Fluid Flow in Wood and Wood-composite Panels: Effects of Nanotechnology

Hamid R Taghiyari,[a,*] and Jack Norton [b]

Wood is a natural, renewable material with continuous porous structure. Density in each wood species significantly depends on its porosity. The continuous porosity in wood provides easy transfer of different fluids through it. Wood is mainly composed of the three polymers cellulose, hemicellulose, and lignin. Many of the hydroxyl groups (-OH) in cellulose and hemicellulose are available for interaction with water molecules. This is the root cause for shrinkage and swelling phenomena in wood and wood-composite materials. In wood-composites, constant and repeated shrinkage and swelling result in break-down of the resin-bonds in the composite-matrix, eventually weakening the whole structure. Moreover, water molecules interact with the resin polymer, significantly affecting its strength. Easy transfer of water vapor and liquid through the composite matrix speeds up this process. It is therefore necessary to monitor, and if possible to decrease, the flow of water and water vapour into the wood-composite matrix, increasing its service life. A brief overview is given of research involving nano-materials in solid wood and wood-composite panels, with emphasis on air and liquid permeability. The pressure used to impregnate solid wood with aqueous nano-suspension affects the pore system, resulting in significant fluctuations in permeability. Moreover, the high thermal conductivity coefficients of metal and mineral nano-materials have demonstrated major effects on permeability and heat treatment of solid wood. The water repellent property of nano-silane compounds also can significantly affect both liquid and gas permeability values.

Keywords: Fluid flow; Nanotechnology; Penetration; Permeability; Wood-composites

*Contact information: a: Wood Science and Technology Department, Faculty of Civil Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran; Correspondence: 0930-2005235; htaghiyari@srttu.edu and htaghiyari@yahoo.com; b: retired, Horticulture and Forestry Science, Queensland Dept. of Agriculture, Australia; *Corresponding author: htaghiyari@srttu.edu*

INTRODUCTION

Fluid flow is a physical property in wood and wood composites that is related to porosity and structure (Shahverdi *et al.* 2012; Tanaka *et al.* 2015). Many factors influence the regeneration and utilization of trees and their fruit (Mosqueda *et al.* 2013; Fernandez and Oliver 2014; Miteva *et al.* 2014), as well as some modification methods that affect the equilibrium moisture content in solid wood (Goli *et al.* 2014), alter the micro-structure of wood and wood composites, and significantly change the gas or liquid permeability. Changes in the porosity and permeability would also affect the marketing and advertisement policies (Oblak and Glavonjic 2015). The way that gases and liquids flow through the matrix of wood-composite materials also affects their properties, and ultimately influences their application (Shibata and Hirohashi 2013; Taghiyari 2013a,b);

Treated and pre-treated wood have different permeability in comparison to the normal wood (Acuna *et al.* 2014). Interaction between wood components as the fluid passes through the complicated network of pores and cavities also have significant effects on the physical and mechanical properties and therefore applications. Wood-destroying fungi produce CO_2, water, and energy by respiration and therefore need oxygen. Fungal activity is therefore affected by the permeability of wood; and in return, permeability is affected by the growth of fungi (Hernandez *et al.* 2012; Maresi *et al.* 2013). There are various reactions occurring in wood fungi that require oxygen, such as degradation of lignin, oxidative polymerization of phenols, and melanin synthesis in blue-stain and other fungi (Schmidt and Moreth 2003; Schmidt 2006, 2007; Morrell *et al.* 2006; Moradi *et al.* 2013; Marzbani *et al.* 2015).

Demand for wood resources and reliance on natural regeneration of forests necessitate the use of fast-growing trees and harvesting at short rotations (Kues 2007). The harvested wood of these trees is not usually suitable for the furniture industry; however, such material provides a sustainable source for paper and composite-manufacturing industries. For many centuries, the size of wooden structures was limited by the natural dimensions of trees and the wood they produced (Kues 2007). Solid wood had an inherent disadvantage in that its strength properties are significantly different in different directions. The strength across the fiber in solid wood is about 1/20 to 1/10 of that in the longitudinal direction (Nowak and Drach 1949). The orientation of cells is also characteristically different, leading to a swelling and shrinking anisotropy. Therefore, a more uniform material not limited by the natural dimensions of trees would be beneficial. The term wood-composite panels (or wood-composites, panels boards, …) refers to any product that is manufactured on the basis of mechanically chopped, milled, ground, or refined wood (such as veneers, strands, particles, fibers, *etc*.) that are bonded by adhesives usually through a process at high temperature and pressure (Youngquist *et al.* 1997; Kharazipour 2004). During the production of wood-composites, the homogenized raw materials are formed to the desired shape, size, dimension, and amount. Current important wood-composite panels are particleboards, medium-density fiberboards (MDF), oriented strand-boards (OSB), and plywood. The term particleboard refers to a wood-based panel manufactured under pressure and heat from wood particles (wood chips), usually by addition of adhesives and under hot press. MDF is made from lignocellulosic fibers mixed with a resin and hot pressed. OSB is manufactured from solid wood shredded into small rectangular strips, layered across each other in the direction of their grain, and bonded together by a resin and hot pressed. Plywood is produced using wood veneer stacked crosswise onto each other (Kues 2007).

