Some Properties of Linoleum and Wood Laminated Flooring Panels with Magnesium Substrate

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This paper presents some of the properties of commercially manufactured laminated flooring having magnesium oxide substrate. Laminated flooring samples with thin veneer of walnut wood and linoleum were tested for their bending characteristics, internal bonding strength, thickness swelling, and surface roughness. The highest modulus of elasticity value of 583,000 psi was found for the samples loaded in the direction of wood veneer overlay. Linoleum overlaid samples resulted in 461,000 psi for the corresponding value. Wood overlaid samples also showed 8% lower internal bond strength values than those of linoleum laminated specimens. Based on the roughness evaluation of the samples conditioned at 55% and 95% relative humidity levels employing a stylus type equipment, no significant adverse effect of high humidity exposure on their surface quality was determined. It appears that magnesium panels overlaid with solid wood and linoleum veneer sheets could serve as value-added flooring with acceptable properties.

Keywords: Flooring; Magnesium; Linoleum; Wood veneer; Bending; Surface roughness

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INTRODUCTION

Solid wood flooring is the most expensive and architecturally desired material among the other floorings in both residential and commercial buildings. However its high cost is one of the disadvantages of wood flooring (Hiziroglu 2008). The overall value of flooring in the construction industry was about $2 billion in 2009 and is predicted to be around $5.8 billion in 2014 (Hiziroglu 2008). It is a well-known fact that engineered composite type of flooring has been getting more popular in North America and other countries. In general they consist of 3 to 9 thin layers of wood ply of various species constructed similar to plywood or laminated veneer lumber; this combination is more functional and less expensive than solid wood flooring (Hiziroglu 2008; Seo *et al.* 2012). Shrinkage and swelling of such flooring material as a result of moisture content fluctuation in the surrounding environment will be limited due to the cross grain orientation of each ply. Therefore, they are dimensionally more stable than solid wood flooring. Both solid wood and engineered wood floorings can be manufactured from different wood species including walnut, oak, maple, ash, and cherry, which are the most commonly used raw materials (Hiziroglu 2008; Seo *et al.* 2012). Increasing costs of solid wood has resulted in the development of laminated flooring, which has been widely used in many countries due to its low cost and simplicity. Typical laminated flooring consists of various layers of elements that are bonded together in the form of a sandwich. High density fiberboard (HDF) is a fiber-based wood composite having a density above 0.90 g/cm^3, which is the most widely used core material in the manufacture of laminated flooring. High density fiberboard is a composite panel produced from waste and residue material of wood products, allowing manufacturers to sustainably make laminated flooring, with a saving of forest resources. However, manufacture of core HDF is still expensive, and it is the main share of overall cost of the final flooring product. Linoleum has also been used as floor covering for many years. Linoleum is generally manufactured from the renewable raw material solidified linseed oil in addition to mineral fillers including calcium carbonate (http://mindat.org/min-3161.html). Pigments are also added to give different colors to such flexible sheet coverings.

Magnesium oxide, commercially called magnesia, is a versatile material used widely in residential and commercial building industries as construction material. Having a strong bond between magnesium and oxygen results in high strength and resistance of the panels against load (Thomas 2007; Manalo 2013). Drywall is one of the major uses of this product (Rio Moeini *et al.* 2005). Having high resistance against moisture fluctuation in the surrounding environment also makes magnesia-based panels an excellent product. Other applications of magnesia are flooring substrate and underlayment (Manalo 2013). In the case of drywall, the surface of the panel is painted, and generally no direct load is applied to its surface. One of the advantages of magnesia-based panels is their low cost as compared to that of solid wood when such material is targeted to be used for the flooring manufacture. Currently there are several small scale manufacturers in Asian countries, primarily in China, using magnesia for flooring panel production lines. However, one of their concerns is to enhance mechanical characteristics of the panels using a sandwich-type construction. Therefore it is necessary to overlay the surface of the substrate with some kind of thin cover so that not only its mechanical strength would be enhanced but also overall appearance of the flooring can be improved. Magnesia board can easily be fastened or laminated to wood or any other thin layers (Premov and Kutha 2009). Most of the properties of both magnesia and linoleum have been investigated in detail, but there is very little information on strength properties of such combined panel product laminated with linoleum and solid wood veneer (Landry *et al.* 2010; Hossain 2000). Therefore the objective of this work was to determine bending, internal bonding, thickness swelling, and surface quality of magnesia substrate laminated with walnut and linoleum for flooring application as a function of 55% and 95% relative humidity exposure. It is expected that data from this work will provide more comprehensive information on basic characteristics of such panels so that they can be used with a better effectiveness without having any major problem during their service life.

