USE OF MULTI-WALLED CARBON NANOTUBES (MWCNTs) IN MEDIUM DENSITY FIBERBOARD TO INCREASE THE FIRE RETARDANCY

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ABSTRACT

Medium Density Fiberboard (MDF) is known as wood composite which are extensively used in furniture manufacture and building construction. In such application enhanced resistance to flame spread is considered as an advantage. The properties of MDF boards can be improved with the use of flame retardant chemicals. As a potential solution, Multi-walled Carbon Nanotubes (MWCNTs) will be used as flame retardant in MDF due to its good thermal properties and stability. Urea formaldehyde (UF) will be used as a binder to bind all the wood fibers. Flame retardant properties of the boards were investigated by IS 1734-1 to 20 (1983): Methods of test for plywood [CED20: Wood and other Lignocellulosic products] standard. The physical and mechanical properties including Thickness Swelling (TS), Internal Bond (IB) and Modulus of Rupture (MOR) of the samples were determined. The TS, MOR and IB tests were conducted as per ASTM D 1037 standard. Throughout the experiment, MDF boards treated with 2.5 wt% MWCNTs showed good fire retardant properties compared to Control board and 1.0wt% + MDF boards. The mechanical and physical properties improved significantly when MWCNTs were added to boards. From the DSC and TGA graph, it can be seen that the thermal conductivity and thermal stability of the samples, based on MWCNTs, were higher than control samples. Furthermore, the FTIR and XRD analysis proved that the presence of MWCNTs in the MDF samples. This research study will be useful in providing an effective way to increase the fire retardancy and as well as mechanical and physical properties of MDF boards

Keywords: Medium density fiberboard, Urea formaldehyde, Multi-walled carbon nanotubes

ABSTRAK

Papan Sederhana Tumpat (MDF) dikenali sebagai komposit kayu yang banyak digunakan dalam pembuatan perabot dan pembinaan bangunan. Rintangan terhadap penyebaran api dianggap sebagai salah satu kelebihan .Sifat-sifat papan MDF boleh diperbaiki dengan penggunaan bahan kimia kalis api . Sebagai penyelesaian yang berpotensi, karbon nanotube pelbagai lapisan (MWCNTs) akan digunakan sebagai kalis api di dalam MDF kerana sifat-sifat termal yang baik dan stabil. Urea formaldehid (UF) akan digunakan sebagai bahan pelekat untuk fiber kayu. Sifat rintanga api MDF dengan menggunakan piawai "IS 1734-1 to 20 (1983): Methods of test for plywood [CED20: Wood and other Lignocellulosic products]". Sifat-sifat fizikal dan mekanikal termasuk Ketebalan Bengkak (TS), Bond Dalam Negeri (IB) dan Modulus pecah (MOR) bagi sampel telah ditentukan. TS , MOR dan IB ujian telah dijalankan seperti ASTM D 1037 standard. Sepanjang kajian, papan MDF dirawat dengan 2.5 % berat MWCNTs menunjukkan baik ciri-ciri tahan api berbanding papan MDF yang tidak rawat dengan MWCNT dan 1.0wt % + papan MDF. Sifat-sifat mekanikal dan fizikal meningkat dengan ketara apabila MWCNTs telah ditambah kepada papan. Graf DSC dan TGA, ia boleh dilihat bahawa kekonduksian haba dan kestabilan terma sampel , berdasarkan MWCNTs , adalah lebih tinggi daripada sampel kawalan. Tambahan pula, FTIR dan XRD analisis membuktikan bahawa kehadiran MWCNTs dalam sampel MDF. Kajian ini akan berguna dalam menyediakan satu cara yang berkesan untuk meningkatkan rencat api dan juga sifat-sifat mekanikal dan fizikal papan MDF.

Katakunci: Papan sederhana tumpat, urea formaldehid, karbon nanotube pelbagai lapisan

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LIST OF SYMBOLS

P	Peak Load
L	Length
a	Thickness
b	Width
W	Width
l	Length
T_i	Initial Thickness
T_f	Final Thickness
W_{wet}	Initial Weight
W_{dry}	Final Weight
ρ	density
M	mass
V	volume
Ca	Carbonized area
Ta	Total area of sample
Wi	Initial Weight
Wa	Weight after test

