USE OF NANOPARTICLE IN THE WOOD COMPOSITE TO ENHANCE THE HEAT TRANSFER

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ABSTRACT

The fast growing demand for engineered wood products and development of Medium Density Fiberboard (MDF) leads to numerous research focusing on process parameter and physical properties of the board. Using conventional process, Medium Density Fiberboard (MDF) is commonly made from wood fibers added with Urea Formaldehyde (UF) resin in a hot press process. Heat transfer is determine during the hot press by which the pressing time will leads to higher quality of the board. Industries are searching for strategies to reduce the hot pressing time, therefore will lower the production costs and increase the wood board output capacity. Thus, this paper will focus on the heat transfer to improve the press time that will produce more quality board. By using conventional method, forming the board needs more time during the hot press as wood fiber is a poor heat conductor. By using the same conventional method, this research intends to make an improvement by adding metal oxide nanoparticles to enhance the heat transfer which lead to higher quality board. The result shows that higher temperature profile observed for board with metal oxide nanoparticles instead of normal board. Higher temperature profile resulting higher heat transfer of the board.

ABSTRAK

Dengan meningkatnya permintaan produk kayu kejuruteraan and pembangunan papan serat berketumpatan sederhana (MDF), berbagai penyelidikan berfokuskan parameter proses dan sifat fizikal sebuah papan. Papan serat berketumpatan sederhana biasanya diperbuat daripada serat kayu ditambah dengan Formaldehyde Urea (UF) resin di dalam proses tekanan bersuhu tinggi. Pemindahan haba ditentukan ketika proses tekanan bersuhu tinggi di mana masa tekanan akan menentukan kualiti sesebuah papan. Industri sedang mencari strategi untuk mengurangkan masa tekanan, oleh itu kos pembuatan akan berkurang dan meningkatkan penghasilan papan. Maka, penyelidikan ini lebih fokus kepada pemindahan haba untuk memperbaiki masa tekanan dimana lebih banyak papan berkualiti tinggi dapat dihasilkan. Pembentukan papan memerlukan masa yang lama kerana serat kayu bukan konduktor haba yang baik. Menggunakan cara yang sama, penyelidikan ini berusaha untuk melakukan penambahbaikan dengan menambahkan besi oksida bersaiz nano untuk meningkatkan pemindahan haba. Hasil penyelidikan ini menunjukkan peningkatan pemindahan haba dengan meningkatnya graf suhu di tengah papan ketika tekanan bersuhu tinggi untuk papan yang ditambah dengan besi oksida bersaiz nano.

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LIST OF SYMBOLS

SYMBOLS	DEFINITIONS
nm	Nanometer
m^3	Cubic Meter
yr	Year
kg	Kilogram
mm	Millimeter
min	Minutes
%	Percentage
kN	Kilonewton
MPa	Megapascal
GPa	Gigapascal
°C	Degree Celcius
s	Second
wt%	Weight Percent
Al_2O_3	Aluminium Oxide

LIST OF ABBREVIATIONS

ABBREVIATIONS	DEFINITIONS
UMP	Universiti Malaysia Pahang
FRIM	Forest Research Institute Malaysia
MATLAB	Matrix Laboratory Software
MDF	Medium-Density Fibreboard
UF	Urea-Formaldehyde
PF	Phenol-Formaldehyde
ASTM	American Society for Testing and Materials
ANSI	American National Standard Institute
CBP	Cement-Bonded Particleboard
UNECE	United Nation Economic Commission for Europe
OSB	Oriented Strand Board
EUWID	Europäischer Wirtschaftsdienst GmbH Company
BSEN	British Standard European Norm
MOR	Modulus of Rupture
MOE	Modulus of Elasticity
IB	Internal Bonding

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Final product properties for panel produced with fibres, flakes, particles and strands are determined from the wood elements, forming and pressing processes. Heat is used to enhance the curing time of adhesive or resin which act as bonding agent for the wood element. Boards consolidated with urea-formaldehyde resins are characterized by their high mechanical strength, dimensional stability, hardness and abrasion. Hot press process is continued to form the wood board but commonly longer pressing time is needed for the resin to cure inside the wood board, thus the wood-based composite industry is searching for a new strategy to reduce the hot pressing time so that production cost can be minimized.

