# The Effects of Using Different Adhesive on the Thickness Swelling Ratio of LVL Produced from Scotch Pine

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Most wood properties are affected by changes in moisture content below the wood fiber saturation point. In this study, the thickness swelling ratios of laminated veneer lumber (LVL) produced from Scotch pine (*Pinus sylvestris* L.) bonded by using polyvinyl acetate (PVAc), polymeric diphenyl methane diisocyanate (pMDI), and a mixture of them were evaluated. Thickness swelling of the samples was calculated after different waiting times under water. While the lowest thickness swelling ratio (1.65%) was determined from bonding with PVAc 92%- pMDI 8%, for 2 hours, the highest thickness swelling ratio (6.35%) was observed from bonding with PVAc 98%- pMDI 2% adhesive for 96 hours. As a result, adding pMDI to the PVAc adhesive reduced the rate of swelling of the test specimens. For this reason, the material can be used potentially in wet or humid places.

*DOI: 10.15376/biores.17.4.5645-5654*

*Keywords: Scotch pine; Thickness swelling; Adhesives; LVL; Swelling ratio*

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## INTRODUCTION

Wood has provided humans with an important building material for all types of structures—houses, bridges, ships, *etc*. Due to its intrinsic natural advantages (İlçe 2018), laminated veneer lumber (LVL) is becoming more common for use in both outdoor and indoor applications in highly humid environments due to its dimensional stability and low swelling ratio with respect to its thickness (Yapıcı *et al.* 2011; Kumar 2022). Additionally, the growing social interest in a construction of almost zero energy consumption and a remarkably lower carbon footprint than concrete, glass, or steel (Tellnes *et al.* 2017) makes wood a great choice in the construction sector. However, wood is restricted in comparison to alternative materials in terms of its lack of fire resistance, homogeneity, and durability (Rescalvo *et al.* 2020).

Unfortunately, increased global demand for wood has caused a dramatic decrease in forest resources. To meet this ever-rising demand, it is crucial to use innovative production techniques (Erdil *et al*. 2017; Zengin 2019). Wood can provide the market with tech-products that address the current construction needs (Rescalvo *et al.* 2020).

Composite wood manufactured material with dissimilar adhesives are being increasingly applied in the furniture frames buildings and construction (Erdil *et al*. 2017). Laminated veneer lumber (LVL) is now popular high-performance engineered wood product for construction (Daoui *et al.* 2011; Pot *et al.* 2014). LVL is made by bonding a few wood veneers together (Rahayu *et al.* 2015) using adhesive and positioning all layers to have a grain structure that runs parallel to the length of the member (Wang and Dai 2013; Boccadoro *et al.* 2017). This kind of system was developed as an engineered wood product as an alternative to solid wood (Aydın *et al.* 2004).

The production of LVL consists of several stages. First, the logs go through soaking and peeling. The veneer pieces obtained by the peeling process are dried and classified. These classified veneer pieces are glued and placed on top of each other in a parallel direction and formed into a sheet under a hot press. Both softwood and hardwood species have the potential for use in LVL production (McGavin 2016; McGavin and Leggate 2019). The choice of proper adhesive depends on the required strength, cost, and demands of the application (USDA 1987). Polyvinyl acetate (PVAc) has many advantages such as low cost, minimum environmental damage, and ease of use and application, but it also has disadvantages. The performance of PVAc weakens in humid conditions and at high temperatures, which is the biggest disadvantage of the adhesive (Qiao *et al*. 2000). These conditions restrain the use of PVAc (Kaboorani *et al.* 2012). Some approaches are used to minimize these disadvantages, including mixing PVAc with other hardeners or adhesives (Kaboorani and Riedl 2011). Polymeric diphenyl methane diisocyanate (pMDI) is used in the automotive, footwear, construction, packaging, adhesive, and coating industries (Randall and Lee 2012). The forest products industry has preferred isocyanate wood binders increasingly in the last thirty years. Polyurethane industry has been rapidly growing in the world (Pizzi and Mittal 2003). Other factors that make it preferable are its fast-curing rate, high resistance to moisture, fast hardening, and low doses (Gülle 2001; Stark *et al.* 2010).

Compared with solid wood, the major advantage of LVL is its high overall quality, decreased material variability, and favorable mechanical properties as in providing higher modulus of elasticity, modulus of rupture, better dimensional stability, availability in large dimensions (Strickler and Pellerin 1971; Youngquist *et al.* 1984; Burdurlu *et al.* 2007; Schuler 2017). In addition, it is much less likely to twist, warp, shrink, or bow (Erdil *et al*. 2017). Previous studies of LVL have shown that better durability can be predicted by low density wood into LVL bonded by phenol formaldehyde (PF) resin. This is an efficient way to increase the wood properties (Paridah 1993; Ashaari *et al.* 2015; Paridah *et al.* 2018). Viguier *et al.* (2018) stated that a first-grade veneered beam of LVL has 6% more bending strength than LVL beams produced with second or third-grade veneers.