LIST OF ABBREVIATIONS

CNTs	Carbon nanotubes
MWCNTs	Multiwalled Carbon Nanotubes
SWCNTs	Single Wall Carbon Nanotubes
MDF	Medium Density Fiberboard
UF	Urea Formaldehyde
MOR	Modulus of Rupture
IB	Internal Bonding
TS	Thickness swelling
UTM	Universal Testing Machine
WPC	Wood Polymer Composite
DSC	Differential Scanning Calorimetry
TGA	Thermogravimetric Analysis
FTIR	Fourier Transform Infrared Spectroscopy
XRD	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Background of study

In recent years, wood composite panels used for several applications that have been gaining importance due to their suitable properties. Wood composite known as engineered wood made from hardwoods and softwoods used to manufacture lumber such as particleboard, fibreboard, plywood and etc. In particular, wood composite panels are broadly used as structural parts for the furniture applications, construction of buildings, and transport industries. Wood composite industry is well established in Malaysia and had been used widely in the furniture industry. Medium density fiberboard (MDF) is one of the extensively used wood composite panels in the wood composite industry. Generally, Medium Density Fiberboard is a wood product formed by breaking down hardwood or softwood residuals into wood fiber combining it with resin (binder) and forming panels by applying high temperature and pressure. MDF is much denser than plywood and particleboard; hence it can be used as a construction material and in the furniture industry.

For furniture applications, MDF is become competitive with particleboards since MDF has number of advantages. They have smother surface, easier machinability, and being ideal panel material as substrate for thin overlays used indoor conditions (Ustaomer et al., 2008). Moreover, MDF board had been trusted to be used because of very strong, provides longevity, and is resistant to warping that occurs over time, effect by moisture.

The common synthetic resin used to bind the wood fibers is Urea Formaldehyde (UF). UF resin is one of the largely used adhesive for interior-grade wood-based panels especially in particleboard (PB), a medium density fiberboard (MDF) manufacturing (Kumar et al. 2013). It has been used widely in wood based industries due to number of advantages like fast curing, less in price and gives good mechanical strength of the wood composite panels.

In the early years of its production, wood fibers were dried and then mixed with an adhesive in a mechanical blender. However, the process resulted in dark resin spots in the prepared MDF boards. Today, most MDF plants use a very different process, a so-called blowline-blending technique, which can reduce the problem of dark resin spots on the board due to bundles (Alyrilmis and Kara, 2013). In this technique, wood fibers are carried from a refiner to a flash tube dryer through the blowline, a tube about 120 to 130 mm in diameter, and an adhesive is added in the blowline before the dryer (Alyrilmis and Kara, 2013). The resin, usually urea-formaldehyde (UF), is injected via water-cooled 3 to 5 mm nozzles at high pressure (12 to 14 bars) into the blowline with other additives, e.g., water, hardener, repellents, etc. (Thoemen et al., 2010).

Besides that, the rubber wood fiber is mostly used in the manufacturing of medium density fiberboards. The abundance of rubberwood becomes direct consequence of rapid growth of MDF sector in Malaysia **(**Food and Agriculture Organization of the United Nations**,** 2014). As per literature, rubberwood has all the required ingredients to make it successful in the wood panel sector (Hong, 1995). Hevea brasiliensis commonly referred to as rubber wood or heveawood has been widely accepted in Asia for the manufacturing of wood based panels. The MDF industry currently has 15 plants with a total annual installed capacity of 2.9 million cubic meter. In 2011, the export of MDF totalled at RM 1.2 billion. Currently, Malaysia is the world’s third largest exports of MDF, after Germany and France with exports going mainly to Japan, People’s Republic of China (PRC), Iran, UAE, Vietnam, Syria and Indonesia. Malaysian MDF has attained international standards such as BS, Japan, Australia and New Zealand Standard

(JANS), and EN standards. A number of companies have also ventured into the production of laminated/printed MDF for exportation **(***Wood Based Industry | Malaysian Investment Development Authority (MIDA)***,** 2012).