MATERIALS AND METHODS

Commercially produced flooring samples used for the experiments were supplied by Pacan International Inc. in Hong Kong, China. Four different types of samples with magnesium substrate had walnut veneer and linoleum overlays having 0.080 in thickness. Wood overlaid samples were classified into two groups namely, with and without varnish applied to their surfaces. A Comten Universal Testing Unit, Model DMC- 026S with equipped 2,000 lbs load cell was used to determine Modulus of Elasticity (MOE) and Modulus of Rupture (MOE). Both properties are important mechanical characteristics of any engineered products. Modulus of elasticity can be defined as a stiffness of a body, while

MOR is the maximum load a member can carry just before it is broken as a result of centrically applied load. A total 36 samples were considered for the bending test based on ASTM standard (ASTM 2006). No differentiation was considered between varnished and unvarnished specimens regarding their bending properties. However they were loaded on laminated and non-laminated sides to determine the effect of their structural behavior. Figure 1 shows a schematic of load application of the samples in static bending test set-up.

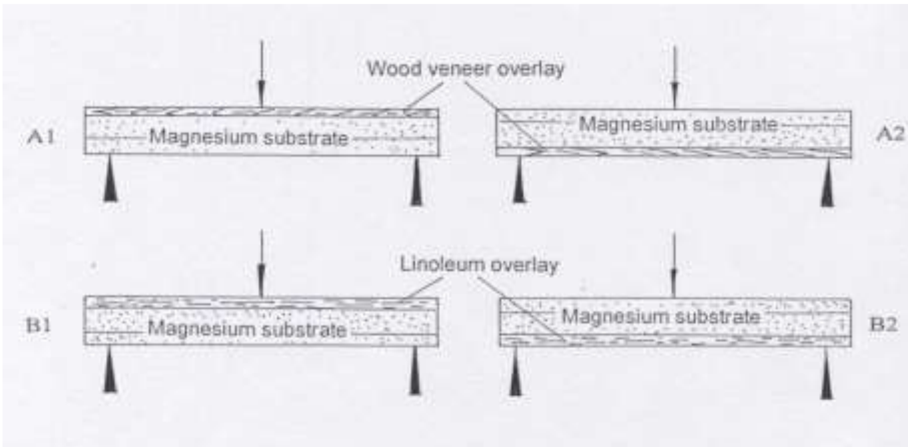

Fig. 1. Load application of the samples overlaid wood and linoleum

Twenty samples with dimensions of 2 in by 2 in for each type of panels were used for internal bond strength (IB) strength. Dimensions of each sample were measured at an accuracy of 0.01 in and weighted with an accuracy of 0.01 g to determine their density. Average density of veneer and linoleum samples was found as 1.09 g/cm^3. Samples were glued to the aluminum block using thermoplastic resin on a hot plate heated at a temperature of 250 ^{o}F. Each sample was kept in a room with a relative humidity of 55% and a temperature of 70 ^{o}F for 24 h prior the testing. A Comtem Universal testing unit was also used for the IB tests. Based on the ASTM-1037 standard, a crosshead speed of 0.0141 in/min was used for the samples (ASTM 1999). A total of 15 samples were soaked into water for a sequence of 2 and 22 h for thickness swelling. Based on the ASTM-1037 standard, the thickness of each sample was measured at four corners at the accuracy of 0.01 in before they were soaked into water (ASTM 1999). The measurements were taken at exact location after 2 and 24 h to determine their thickness swelling.

Roughness is a measure of the fine irregularities on a surface (Hiziroglu 1996). The height, width, and shape of these irregularities establish the surface quality of a product. The surface roughness of engineered wood composites is important when they are used as substrate for thin overlay or finish applied directly to the surface. Fine irregularities on the panel surface will show through overlays, and this affects overall products grade, quality, finishing, and gluing (Mummery 1993; Hiziroglu and Iyengar 1996). Moreover, surface instability is a latent condition, and may never occur unless environmental conditions are favorable to cause a change in the moisture content of the substrate. A total of 10 wood-veneered specimens with the size of 6.0 in by 6.0 in were considered for roughness measurements. The Hommel T-500 surface roughness profilometer was used to evaluate roughness characteristics of the panels. The equipment consists of the main unit and pick up model T5E (Mummery 1993). The pick-up has a skid-type diamond stylus with a 5 µm tip radius and 90-degree tip angle. The stylus traverses the surface at a constant speed of 0.039

in/sec over 0.59 in tracing length, converting the vertical displacement of the stylus into an electrical signal. This signal is amplified before it is converted into digital information (Hiziroglu and Iyengar 1996). Different types of surface roughness parameters such as average roughness (R_a), mean peak-to-valley height (R_z), and maximum roughness (R_{max}) can be calculated when digital information is transferred to a computer (Kalaycioglu and Hiziroglu 2006). Ten random measurements were taken from the surface of five samples of varnished and unvarnished walnut overlaid samples conditioned at 55% relative humidity. Later the samples were exposed to 93% relative humidity until they reach to equilibrium moisture content. Measurements were taken from the exact locations on the samples to evaluate influence of high moisture exposure on the surface quality of the specimens. Average roughness, R_z and R_{max} were used to evaluate surface properties of the samples. Since linoleum-overlaid samples had very rough surface, no roughness evaluation of such specimens was considered in this work. Vertical density profiles of the samples were also determined by using a X-ray density profilometer. A typical density profile of the sample is shown in Fig. 3 (Hiziroglu and Graham 1998).

