SUPERVISOR DECLARATION

'I hereby declared that I have read through this dissertation and
I found that it has comply the partial fulfilment for awarding the degree of
Bachelor of Mechanical Engineering (Thermal Fluid)'

Signature : ……………………………

Supervisor : Mr. Mohd Afzanizam B. Mohd Rosli

Date : …………………………………

A STUDY OF FLOW PATTERN IN AUTOCLAVE USING COMPUTATIONAL FLUID DYNAMICS (CFD)

MUHAMMAD HILMI BIN HASSIM

This dissertation is submitted as partial fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering (Thermal Fluid)

Faculty of Mechanical Engineering
University Teknikal Malaysia Melaka

MAY 2011

STUDENT DECLARATION

"I hereby declare that this dissertation entitle "A Study of Flow Pattern In Autoclave Using Computational Fluid Dynamics (CFD)" is my own work and result except for the work that had clearly stated the sources."

Signature : ……………………………

Student : Muhammad Hilmi b. Hassim

Date : …………………………………

ACKNOWLEDGEMENTS

Here i would like to thank my supervisor Mr Mohd Afzanizam B. Mohd Rosli for all his guidance and instruction during the completion of this dissertation. Many thank for Mr Muhammad Fairuz B Abu Bakar for all the information and time spend for discussion. Thanks to authors of material that in use either in digital or written form and utilized during my dissertation progress. I also thank my cousin Muhd Afdhal for all the help given during completion of this dissertation. I thank my mother Jamilah bt A. Samah and to my brother Muhammad Lutfi B Hassim for their love and support for duration of my study. Here i also acknowledge all party that have helped directly or indirect in completion of my dissertation.

ABSTRAK

Laporan ini membentangkan kajian tentang corak aliran di dalam Autoclave memggunakan dinamik bendalir berkomputer (CFD) oleh perisian FLUENT. Ini adalah untuk menganalisis aliran di dalam autoclave semasa proses permulaan operasi. Laporan ini memberikan pembaca sedikit maklumat tentang composit, sistem pembuatan dan autoclave operasi sistem. Dinamik bendalir berkomputer telah muncul sebagai alat analisis and rekabentuk penting dimana di dalam laporan ini ia digunakan untuk mencari kedudukan terbaik bagi acuan dibawah beberapa syarat. Peredaran corak udara akan menjadi topik utama di dalam laporan untuk mencari kesamaan permukaan acuan cure sebagai hasil. Dari segi corak visualisasi, perisian dinamik bendalir berkomputer mampu menghasilkan jawapan dalam bentuk grafik dan memaparkan sifat aliran seperti gelora dan pusaran. Laporan ini ada memasukkan maklumat daripada penyelidik terdahulu dan hasil simulasi sebagai perbandingan. Di dalam bahagian akhir laporan ini, hasil dan analisis dikeluarkan dalam beberapa keadaan, di mana hasil menunjukkan posisi terbaik untuk acuan adalah di kawasan belakang autoclave kerana kelajuan udara di situ adalah sama. Cadangan penambahbaikan untuk masa hadapan terdapat di bahagian akhir laporan.

ABSTRACT

This dissertation presents the study of flow pattern in Autoclave using computational fluid dynamics (CFD) by FLUENT software. This is to analyze the flow inside autoclave during initialization operation. This report gives reader some information about composite, its manufacturing system and operation involving autoclave. Computational fluid dynamics has emerged as an important design and analysis tool where in this dissertation it's is used to find the best placement of mould on several condition. The air flow circulations will be the main topic of this dissertation for uniform cure mould surface outcome. In term of flow visualization, Computational fluid dynamics software are able to produce graphically solution and the behaviour of low such as turbulent and vortex. This dissertation included data from previous researchers and simulation outcome as comparison. In final part, the result and analysis is produced under several conditions, where the result shown the best placement of mould in autoclave is in the back area of autoclave because of uniformity of air velocity in the area. The recommendation of future study is available on final part of dissertation.

