CHAPTER 1
INTRODUCTION

1.1 PROJECT BACKGROUND

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material (ceramic or organic compound) [1].

Aluminum alloys were some of the most widely used material as the matrix in MMCs. This is mainly due to the low density of aluminum alloys. Moreover, they are cheap if compared with other low density alloys (such as Mg or Ti). Finally, aluminum alloys are very well-known alloys due to their high use in several industries, from automotive and aeronautic to leisure. Their excellent behavior, from different points of view (strength, ductility, corrosion), is very well known and can be modified in order to satisfy different applications [2].

Carbon Nanotubes (CNTs), acts as reinforcement material to the Aluminum, are molecular-scale tubes of graphitic carbon with outstanding properties. They are among the stiffest and strongest fibers known, with Young's modulus as high as 1 TPa and tensile strengths of up to 150 GPa. They also have remarkable electronic properties and can be metallic or semiconducting depending on their structure and diameter [3, 4].

Material for this project is CNTs reinforced aluminum composite. The material samples will be fabricated using Powder Metallurgy (P/M) technique. P/M process involves mixing elemental or alloy powders, compact the mixture in a die and the resultant shapes are then sintered or heated in a controlled-atmosphere furnace to bond the particles metallurgically [5]. However, the effect of sintering time in P/M technique on properties of CNTs reinforced aluminum composite is not well understood yet.

1.2 PROBLEM STATEMENT

To obtain the higher strength to weight ratio encourage for the fabrication of new composite materials which fulfill the requirement of advanced industries towards reducing energy consumption and cost as well. CNTs reinforced aluminum composite is one of the newly fabricated materials how fulfilling the requirement of new era.

1.3 OBJECTIVE AND SCOPE OF STUDY

1.3.1 Objectives

The objectives of this project are to fabricate CNTs reinforced aluminum composite using Powder Metallurgy technique and to study the effect of sintering time on properties of CNTs reinforced aluminum composite.

1.3.2 Scope of Study

The scope of this project involves characterization of initial aluminum powder and CNTs powder using Scanning Electron Microscope (SEM), X-ray Energy Dispersion (EDX) and particle size analyzer, fabrication of green test samples by using powder metallurgy technique, follow by sintering the green samples for different interval of time (60 min, 90 min and 120 min) and finally, characterization of the sintered test samples for their properties (dimension, density, hardness and correlated tensile strength) and microstructure analysis for justification.

CHAPTER 2

LITERATURE REVIEW

2.1 MATERIAL SELECTION

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material (ceramic or organic compound). MMC are made by dispersing a reinforcing material into a metal matrix. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity [1].

For a long period of time, aluminum alloys were some of the most widely used material as the matrix in MMCs, both in research and development and in industrial applications. This is mainly due to the low density of aluminum alloys (the first requirement in most applications). Moreover, they are cheap if compared with other low density alloys (such as Mg or Ti). Finally, aluminum alloys are very well-known alloys due to their high use in several industries, from automotive and aeronautic to leisure. Their excellent behavior, from different points of view (strength, ductility, corrosion), is very well known and can be modified in order to satisfy different applications [2].

The most common reinforcing materials are alumina and silica carbide [1]. There is growing interest in the addition of carbon nanotubes to metal matrices, although only a small number of studies have been published to date. Carbon Nanotubes (CNTs) are molecular-scale tubes of graphitic carbon with outstanding properties. They are among the stiffest and strongest fibers known, with Young’s modulus as high as 1 TPa and tensile strengths of up to 150 GPa. They also have remarkable electronic properties and can be metallic or semiconducting depending on their structure and diameter [3, 4]. CNTs could be an ideal reinforcing phase to design aluminum matrix composites to improve aluminum alloys wear and creep resistance. Multi-wall carbon nanotubes (MWCNTs) are much cheaper than single-wall carbon nanotubes (SWCNTs) and hence we will be using MWCNTs in the current experimental studies for cost-effectiveness. Carbon nanotubes are able to bend over to surprisingly large angles, before they start to ripple and buckle, and then finally develop kinks as well. The amazing thing about carbon nanotubes is that these deformations are elastic - they all disappear completely when the load is removed [3, 6]. P. J. F. Harris described the preparation of carbon nanotube/metal composites in 2004. The method involved mixing a nanotube sample with a fine aluminum powder, mounting the mixture in a 6 mm silver sheath, and then drawing and heating the wire at 700^{o}C in a vacuum furnace. The result was a composite wire in which the nanotubes were partially aligned along the axial direction. The tensile strength was comparable with pure aluminum, but the composite wires retained this strength after prolonged annealing at 600^{o}C, while the strength of pure aluminum decreased by about 50% after this treatment [3]. The fabrication technique used by P. J. F. Harris is different with this project which this project does not require the mixing sample to be drawn. Instead, the mixing sample will be compact before sinter in an inert atmosphere furnace.

Most available CNTs for commercial composite application are grown by chemical vapor deposition (CVD), which can produce CNTs at large scale in low cost. However, CVD CNTs have more defects along their outer walls and impurities such as amorphous carbon. The impurities are prone to reacting with metal matrix during processing of composites, and greatly affect the dispersion of CNTs. Hence, the purification and dispersion of CNTs before the fabrication of the composite is very important to obtain the uniform distribution of CNTs in metal matrix [7]. The MWCNTs are first cleaned by distilled water and then surface-treated before mixing with aluminum powder. Initially, MWCNTs are sonicated for 4 hours in 63 vol. % nitric acid and filtered. The filtered acidic MWCNTs are neutralized with sodium hydroxide solution, and then dried by heating them in an oven at 110^{o}C for 2 hours. Finally for better adhesion between the MWCNTs and Al powder, they were treated with sodium dodecyl sulfate (SDS) surfactant, which decreases the van de Walls force of attraction between the MWCNTs [8].

Deng Chunfeng et al. claim that when the content of MWCNTs is less than 1.0 wt. %, MWCNTs can uniformly distributed on the surface of aluminum powder; however, when the content of MWCNTs is 2.0 wt. %, MWCNTs entangle with each other on the surface of aluminum powder [7].

2.2 FABRICATION TECHNIQUE

Powder Metallurgy (P/M) technique will be used to fabricate the CNTs reinforced aluminum composite samples. P/M is a highly developed method of manufacturing reliable ferrous and nonferrous parts. The aluminum P/M process consists of three basic steps:

2.2.1 Aluminum powders with 99% purity and particle size are mixed with alloying metal powders in precisely controlled quantities. Generally a powdered lubricant is added to permit the consistent production of high density parts without seizing of the punches or cold welding to the die wall. The lubricant is carefully chosen to ensure that there is no residual ash to interfere with bonding during sintering.

2.2.2 The premix is compacted using precision metal die in specially designed P/M presses to yield a green compact. Aluminum premixes exhibit excellent compressibility and yield high density parts at low compaction and ejection pressure.