RESULTS AND DISCUSSION

Table 1 displays mechanical test results of the samples. The samples with wood veneer with application of load on the side of magnesium substrate had the highest MOR value of 7,387 psi.

Table 1. Modulus of Elasticity and Modulus of Rupture Values of the Specimens

Panel Type	A		B	
	A1	A2	B1	B2
MOE (psi)	373,686 (50,336)*	583,452 (90,020)	359,664 (67,497)	460,563 (87,604)
MOR (psi)	1,669 (145)	7,387 (1,400)	1,394 (141)	2,979 (137)
IB (psi)	143.5 (25.7)		155.1 (24.3)	
Thickness swelling	2 h 0.12	24 h 0.16	2 h 0.11	24 h 0.21

A: Wood veneered sample; B: Linoleum overlaid samples
* Numbers in parentheses are standard deviations.(18 Samples were tested for type A and B; 9 tests for each load direction.)

The same type of panels also had the highest MOE value of approximately 583,000 psi with two different load applications. Based on the statistical analysis, no significant difference was found between MOE values of wood veneer and linoleum overlaid panels at the 95% confidence level. However, a significant difference was found between two load applications of both types of panels (Manalo and Aravinthan 2012). Since application of load direction will not play an important role on flooring material during their service life, the choice of either wood or linoleum overlaid flooring material will simply depend on the customer preference.

Average IB strength for linoleum samples was 143.5 psi, while 155.1 psi was found as an average value for wood veneered panels. Most of the samples resulted in failure in linoleum or veneer overlay rather than magnesium portion of the samples. Approximately

10% of the specimens had glue failure, which could be due to weak glue line on the varnished and linoleum overlay. The weak glue line could also have resulted from the smooth surface of veneer and the chemical structure of linoleum. Based on the test results the glue lines between magnesium substrate and both types of overlays are relatively strong and should not give any problems such as peeling off during the service life of the flooring material. Only several failures took place within the magnesium portion of the samples.

Table 2. Roughness Values of Varnished and Unvarnished Specimens Exposed to Two Relative Humidity Levels

	55% Relative Humidity			93% Relative Humidity		
Parameters	R_a	R_z	R_{max}	R_a	R_z	R_{max}
Varnished	0.80 (0.20)*	4.36 (1.28)	6.59 (3.69)	0.85 (0.23)	4.50 (1.33)	7.10 (2.50)
Unvarnished	6.95 (1.81)	49.78 (9.31)	73.03 (17.78)	7.20 (2.10)	59.80 (7.15)	89.06 (15.75)

* Numbers in parentheses are standard deviation values.