NO.	LIST OF TABLE	PAGE

1.	Table 1. Comparison of Pressurize Gases	4
2.	Table 2. Thermal conductivity *k* values for various materials at 300K	16
3.	Table 3. Typical value of *h*.	18
4.	Table 4. Reynolds value and flow type	21
5.	Table 5. Models Menu setting	35
6.	Table 6. Models Menu setting	48
7.	Table 7. Computer Specification	60

NO.	LIST OF FIGURE	PAGE

1.	Figure 1. Industrial Horizontal Autoclave	3
2.	Figure 2. Schematic of Autoclave	4
3.	Figure 3. Flow diagram of the autoclave-based manufacturing process	5
4.	Figure 4. Typical Cure Cycle Diagram	6
5.	Figure 5. Prepreg Schematic	7
6.	Figure 6. Type of Composite material	9
7.	Figure 7. Fibre Orientation	9
8.	Figure 8. Schematic diagram of heat transfer mechanisms through a typical mould and lay-out.	14
9.	Figure 9. Conduction heat transfer	16
10.	Figure 10. Temperature and velocity distributions near a surface	17
11.	Figure 11. Radiation Component	20
12.	Figure 12. CAD process flow	26
13.	Figure 13. Project Flow Chart	27
14.	Figure 14. Literature Autoclave Dimension	28
15.	Figure 15. Body of Autoclave	29
16.	Figure 16. Autoclave floor	30
17.	Figure 17. Autoclave door	30
18.	Figure 18. Autoclave inlet	31
19.	Figure 19. Fan Installation	31
20.	Figure 20. 3D Model in Gambit	32
21.	Figure 21. Completed Mesh	32
22.	Figure 22. Boundary Input	33
23.	Figure 23. Boundary Placement	33
24.	Figure 24. Continuum Types	34
25.	Figure 25. Solver Setting menu	34
26.	Figure 26. Operating Conditions menu	35

27.	Figure 27. Velocity Inlet Boundary Condition	36
28.	Figure 28. Solution Controls menu	36
29.	Figure 29. Solution Initialization menu	37
30.	Figure 30. Residual Monitors menu	37
31.	Figure 31. Iterate menu	38
32.	Figure 32. Velocity Contour	38
33.	Figure 33. Literature CFD Result	39
34.	Figure 34. Velocity Vector	40
35.	Figure 35. Literature CFD Result	40
36.	Figure 36. Pathline View	41
37.	Figure 37. Body of Autoclave	42
38.	Figure 38. Autoclave floor	43
39.	Figure 39. Autoclave door	43
40.	Figure 40. Rectangular Cut Extrude	44
41.	Figure 41. Full half autoclave drawing with dimension	44
42.	Figure 42. 3D Model in Gambit	45
43.	Figure 43. Completed Mesh	45
44.	Figure 44. Boundary Input	46
45.	Figure 43. Boundary Placement	46
46.	Figure 46 Continuum Types	47
47.	Figure 47. Solver Setting menu	47
48.	Figure 48. Operating Conditions menu	48
49.	Figure 49. Velocity Inlet Boundary Condition	49
50.	Figure 50. Solution Controls menu	49
51.	Figure 51. Solution Initialization menu	50
52.	Figure 52. Residual Monitors menu	50
53.	Figure 53. Iterate menu	51
54.	Figure 54. Empty Autoclave Velocity Contour Result	52
55.	Figure 55. Empty Autoclave Velocity Vector Result	53
56.	Figure 56. Empty Autoclave Pathline Result	54
57.	Figure 57. Velocity Contour (Side View)	55
58.	Figure 58. Velocity Contour (Mould View)	56
59.	Figure 59. Velocity Vectors (Side View)	56
60.	Figure 60. Velocity Vectors (Mould View)	57

61.	Figure 61. Velocity Pathline (Side View)	58
62.	Figure 62. Velocity Pathline (Mould View)	58

LIST OF SYMBOL

SYMBOL	DEFINITION
$\circ$	Degree
T	Temperature
t	Time
r	Reaction rate
C	Heat capacity
w	Resin mass fraction
ΔH	Resin heat of reaction
α	Thermal diffusivity
Q	Heat flux
k	Thermal conductivity of solid
A	Area of solid
x	Distance
δ	Region of thickness
T_w	Temperature Wall
T_∞	Temperature Fluid
h	Convective heat transfer coefficient
c	Speed of light
λ	Product of wavelength
f	Frequency
ε	Emissivity of the surface
σ	Stefan-Boltzmanns constant
ρ	Density of fluid
V	Mean velocity of fluid
L	Characteristic linear dimension
μ	Dynamic viscosity of fluid

v	Kinematics viscosity of fluid
Re	Reynold number
Nu	Nusselt number
K_f	Thermal conductivity of the fluid
Pr	Prantle number
C_p	Specific heat
Bi	Biot number
K_s	Thermal conductivity of the solid