1.2 Motivation

The flammability of MDF is one of the main drawbacks that affecting the common applications of MDF products in everyday life. This is due to the properties of wood fibers and resins which able to capture fire rapidly. There is no way to prevent the factors from happening and aggravating fire development. Treating wood composites with fire retardant is one of the most effective ways to prevent such occurrence. The need for fire protection treatment of MDF has been identified by White and Sweet (1992) in his review article on the status of the fire retardant treated wood. Fire retardant treatments have proven to be effective in reducing combustibility of wood-based composites (Izran et al., 2011; 2009a). From the literature, such treatment drastically reduces the rate at which flames travel across the wood surface and reduces the amount of potential heat (LeVan & Winandy, 1990). For the treatments, various fire retardant chemicals can be utilized. Fire-retardant treated (FRT) medium density fiberboard (MDF) is being used increasingly, in exterior exposures, for both roofing and siding. Now, FRT-molded wall panels are being produced such that the composite becomes both skin and structural elements (Ayrilmis, 2007). In this present work MWCNTs will be used as fire retardant in order to explore its effects on fire retardancy as well as mechanical and physical properties of MDF. Multiwalled Carbon Nanotubes (MWCNTs) have very good thermal properties and it can act as fire retardant for MDF.

1.3 Problem Statement

Currently, most of the MDF industries, have been facing the flammability of MDFs. Some researchers believe that fire retardant treatments with fire retardant chemicals will reduce the flame spread in MDFs. In response to this problem, this study proposes the use of multi-walled carbon nanotubes (MWCNTs) in MDF to increase the fire retardancy. In this study, different percentages of MWCNTs will be used in MDFs to test the flame retardancy and the physical and mechanical properties of MDF also evaluated. In this research, the wood fiber can be characterized it as the matrix because it is used to surround the MWCNTs. The matrix used to protect the surface of the MWCNTs from any defect caused by external forces. It would cause of minimizing the strength of the fiber that would lead to crack propagation.

1.4 Research Objectives

1) To study the effect of MWCNTs on the flame retardancy of MDF boards
2) To study the effect of MWCNTs on the physical and mechanical properties of MDF boards
3) To study the morphology of MDF boards using Differential Scanning Calorimetry (DSC), Fourier Transform Infrared Spectroscopy (FTIR), Thermogravimetric Analysis (TGA) and X-ray Diffraction Analysis (XRD)

1.5 Scope

The focus of this research is to investigate the effect of MWCNTS on the flame retardancy of MDF boards. Then, Thickness swelling, Modulus of Rupture and Internal bond of MDF boards will be tested to study the physical and mechanical properties. Eventually, morphological studies of MDF and resin samples were analysed using DSC, FTIR, TGA and XRD analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 Wood Composites

Composite is known as a combination of two or more different materials. Composite materials are designed so to give unusual combinations of mechanical, physical and thermal properties. Most of composites have been created to improve combinations of mechanical characteristics such as stiffness, toughness and ambient and high temperature strength (Callister, W. D. & Rethwisch, D. G., 2008). Many composite materials are composed of just two phases. One is termed the matrix, which is continuous and surrounded the other phase, often called the dispersed phase (Callister, W. D. & Rethwisch, D. G., 2008).

In the past, wood was the only solid used as large timber/lumbers for furniture and constructional applications. The dependence on natural forests for this raw material led to gradual reduction and increased prices of larger diameter trees. The growing of social demand for wood and wood based products resulted in the need to find newer wood resources and/or more efficient utilization of current available resources. The entire trees were utilized in the development of wood based composites by wood composite industries. The term wood composite is used to describe all products manufactured by binding together woody materials such as strands, particles, fibers or veneers with non woody materials like adhesives and/or wax (Walker, 2006). Furthermore, wood based composites and panel products have several advantages over solid wood. Rubberwood is popular as a raw material for manufacturing wood composites such as particleboard and medium density fiberboard (Zaidon et al., 2007a; Loh et al., 2010; Jarusombuthi et al., 2010). Rubberwood composites are available in many sizes and are frequently used as furniture and partitioning inputs (Izran et al., 2011).

Additionally natural defects like knots and slope of grain can be reduced, removed or evenly distributed within the composite (Obeng, 2011). Particle size can also be reduced which further increases composite uniformity. Increased uniformity is beneficial and makes the prediction of engineering performance easier due to lower strength and stiffness variation (Marra, 1979). The mechanical properties of wood based composites are derived from the particulate nature of the woody raw material (Youngquist, 1999). Suchsland and Woodson (1986) have classified various wood composite boards based on particle size, density and process type **(Figure 2.1)**.