2.2.3 The green compacts are sintered in a controlled atmosphere furnace at closely regulated temperatures. This process metallurgically bonds the powder particles together and develops the desired physical and mechanical properties. Aluminum powder sintering is difficult to achieve because the aluminum oxide is not reduced by common furnace atmosphere at sintering temperatures. However, successful sintering is accomplished in environment containing hydrogen, nitrogen and argon as long as the following conditions are observed:

- The lubricant is essentially free of moisture and low in ash contact.
- Atmospheres contain low levels of moisture and oxidizing gases.
- Alloying elements having a high solubility in aluminum are added to generate low melting phases [9].

Advantages of the P/M process are eliminates or minimizes machining by producing parts at, or close to, final dimensions, eliminates of minimizes scrap losses by typically using more than 97% of the starting raw material in the finished part, permits a wide variety of alloy systems, produces good surface finishes, provides materials which may be heat treated for increased strength or increased wear resistance, provides controlled porosity for self lubrication or filtration, facilitates manufacture of complex or unique shapes which would be impractical or impossible with other metalworking processes, is suited to moderate- to high-volume component production requirements, offers long-term performance reliability in critical applications and is cost effective [5].

The sintering temperature is below the melting temperature of the metal matrix in P/M restraining the interfacial reaction between the CNT and the metal matrix [7].

2.3 CHARACTERIZATION OF SINTERED SAMPLES

Characterization of the sintered samples are based on density, dimensions, mechanical properties (hardness and tensile strength) and microstructure analysis before and after the sintering using tools that are available in the UTP.

CHAPTER 3

METHADOLOGY

3.1 RESEARCH METHODOLOGY FOR FINAL YEAR PROJECT I

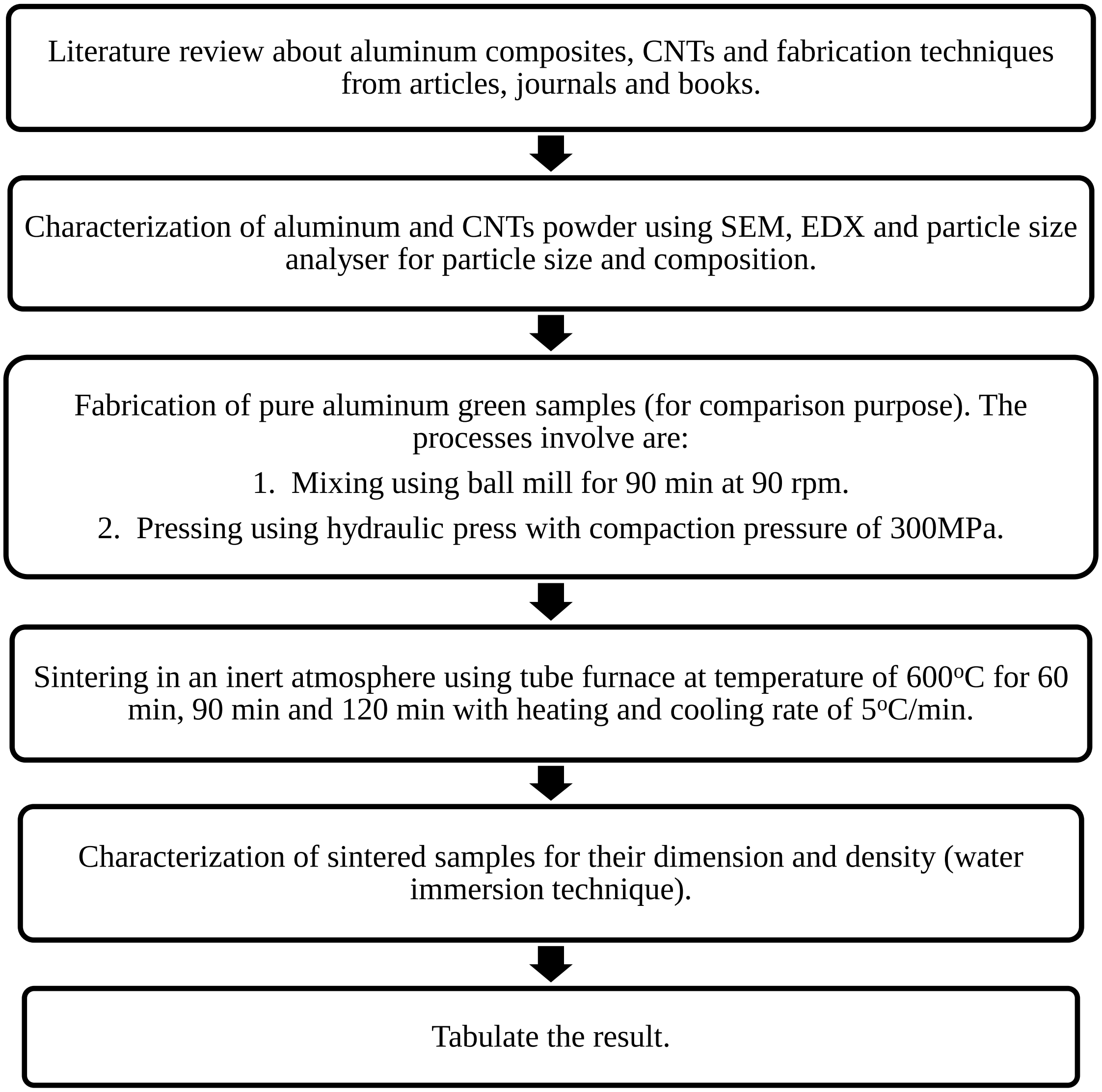
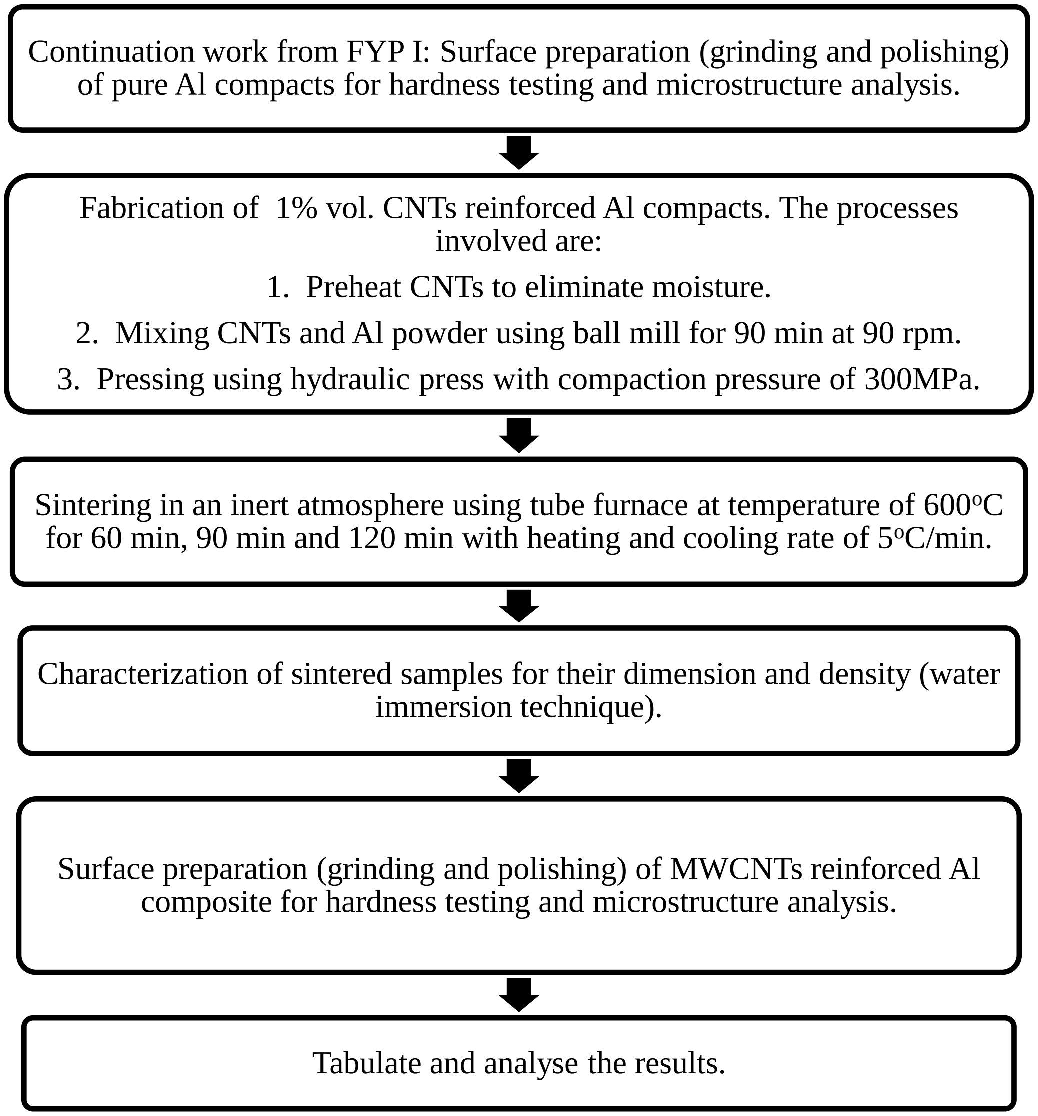