LVL manufacturing requires a large amount of adhesive, which could be 20% of its total mass (Daoui *et al.* 2011). According to De Melo and Menezzi (2014), the adhesive presents a remarkable economic and technical implications and wood products utilization. Adhesive can cost approximately half of the price of manufacturing. Therefore, the cost of LVL manufacturing can be reduced by increasing the thickness of veneer.

There is an increased usage of LVL in both indoor and outdoor applications. Thickness ratio and dimensional stability is important due to variations in relative humidity. Researchers have been trying new modified methods to improve performance characteristics of LVL. For example, De Melo and Menezzi (2014) evaluated the impact of the veneer thickness on mechanical and physical properties of LVL. They found that the utilization of thinner veneer results in improved mechanical properties, while using thicker veneer results in less water absorption.

Chui *et al.* (1994) examined resin impregnation effects and processing parameters on different properties of poplar LVL by producing qualitative information on the effects of process parameters on laminated veneer lumber (LVL) properties manufactured by poplar (*Populus* spp.) and resin impregnation of veneer. İstek ve Özlüsoy (2018) analyzed the effect of PMDI glue on the performance properties of the boards and found that it was sufficient to use 3% pMDI glue; if this ratio increases, other resistance properties also increase. Swelling happens for each solid wood and wood-based materials during moisture absorption, and thickness swelling is significantly higher as a result of the cross-bonding of the wood elements (Halligan 1970; Wu and Suchsland 1996).

Additionally, Halligan (1970) and Stamm (1935) stated that wood-based materials act differently from solid wood in terms of swelling to thickness. While solid wood returns to the same dimensions after swelling and re-drying, wood-based materials retain some of the swelling thickness after drying. Aydin (2006) and Böhm (2009) found that the retained swelling thickness reduced the strength of the glued joints.

This study examined the effects of using polyvinyl acetate (PVAc), as an adhesive in LVL production with polymeric diphenyl methane diisocyanate (pMDI). The dimensional stability of the products was measured. The LVL swelling resistance produced from using Scotch pine wood was tested with different adhesive combinations (PVAc 100% (PVAc), PVAc 98%- pMDI 2%, PVAc 96%- pMDI 4%, PVAc 94%- pMDI 6%, PVAc 92%- pMDI 8%, PVAc. 90% - pMDI 10%).

## EXPERIMENTAL

### Wood Materials

Yellow pine (*Pinus sylvestris* L.) was procured from the market in the western Black Sea region in Turkey. Stark *et al.* (2010) stated that veneer for LVL manufacturing should be chosen carefully to achieve the intended strength properties. Therefore, smooth, knot-free, normally grown wood materials (without rot, reaction wood, fungal or insect damage) were chosen.

### Adhesives

The adhesives applied in panel production affect the performance of wood-based panels. Polyvinyl acetate (PVAc) is an adhesive used in the production of LVL. According to Uysal (2005), PVAc is an odorless, non-flammable adhesive that does not harm cutting tools during the cutting process. This adhesive is easy to apply, and it is appropriate to use 150 to 200 g per square meter on a single surface. PVAc, which is water-soluble and has high chemical resistance, does not have a toxic effect on the human body, unlike formaldehyde-containing adhesives, which highlights its use in the production of wood composite materials.-Polyvinyl acetate and polymeric methylene diphenylin isocyanate are used in this study as adhesives.

Although cured pMDI resin does not pose a health problem, some chemicals that are harmful to human health are released during its production. For this reason, special protection measures are required for facilities using pMDI to protect people who are exposed to it (Güller 2001; Stark, *et al.* 2010). The pMDI adhesive used in this study was obtained from Organic Chemical company in Istanbul.

### Preparation of Test Samples

The test samples that had the rough size were acclimatized because they are stable at 65±3 % relative humidity and 20±2 °C in the acclimatization cabin. The samples were cut to 5 x 100 x 100 mm, and 4 pieces were adhered to get 20 x 100 x 100 mm for dimensional stability tests, as specified by TS 4084 (1983). The adhesives were spread over surface of the samples, approximately 180 $g/m^2$. The press was applied at 1.8 $N/mm^2$ for 10 min. Test specimens were cured 24h in in the acclimatization cabin.