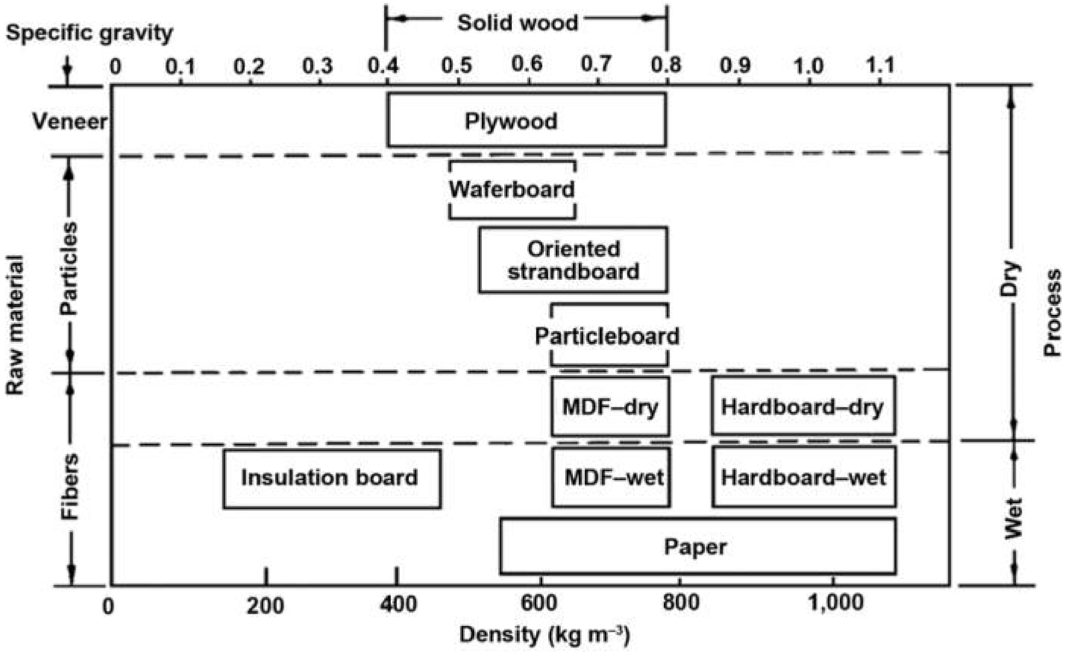

Figure 2.1: Classification of Wood Composite Board Materials by Particle size, Density and Processing Principle (Suchsland & Woodson, 1986). Note that insulation board is now known as cellulosic fiber-board.

Usually different wood particle sizes will yield different densities and consequent product properties. From the literature, currently engineered wood panels are categorized into five based on the physical processes used in their manufacture: plywood, oriented standard board, particleboard, hardboard and cellulosic fibreboard (Simpson and TenWolde, 1999). Wood composites have been used for structural and industrial applications such as concrete forming, interior and exterior flooring, roof sheathing, wall sheathing, and furniture.

Wood Polymer Composite (WPC) known as a newly introduced composite in the industry currently. Hietala et al. (2011) defined that wood polymer composites (WPCs) are materials which combine the properties of wood and thermoplastic polymers. According to Oksman and Bengtsson (2007) they are considered more environmentally friendly options for wood and plastic products in several applications, such as outdoor building materials furniture and interior panels in automobiles. WPCs are manufactured by compounding wood raw material with a molten matrix polymer together with additives such as lubricants, antioxidants and coupling agents in various compositions (Hietala et. al., 2011). In commercial manufacturing of wood polymer composites the main wood raw material used is wood flour. Wood flour is typically produced from the residues of wood processors by milling and screening the material into a specific particle size range (Clemons, 2008). So the composite materials are designed to give extraordinary performances in their mechanical, physical and thermal properties using the properties of all components involved.

2.2 Urea Formaldehyde

Urea-Formaldehyde (UF) resins have been broadly used as in the manufacturing of wood composite boards, such as particle board (PB) and medium density fiberboard (MDF). Therefore wood panel industries are major consumers of UF resins. As per literature, more than 70 % of this urea-formaldehyde resin is used by the forest products industry for a variety of purposes (Conner, 1996). According to Park et al. (2006) the UF resin is a polymeric condensation product of the chemical reaction of formaldehyde with urea and regarded as one of the most important types of adhesive in the wood-based panel industry. Other than that, UF resins are thermosetting resins which are usually referred to as amino resins. Amino resins are thermosetting synthetic resin formed by copolymerization of amines or amides with aldehydes which are used to transform the properties of other materials. Conner (1996) states that the use of urea-formaldehyde resins as a major adhesive by the forest products industry is due to a number of advantages, including low cost, ease of use under a wide variety of curing conditions, low cure temperatures water solubility, resistance to microorganism and to abrasion, hardness, excellent thermal properties, and lack of colour, especially of the cured resin.