Fig. 1: Research Methodology of the FYP I

3.2 RESEARCH METHODOLOGY FOR FINAL YEAR PROJECT II



Continuation work from FYP I: Surface preparation (grinding and polishing) of pure Al compacts for hardness testing and microstructure analysis.

Fabrication of 1% vol. CNTs reinforced Al compacts. The processes involved are:

1. Preheat CNTs to eliminate moisture.
2. Mixing CNTs and Al powder using ball mill for 90 min at 90 rpm.
3. Pressing using hydraulic press with compaction pressure of 300MPa.

Sintering in an inert atmosphere using tube furnace at temperature of 600°C for 60 min, 90 min and 120 min with heating and cooling rate of 5°C/min.

Characterization of sintered samples for their dimension and density (water immersion technique).

Surface preparation (grinding and polishing) of MWCNTs reinforced Al composite for hardness testing and microstructure analysis.

Tabulate and analyse the results.

Fig. 2: Research Methodology of the FYP II

3.3 TOOLS REQUIRED

All tools required are available in UTP. The tools are Ball Mill, hydraulic press, Tube Furnace, Scanning Electron Microscope (SEM), Energy-dispersive X-ray spectroscopy (EDX), particle size analyzer and Water immersion technique (for density).

3.4 GANTT CHART FOR FINAL YEAR PROJECT I

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Selection of project topic	■	■						Mid-Semester Break							
2.	Background study and literature review			■	■	■	■	■		■	■	■	■	■	■	■
3.	Submission of Preliminary Report				▲											
4.	Initial material characterization					■	■	■								
5.	Submission of Progress Report									▲						
6.	Seminar									▲						
7.	Fabrication of pure aluminum samples for comparison purpose									■	■	■				
8.	Characterization of sintered pure aluminum samples (dimension and density)												■	■	■	■
9.	Submission of Interim Report Final Draft															▲
10.	Oral Presentation									During Study Week						

▲ Milestone

■ Process

Table 1: Gantt chart for the FYP I

3.5 GANTT CHART FOR FINAL YEAR PROJECT II

No	Detail/Week	1	2	3	4	5	6		9	10	11	12	13	14
1.	Grinding and polishing pure Al compacts	▨	▨	▨	▨			Mid-Semester Break						
2.	Fabrication of 1% vol. MWCNTs reinforced Al composite		▨	▨	▨	▨	▨							
3.	Submission of Progress Report I				▲									
4.	Hardness testing of pure Al compacts					▨	▨							
5.	Submission of Progress Report II								▲					
6.	Seminar									▲				
7.	Surface preparation and hardness testing of 1% vol. MWCNTs reinforced Al compacts								▨	▨	▨	▨		
8.	Microstructure analysis of pure Al compacts									▨				
9.	Microstructure analysis of MWCNTs reinforced Al compacts										▨	▨		
10.	Poster Exhibition										▲			
11.	Submission of Dissertation Final Draft													▲
12.	Oral Presentation								During Study Week					
13.	Submission of Dissertation (hard bound)								7 days after oral presentation					

▲ Milestone

▨ Process

Table 2: Gantt chart for the FYP II

3.6 PROJECT PLANNING

3.6.1 Material characterization:

3.6.1.1 Al powder – SEM (particle shape, EDX and particle size) and Particle Size Analyzer

3.6.1.2 CNTs powder – SEM (particle shape, EDX and particle size)

3.6.2 Mixing

3.6.2.1 Ball Mill – 90 min. at 90 rpm

3.6.3 Pressing

3.6.3.1 Hydraulic press

3.6.3.2 Compaction pressure – 300 MPa [4]

3.6.3.3 Characterization of green samples

- Dimension
- Density – water immersion technique

3.6.4 Sintering

3.6.4.1 Tube Furnace

3.6.4.2 Heating and cooling rate – 5^{o}C/min

3.6.4.3 Sintering temperature – 600^{o}C (91% from Al melting point) [10]

3.6.4.4 Sintering atmosphere – Nitrogen [11]

3.6.4.5 Sintering time [4, 10]

- 60 min
- 90 min
- 120 min

3.6.5 Characterization of sintered samples

3.6.5.1 Dimension
3.6.5.2 Density – water immersion technique
3.6.5.3 Hardness – Vickers hardness tester
3.6.5.4 Correlated tensile strength from hardness data
3.6.5.5 Microstructure analysis (for justification purpose)

- Optical Microscope
- FESEM

Total samples required = 9 samples of CNTs reinforces Al composite.