LIST OF ABBREVIATION

ABBREVIATION	DEFINITION
ASME	American Society of Mechanical Engineers
BMI	Bismaleimide
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CFD	Computational Fluid Dynamics
CMC	Ceramix Matrix Composites
FEM	Finite Element Method
FRP	Fibre Reinforced Polymers
MMC	Metal Matrix Composites
NC	Numerical Control
PMC	Polymer Matrix Composites
2D	2 Dimensional
3D	3 Dimensional

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	i
	ABSTRACT	ii
	LIST OF TABLE	iv
	LIST OF FIGURE	v
	LIST OF SYMBOL	viii
	LIST OF ABBREVIATION	x
1	**INTRODUCTION**	
	1.1 PROJECT OBJECTIVE	2
	1.2 PROBLEM STATEMENT	2
	1.3 PROJECT SCOPE	2
2	**LITERATURE REVIEW**	
	2.1 INTRODUCTION TO AUTOCLAVE	3
	2.1.1 Structure of Autoclave	4
	2.1.2 Operation Principle	6
	2.2 INTRODUCTION OF COMPOSITE	8
	2.2.1 Fibre Orientations	9
	2.2.2 Fibre Properties	10
	2.2.3 Matrix Properties	10
	2.3 HEAT TRANSFER MECHANISMS	12
	2.3.1 Heat transfer through mould and lay-up	13
	2.3.2 Composite Heat Transfer Model	15
	2.3.3 Conduction Heat Transfer	16

2.3.4 Convective Heat Transfer 17
2.3.5 Radiation Heat Transfer 19
2.3.6 Reynold Number 21
2.3.7 Nusselt Number 22
2.3.8 Prantel Number 23
2.3.9 Biot Number 24

3 **METHODOLOGY**
3.1 COMPUTER AIDED DESIGN INTRODUCTION 25
3.2 COMPUTER-AIDED DESIGN 26
3.3 COMPARISON WITH LITERATURE REVIEW 28
3.4 COMPUTATIONAL FLUID DYNAMICS 28
3.5 MODEL CREATION 29
3.5.1 MESHING 32
3.5.2 FLUENT 34
3.6 CFD RESULT 38
3.6.1 Velocity Contour 38
3.6.2 Velocity Vector 39
3.6.3 Pathline 41
3.7 3-DIMENSIONAL MODEL CREATION 42
3.7.1 3-D CFD MODEL 45
3.7.1.1 GAMBIT 45
3.7.1.2 FLUENT 47

4 **RESULT AND ANALYSIS**
4.1 CFD RESULT (Empty Autoclave) 52
4.1.1 Velocity Contour 52
4.1.2 Velocity Vector 53
4.1.3 Pathline 54
4.2 CFD RESULT (With Mould) 55
4.2.1 Velocity Contour 55
4.2.2 Velocity Vector 56

4.2.3 Pathline 57

5 **DISCUSSION**

5.1 RESULT COMPARISON 59

6 **CONCLUSION AND RECOMMENDATION**

6.1 CONCLUSION 61

6.2 RECOMMENDATION 62

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

In the last decade, the use of composite materials has increased considerably. In particular, the aerospace and automotive industries have adopted such high-performance and lightweight materials in a variety of products. Among the fabrication techniques for the composite materials, autoclave curing is used most often. However, the quality of the product manufactured using this technique is significantly affected by the process conditions. To ensure the product quality and reduce the manufacturing cost, on-line control and process optimization are required. This thesis is to develop a simulation model of air circulation visualisation inside autoclave and analyze it using computational fluid dynamics software. The heat flow cannot be seen by human eyes because the medium used are invisible to naked eyes. By utilizing CFD software, the heat flow can be visualized and analyzed. Bakker et al, state that CFD results can illustrate how a piece of equipment operates, how to troubleshoot problems, how to optimize performance, and how to design new equipment. This research to develop the best air flow and heat flow under single mould and multiple mould during curing in autoclave.

1.1 PROJECT OBJECTIVE

- To investigate the flow pattern of air in autoclave using CFD without mould.
- To investigate the flow pattern of air in autoclave using CFD with mould.
- To develop a simulation of air circulation using CFD with mould.