### Test Method

All test samples were held in a container having 120 cm width and 60 cm length and including pure water at 2, 6, 12, 24, 48, and 96 h. After each period, radial swelling of the test samples were measured from different points (four), and the average value was noted. Thickness swelling, that is, radial swelling of the samples, was computed using the following formula according to TS 4084 (1983),

$$G = ([a_{2.96} - a_0] \times 100) / a_0 \quad (1)$$

where $a_0$ is the initial thickness (mm) and $a_{2.96}$ is the changed thickness (mm). A ±0.01 sensitivity compass was used for measurements.

### Statistical Analysis

The data were statistically analyzed by ANOVA to determine for significance between levels and factors. When the ANOVA pointed to a significant difference among the factors and levels, a comparison of the means was conducted employing a Duncan test.

## RESULTS AND DISCUSSION

The effects of using polyvinyl acetate (PVAc) with pMDI on the thickness of LVL materials were investigated. The standard deviation and average values of thickness swelling (TS) of test samples are shown in Table 1.

With the addition of pMDI into the PVAc adhesive, the thickness swelling ratios of samples slightly decreased compared with the samples bonded with only PVAc 100% adhesive. The lowest thickness swelling was determined in LVL bonded with PVAc 90%-pMDI 10% for 2 h. The thickness swelling rate ranged between 1.65% and 6.35% after the sample has been kept in the water for 96 h. When all time intervals were compared within themselves, the lowest swelling ratios to its thickness were noticed in LVL samples that were bonded with PVAc 90% - pMDI 10% and PVAc 92% - pMDI 8% adhesives.

**Table 1.** Average Thickness Swelling Ratio According to Adhesive Types

| Mixed Type of Adhesive | Waiting Time in Water (h) | Average TS (%) | Std. Dev. | Mixed Type of Adhesive | Waiting Time in Water (h) | Average TS (%) | Std. Dev. |
|---|---|---|---|---|---|---|---|
| PVAc 90%-pMDI 10% | 2 | 1.88 | 0.70 | PVAc 96%-pMDI 4% | 2 | 3.21 | 1.24 |
| | 6 | 2.17 | 0.72 | | 6 | 3.54 | 1.36 |
| | 12 | 2.66 | 0.71 | | 12 | 4.12 | 1.34 |
| | 24 | 2.69 | 0.61 | | 24 | 4.70 | 1.15 |
| | 48 | 3.09 | 0.74 | | 48 | 5.17 | 0.95 |
| | 96 | 3.31 | 0.86 | | 96 | 5.08 | 2.10 |
| PVAc 92%-pMDI 8% | 2 | 1.65 | 0.66 | PVAc 98%-pMDI 2% | 2 | 2.98 | 1.56 |
| | 6 | 2.17 | 0.59 | | 6 | 3.48 | 1.31 |
| | 12 | 2.53 | 0.81 | | 12 | 4.32 | 1.68 |
| | 24 | 2.71 | 0.84 | | 24 | 5.35 | 1.81 |
| | 48 | 2.89 | 0.69 | | 48 | 5.90 | 1.69 |
| | 96 | 3.11 | 0.66 | | 96 | 6.35 | 1.20 |
| PVAc 94%-pMDI 6% | 2 | 3.32 | 1.19 | PVAc 100 %-pMDI 0% | 2 | 2.84 | 1.60 |
| | 6 | 3.67 | 0.80 | | 6 | 3.30 | 1.59 |
| | 12 | 4.02 | 0.78 | | 12 | 4.05 | 1.37 |
| | 24 | 4.08 | 1.15 | | 24 | 4.32 | 1.39 |
| | 48 | 4.88 | 1.03 | | 48 | 4.74 | 1.54 |
| | 96 | 4.91 | 0.99 | | 96 | 5.02 | 1.39 |

The variance analysis of thickness swelling was based on the types of LVL produced by using the various adhesive ratio. The variance results are shown in Table 2.

**Table 2.** The Variance Results of Analysis

| Source | Type III Sum of Squares | df | Mean Square | F-Value | Significant level ($p<0.05$) |
|---|---|---|---|---|---|
| Corrected Model | 372.83 | 35 | 10.65 | 7.40 | 0.00 |
| Intercept | 4002.29 | 1 | 4002.29 | 2780.08 | 0.00 |
| A | 205.71 | 5 | 41.14 | 28.58 | 0.00 |
| B | 144.78 | 5 | 28.96 | 20.11 | 0.00 |
| AXB | 22.34 | 25 | 0.89 | 0.62 | 0.92 |
| Error | 362.79 | 252 | 1.44 | | |
| Total | 4737.91 | 288 | | | |
| A: Mixed type of adhesive; B: Waiting time in water (h) | | | | | |

According to the variance analysis, the effects of adhesive types and waiting time were found statically meaningful at the 95% significance level, but their interaction was not statically significant at the 95% significance level. The mean variation values sources that were serious were compared using Duncan's test, and the results are shown in Table 3.