= 9 samples of pure Al for comparison purpose.

3.7 CALCULATION

3.7.1 Volume of one tablet

One tablet is estimated to have diameter of 13mm and height of 3mm.

D=13mm

h=3mm

$V=\pi r^2 h = \pi (13/2)^2(3)$

$= 398.2\ \text{mm}^3$

$= 0.3982\ \text{cm}^3$

3.7.2 Mass of one tablet of pure aluminum

$$\rho = \frac{m}{V}$$

$$m = \rho . V$$

$= (2.7\ \text{g/cm}^3)\ (0.3982\ \text{cm}^3)$

$= 1.075\ \text{g}$

3.6.3. 1% volume of CNTs reinforcement

$$\rho_{th} = \rho_{Al} . V_{Al} + \rho_{CNTs} . V_{CNTs}$$

$= (2.7\ \text{g/cm}^3)\ (0.99) + (1.8\ \text{g/cm}^3)(0.01)$

$= 2.691\ \text{g/cm}^3$

$$m = \rho_{th} . V$$

$= (2.691\ \text{g/cm}^3)\ (0.3982\ \text{cm}^3)$

$= 1.0716\ \text{g}$

$$m_{CNTs} = \frac{1}{100}\, x\ 1.0716\ g = 0.010716\ g$$

$$m_{Al} = \frac{99}{100}\, x\ 1.0716\ g = 1.0609\ g$$

3.6.4. Compaction pressure

= 300 MPa

$$P = \frac{F}{A}$$

$$A = \pi r^2$$

$= \pi\ (13/2)^2 = 132.7\ mm^2$

$F = PA = 300 \times 10^6 \times 132.7 \times 10^{-6}$

$= 40\ 000$ N

F = mg

$$m = \frac{F}{g} = \frac{40\ 000\ N}{10}$$

= **4000 kg**

CHAPTER 4
RESULT AND DISCUSSION

4.1 MATERIAL CHARACTERIZATION

Initial characterization of aluminum and MWCNTs powders is done using Scanning Electron Microscope (SEM) as shown in the figures below. SEM micrograph of aluminum powder shows irregularity in particle shape, given as Figure 3.

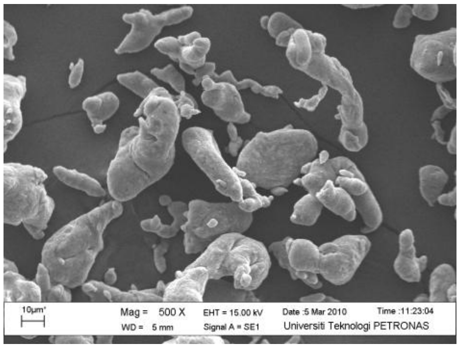


Fig. 3: SEM micrograph of
aluminum powder: 500x

The micrograph of MWCNTs obtained through SEM is shown in Figure 4 below. The MWCNTs have tubular shape with nominal diameter of 190 nm, and average length of 5-10 µm. The SEM micrograph below shows that the CNTs tend to clump together due to van de Walls force of attraction between them [8].

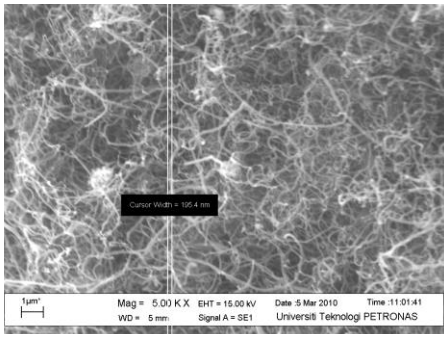


Fig. 4: SEM micrograph of
MWCNTs: 5000x

Particle size distribution for pure aluminum was between 2.884 µm to 158.489 µm as measured by Particle Size Analyzer and the result is shown in Figure 5.

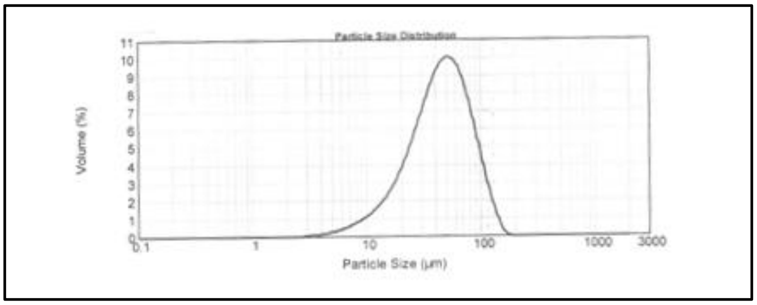


Figure 5: Particle size distribution of pure aluminum powder

The aluminum powder used contains 96.43 weight % of aluminum and with little presence of Oxygen and Argentum as shown in the Table 3 and Figure 6 below.

Element	Weight%	Atomic%
O K	2.68	4.46
Al K	96.43	95.32
Ag L	0.90	0.22
Totals	100.00	

Table 3: Elemental composition of aluminum powder

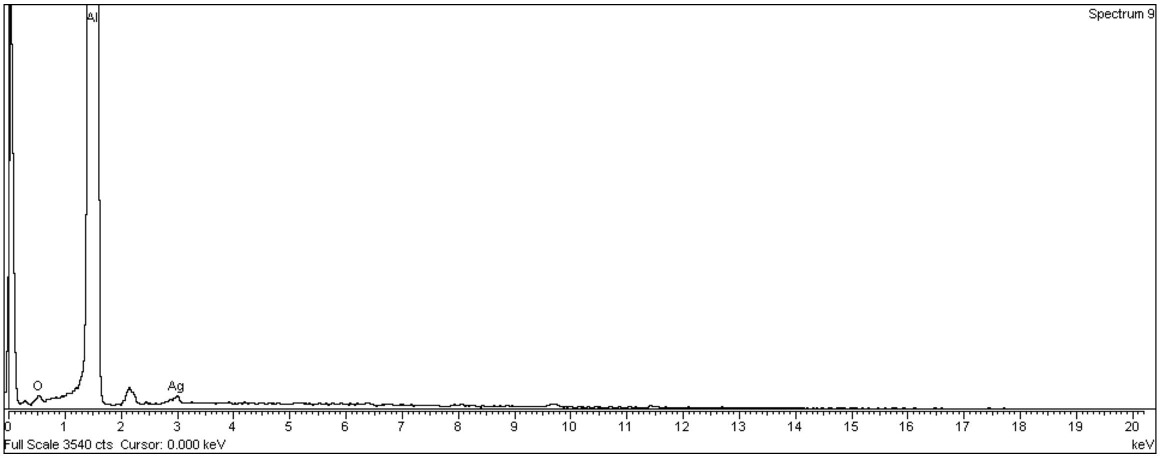


Fig. 6: EDX spectra of aluminum powder

The MWCNTs used consists 93.22 weight % of MWCNTs with little presence of Oxygen and Nickel as shown in Table 4 and Figure 7 below.