Wood-composite materials have the advantage of offering a homogeneous product, which is important for many design purposes (Doost-hoseini *et al.* 2014). Wood-composite materials also have the advantage of in-process treatments. This particular property is quite useful when the end-uses involve treatment of wood chips and fibers with nano-materials and resins during the process of wood-composite production (Manning 2002; Gardner *et al.* 2003; Bekhta *et al.* 2015). During the production of wood-composite materials, the passage of fluid may affect other components, such as resin and paraffin used in their production.

Better knowledge of the porous structure of wood and wood-composite materials would therefore provide us with useful information on how they might react under different conditions, including the relative humidity in which the wood-composite materials are installed. Wood has thermo-hygromechanical behaviour, and its properties depend on the combined action of temperature, relative humidity, and mechanical load variations (Figueroa *et al.* 2012), the temperature of the surrounding environment, exposure to sunlight and UV-radiation, exposure to high temperature and possibly fire (Ozdemir and Tutus 2013; Haghighi *et al.* 2013; Haghighi *et al.* 2014), the presenceof biological wood deteriorating agents (Schmidt and Moreth 2003; Schmidt 2007; Karimi *et al.* 2013) such as fungi (Akhtari *et al.* 2012, 2013; Habibzade *et al.* 2014), wood-boring beetles, and termites, as well as bacteria and microorganisms, *etc*.

Many methods have been used to measure permeability in wood and wood-composite materials with different levels of precision (Siau 1995; Perre and Karimi 2002; Shi 2007; Pokki *et al.* 2010). In recent years it has become possible to measure gas permeability values in solid wood and wood-composite materials due to the development of gas permeability measurement apparatus with 0.001 second precision (Taghiyari *et al.* 2010; Taghiyari and Sarvari Samadi 2010). Due to the high precision and ease of use, the results obtained from this apparatus are regarded as credit-worthy for scientific and industrial purposes (Taghiyari and Farajpour 2013). Gases usually don't interact with wood material components, while liquids may interact chemically and physically with them, mostly with their hydroxyl groups (Taghiyari 2013a,b). Most industries in which permeability is important involve applications in which solid wood is impregnated with liquid or applications where liquid is extracted from them. Therefore, liquid permeability measurement is important, in order to better understand the behaviour of wood to the penetration of liquids. Finding a correlation between gas and liquid permeability is also important for industrial decision-making processes.

Wood is a biological material that is greatly affected by its moisture content (MC) (Schmidt 2006). Different modification methods have been tried to ameliorate the effects of water movement, such as acetylation and thermal modification (Hill 2006; Borrega and Karenlampi 2010). The thermal modification of wood has long been recognized as a potentially useful method to improve the dimensional stabilization of wood and increase its decay resistance (Hill 2006). Although thermal modification has negative effects on the strength properties of wood, there are mitigating techniques (Awoyemi and Westermark 2005; Awoyemi 2007). The thermal conductivity coefficient of wood is quite low (Taghiyari 2011a; Taghiyari *et al.* 2012, 2013b), and the thermal conductivity of nanofluids containing dispersed metallic nanoparticles has been studied for its potential to improve the rate of heat penetration (Ayesh and Awwad 2012; Taghiyari 2012a). Enhancement in the thermal conductivity of common heat transfer fluids when small amounts of metallic and other nanoparticles are dispersed in these fluids has been reported by many researchers (Yu *et al.* 2010; Azarakhshi and Farhadyar 2012; Sadeghi and Rastgo 2012; Saber *et al.* 2013). It is appropriate to investigate improving the thermal conductivity in wood-composite materials.

In the present reviewing paper, the effects of using different nano-materials (metal nano-particles, mineral nano-fibers, mineral nano-sheets …) on the gas and liquid permeability in solid wood and wood-composite panels is discussed.

PERMEABILITY MEASUREMENT

Gas Permeability Measurement

A gas permeability measurement apparatus can measure permeability values in porous media (including solid wood, wood-composite materials, carton and paper, light-weight cement, …) with milli-second precision (USPTO No. US 8,079,249, B2; approved by The Iranian Research Organization for Scientific and Technology under certificate No. 47022) (Taghiyari 2012b; Taghiyari and Efhami, 2011; Choo *et al.* 2013). As shown in Fig. 1, a 7-level automated-time-measurement device has been developed (Taghiyari *et al.* 2009). A falling-water volume-displacement method is used to calculate specific longitudinal gas permeability values based on the microstructure porosity of wood (Siau 1995; Shi 2007; Taghiyari 2013b). Specimens can be prepared on a lathe, or by a plug saw. The optimum diameter of specimens is 17.5 mm. The connection between the specimen and holder was made fully air-tight. For each specimen, gas permeability values can be measured at 7 different water-column heights, that is 7 different vacuum pressures, in a single run. The internal diameter of the glass tube was 13 mm. The water level is15 cm above the starting sensor for the first time-measurement point (Gas 1). A pressure gauge with milli-bar precision was connected to the whole structure to monitor pressure gradient (ΔP) and vacuum pressure at any particular time as well as height of water column. Vacuum pressures at starting and stopping points for each of the 7 different heights are listed in Table 1.

Table 1. Vacuum Pressures at Starting and Stopping Points for each of the 7 Water Column Heights (Taghiyari 2013a)

Code of the 7 Water Columns	Height of the 7 Water Columns at Starting Point (cm)	Height of the 7 Water Columns at Stopping Point (cm)	Starting point vacuum pressure (minus milli-bar)	Stopping point vacuum pressure (minus milli-bar)
Gas 1	149.5	139.5	155.0	146.5
Gas 2	134.5	124.5	141.5	132.0
Gas 3	119.5	109.5	126.5	117.0
Gas 4	104.5	94.5	112.0	101.5
Gas 5	89.5	79.5	97.5	86.5
Gas 6	74.5	64.5	82	72
Gas 7	59.5	49.5	66.5	56

Three measurements are taken for each specimen to obtain a mean value. Superficial permeability coefficient is then calculated using Siau's Equations (Siau 1995; Avramidis *et al.* 2005; Taghiyari and Efhami 2011) (Eqs. 1 and 2).