1.2 PROBLEM STATEMENT

The visualization of air flow pattern in Autoclave resulted from simulation of CFD software to allows the user to fully optimize the usage of autoclave by the means of simulations.

1.3 PROJECT SCOPE

- Flow simulation in steady state condition without part(mould) on point A.
- Flow simulation in steady state condition with part(mould) on point A.
- Flow simulation in Horizontal Autoclave.
- Material of part are composite.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION TO AUTOCLAVE

Autoclave is classified as modification of Pressure Vessel. Pressure vessel has to comply to strict regulation such as American Society of Mechanical Engineers (ASME). Donald define autoclave as an airtight steel vessel used to heat substances and objects under very high pressures. An autoclave have many size and construction. The operation principle for many type of autoclave are nearly the same. Autoclave are used in many area such composite manufacturing and sterilization of medical equipment.

Figure 1. Industrial Horizontal Autoclave

(Source : ASC Process Systems,2006)

Figure 1. shown the Horizontal Autoclave for Industrial purposed. The operating pressure can range from 275 kPa to 67000 kPa and temperature range of 1200 °C to 7600 °C (Taricco - 2007). An autoclave allow a chemical reaction to occur at higher temperature and pressure depending on the material type and purposes. The pressurize gases used in autoclave are air, nitrogen and carbon dioxide. The comparison of gases shown in Table 1.

Table 1. Comparison of Pressurize Gases

	Air	Nitrogen	Carbon dioxide
Advantage	Cost Cheap No Pollution	Low combustibility No Pollution	Cost Intermediate
Disadvantage	High combustibility	Cost Expensive	Hazardous to Human High Density

2.1.1 Structure Of Autoclave

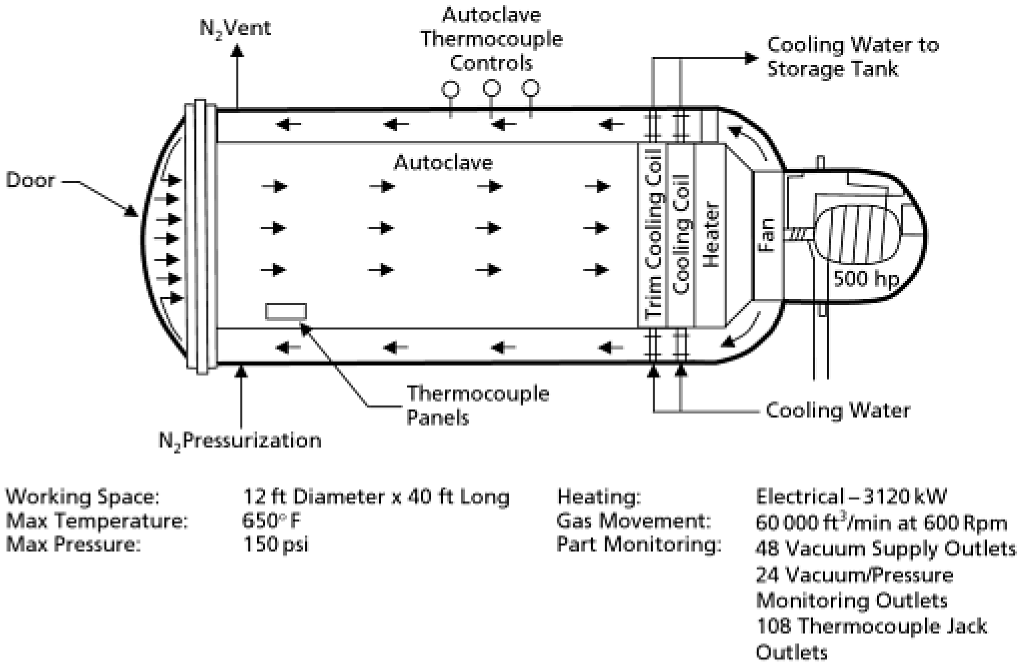

Figure 2. Schematic of Autoclave

(Source : Flake C. Campbell,2006)

Figure 2. shown the typical schematic of an autoclave. An autoclave are equipped with an heating element, insulation element, autoclave cart, vacuum pump, circulation fan, temperature with cure connection and a sealed door. Heating element can be compose of electric heater, indirect gas firing based heater or steam heater. Heating element release heat into autoclave during cure processes. Insulation element is used to prevent too much heat loss and its end result reduce the heating cost during cure process. Insulation are also used to prevent the autoclave from exceeding maximum operating temperature. Circulation fan is used to provide mass flow for temperature uniform and heat transfer to mould. This accomplished with a blower mounted at rear of autoclave. The airspeed varies from application but normally in range of 1 m/s to 10 m/s.