Research has been conducted and conventional approach has been taken whereby high press temperature or external catalyst is used to accelerate the resin cure rate, thus obtain acceptable press time. Usually 20% to 30% aqueous solutions of diluted acid or an acidic salt such as ammonium sulphate and chloride become the external catalysts. (Matuana & King, 2004). Sodium hydroxide, carbonate and other similar basic compound also can become external catalyst. These external catalysts only acceptable if it produce shorter press time at low concentration of catalyst in the range of 0.25% to 1% by weight of resin. (Matuana et. al.,2004)

Higher pressing temperature is not preferable as it may lead to higher energy consumption. More volatile organic compounds will be generated if using high pressing temperature which may endanger the environment. According to Matuana, although high pressing temperature may shorten the press time, more development of cost-effective and environmental friendly approaches to reduce press time are needed.

Nanotechnology has received very significant investment over the past ten years with national governments providing an investment with estimates ranging as high as $18 billion between 1997 and 2005. Through this investment, many product related or contain nanomaterials are already on the market. Engineered nanomaterial is a nanomaterial that has been synthesized for a specific purpose and may be found in one of several different shapes. It may be subdivided into organic and inorganic types, with the former including carbon itself and polymeric structures with specific nano characteristics. Inorganic include metals, metal and metalloid oxides, clays and a specific subset of compounds known as quantum dots. (Park, 2007)

Research by Hanz Joachim Denzer and Oliver Frederik Klaeusler discloses a film forming composition comprising nanoparticles, a resin, a surface active material and a polymeric dispersant. The film forming composition may be used with wood objects including furniture, doors and floors to enhance scratch resistance.

Moreover, they also discloses nanosized silica, titanium oxide and zinc oxide compounded materials for surface modification of wood wall to improve chemical stability resistance and the capacity to repel and disperse water, oil, bacteria, organic dust, gas electricity, magnetism and light. For application, the nanosized material is sprayed onto the body surface.

By introducing nanomaterials in the wood board, it seems that lots of properties can be improved. According to Barry Park, aluminium is a highly reactive metal when produced as a nanopowder and when in formulations such as metastable intermolecular composites (MIC) reacts to produce a large amount of heat energy. Thus, aluminium nanoparticles have been introduced in this research to increase the heat transfer in the wood board. Performance of the board can be determined through a lot of testing and since nano industries are increasing rapidly, the supply of nanoparticles will be available.

Invention from Kunnemeyer relates to introducing fine wood dust as the initial manufactured surface layer in the improve process of wood fibre board manufacturing. The wood dusts retain the properties of wood fibre boards, board structures and avoid the sanding loss during hot pressing process. Small density drop occurred throughout the entire board thickness and sanding the outer zone would barely affects the wood fibre boards. Further invention by Kunnemeyer stated that mixing of hardeners to the wood dust will accelerate the pressing time.

Further process of reducing the press time has been described by Pungs and Lamberts whereby a particleboard web is heated by high frequency heating rather than by heating plates. The heat is uniformly distributed through the entire thickness of the board but it consumed a lot of energy. Aside from high energy consumption, it is also difficult to shield and structure the fibre board support from adjacent support component without using metal. (Thole & Jahic, 1999)

Other methods have been proposed in DE F1658 XII/381 whereby moisture in the individual layers of boards or webs is varied. The heat penetration is enhanced if the cover layers are significantly moisture than the core layer. Rapid heating to the core layer occur but internal pressure are build up during the process which will destroy the adhesive. (Thole et. al., 1999)

Through lot of previous research studies, heat transfer can be enhanced with lots of strategies but it is not commercialize since it is just a research paper. Improving heat transfer has helped a lot in reducing hot pressing time. Some researchers develop coating strategies to reduce the press time but since nanoparticles are expensive, it is not possible to reduce the cost by coating the wood board with it. Thus, mixing the wood fibre with nanoparticles is another solution to reduce cost and usage of nanoparticles.