The superficial permeability coefficients were then multiplied by the viscosity of air (μ=1.81×10^{-5} Pa s) for the calculation of the specific permeability ($K=k_g\,\mu$),

$$k_g = \frac{V_d C L (P_{atm} - 0.074\bar{z})}{tA(0.074\bar{z})(P_{atm} - 0.037\bar{z})} \times \frac{0.760 mHg}{1.013\times10^6 Pa} \quad (1)$$

$$C = 1 + \frac{V_r(0.074\Delta z)}{V_d(P_{atm} - 0.074\bar{z})} \quad (2)$$

where k_g is the longitudinal specific permeability (m^3 m^{-1}), $V_d = \pi r^2 \Delta z$ [r = radius of measuring tube (m)] (m^3), C is a correction factor for gas expansion as a result of change in static head and viscosity of water, L is the length of wood specimen (m), P_{atm} is the atmospheric pressure (m Hg), $\bar{z}$ is the average height of water over surface of reservoir during period of measurement (m), t is time (s), A is the cross-sectional area of wood specimen (m^2), Δz is the change in height of water during time t (m), and V_r is the total volume of apparatus above point 1 (including volume of hoses) (m^3).

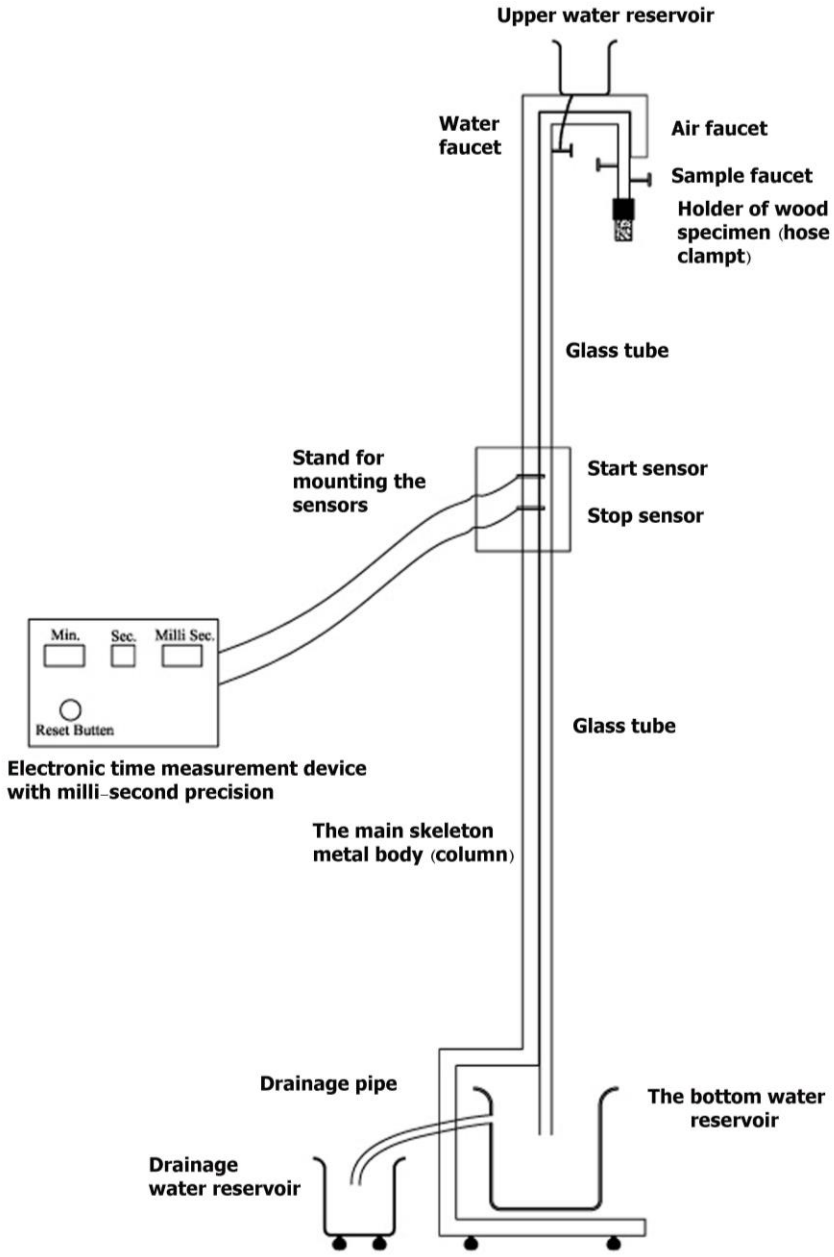

Fig. 1. Schematic of the gas permeability apparatus (Taghiyari and Efhami 2011; Taghiyari 2012b; Taghiyari and Sarvari Samadi 2015)

Gas permeability values in 30 or 50 mm long solid wood specimens with 17 to 18 mm diameter have been reported previously (Taghiyari and Sarvari 2010). Round specimens were preferred to square specimens due to the greater perimeter of square specimens. Square specimens have more vessel elements to be cut and blocked than round specimens (Taghiyari and Moradi 2014). In wood-composite materials, the length of specimens is limited to the thickness of composite panels (Taghiyari and Farajpour 2013).