**Table 3.** Duncan Test Results

| Mixed Type of Adhesive | Mean | HG | Waiting time (h) | Mean | HG |
|---|---|---|---|---|---|
| PVAc 92%- pMDI 8% | 2.51 | A | 2.00 | 2.65 | A |
| PVAc 90%- pMDI 10% | 2.63 | A | 6.00 | 3.06 | A |
| PVAc 100 %- pMDI 0% | 4.05 | B | 12.00 | 3.62 | B |
| PVAc 94%- pMDI 6% | 4.15 | B | 24.00 | 3.97 | BC |
| PVAc 96%- pMDI 4% | 4.30 | BC | 48.00 | 4.45 | CD |
| PVAc 98%- pMDI 2% | 4.73 | C | 96.00 | 4.63 | D |

According to the Duncan test results, the identified differences were shown in different homogenous groups.

The changes of the thickness swelling ratio of test samples as both added pMDI adhesive and waiting time are shown in Fig. 1. The data showed that pMDI mixed with PVAc had a positive impact on values of thickness swelling (TS) of test samples. This situation reflects that pMDI is not soluble in water after curing (Boeglin *et al.* 1995). pMDI reacts with active hydrogen atoms, and wood surfaces are covered with –OH groups with active hydrogen. The pMDI uses them to cure and to become bonded with –OH groups. Thus, depending on the reduction of the wood hygroscopicity, thickness swelling ratio decreases (Özen 1980). pMDI is highly stable in water; conversely, the resin of pMDI does not cure in the absence of water (Scoville 2001). With increasing waiting time in the water, the thickness swelling ratio of test samples increased. The swelling ratio of all the Scotch pine LVL samples produced with pMDI (8-10%) adhesive was lower than the others.

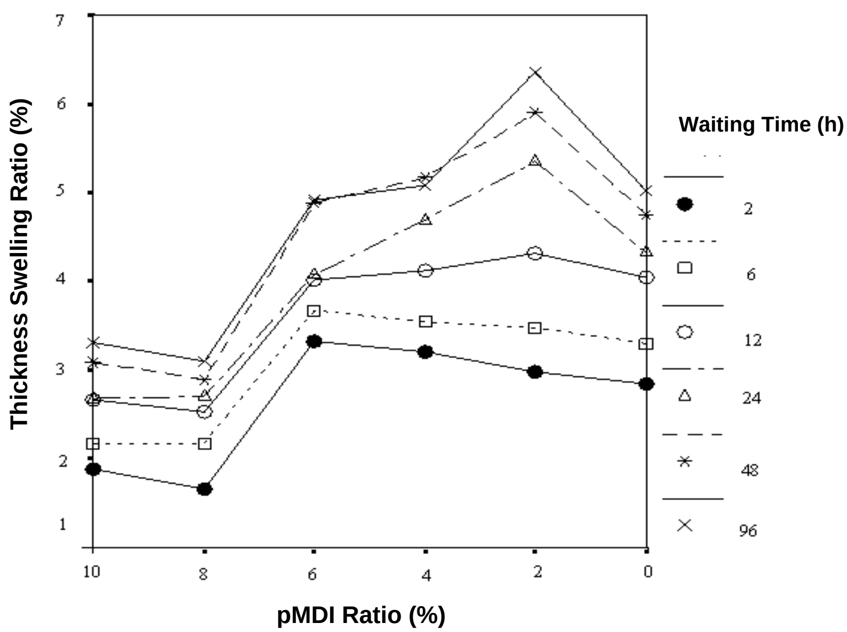


**Fig. 1.** Changes of the thickness swelling ratio

## CONCLUSIONS

1. Thickness swelling ratio of the samples were observed between 1.65% and 6.35%. The lowest average swelling ratio value was achieved from the samples adhered with poly(vinylacetate) (PVAc) 92%-popy(methyldiphenyl isocyante) (pMDI) 8% adhesive and left in water for 2 h. In addition, there was no significant difference between laminated veneer lumber (LVL) samples adhered with PVAc 90%- pMDI 10% and PVAc 92%- pMDI 8% adhesives.
2. The swelling ratio to the thickness of the test specimens decreased with the addition of PMDI to the PVAc adhesive. Thus, it prevented the performance loss of PVAc adhesive in humid conditions. In the production of LVL panels to be used in wet or humid places, it is recommended that adding pMDI adhesive to PVAc in applications where swelling thickness is not desired and where deminsional stability is desired.
3. Using 8% pMDI is sufficient for increased LVL swelling resistance in wet or humid places.

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Article submitted: April 25, 2022; Peer review completed: July 11, 2022; Revised version received and accepted: August 2, 2022; Published: August 10, 2022.
DOI: 10.15376/biores.17.4.5645-5654