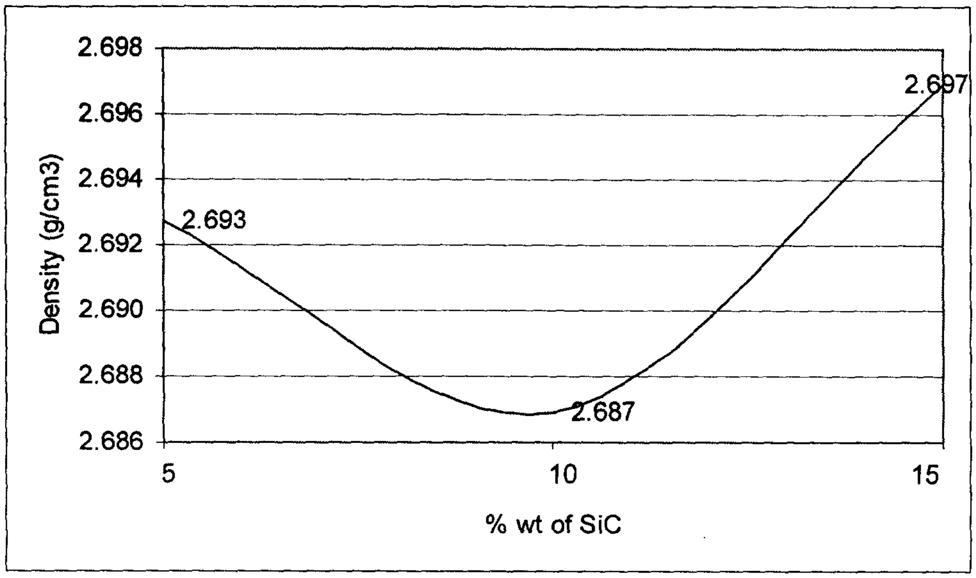


Figure 4.14: Effect of weight percentage of SiC on density

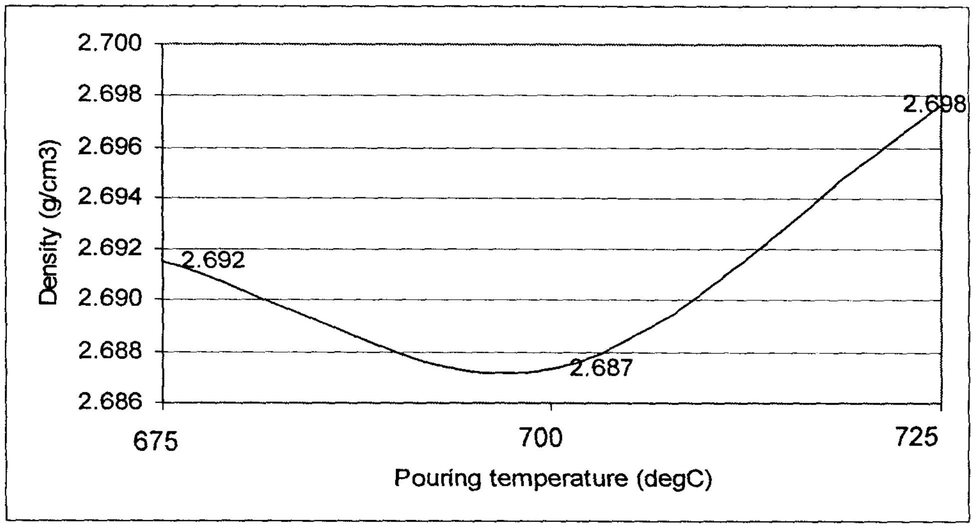


Figure 4.15: Effect of pouring temperature on density

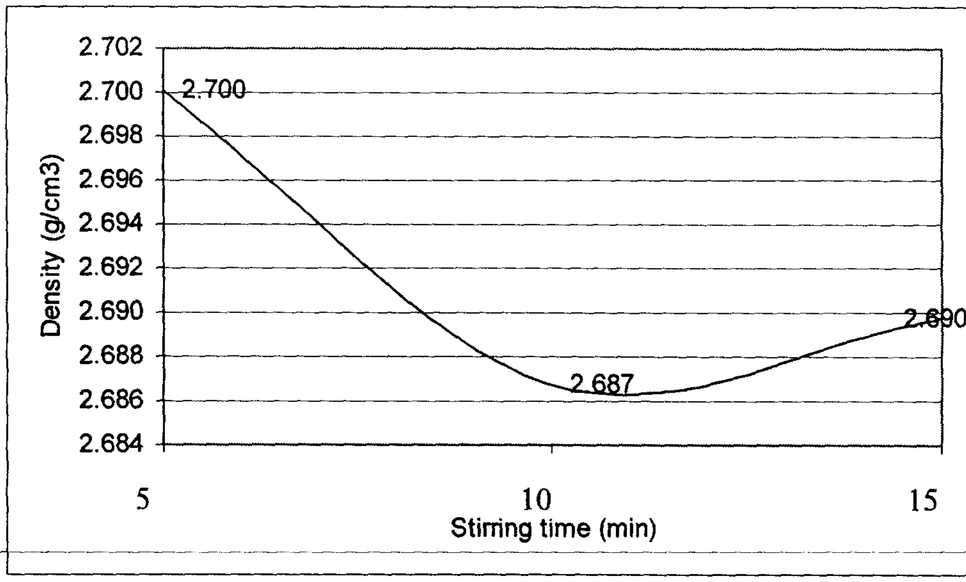


Figure 4.16: Effect of stirring time on density

From the graph in Figure 4.13, it shows the density increased with the increasing of particle size. This study aimed to have lowest density for lighter material. Density of the composite predicted becomes stable as the slant of the graph show very small increment as the particle size of particle increased. Minimum density recorded 2.67 g/cm^3 for 40 μm of SiC particles. This phenomenon may cause by bigger particles of SiC restricted the growth of porosity. Increases in size of particles might lead to bigger grain size formation which reduced the porosity. Density increased as porosity reduced. Even though porosity influenced on reduction of density but it also might decrease the hardness value of the material. In addition, increasing in wear rate might occur as the porosity could cause weaker bonding between grains resulting easier pulled out of particles. It also lowers the level of compressive strength. Therefore, optimum density needs to be determined with minimum level of porosity, so that other properties remain optimum.

Sahin (2003) found the density of the composite increased with increasing SiC volume fraction. Similar trend found in this study as shown in Figure 4.14. The graph shows density decreased from 5 percent to 10 percent of weight of SiC. But, when look at the value of density in particular, it was very small differences. Porosity level decrease with increasing of particle content. Higher volume of particles, geometric capturing of the particles restricts their movement inside the melt during solidification (Bindumadhavan et. al., 2001). Also, the presence of larger volume fraction of particles tends to physically restrict the growth of porosity (Samuel et. al., 1995). This density value also show similar trend for pouring temperature effect as shown in Figure 4.15. Furthermore, stirring effect contribute 14.68 percent of total contribution. 