1.2 PROBLEM STATEMENT

Improve the heat transfer in the wood board, thus will improve the quality of the board specifically in mechanical properties.

1.3 OBJECTIVES

Study the heat transfer in the wood board after introducing nanoparticles.

1.4 SCOPE

Observe the improvement of heat transfer in the wood board as nanoparticles being mixed with the wood fibres.

1.5 RATIONALE AND SIGNIFICANCE

This project has been conducted by adding nanoparticles which is the metal oxide to the wood fibres as to increase the heat transfer and to shorten the press time. Metal oxide is a good conductor and it helps to transfer the heat from faces of the wood to the core much faster. In the same time, press time will be shorter and less time is needed to form the board. Hot pressing time are major industrial problem as improv this process will helps on saving the production cost and energy consumption.

CHAPTER 2

LITERATURE REVIEW

2.1 WOOD-BASED COMPOSITES

Wood-based composites can be categorized into two types which is veneer type and short fibre type. Veneer type such as plywood, laminated veneer lumber and parallel strand lumber while short fibre type such as fibreboard, particleboard and oriented strand board. Wood composite boards consist of 95% wood element (veneer, flakes, particles and fibres), 5% resin and other additives (Dai & Steiner, 1996), unlike any other composites. Loose mat structures are consolidate to produce effective bonding which needs contact between constituents. Thus, the global densities of composite boards are usually 1.6 to 1.8 times the original wood.

Figure 2.1(a): Common Wood Elements used in Wood based Composites

(From top left; shavings, sawdust, fibres, large particle, wafers and strands)

These wood-based composite boards mainly produce from wood materials such as particles, flakes, waferboard or fibres, mixed with thermoset resin and bonded at elevated temperature and pressure in a hot press. Productivity of a plant during manufacturing process depends heavily on the major production steps including wood drying, resin application and hot pressing. Hot press is a costly unit operation, thus reducing the process will gives positive impact on lowering production cost and increasing wood board output capacity. (Matuana et.al., 2004)

Source: Metsäliitto, 2010.

Figure 2.1(b): Wood Board Final Products

Global density are not only affected the physical and mechanical properties of short fibre wood composites, but also the pressing time of the wood mat.

2.2 WOOD FIBRE BOARD

Fibreboard is a type of engineered wood product that is made out of wood fibres. Types of fibreboard include particleboard, medium-density fibreboard, and hardboard which are in order of increasing density. Fiberboard is sometimes called particleboard, but particleboard usually refers to low-density fibreboard. Medium-Density Fibreboard (MDF) is typically used in the furniture industry and veneer wood is commonly glued to the surface of the board to give it a conventional appearance.

Figure 2.2(a): Wood Fibreboard with Veneer Wood as the Surface

Fibreboard is also used in the auto industry to create free-form shapes such as dashboards, rear parcel shelves, and inner door shells which are usually covered with a skin, foil, or fabric. Urea-Formaldehyde (UF) resins are dominantly used in the medium density fibreboard (MDF) industry because of low cost and fast curing characteristics. However, UF resin will release formaldehyde to the environment which is a growing health concern. On the other hand, phenol-formaldehyde (PF) resins are more durable and do not emit formaldehyde after cure. Moreover, industry is not prefer on using PF resins due to their higher cost and much slower curing rate than UF resins.

However, the press time PF bonded fibreboard can be reduced by manipulating the fiber mat temperatures, molecular weight distribution of PE resins and pressing parameters. As a result, the press times for PF bonded fibreboard is comparable to those for UF bonded fibreboard. Also, less than 5% resin content is required for PF bonded fibreboard to achieve a good board which is considerably lower than the required for UF bonded fibreboard.

Figure 2.2(b): Wood Fibreboard after Pressing

Fibreboard consists of bio-based and secondary raw materials recovered from within 100 miles from manufacturing facilities such as wood chip or sugarcane fibres can be considered as green building products. The binding agent used in this type of fibreboard is natural product consisting of vegetable starch with no formaldehyde.