2.3 Flame Retardancy of MDF

When heated, wood burns by producing flammable volatiles that may ignite (LeVan & Winandy, 1990). Fire retardant treatments have proven to be effective in reducing combustibility of wood-based composites (Izran et al., 2011; 2009a). From the literature, such treatment drastically reduces the rate at which flames travel across the wood surface and reduces the amount of potential heat (LeVan & Winandy, 1990). According to Izran et al. (2011) fire retardants can be applied in two ways, either by incorporating them into wood fibers of the composites or by spreading them on the surface through coating. Incorporating fire retardants into wood fibers provides much better protection than coating. For the treatments, various fire retardant chemicals can be utilized. Hashim et al. (2009) stress that, like most wood composites a major consideration in the manufacture of flame retardant MDF is maintaining the acceptable physical and mechanical properties. Study by Garba (1999) found that zinc borate functioned effectively as flame retardant for wood when used in the vapour phase and in the condensed phase. According to Brown and Herbert (1992) aluminium trihydrate is widely used as fire retardant additives for plastics and elastomers. Work on the use of hydrated alumina in MDF has been carried out by Barnes and Farrell (1978) indicating it’s potential. It has been indicated by Misra (1986) that sodium aluminate is an important industrial inorganic chemical. It is used in water treatment and as a source of aluminium synthetic applications (Hashim et al., 2009). AG®PI is an ammonium polyphosphate (N_4NO_2P) - formulated fire retardant (Abood et al., 2012). So, various chemicals have been used to increase the flame retardancy of the MDF boards.

2.4 Carbon Nanotubes

For the past few years have witnessed the discovery, development and, some cases, large-scale manufacturing and production of novel materials that lie within the nanometer scale. Such novel nanomaterials consist of inorganic or organic matter in most cases have been studied in various field of study. Carbon nanotubes (CNTs) are one of them. CNTs are allotropes of carbon. They are tube-shaped materials, made of carbon, and the diameter measured in nanometer scale. The first evidence of carbon nanotubes comes from transmission electron microscope (TEM) micrographs published by Radushkevich in 1952 (Aqel et al. 2010). Iijima effectively rediscovered and introduced carbon nanotubes to the scientific community as a by-product of an electric arc discharge method of synthesizing C_{60} fullerrences (Iijima, 1991). According to Aqel et al. (2010) carbon nanotube (CNT) is one form of carbon, with nanometer-sized diameter and micrometer-sized length (where the length to diameter ratio exceeds 1000). The atoms are arranged in hexagons, the same arrangement as in graphite (Aqel et al. 2010). From the literature, the structure of CNT consists of enrolled cylindrical graphic sheet (called graphene) rolled up into a seamless cylinder with diameter of the order of a nanometer (Aqel et al., 2010).

It is understood that CNT is the material lying in between fullerences and graphite as a quite new member of carbon allotropes (Tanaka et al., 1999). The cylindrical molecules with novel properties which can produce outstanding mechanical, electrical, thermal and chemical properties. According to Aqel et al. (2010), CNTs name is derived from their size,since the diameter of a CNT is on the order of a few nanometers (approximately 50,000 times smaller than the width of human hair), while they can be up to several micrometer in length. Carbon nanotubes are sheets of graphite that have been rolled into a tube (Thostenson et al.,2001). There are two types of CNTs ; (1) single-walled carbon nanotubes (SWCNTs) and (2) multi-walled carbon nanotubes

(MWCNTs). A single-walled carbon nanotubes (SWCNTs) can be considered to be formed by the rolling of a single layer of graphite (called a graphene layer) into a seamless cylinder (long wrapped graphene sheets) (Aqel et al., 2010). The comparison between SWCNTs and MWCNTs are shown in **Table 2.1.**