Liquid Permeability Measurement

Liquid permeability was measured using the Rilem test method II.4 (Fig. 2) (Taghiyari 2012b) Penetration tests were conducted under laboratory conditions according to ASTM E-514. Two times were recorded: the time the first drop of water falls off the bottom surface of the specimens and the time taken for the level of water in the Rilem tube to drop by 50 mm (6.6 cc of water). Correlations between each of the 7 permeability times were separately calculated for the-first-drop time, and the 50-mm-lowering time.

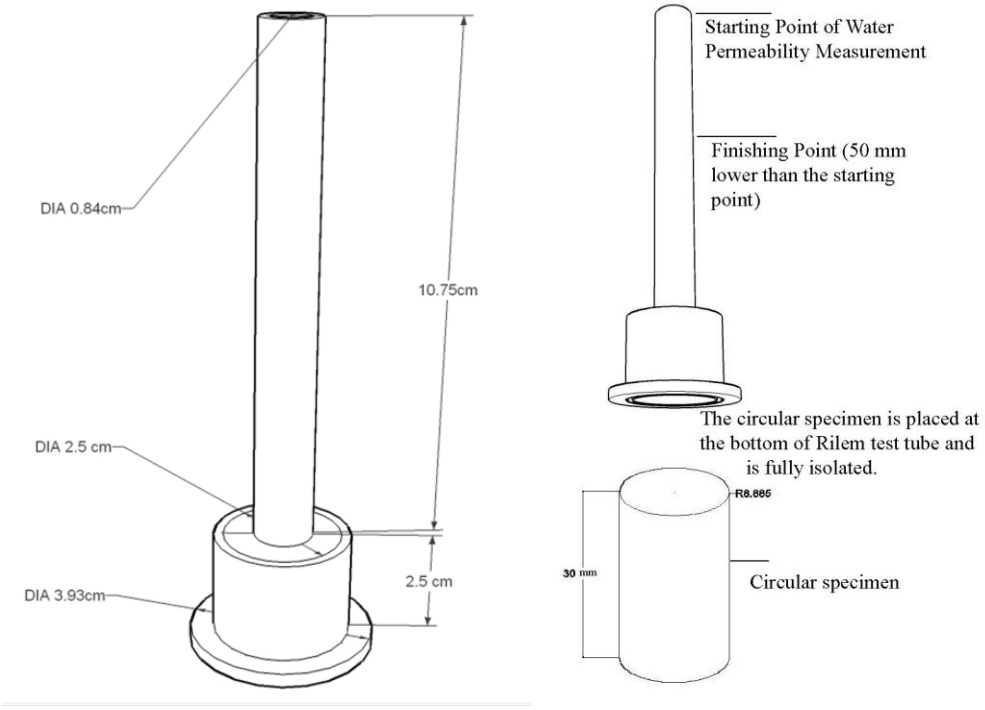

Fig. 2. Liquid permeability measurement apparatus (Rilem) (Taghiyari 2012b)

Effects of Nanomateriala on Permeability

Permeability in solid wood

Permeability in solid wood is significantly influenced by the density, porosity system in the wood structure, the way cell and vessel cavities are inter-connected through perforation plates and pits, tyloses, extractive contents, pitch deposits, growth of different fungi and mold hyphae along vessel elements and in pits, *etc*. (Avramidis and Mansfield

2005; Taghiyari *et al.* 2010; Taghiyari 2014a,b; Taghiyari and Sarvari 2010; Taghiyari 2012; Taghiyari *et al.* 2014a,b).

In hardwood, the main path for fluid transfer is through the vessels (Eaton and Hale 1993; Taghiyari and Moradi 2014) due to the size of vessel cavities in comparison to fiber pits (Fig. 3). It was therefore best to prepare wood specimens as a cylinders to minimize the number of vessel elements to be cut and blocked by the silicone adhesive (Taghiyari and Moradi 2014).

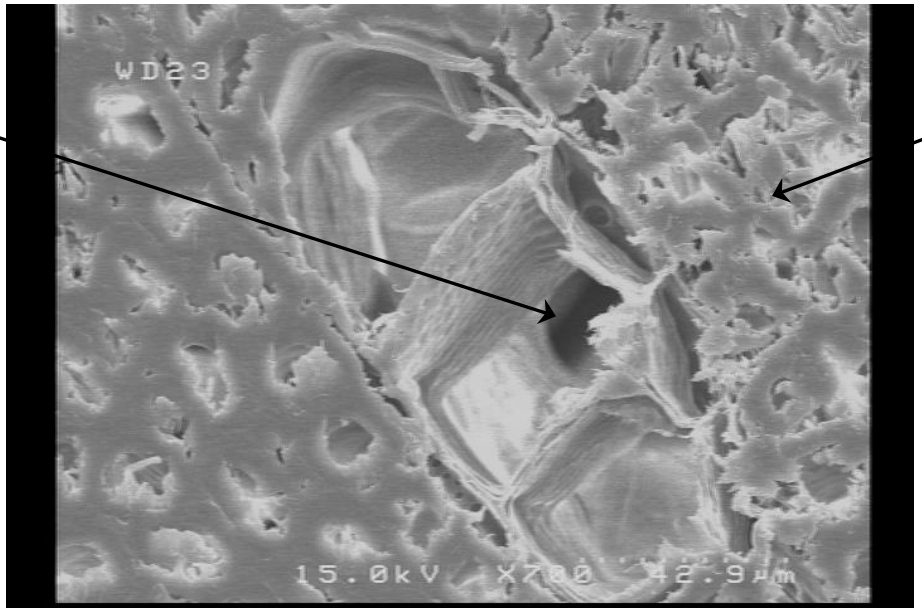

Fig. 3. SEM micrographs of the cross-sectional view in poplar, showing a large vessel in comparison to small fibers (Taghiyari and Moradi 2014)