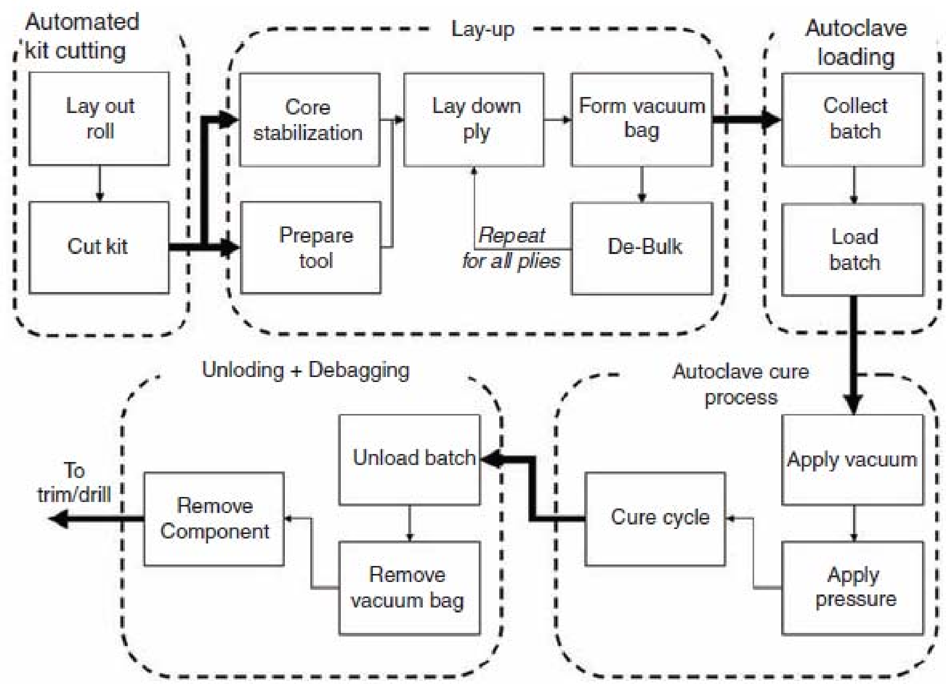

Figure 3. Flow diagram of the autoclave-based manufacturing process

(Source :D.A. Crump,2010)

2.1.2 Operation Principle

Autoclave operate principle are nearly the same as pressure cooker. The mould are place on top of autoclave trolley. In order to cure the part, pressure and temperature are applied to the laminate in a predetermined cure cycle (Figure. 4). The temperature cycle is necessary to trigger the resin polymerization reaction. After the autoclave door are secured, the air inside bag is removed by vacuum pump. The chamber are then pressurize until reached cure pressure. The heater are turn on slowly on the beginning of cure process and increased pressure. Dwell allows the temperatures to equilibrate in the moulding and can be used to control the time at which gelation occurs. Note that initially the resin viscosity drops as the laminate heats up. Hold serves to extend the time that the resin remains at low viscosity, allowing consolidation and elimination of porosity. This pressure and temperature are hold until 90 minutes where second pressurize process occur. The higher pressure increased the temperature as well. The second stage will occur around 2 hour or more. The cooling process are done slowly to allow heat escape the chamber and reduce the risk of danger to operator. The mould are removed after cure process is completed.