Fiberboard, classified by ASTM C208, Standard Specification for Cellulosic Fiber Insulating Board, has many benefits and is used in residential and commercial construction. The uses and applications include (Stark et.al, 2008):

- sound proofing/deadening
- structural sheathing
- low-slope roofing
- sound deadening flooring underlayment

Theory of fibre reinforcement stated that longer fibre produce better strength to the composite and for shorter fibres, it is easily dispersed. Based on common impression, properties of fibres will increase more than adhesion with a good dispersion. These properties depend on the content of the fibre such that increasing fibre content resulting in increasing stiffness but strain and impact will decrease.

2.3 METAL OXIDE NANOPARTICLES

Based on this research topic, filling wood composites with nanoparticles is an interesting work. The trend of modern chemistry are producing new product by mixing two or more common materials. The term ‘nanoparticle’ includes terms such as nanopowder, nanocluster, nanocrystal particle with at least one dimension less than 100 nm, preferably below 50 nm but below 30 nm is more preferable. (Danzer et.al, 2010).

Nowadays, nanocomposites have become an expanding field of research. Researchers have focused their research on the processing of the nanocomposites to enhance mechanical and physical properties. (Dufresne, 2006 & Bondeson, Mathew, Oksman, 2006). Nanoparticles use a matrix where the nanosized reinforcement elements are dispersed, whereby the reinforcement is considered as a nanoparticles when at least one of its dimensions lower than 100nm. This particular feature provides nanoparticles unique and outstanding properties never found in conventional composites. (Bondeson et.al, 2006 & Azizi Samir, Alloin, Dufresne, 2005).

The largest group of inorganic nanomaterials comprises metal oxides are titanium dioxide, zinc oxide and silicon dioxide. (Park, 2007). Aluminium oxide is one of the commercially produce product and are available in bulk. Conducting an internet search for nanomaterial manufacturers generates many hits, with most of the companies identified offering a range of metal oxide nanomaterials. These may or may not be currently produced in significant commercial quantities, but the manufacturing technology is generally capable of producing such materials in large quantities.