Impregnation of solid wood with nano-suspensions is reported to significantly affect permeability. Some of the extractives that block the pathways through which fluid can pass were washed out, resulting in a significant increase in permeability. It was reported that impregnation with aqueous nano-suspension resulted in a significant increase in permeability in poplar with high extractive content and simple perforation plates (Taghiyari 2012b).

The pressure during the impregnation process collapses the pits and scalariform perforation plates in beech, again resulting in an increase in permeability (Taghiyari 2012b; Taghiyari *et al.* 2014c). However, it should be noted that in cases where the pressure is very high and there is a high proportion of perforation plates, accumulation of the broken plates would block the way through which fluid can transfer, resulting in a decrease in permeability (Taghiyari 2012b; Taghiyari *et al.* 2014c).

Heat treatment of solid wood at temperatures lower than about 60°C increases permeability due to the loss of bound water and the shrinkage (Taghiyari 2013b; Taghiyari and Moradi 2014). Temperatures up to about 170°C decrease permeability due to irreversible hydrogen bonding in the course of water movement within the pore system and the resulting stiffness of the cell wall (Oltean *et al.* 2007; Borrega and Karenlampi 2010; Taghiyari and Samandarpour 2015). Heating solid wood more than about 180°C

creates micro-checks (micro-cracks) in the cell wall, resulting in an increase in permeability (Taghiyari and Moradi 2014) (Fig. 4).

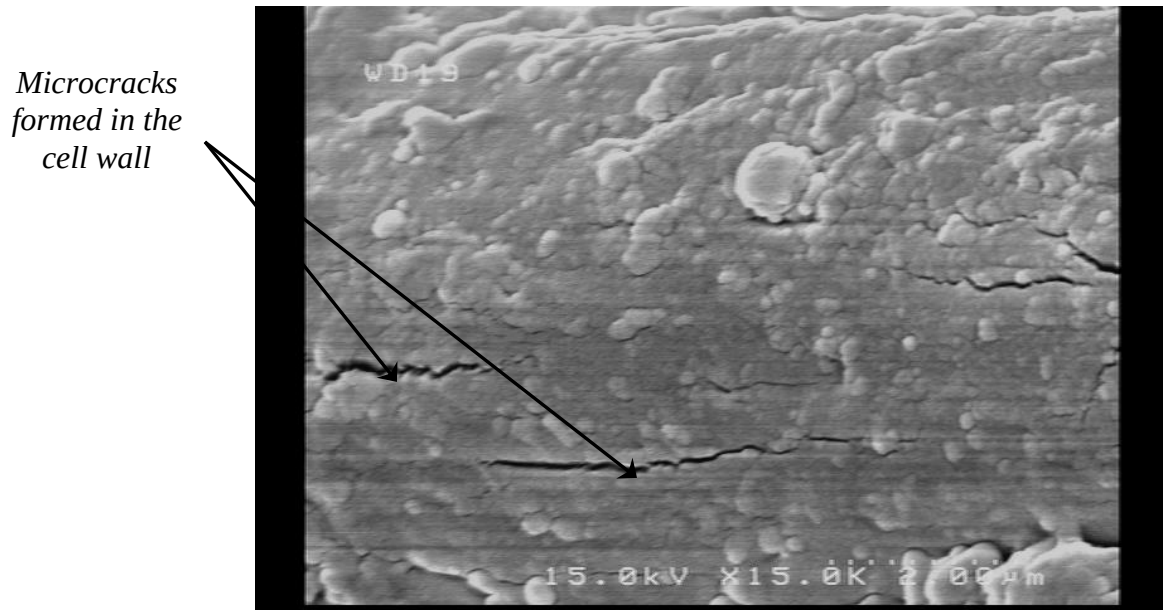

Fig. 4. SEM micrographs showing micro-cracks in the cell wall of poplar (Taghiyari and Moradi 2014)

The high thermal conductivity coefficient of metal nanoparticles (Li 2012; Saber *et al.* 2013) scattered over the surface of wall cells and fibers was reported to significantly facilitate heat transfer to the inner parts of wood and wood-composite specimens, resulting in an accelerated increase or decrease in permeability (Taghiyari 2011a, 2013b; Taghiyari *et al.* 2013b) (Fig. 5).