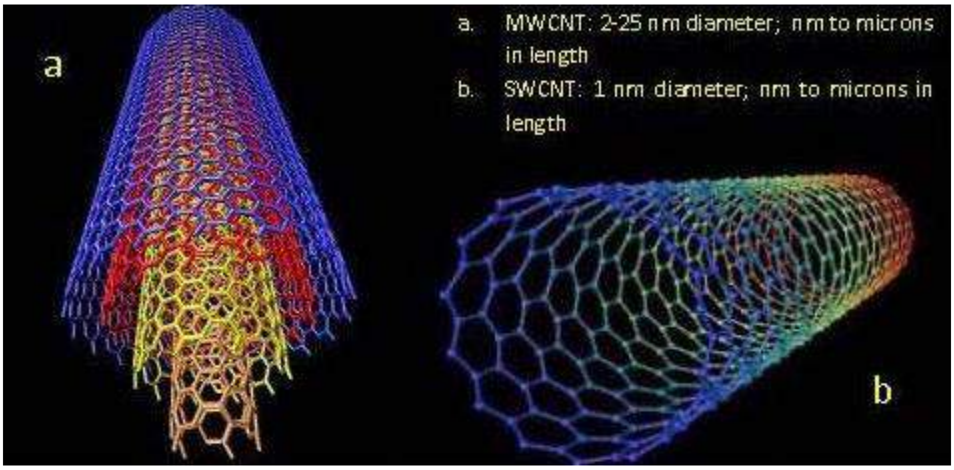

Figure 2.2: Structure of MWCNT (a) and SWCNT (b)

Table 2.1: Comparison between SWCNTs and MWCNTs

No	SWCNT	MWCNT
1.	Single layer of graphene.	Multiple layer of graphene.
2.	Catalyst is required for synthesis.	Can be produced without catalyst.
3.	Bulk synthesis is difficult as it requires proper control over growth and atmospheric condition.	Bulk sythesis is easy.
4.	Purity is poor.	Purity is high.
5.	A chance of defect is more during fuctionalization.	A chance of defect is less but once occurred it’s difficult to improve.
6.	Less acculmulation in body.	More accumulation in body.
7.	Characterization and evaluation is easy.	It has very complex structure.
8.	It can be easily twisted and are more pliable.	It cannot be easily twisted.

(Source : Hirlekar et al.,2009)

As shown in **Table 2.1** it can be conclude that MWCNTs gives good properties than SWCNTs. SWCNTs are expensive to produce and currently,available in only small quantities on the order of ten to hundreds of grams. Meanwhile , MWCNTs are produced in quantities of tens to hundreds of tons per year by a number of manufacturers and are available at much lower cost than single walls.

Under high pressure, CNTs can merge together, trading some sp^2 bonds for sp^3 bonds, giving great possibility for producing strong, unlimited length wires through high pressure CNT linking (Antonini et al., 2009). Multi-walled carbon nanotubes (MWCNTs) can be considered as a collection of concentric SWCNTs (consist of multiple layers of graphite rolled in on themselves to form a tube shape) with different diameters (Aqel et al., 2010). Study by Iijima and Ichihashi (1993) found that the length and diameter of these structures differ a lot from those of SWCNTs and, of course, their properties are also very different. Since carbon-carbon covalent bonds are the strongest in nature, nanotubes would ideally produce an exceedingly strong material (Ajayan, 2007). It has been indicated by Ajayan (2007) that MWCNTs are also larger than in diameter (2-50 nm, typically) compared to the tiny SWCNTs (1-2 nm diameter). The comparison of mechanical properties of different materials with CNTs is shown in **Table 2.2**.

Table 2.2: Comparison of Mechanical Properties of Different Materials with CNTs

Material	Young's Modulus (GPa)	Tensile Strength (GPa)	Density (gcm^{-3})
SWCNT/MWCNT	~1000	~ 100-200	~0.7-1.7
High tensile steel	210	1.3	7.8
Toray carbon fibers	230	3.5	1.75
Kevlar	60	3.6	1.44
Glass fibers	22	3.4	2.6

(Source : Ajayan, 2007)

As briefly mentioned earlier, the combination of physical properties of nanotubes make them ideal fillar material in composites (Ajayan, 2007). Research by Ajayan (2007) shown that there has been some work done in the area of metal matrix as well as ceramic matrix composites with nanotube fillars, but the majority of the work to date has focused on polymer composites. The metal matrix composites (MWCNT in metals such as Al, Cu,Ti) have been used to mold mechanical parts. According to Ajayan (2007) the nanotubes (especially MWCNTs) in these (advanced material) increase the strength and electrical conductivity and impart thermal stability to the composite, but the enhancements of properties by additon of nanotubes have been far from significant.