Element	Weight%	Atomic%
C K	93.22	95.03
O K	6.39	4.89
Ni K	0.39	0.08
Totals	100.00	

Table 4: Elemental composition of MWCNTs powder

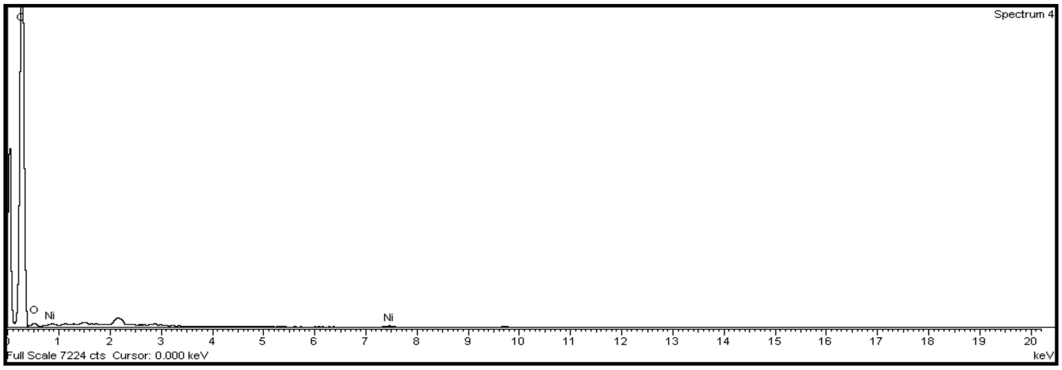


Fig. 7: EDX spectra of MWCNTs powder

4.2 FABRICATION OF GREEN SAMPLES

Nine pure aluminum samples were fabricated for comparison purpose. All the samples were compacted in hydraulic press for 300 MPa. The samples were sintered in Nitrogen atmosphere with sintering time as shown below:

4.2.1. 60 minutes sintering time:

- AL60a
- AL60b
- AL60c

4.2.2. 90 minutes sintering time:

- AL90a
- AL90b
- AL90c

4.2.3. 120 minutes sintering time:

- AL120a
- AL120b
- AL120c

Nine samples of 1% vol. MWCNTs reinforced aluminum composite were fabricated using hydraulic press and sintered with sintering time as shown below:

4.2.4. 60 minutes sintering time:

- AMC60a
- AMC60b
- AMC60c

4.2.5. 90 minutes sintering time:

- AMC90a
- AMC90b
- AMC90c

4.2.6. 120 minutes sintering time:

- AMC120a
- AMC120b
- AMC120c

Pictures of compacted pure aluminum sample are as shown in Figure 8 and 9.

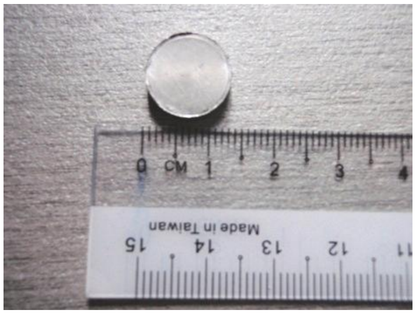


Fig. 8: Diameter of compacted pure Al sample is 13mm.

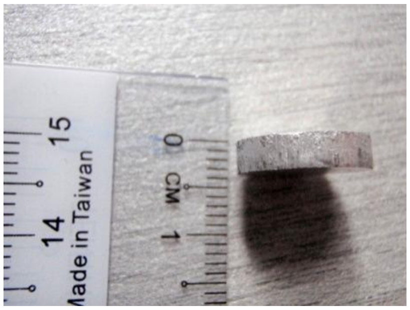


Fig. 9: Thickness of compacted pure Al sample is 3mm.

After measured the dimension and density of the sintered pure aluminum samples, the samples were mounted using hot mounting press as shown in Figure 10 and grinded using different grit papers (600-4000 grit) followed by polishing using 5µm and 1µm alumina paste to obtain good surface finish before proceed with the hardness measurement and microstructure analysis.

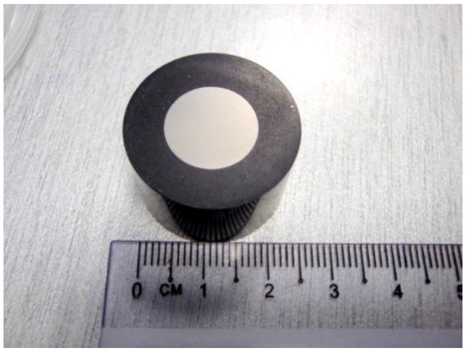


Fig. 10: Mounted pure aluminum sample

4.3 EXPANSION OF ALUMINUM AND MWCNTs REINFORCED ALUMINUM COMPOSITE AFTER SINTERING

The volumetric thermal expansion of the samples is shown in the Table 5 and Figure 11 below. All substances expand or contract when their temperature changes, and the expansion or contraction always occurs in all directions. Substances that expand at the same rate in any direction are called isotropic.

Fabricated Composite	Sintering Time (min) Thermal Expansion (%)		
	60	90	120
Pure Al	0.41	0.98	-0.56
AMC	4.72	3.34	2.91

Table 5: Volumetric thermal expansion of Al and MWCNTs reinforced Al composite

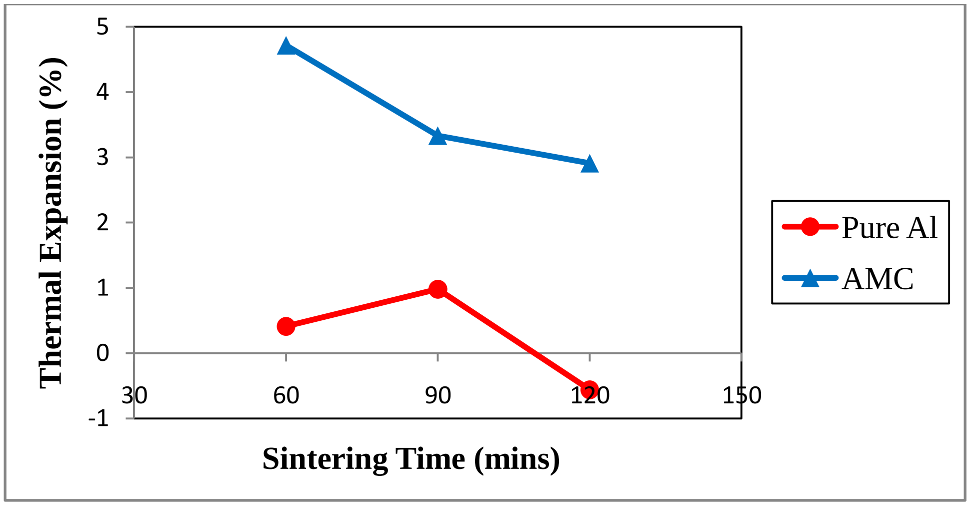


Fig. 11: Relationship between thermal expansion and sintering time of Al and MWCNTs reinforced Al composite

AMC shows more expansion than aluminum. AMC experienced 5% expansion after sintered for 60 minutes and as sintering time increases, the thermal expansion of AMC decreases. AMC expanded more than aluminum may be due to poor dispersion of MWCNTs with the matrix material which causes more porosity at the grain boundary.