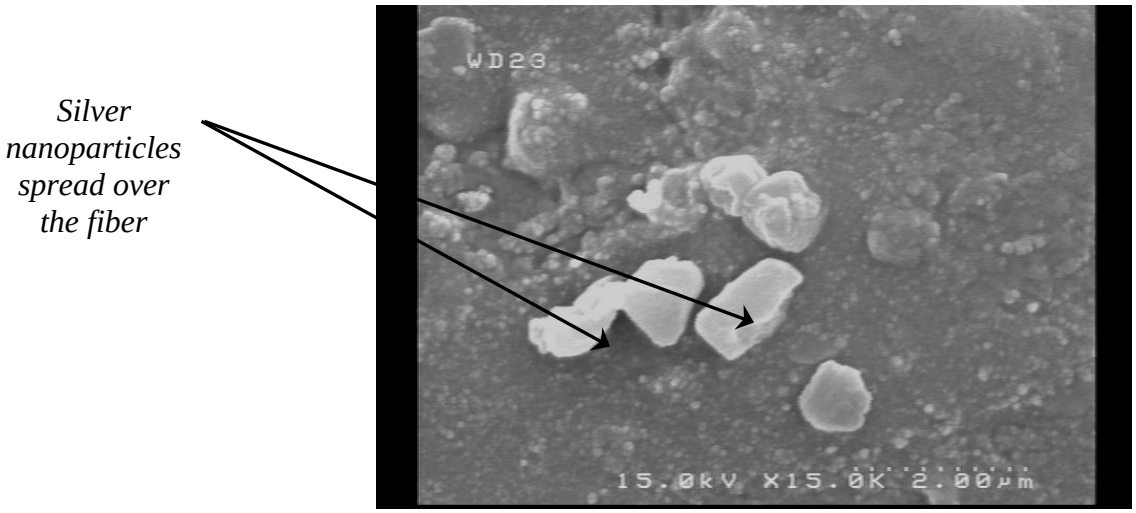

Fig. 5. SEM micrograph showing silver nanoparticles scattered all over the fibers (Taghiyari *et al.* 2013b)

Permeability in wood-composite panels

One of the characteristics of wood that has been reported by scientists is that it absorbs water when placed in wet or moist environments (Mantanis and Papadopoulos 2010). The movement of water vapor and liquid through composite material is due to its continuous porous structure. This affects wood-composite materials in different ways. First, the dimensions of wood-composite products change due to swelling. Swelling not only has undesirable side-effects on the dimensions of the wood-composite products that are used in a structure, but also the component wood chips and fibers lose their integrity because of micro-movements caused by the swelling. Secondly, water also breaks down the resin bonds that have stuck wood chips or fibers together in the matrix, again decreasing the overall strength of the composite matrix (Papadopoulos 2006). A highly significant correlation has been reported between air and liquid permeability values and swelling in wood-composite materials (Taghiyari 2011b, 2013a).

The water-repellent properties of nano-zycosil (NZ) was used to decrease water absorption in medium-density fiberboard (MDF), (Taghiyari 2013a, 2014a; Taghiyari *et al.* 2014d). The NZ-liquid used was the product of organo silane reacted with an organic reactant. Its color was pale yellow, with the flash point at more than 85°C and auto-ignition temperature at more than 200°C, and specific gravity of 1.05 g/mL (at 25°C), viscosity of 500-1000 cps (at 25°C). The NZliquid was comprised of 38 to 42% hydroxyalkyl-alkoxy-alkylsilyl compounds and the solvent was ethylene glycol (58 to 62%). NZ was used at 0, 50, 100, and 150 g/kg dry wood fibers. The NZ-liquid was smoothly mixed with the resin. NZ-content was based on the solid parts in the suspension. For each treatment, the weight of NZ-solids was deducted from the fiber used; this way, the density of panels in different treatments with different fiber-content was kept constant. The final mixture of NZ+resin was smoothly sprayed on the fibers. The pH and viscosity of the resin were kept constant for all treatments in the present study. The density for all treatments was kept constant at 0.67 g/cm^3. The cited author reported that NZ significantly decreased liquid permeability in MDF (Fig. 6), although the amount of wood fibers was lower in NZ-treated panels and micro-cavities formed in the composite-matrix (Fig. 7). This resulted in the NZ100-treatment being clustered with the control panels (Fig. 8).

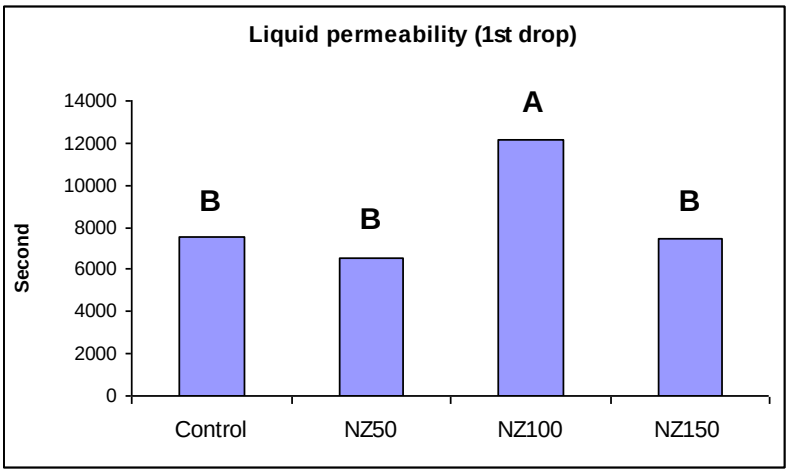

Fig. 6. Liquid permeability of the 1st-Drop for the four treatments of control, NZ-50, NZ-100, and NZ-150 treatments (s) (NZ=nanozycosil) (Taghiyari 2013a)