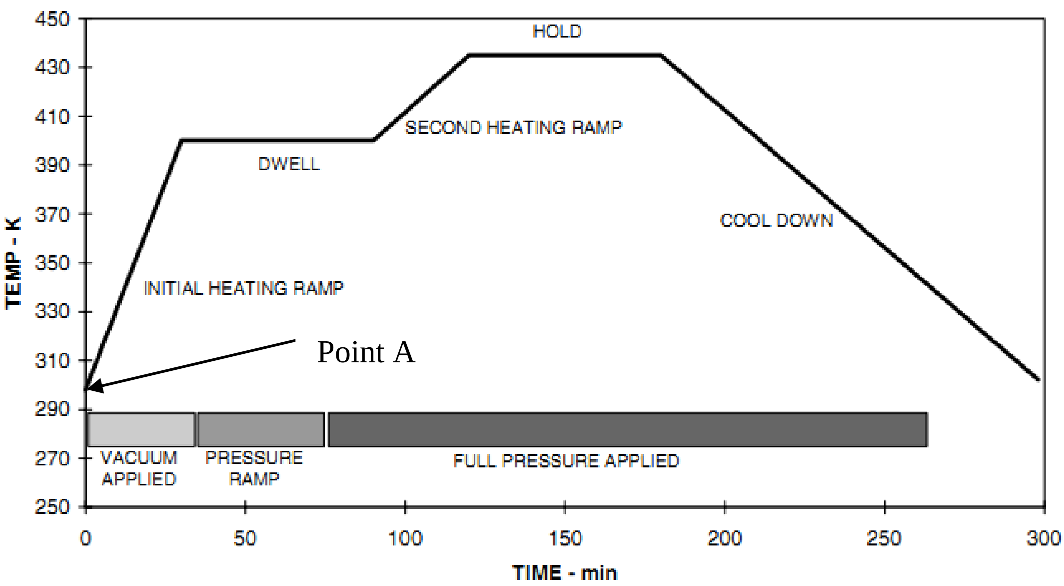

Figure 4. Typical Cure Cycle Diagram

(Source : Myer Kutz,2002)

The convectional cure cycle is composed of two stages; first stage for consolidation and second stage for full cure. The base material used in autoclave processing is a pre-impregnated sheet, commonly called prepreg. This prepreg contains fibres pre-impregnated with a catalyzed thermoset resin which will cure at high temperatures.

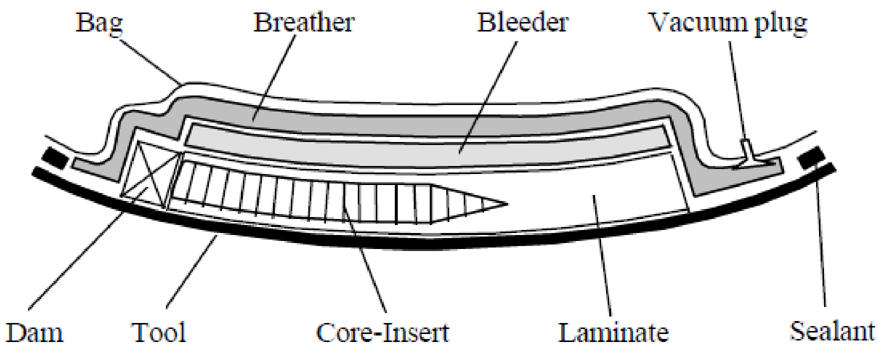

Figure 5. Prepreg Schematic

(Source : Pascal Hubert,1996)

The first step of the autoclave process is the lay-up and bagging procedure outlined in Figure 5. The prepreg plies are laid-up, forming a laminate, on a tool having the shape of the final part. The plies can be oriented in any direction to obtain the desired mechanical properties. Layers of an absorbing material forming the bleeder can be placed around the laminate if excess resin has to be absorbed from the laminate. Dams are placed around the edges of the laminate to restrict resin flow in those directions. Inserts and honeycomb cores can be included in the laminate for moulding purposes or structural requirements. A breather cloth covers the laminate assembly to provide a path for air flow. The complete assembly consisting of tool, laminate, bleeder, breather and inserts is bagged in a plastic film (called the vacuum bag) that is sealed at the tool plate. A vacuum plug connects the interior of the bag to an external vacuum pump.

2.2 INTRODUCTION OF COMPOSITE

Composite in its most basic form is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the matrix), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. This reinforcement is usually in fibre form.

Three main groups:

- Polymer Matrix Composites (PMCs) :
  Also known as FRP - Fibre Reinforced Polymers (or Plastics) These materials use a polymer-based resin as the matrix, and a variety of fibres such as glass, carbon and aramid as the reinforcement. This type are the most common.

- Metal Matrix Composites (MMCs) :
  Increasingly found in the automotive industry, these materials use a metal such as aluminium as the matrix, and reinforce it with fibres such as silicon carbide.

- Ceramic Matrix Composites (CMCs) :
  Used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibres, or whiskers such as those made from silicon carbide and boron nitride.