2.4 BOARD FORMATION

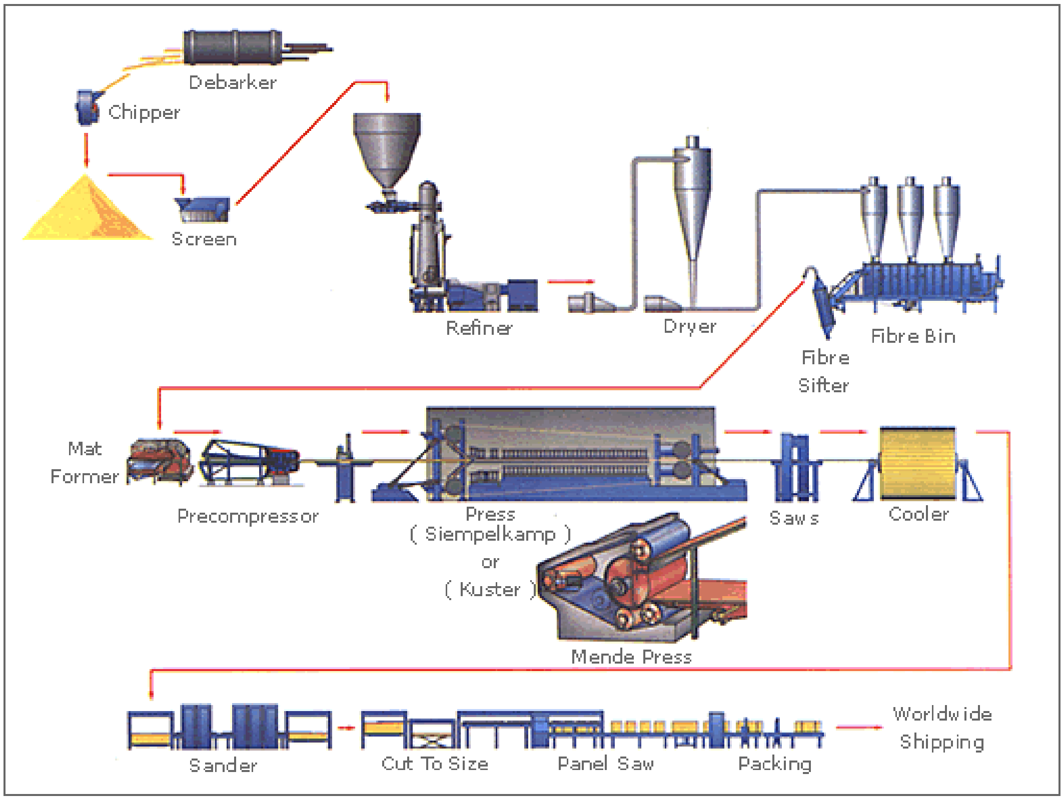

Figure 2.4(a): Industrial Wood Boards Manufacturing Process.

Dry-process fiberboard is made in a similar fashion to particleboard. Resin and other additives are applied to the fibres by spraying in short-retention blenders or introduced as wet fibres are fed from the refiner into a blow-line dryer. Alternatively, the resin is added in the refiner. The adhesive-coated fibres are then air-laid into a mat for subsequent pressing, much the same as mat formation for particleboard. (Stark, 2006).

After mat formation, fibre needs to be pre-pressed in a band press procedures. It is then trimmed by disk cutter and transfer to caul plates for hot pressing operation. For MDF, the trimmed mat is transferred directly to the press. Many dry-formed boards are pressed in multiopening presses. Continuous pressing using large, high-pressure band presses is also gaining in popularity. Panel density is constantly monitored by moisture sensors using infrared light as an indicator of panel quality. (Stark, 2006).

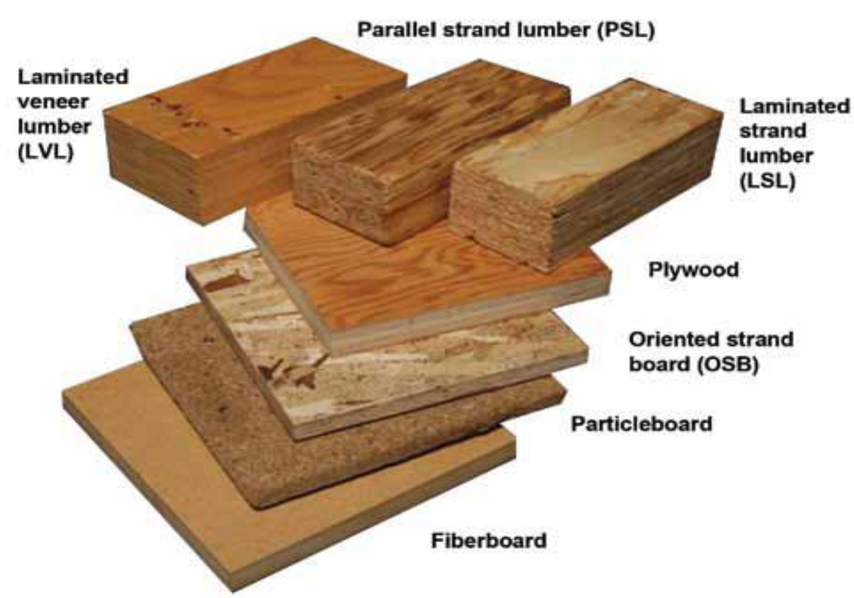

Figure 2.4(b): Examples of Various Composite Products

Source: Stark 2006.

MDF is frequently used in furniture industry in place of solid wood, plywood and particleboard. It is also used for interior door skins, mouldings, and interior trim components. ANSI A208.2 classifies MDF by physical and mechanical properties, and identifies dimensional tolerances and formaldehyde emission limits. (CPA 2009b). An example of an MDF formaldehyde emissions certification tag is shown in figure.

Sample Bundle Tag for non-EPP MDF Certified to ANSI A208.2-2009.