4.4 EFFECT OF SINTERING TIME ON DENSITY

Theoretical density was calculated by rule of mixture. Green density and sintered density were measured by water immersion technique. The samples were sintered for 60, 90 and 120 minutes and results were examined. The effect of sintering time on density of samples is shown in the Table 6, Table 7 and Figure 12 below.

Green sample	Theoretical density (g/cm^3)	Green density (g/cm^3)	Sintered density (g/cm^3)	Relative density (%)
AL60a	2.70	2.54	2.59	96.00
AL60b	2.70	2.52	2.60	96.19
AL60c	2.70	2.58	2.62	96.85
AL90a	2.70	2.51	2.63	97.37
AL90b	2.70	2.52	2.62	96.96
AL90c	2.70	2.60	2.61	96.67
AL120a	2.70	2.58	2.62	97.07
AL120b	2.70	2.52	2.60	96.44
AL120c	2.70	2.53	2.61	96.52
AMC60a	2.69	2.51	2.57	95.65
AMC60b	2.69	2.52	2.58	95.73
AMC60c	2.69	2.51	2.58	95.99
AMC90a	2.69	2.48	2.59	96.32
AMC90b	2.69	2.48	2.63	97.59
AMC90c	2.69	2.48	2.59	96.40
AMC120a	2.69	2.48	2.59	96.40
AMC120b	2.69	2.48	2.42	89.74
AMC120c	2.69	2.51	2.57	95.58

Table 6: Effect of sintering time on relative density of Al and MWCNTs reinforced Al composite

The average of green density and sintered density of pure aluminum and MWCNTs reinforced aluminum composite was measured from the 3 samples of every sintering time to study the effect of sintering time on the compacts' density.

Fabricated Composite	Theoretical Density (g/mm^3)	Green Density (g/mm^3)	Sintering Time (min) / Sintered Density (g/mm^3)		
			60	90	120
Pure Al	2.70	2.55	2.60	2.62	2.61
AMC	2.69	2.49	2.58	2.60	2.53

Table 7: Comparison between densities of pure Al and MWCNTs reinforced Al composites

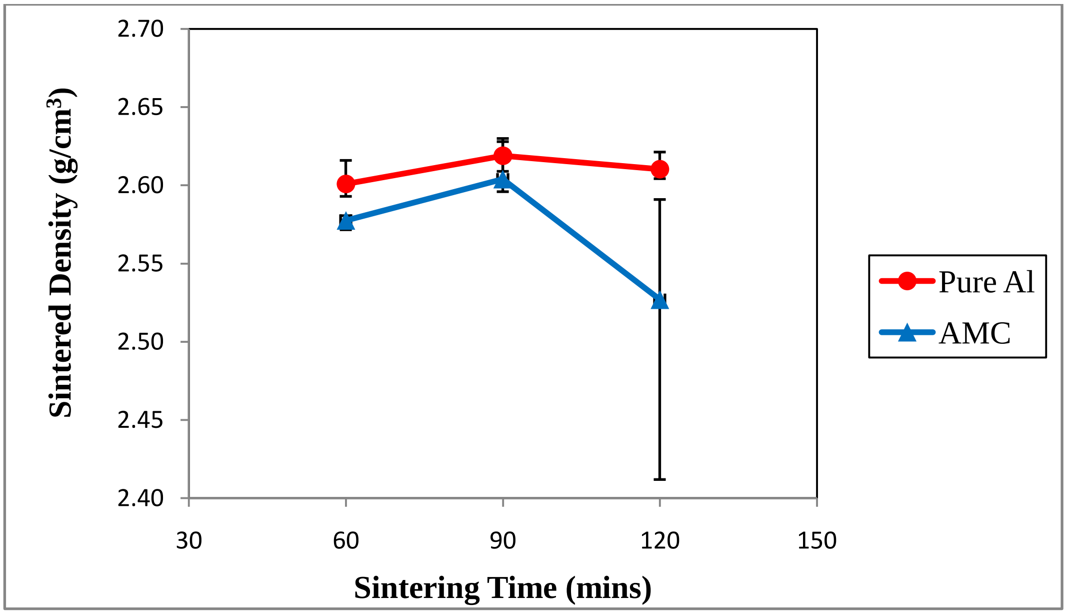


Fig. 12: Sintered density of Al and MWCNTs reinforced Al composite versus sintering time

Figure 12 shows that density of pure aluminum increases as sintering time is increased before it is slightly decreased when sintering for 120 minutes. The density of pure aluminum sintered for 60 minutes is 2% increased from the green density and 96% of its theoretical density. An increase of 1% was observed when sintering time was increased to 90 minutes. However, the density slightly 0.4% decreased as sintered at 120 minutes.

The graph shows that AMC sintered for 60 minutes achieved 4% increment in density over the green density. The density of AMC shows further increment of 1% when sintering time increased from 60 minutes to 90 minutes. However, 3% decrease in density of AMC was observed when sintering time increased to 120 minutes. It may be due to over sintering in which material loss its properties with large sintering time at peak temperature. The microstructure gets large grain and enlarged porosity. Presence of porosity can be seen through the Optical Microscope (OM) as shown in Figure 13 and 14 below:

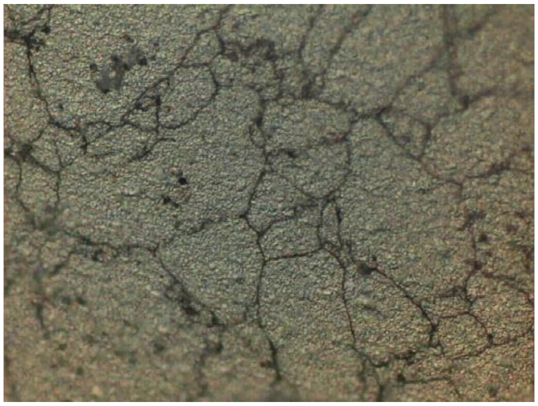


Fig. 13: OM micrograph of Al sintered for 120 min. shows grain growth and porosity: 100x

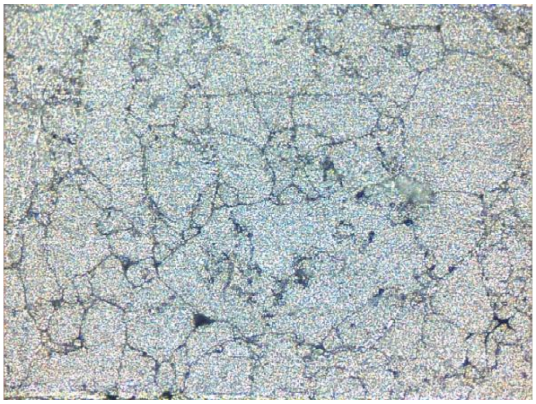


Fig. 14: OM micrograph of sintered Al for 120 min. shows presence of porosity: 50x

4.5 EFFECT OF SINTERING TIME ON HARDNESS

Every three compacts of each sintering time has been indented at five different places and the hardness values of the aluminum and MWCNTs reinforced aluminum composite are shown in the Table 8.