10 minutes become optimum time of stirring. Density decreased as the time of stirring increased, this might because of porosity had decreased. As mentioned before, stirring process might lead to porosity of the composite. This might best explanation why density decreases as stirring time increase.

4.2 Example of Calculations

This section will explain the example of calculations for analysis. It shows how the data were manipulated and constructive conclusions could be made based on the analysis.

4.2.1 Calculation of Signal to Noise Ratio (SN)

The calculation of SN ratio is based on the case of the test either:

i) Larger-the-better characteristics

$$SN_i = -10\log\left(\frac{1}{n}\sum_{j=1}^{n}\frac{1}{y_{ij}^2}\right) \quad \text{(Equation 4.1)}$$

ii) Smaller-the-better characteristic

$$SN_i = -10\log\left(\frac{1}{n}\sum_{j=1}^{n}y_{ij}^2\right) \quad \text{(Equation 4.2)}$$

iii) Nominal-is-the best caharacteristic

$$SN_i = 10\log\left[\frac{1}{n}\left(S_{m(i)}\right)/V_i\right] = 10\log\left[\frac{\left(\bar{y}_i\right)^2}{V_i}\right] \quad \text{(Equation 4.3)}$$

Where;
SN = Signal to Noise Ratio
n = number of observation in each row
y = value of data from observations in each row *i*

Larger-the-better characteristic was chosen for hardness, compressive strength and flexural break stress. While *smaller-the-better characteristic* is most suitable to apply for wear rate and density.

By referring to Table 4.1,

For instance for experiment no. 1 hardness test

Values given;

n = 2; y_{11} = 75.6; y_{12}= 76.3

$$SN_1 = -10\log\left[(\frac{1}{2})(\frac{1}{75.6^2}+\frac{1}{76.3^2})\right] = 37.61$$

4.2.2 Calculation of Pareto ANOVA table

By referring to Table 4.2: Pareto ANOVA for Hardness, examples of calculation for filling the table will be shown.