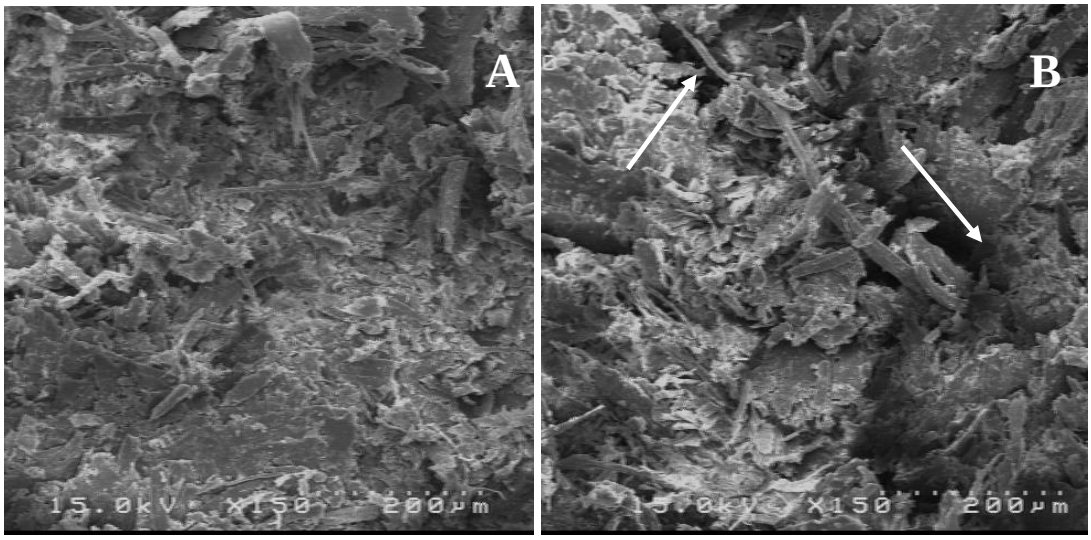

Fig. 7. MDF texture (A) control specimen: fibers are integrated more intensely; (B) NZ-150: some void spaces are observed in the texture allowing air to pass through much more easily (Taghiyari 2013a)

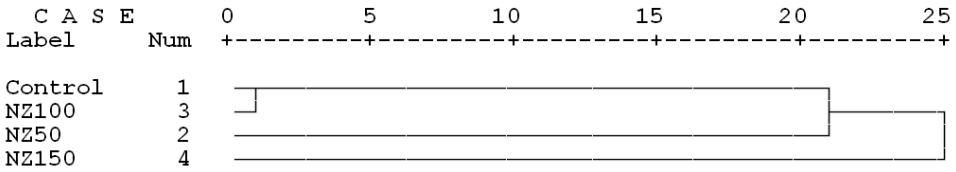

Fig. 8. Cluster analysis based on gas permeability value, as well as the two liquid permeability times for the four treatments of control, NZ-50, NZ-100, and NZ-150 (NZ=nanozycosil) (Taghiyari 2013a)

Cluster analysis was carried to group different treatments based on more than one property (Ada 2013). In another study, NZ was reported to decrease water absorption and thickness swelling in MDF (Taghiyari *et al.* 2013c). NZ-treatment affected the wood-composite in two ways. First, the water-repellant property of NZ nano-particles acted as a physical barrier towards penetration of liquid (water in this case). And second, NZ contributed in the process of sticking wood fibers together; that is, NZ acted as an additional resin, although not as strong as the urea-formaldehyde resin used in the process (Taghiyari et al. 2014d).

Nano-silver (NS) and nano-copper (NC) were also reported to significantly decrease both gas and liquid permeability in particleboard produced at industrial scale (Taghiyari 2011; Taghiyari and Farajpour 2013). NS and NC suspensions were added to the mat at 100 and 150 milli-liters/kg dry weight wood particles.. Permeability values were significantly decreased in all nano-treated composite panels compared to untreated control material. The decrease was due to the high thermal conductivity coefficient of metal nanoparticles, resulting in better heat-transfer to the core of the mat, eventually causing better cure of the resin (Taghiyari *et al.* 2013a). However, the optimum consumption levels of NS and NC were reported to be different. This was due to the

significant difference in the thermal conductivity coefficients of silver and copper. In the case of silver nanoparticles, over-heating of the surface layer of the composite mat resulted in de-polymerization of resin in the surface layer. A lower consumption level of 100 mL was recommended.

The optimum NC-consumption level was 150 mL/kg. Water absorption and thickness swelling were also reported to significantly decrease after addition of NS and NC to the particleboard matrix (Taghiyari *et al.* 2011; Taghiyari and Farajpour 2013). The high thermal conductivity coefficient of metal nanoparticles helped UF-resin cure more effectively. The wood chips were better integrated in the composite-matrix, resulting in the decreased gas and liquid permeability values. Due to the close relation between permeability, water absorption and thickness swelling, the non-destructive nature of air permeability (gas permeability) can be very helpful for industrial purposes.