Hardness	HV1	HV2	HV3	HV4	HV5	Avg. HV
AL60a	26.10	27.60	27.80	27.20	27.50	27.24
AL60b	28.60	26.40	28.90	25.20	29.00	27.62
AL60c	25.10	26.10	29.10	29.10	27.90	27.46
AL90a	29.40	30.10	28.40	27.50	30.90	29.26
AL90b	30.70	32.50	29.70	28.50	24.50	29.18
AL90c	28.80	30.70	29.60	24.80	29.80	28.74
AL120a	32.90	30.20	31.60	29.20	30.70	30.92
AL120b	28.00	29.20	29.40	31.30	30.20	29.62
AL120c	29.70	31.40	30.20	29.70	30.00	30.20
AMC60a	31.00	28.90	25.60	30.60	29.40	29.10
AMC60b	27.40	28.70	30.40	31.00	31.50	29.80
AMC60c	26.10	30.40	31.10	29.60	29.20	29.28
AMC90a	27.10	32.10	30.40	31.20	30.20	30.20
AMC90b	30.10	32.10	34.70	28.60	31.70	31.44
AMC90c	36.80	34.40	33.50	32.40	30.20	33.46
AMC120a	30.20	30.10	30.90	29.90	32.90	30.80
AMC120b	31.80	31.20	31.60	33.00	32.20	32.00
AMC120c	33.70	33.40	30.90	30.80	32.10	32.00

Table 8: Hardness values of the aluminum and MWCNTs reinforced Al composite

The average hardness of aluminum and WMCNTs reinforced aluminum compacts is taken to study the effect of sintering time on the compacts' ability to resist plastic deformation. The results are as shown in the Table 9 and Figure 15 below:

Fabricated Composite	Sintering Time (min) Hardness (HV)		
	60	90	120
Pure Al	27.44	29.06	30.25
AMC	29.39	31.70	31.65

Table 9: Effect of sintering time on hardness (HV)

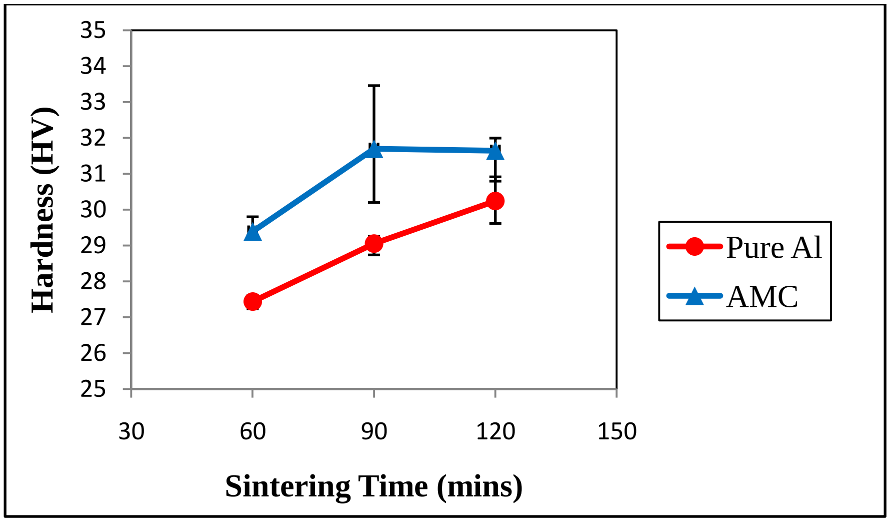


Fig. 15: Hardness versus sintering time of Al and MWCNTs reinforced Al composite

Figure 15 shows the effect of sintering time on compacts hardness after being sintered for 60, 90 and 120 minutes. Results showed that the hardness of aluminum sintered for 60 min was 27.44 HV. Pure aluminum sintered for 90 min shows increase of 6% in hardness compare to aluminum sintered for 60 min. Aluminum sintered for 120 min shows further increase of 4% in hardness.

MWCNTs reinforced aluminum composite with 1% fiber volume fraction (AMC) shows increase in hardness for approximately 7% compared to aluminum sintered for 60 min. AMC sintered for 90 min and 120 min show further increment of 9% and 5% respectively in hardness for the same sintering time of pure aluminum.

4.6 CORRELATED TENSILE STRENGTH WITH HARDNESS

The tensile strength was calculated based on the relationship as shown by the formula taken from An Introduction to Materials Science and Engineering textbook, page 160.

$$TS\ (MPa) = 3.45 \times HB$$

The Vickers hardness data shows in Table 9 were first converted to Brinell hardness before multiply with 3.45.

Table 10 and 11 below show the results of Brinell hardness value after being converted using conversion table and value of correlated tensile strength.

Pure Al	60min	90min	120min
Avg. HV	27.44	29.06	30.25
Brinell Hardness (HB)	20.72	21.35	21.75
Tensile Strength	71.48	73.66	75.04

Table 10: Value of Brinell hardness and correlated tensile strength for pure Al

AMC	60min	90min	120min
Avg. HV	29.39	31.70	31.65
Brinell Hardness (HB)	21.46	22.70	22.65
Tensile Strength	74.04	78.32	78.14

Table 11: Value of Brinell hardness and correlated tensile strength for MWCNTs reinforced Al composite

The correlated tensile strength of aluminum and WMCNTs reinforced aluminum composite with the hardness data is tabulated to study the effect of sintering time on the compacts' tensile strength. The results are as shown in the Table 12 and Figure 16 below:

Fabricated Composite	Sintering Time (min) / Tensile Strength (MPa)		
	60	90	120
Pure Al	71.48	73.66	75.04
AMC	74.04	78.32	78.14

Table 12: Correlated tensile strength (MPa) to the hardness of Al and MWCNTs reinforced Al composite