Calculation of Sum at Factor

For instance Sum at factor A level 0 (A_0);

Sum at A_0 Factor = $SN_1 + SN_2 + SN_3$ (Equation 4.4)

= 37.61 + 36.24 + 37.71 = 111.56

Calculation of Sum of squares of differences (S)

For instance sum of squares of differences (S) for factor A;

$S_a = (A_0-A_1)^2 + (A_0-A_2)^2 + (A_1-A_2)^2$ (Equation 4.5)

$= (111.56 - 113.62)^2 + (111.56 - 112.42)^2 + (113.62 - 112.42)^2$

= 4.2436 + 0.7396 + 1.44 = 6.4232

Calculation of Contribution Ratio

For instance contribution ratio for factor A;

% Contribution ratio for factor A = $(S_a / S_{total}) \times 100\%$ (Equation 4.6)

$= (6.4232 / 32.525) \times 100\%$

$= 19.75\ \%$

Determination of Significant and Optimum factor

Optimum factor is chosen based on values of sum at significant factor. From Table 4.2, factor A, B and D are identified as significant factor. From these factors, the largest value of sum at each significant factor is chosen as optimum factor. Largest value is chosen because "largest- better characteristic" approach was used in this calculation.

For instance; Factor A

Sum at factor level 0, $A_0 = 111.56$

Sum at factor level 1, $A_1 = 113.62$ **(Largest value)**

Sum at factor level 2, $A_2 = 112.42$

A_1 is chosen as optimum factor A because it has largest value.

4.3 Comparison between Gray Cast Iron and Al-Cu-SiC$_p$ MMC

In this experimental study, the newly developed Al-Cu-SiC$_p$ MMC will be compared with gray cast iron from the aspect of density and hardness. Comparison is made to determine whether Al-Cu-SiC$_p$ MMC is suitable be an alternative material for disc brake in the aspect of density and hardness. For wear resistance, comparison will not be conducted due to wear resistance's data for gray cast iron is not available. Besides from hardness and density, there are also others mechanical and physical properties which are important to composite brakes. It includes thermal conductivity, specific heat, shear strength, flexural strength and compressive strength (Blau, 2001). However due to materials, and time constrains; only hardness and density test to be conducted. Table 4.11 shows comparison between gray cast iron and Al-Cu-SiC$_p$ MMC.

Table 4.8 Comparison Between Gray Cast Iron and Al-Cu-SiC$_p$ MMC

Num	Types of Material	Density (g/cm^3)	Vickers Hardness (HV)
1	Gray Cast Iron		246
2	SAE J431 automotive gray cast iron, SAE grade G1800		195
3	SAE J431 automotive gray cast iron, SAE grade G2500		209
4	SAE J431 automotive gray cast iron, SAE grade G3000		225
5	SAE J431 automotive gray cast iron, SAE grade G3500	7.15	243
7	SAE J431 automotive gray cast iron, SAE grade G4000		256
8	Al-Cu-SiC$_p$ MMC *(lowest value of density)	2.6332	65.2
9	Al-Cu-SiC$_p$ MMC *(highest value of density)	2.7143	80.4

* Specimen developed in this experimental study

As we all know, the density of Al-Cu-SiC$_p$ MMC is lower than cast iron. And there is no doubt on this theory. This shows the addition of SiC particles in the aluminum matrix will reduces the composite's density.

Therefore by using Al-Cu-SiC_p MMC as brake material, it will reduce the weight of the vehicle significantly. Consequently, lesser petrol will be used. However, when compare to the aspect of hardness, there is a doubt on its hardness reliability. It seems that Al-Cu-SiC_p MMC possesses lower hardness value than gray cast iron. It may due to lower hardness of matrix material, aluminum. The addition of hard ceramic particles (SiC) to the aluminum is not good enough to resist any plastic deformation from the indenter. Other factors such as porosity and segregation of SiC particles in the matrix also contribute to these results. When porosity or segregation occurred in Al-Cu-SiC_p MMC, the applied force from the indenter is not distributed evenly to the ceramic reinforcements. As the results, aluminum has to sustain the force. This leads to lower hardness result. Disc brakes with lower hardness value is dangerous as it tends to fail when the pad shoe apply force into it.