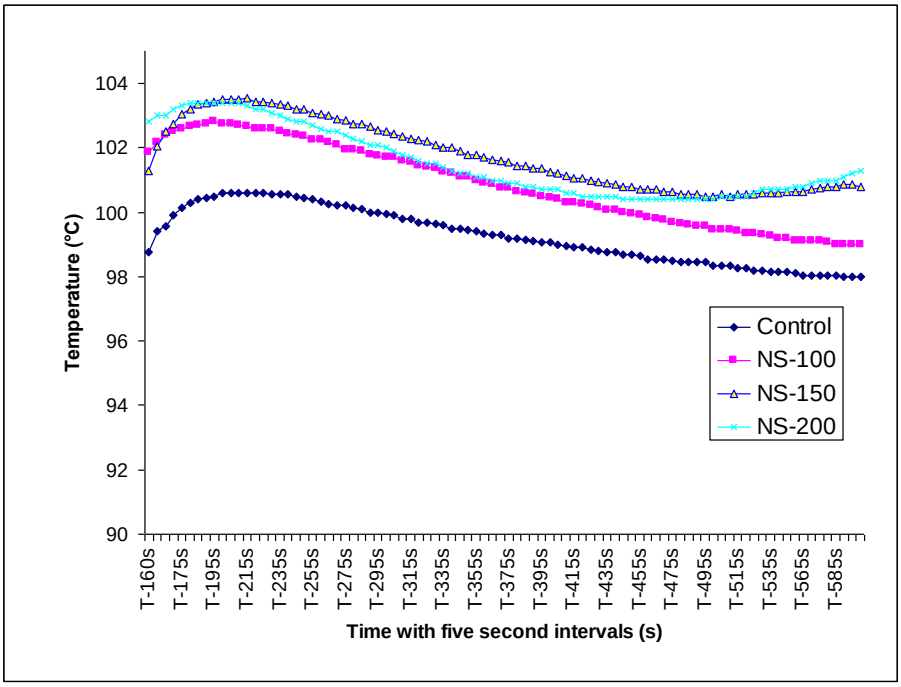

Fig. 9. Temperature at the core section of the medium-density fiberboard mat after the third minute of hot-pressing with five-second intervals (NS= nanosilver content mL/kg) (Taghiyari *et al.* 2013a)

Accelerated heat-transfer in NS and NC-treated composite panels can influence permeability from another point of view. Heat-treatment was reported to have significant effects on fluctuations in permeability in different wood species (Taghiyari 2013b). In this case, structural modification and chemical changes of lignin occur while heating wood (Repellin and Guyonnet 2005). The irreversible hydrogen bonding during water movement within the pore system also affects the fluid transfer process (Borrega and Karenhampi 2010). These processes caused permeability to increase when wood was heated between75 °C and 150 °C. As is the case for solid wood, higher temperatures increase internal stresses that are released as cracks (Oltean *et al.* 2007). These micro-cracks facilitate the process of fluid transfer through the porous material causing the gradual increase in permeability. Heat-treatment at 185°C made permeability values

decrease. These processes are present during hot-pressing in wood-composite panels too. The fluctuations in permeability alter evaporation behavior during hot-press time.

Nanoclay was reported to have no significant effects on permeability in plywood; however, moisture diffusion decreased significantly (Dashti *et al.* 2012). The authors used nanoclay at 3 and 5%. Hot press time was also studied at 4 and 5 minutes. It was concluded that due to the hydrophobic property of clay nanoparticles, an increase in the level of consumption of filler resulted in reduction in thickness swelling and diffusion coefficient. Silicated clay-polymer nanocomposites acted as a barrier to permeation of gases, *e.g.* O_2, H_2O, and CO_2 (Cai *et al.* 2010). It was also reported that at 2% clay content, permeation to water vapor in a polyimide/layered silicate nanocomposites decreased ten-fold (Ray and Okamoto 2003).

Wollastonite is another mineral material that has recently been used to improve the physical and mechanical properties of wood-composite panels (Taghiyari *et al.* 2014d,e), thermal conductivity (Taghiyari *et al.* 2013e, 2014e), biological resistance against fungi (Karimi *et al.* 2013; Taghiyari *et al.* 2014f,g), and fire properties (Haghighi *et al.* 2013, 2014; Taghiyari *et al.* 2013d). Due to its non-toxic nature to humans (Maxim and McConnell 2005; Aitken 2010), its application in the forest products industry is expanding rapidly (Taghiyari 2014c). Although it was reported to decrease water absorption and thickness swelling in both solid wood and wood-composite panels (Haghighi *et al.* 2013, 2014; Taghiyari *et al.* 2013c, 2014e), to date, no direct study has been published, dealing with its effects on gas or liquid permeability.

This brief review of the nanomaterials applied in solid wood and wood composites has revealed the potential for metal and mineral materials to improve physical properties. However, the high price of some metals and minerals could make their utilization uneconomical at industrial scale. Further studies should be carried out to achieve the same positive results from nanomaterials at a lower cost. Furthermore, production of nanomaterials is costly; therefore, researchers are encouraged to study using materials at micro-scale to find out if similar promising results can be obtained.

CONCLUSIONS

Different kinds of materials have been used at nano-scale in solid wood and wood-composite panels to improve their properties. The porous structures of solid and composite products are influenced by nano-materials, significantly affecting the way different gasses and liquid pass through them. Impregnating solid wood with aqueous nano-suspension causes part of the extractives to dissolve in water and be washed out from the wood, increasing its permeability. The impregnation pressure in during preservative or other treatments involving pressure would also break some pits and perforation plates that would be blocking the transfer of fluids, thus significantly increasing permeability. However, if the pressure is too high, or there are many perforation plates, the broken plates accumulate at points of constriction and block the transfer of fluids, decreasing permeability. The high thermal conductivity coefficient of metal nanoparticles leads to better resin cure in wood-composite panels, resulting in better integration of wood particles or fibers, eventually decreasing permeability. The

water-repellant nature of nano-silane is also a primary cause of significant decrease in liquid permeability. More studies on the effects of mineral nano-materials should still to be done.

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