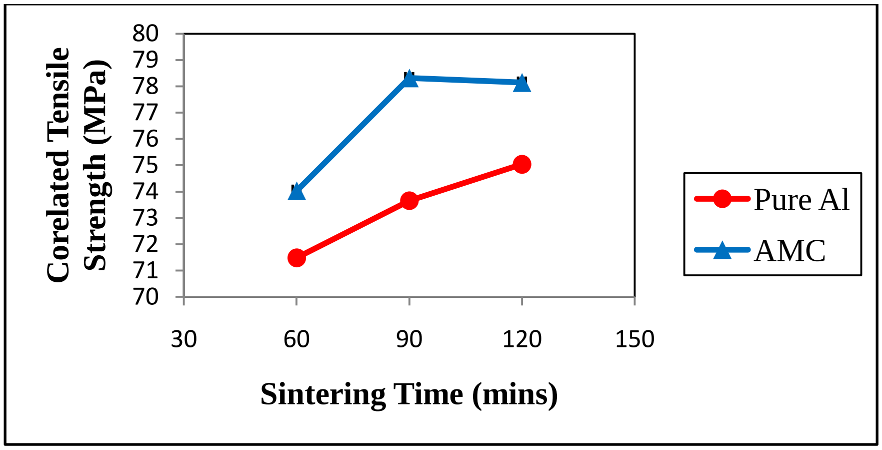


Fig. 16: Relationship of correlated tensile strength with the sintering time of Al and MWCNTs reinforced Al composite

Tensile strength of aluminum sintered for 60 min was 71.48 MPa and increase of 3% in tensile strength was noted for aluminum sintered for 90 min. The tensile strength of aluminum shows further increase of 2% as sintering time increased to 120 min.

Sintered AMC for 60 min shows 4% increase in tensile strength compared to pure aluminum with the same sintering time. AMC sintered for 90 min and 120 min also show further increase of 6% and 4% respectively in tensile strength compared to aluminum sintered for 90 min and 120 min. As sintering time increase from 60 to 90 min, the correlated tensile strength of AMC shows an increment of 6%. However, as sintering time reached 120 min, AMC shows slightly decrease of 0.2% in tensile strength.

4.7 MICRO STRUCTURAL CHARACTERIZATION

The microstructure of sintered MWCNTs reinforced aluminum composite was examined under FESEM and discussed here. The FESEM micrograph showing the microstructure of MWCNTs reinforced aluminum composite sintered for 120 minutes as shown in Figure 17 (a) and (b). The micrograph showed the non homogeneous distribution of the MWCNTs in the aluminum matrix which reduced the hardness and tensile strength.

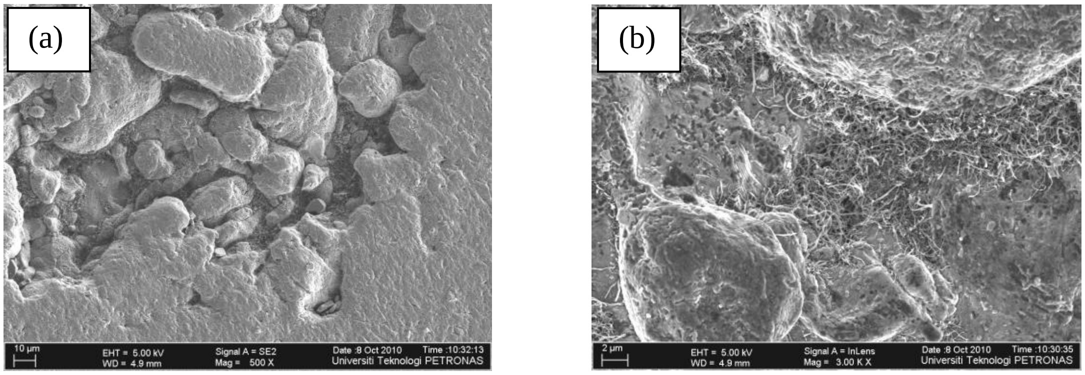


Fig. 17: FESEM micrograph of AMC sintered for 120 min shows non homogeneous distribution of MWCNTs in the matrix: (a) 500x; (b) 3000x

A decreasing trend in hardness and correlated tensile strength for AMC at higher temperature was noted due to insufficient bonding between MWCNTs and matrix. The non-homogeneous mixing of aluminum and MWCNTs as shown in Figure 17 also affect the efficiency of load transfer from matrix to the fibers which resulting in lower value of hardness and correlated tensile strength of AMC. The presence of porosity (Figure 13 and 14) at the grain boundary also reduced the hardness and correlated tensile strength of AMC. Figure 18 shows porosity on the surface of the sintered sample of AMC due to the grinding and polishing process where MWCNTs tend to leave the surface during the grinding operation leaving behind porous surface.

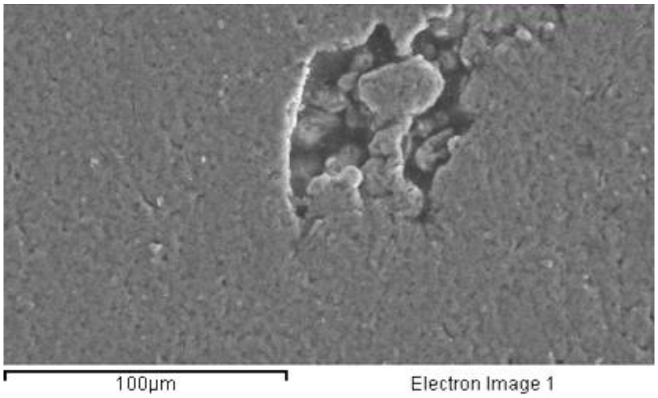


Fig. 18: Presence of porosity on the sintered AMC surface

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The objective of this project to fabricate MWCNTs reinforced aluminum composite using powder metallurgy technique and to study the effect of sintering time on properties of carbon nanotubes reinforced aluminum composite were achieved. Sintered samples were characterized base on dimension, density, hardness and correlated tensile strength to the hardness data. MWCNTs reinforced aluminum composite shows more thermal expansion than pure aluminum with highest expansion of 5% at 60 min sintering time. Aluminum compacts sintered for 90 minutes showed higher density compare to that sintered for 60 and 120 minutes. MWCNTs reinforced aluminum composite showed higher hardness and correlated tensile strength compared with aluminum. The highest hardness achieved was at sintering time of 90 minutes. Reduction in density, hardness and correlated tensile strength of MWCNTs reinforced aluminum composite at higher temperature was noted due to improper mixing of MWCNTs with the aluminum powder. This will resulted in presence of porosity and non homogeneous distribution of MWCNTs in the matrix.

5.2 RECOMMENDATION

Optimization of other parameters is recommended to produce composite with higher strength to weight ratio. For example, increasing the mixing time of aluminum and CNTs powder in ball mill will give better distribution of CNTs in the aluminum matrix. Use of higher compaction pressure also will enhance the hardness of the sintered compacts. Use of wax or binder while mixing and compacting the powder may promote a good dispersion of MWCNTs in the matrix and reduce porosity.

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