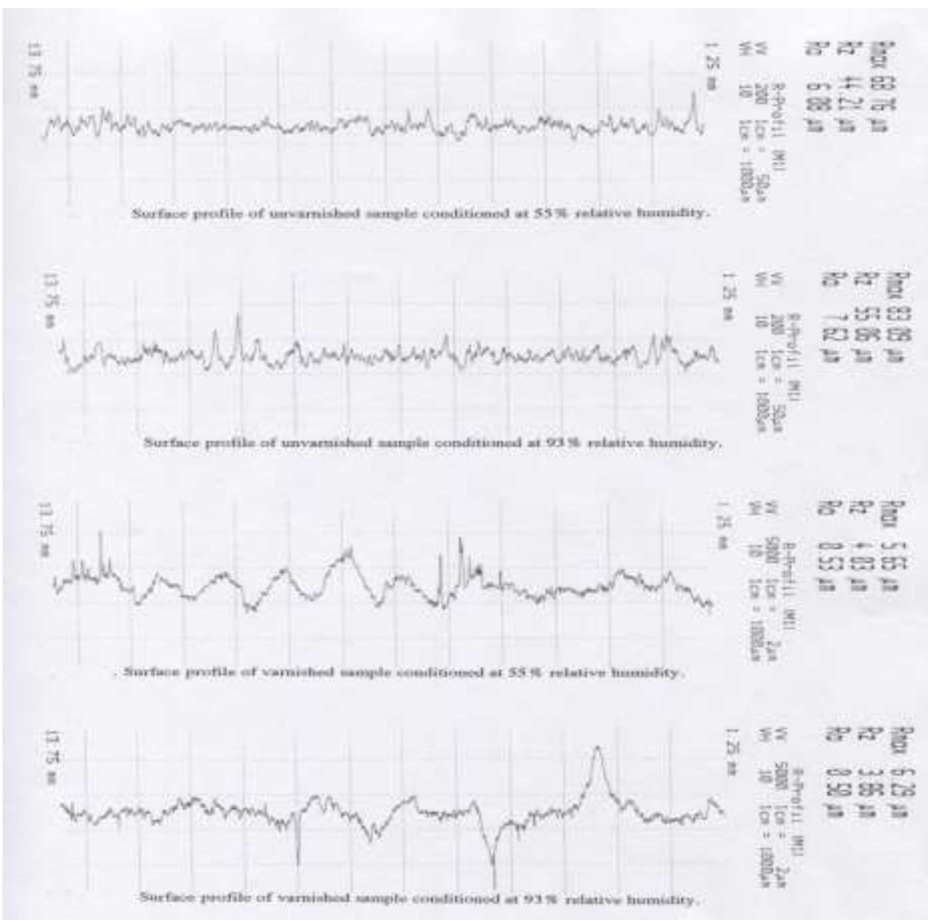

Fig. 2. Surface roughness profiles of different samples.

Linoleum samples did not show any thickness swelling as a result of the water soaking test. Both samples resulted in a very small amount of thickness swelling, ranging from 0.11% to 0.21% with an average value of 0.185 % at the end of the 24 h water soaking test. Surface of specimens also did not show any deterioration due to water exposure. However, unvarnished samples had some roughness and deterioration on their surface, which can be related to hygroscopic behavior of wood. Overall thickness swelling properties of veneered samples were found to be extremely low. Based on the results of testing it can be concluded that such samples would have very high dimensional stability in their service life.

As can be seen from Table 2, no significant difference was determined between all three roughness parameters obtained from the surface of the specimens conditioned at initial and final relative humidity levels. This finding suggests that both types of flooring material are not very sensitive to high humidity to develop roughness on their surfaces. Figure 2 depicts typical roughness profiles of panels conditioned at 55% and 93% relative humidity levels, respectively.

Vertical density profiles of eight samples, four veneer and four linoleum overlaid, were determined using non-destructive X-ray equipment. All of the four samples in each batch showed relatively consistent density profiles. Joint layer of two magnesium portions was clearly observed in the profiles. Figure 3 illustrates the typical density profile of the sample.

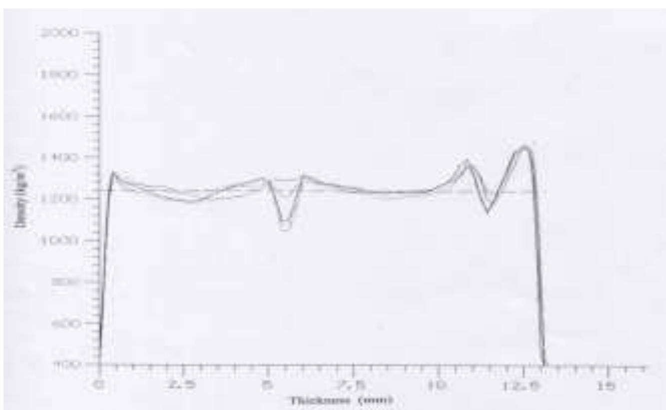

Fig. 3. Typical density profile of the linoleum overlaid sample

CONCLUSIONS

1. Both MOE and MOR values of the samples were found to be relatively higher than those of typical medium density fiberboard based on American National Standard Institute A-208.2 (ANSI 2002)
2. In the case of such sandwich type samples, peeling strength of the overlay can be considered as internal bond strength of both linoleum and veneer overlaid specimens. Their IB strength values were also are within the ranges listed as above standard.
3. Linoleum being a non-hygroscopic material resulted in no dimensional changes in the form of thickness swelling, while such values of veneer overlaid samples was extremely low. These findings suggest that sandwich type panels considered in this work would have high resistance to exposure of any kind of high level of relative humidity.

4. Varnished specimens were found to be superior to unvarnished ones as far as their surface stability against high relative humidity exposure is concerned.
5. Based on the physical and mechanical test results, it appears that such type of flooring samples should not give any noticeable problems during their service life, even if they are exposed to high relative humidity conditions.
6. It seems that magnesia-based overlaid panels would have potential to be used in flooring manufacture with satisfactory physical and mechanical properties.
7. Magnesium substrate flooring panels have high density, which would be considered as the most important disadvantage increasing overall transportation cost.

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