Similarly, nanotubes (SWCNTs and MWCNTs) have been added to ceramic materials (e.g, alumina) to enhance the fracture toughness of the ceramic material. Unfortunately, not much enhancement in the fracture toughness was observed in the system (Ajayan, 2007). From the literature, one possible application that can be envisioned, if substantial improvements in fracture toughness can be obtained, is in body armor, where the addition of nanotubes in ceramics not only improves the fracture properties, but also provides a significant weight advantage (Ajayan, 2007). Research by Ajayan (2007) found that nanotube fillars differ in morphology and conformations compared to traditional carbon fibers because they remain highly flexible and also form easy entanglements during dispersion in the polymer matrix. According to Wu et al. (2013) using thermalgravimetric analysis (TGA) and cone calorimeter, several groups reported improved thermal stability and flame retardancy of CNT/polymer composites. They attribute the improved flame resistance to the formation of a protective nanotube network structure that act as a heat shield for composites (Wu et al., 2010).

MWCNTs are expected to play major role in numerous applications because of their special physico-chemical properties. Development time is an essenstial criterion that determines when an application will reach the market. When plotted against time, several broad categories of applications can be recognized: those in place currently or available in the short term, those to be expected mid-term, and those still in the realm of early R&D,classified as long-term **(**Cefic | European Chemical Industry Council**,** 2014). The current,mid and long-term applications of MWCNTs are shown in the **Table 2.3.**

Table 2.3: Applications of MWCNTs on the short,mid and long-term.

Current /Short-term	Mid-term	Long-term
Conductive polymers & composites (automobiles and electronics)	Coatings (conductive thin films)	Microwaves antennas
Sensors and instruments (microscope probe tips, gas leak detectors)	Catalysts (petrochemical)	Seld-assembling yarns
Electromagnetic Shielding	Textiles & fibers	Aerospace
Sporting goods (tennis rackets)	Lithium ion batteries	Medical implants
	Membrane and filters	Drug delivery
	Lamps	
	Semiconducting materials	
	Advanced ceramics	
	Fuel cells	
	Caulks and sealants	

(Source: Cefic | European Chemical Industry Council, 2014).

As a conclusion, the combination of these impressive properties of MWCNTs enables a whole new variety of useful and beneficial applications. The short, mid and long-term applications depends on the research and developments (R&D) to bring particular invention to the market.Today, the manufacturing of MWCNTs in the bulk volumes reaches a few hundred tons per year due to its applications in various fields.

2.5 Modulus of Rupture

Modulus of Rupture (MOR) is a measure of a specimen's strength (bending strength) before rupture. MDF board is not suitable to undergo tensile test since it is brittle specimen. The bending test also known as three-point bend test, where the load applied on the top surface of the specimen. Torrey (2001) stated that MOR is test the bending strength, which is tested to ensure that the addition of fillers did not change or damage the bending qualities of the board. The bend testing determines the ductility or the strength of a material by bending the material over a given radius which is applied force is perpendicular with the position of the specimen. The specimen can be rectangular or rod form. The maximum force will be shown on the result after the specimen start to break. That value also known as peak load and use in the calculation of MOR. The calculation of MOR was performed using the following equation:

$$MOR = \frac{3PL}{2ba^2} \tag{2.1}$$

(Source: Torrey, 2001)

Where:

MOR = Modulus of Rupture (N/mm^2)

P = Peak Load (N)

L = Length (mm)

a = Thickness (mm)

b = Width (mm)

2.6 Internal Bonding

Internal bonding (IB) test is used to test the strength of the bonding formed between matrix and the resin.A steel or aluminium block is glued to the sample and used to hold the sample in the test machine. The test machine then pulls the sample apart at a uniform rate of motion dependent upon the thickness of the sample. The test continues until the sample fails. The important data point in this test is the maximum load on the sample before it fails (breaks) (Torrey, 2001). The better IB value will be obtained for the better bonding formed between matrix and resin as per theory. The better the bond between the glue and strands, the better the strength properties of the boards (Torrey, 2001). Torrey (2001) also mentioned that the standard size for the specimen is around 50mm in length and 50mm in width. He added that the specimen was glued on the aluminium block and after the specimen settle run the testing it will reheat to substitute with others. Better cohesion of the board means better or more fully cured resin and thus higher internal bonding within the board (Barry & Corneau, 1999). As per literature review, the Internal Bonding (IB) calculated by using the given equation:

$$IB = \frac{P}{w \times l} \tag{2.2}$$

(Source: Torrey, 2001)

Where,

IB = Internal Bonding (N/mm^2)

P = Maximum load or Peak load (N)

w = Width (mm)

l = Length (mm)