COMPLIES WITH ANSI A208.1-2009 AND
CALIFORNIA 93120 PHASE 1 FORMALDEHYDE
EMISSION LIMITS

C P A
CERTIFIED

MILL 000

CALIFORNIA ARB APPROVED THIRD PARTY CERTIFIER TPC-1

MANUFACTURER'S NAME
LOCATION
PRODUCTION SHIFT/CREW
PRODUCTION LOT/BATCH

Figure 2.4(c): Example of MDF Formaldehyde Emissions Certification Tag

(Courtesy for Composite Panel Association, Leesburg, Virginia. Sources of Wood Based Composite Material Handbook)

Thermosetting polymers such as urea formaldehyde (UF) and melamine formaldehyde are the most widely used amino resins (Conner, 1996; Pizzi et al., 2001; Updegraff, 1990). MDF and particleboard are primarily using UF resin in interior applications. Moisture exposure leads to a breakdown of the bond-forming reactions due to excessive heat exposure will result in chemical breakdown of cured UF resins, therefore UF bonded panels are cooled after the press. Advantages of UF resins include lower curing temperatures than PF resins and ease of use under a variety of curing conditions. UF resins are the lowest cost thermosetting adhesive resins and offer light color, which often used in the manufacture of decorative products. (Stark et.al., 2006). However, UF resin will produce formaldehyde emissions which are very dangerous to the environment.

2.5 MECHANICAL TESTING

Degree of deformation can be determined when wood undergo deformation after a large amount of load applied. Wood has elastic properties in which it will spring back if the load applied is below the elastic limit but it will started to break when the load applied is exceeding the elastic limit. Partial of the wood will spring back to its original shape or it will fully damage due to the damage of wood properties. The pressure is too much for the wood to stand and the wood is no longer able to support the high loads.

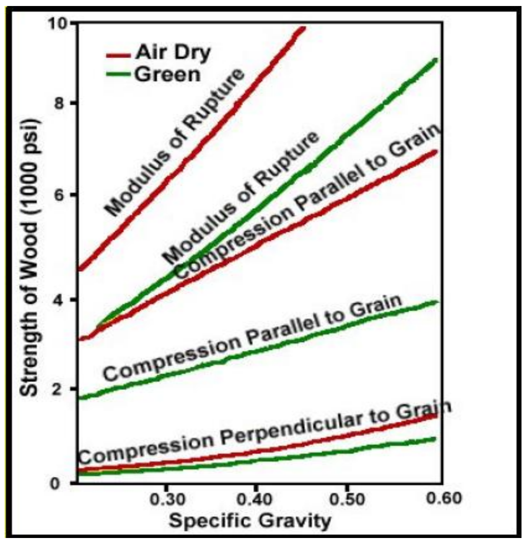

Figure 2.5(a): Strength of Wood Board on Specific Gravity

In general, wood is stronger when loads are applied parallel to the grain than perpendicular to the grain. This is due to the anisotropic properties of wood whereby its structure and properties vary in different directions.

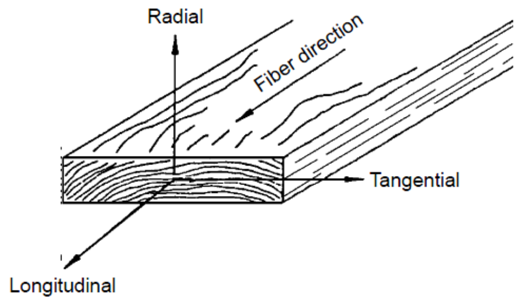

Figure 2.5(b): Anisotropic Properties of Wood

2.6 MARKET REVIEW

2.6.1 Market Demand

Table 2.6(a): The Relationship between Hierarchy of Human Needs and Demand Placed on the Forest Sector.

Order	Human Need	Demand Placed on the Forest Sector
Basic	Food	Harvesting of food from the forest out of necessity. Not currently important in most European country.
Basic	Shelter	Demand for basic construction materials. Still important in all European countries.
Basic	Security	Not very relevant for the forest sector.
Low	Possessions	Demand for wooden furniture, packaging materials and other articles. Still important in all European countries.
Medium	Personal Development	Demand for improve health and leisure. Expressed as higher demand for forest recreation. Greater interest in protecting the environment.
High	Knowledge	Demand for paper, especially for books, magazines and newspaper.
Very High	Self-awareness	Demand for high quality forest products with a greater focus on fashion and design.