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Short notes

COMPARATIVE STUDY OF THE IMPACT OF THERMAL MODIFICATION PARAMETERS ON THE THERMAL CONDUCTIVITY OF DIFFERENT WOOD COMPOSITE PANELS

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ABSTRACT

This study examined how thermal modification influenced the thermal conductivity of plywood, oriented strand board, and medium-density fiberboard. Samples were exposed to two temperature levels, 130°C and 180°C, for 20 and 40 min, while untreated panels were retained as controls. Measurements were carried out under controlled laboratory conditions using the steady-state hot-box method. The thermal modification consistently reduced thermal conductivity across all materials, which suggests improved insulation properties. The observed reductions varied. OSB exhibited the most significant overall decrease in thermal conductivity, while plywood displayed relative stability; conversely, MDF demonstrated a marked reaction under the more rigorous treatment conditions. The type of material used had the most significant overall statistical effect. The duration of the treatment was more important than the temperature. The interaction between temperature and time did not achieve statistical significance within the parameters of the experiment; conversely, interactions involving material type were significant.

KEYWORDS: Thermal conductivity, wood composite panels, thermal modification.

INTRODUCTION

Thermal modification has become a useful and environmentally friendly way to improve the properties of wood composite panels. Most of physical properties are positively impacted by decreasing the interaction with water, while mechanical properties decrease with different intensities, depending on the temperatures and duration of the process as well as on the system applied. For severe regime the impact is stronger. (Oliveira et al. 2017; Cetera et al. 2018; Pereira et al. 2021; Sugahara et. al. 2022, Marcon et al. 2023).

Thermal conductivity (λ) measures how well a material conducts heat. In contrast, thermal transmittance (U-value) indicates how quickly heat moves through a panel of a specific thickness. These properties are strongly affected by density, moisture content, porosity, and internal structure, as well as by fiber or strand orientation in the case of composite panels (Czajkowski et al. 2020; Čabalová et al. 2021). Heat treatment can reduce bound water, generate additional microvoids, and alter the continuity of solid heat-transfer pathways. In many cases, these changes are associated with improved thermal insulation performance. Published findings indicate that the magnitude of this effect differs by product type and treatment regime. Oriented strand board (OSB) often responds favourably because its heterogeneous structure and pre-existing void network can disrupt heat transfer more effectively after treatment. Medium density fiberboard (MDF), by contrast, combines high density with a more homogeneous fiber matrix, so changes in bonding, porosity, and moisture distribution may produce a marked response. Plywood generally shows less thermal expansion than other materials. This is partly because its layered structure helps it stay stable when exposed to heat (Aro et al. 2014; Božiková et al. 2021).

Although there's a lot of research on thermal modification, direct comparisons of OSB, MDF and plywood, all treated the same way, are still somewhat limited. The differences are mainly due to the materials used, the type of resin, the panel's density, and the specific treatment methods.

This study investigates how two different treatment temperatures and two treatment durations affect the thermal conductivity properties of three common wood-based composite panels. The experiments were conducted in a controlled laboratory setting, and the resulting changes in density, along with their statistical significance, were also assessed.

MATERIALS AND METHODS

The study used an experimental design to compare different conditions, based on laboratory measurements. The main factor being measured was how well heat passed through the materials. The main factors that were changed were the treatment temperature, the length of time it was applied, and the type of material used. Commercial OSB, MDF, and plywood panels of 18 mm thickness were sourced from the local market. The panels were manufactured using urea-formaldehyde adhesives. For each panel type, five specimen groups were established. Four of the groups underwent thermal modification, while one group was kept as an untreated control. Each group consisted of 10 samples with dimensions of 240 × 240 mm. The mean moisture content (EMC) before treatment was 8.45% (SD = 0.68) for plywood, 8.47% (SD = 0.76) for OSB, and 8.33% (SD = 0.97) for MDF, determined in accordance with EN 322-1993. Mean density values measured according to EN 323-1993 were respectively 0.56 g/cm³ (SD = 0.017) for plywood, 0.61 g/cm³ (SD = 0.038) for OSB, and 0.76 g/cm³ (SD = 0.009) for MDF.

Thermal modification

Thermal modification was carried out at atmospheric pressure in a temperature-controlled chamber (France Etuves, FRANCE). Before treatment, the samples were oven-dried at 103 ± 2°C. The treated groups were then exposed to four regimes: 130°C for 20 min, 130°C for 40 min, 180°C for 20 min, and 180°C for 40 min. After treatment, the samples were cooled and conditioned until constant mass was reached.

Thermal measurements

Thermal measurements were performed using a PHYWE apparatus (Fig. 1), installed at the Department of Physics of the Faculty of Natural Sciences of the University of Tirana. The PHYWE apparatus simulates a building model with interchangeable wall elements. Thermal conductivity (λ) was determined by the steady-state hot-box method, with an internal heat source within a temperature range of 20°C÷80°C, according to Procedure 2 (winter conditions) specified in the PHYWE operating manual.

Fig. 1: PHYWE apparatus for measurement of thermal conductivity.

Statistical analysis

The results were analysed by three-factor of variance (ANOVA) to identify significant effect of analysed factors (temperature of modification, duration of treatment, panel typology), using IBM SPSS Statistics 24. Statistical significance was accepted at $p < 0.05$. Duncan's multiple range test was applied to compare mean values.

RESULTS AND DISCUSSION

Tab. 1 summarizes the mean densities recorded for the modified samples under the four thermal-modification regimes. Density declined in all materials after thermal treatment, and the decrease became more evident as treatment intensity increased. The greatest proportional reduction was observed in plywood, which fell from 0.56 to 0.45 g/cm³ at 180°C/40 min (approx. 19.6%). OSB showed a more moderate reduction, from 0.61 to 0.54 g/cm³ (about 11.5%), while MDF decreased from 0.76 to 0.68 g/cm³ (about 10.5%).

Tab. 1: Mean density of modified samples under the applied regimes.

Material	Control	130°C/20 min	130°C/40 min	180°C/20 min	180°C/40 min
Plywood	0.56 g/cm³ (0.017)	0.48 g/cm³ (0.020)	0.47 g/cm³ (0.021)	0.46 g/cm³ (0.013)	0.45 g/cm³ (0.010)
OSB	0.61 g/cm³ (0.038)	0.55 g/cm³ (0.018)	0.54 g/cm³ (0.031)	0.55 g/cm³ (0.043)	0.54 g/cm³ (0.023)
MDF	0.76 g/cm³ (0.009)	0.72 g/cm³ (0.006)	0.71 g/cm³ (0.008)	0.69 g/cm³ (0.002)	0.68 g/cm³ (0.001)

Note: Values in parentheses present standard deviations.

These alterations align with the thermal breakdown of hemicelluloses, the evaporation of volatile substances, and a decrease in bound water, all of which contribute to mass reduction and the creation or expansion of voids within the panel's composition (Esteves & Pereira 2009; Sandberg et al. 2017). Consequently, the observed variations in density reduction suggest that the panel's composition played a role in its performance. The relatively small change seen in OSB could be due to its construction with strands and a resin matrix. In contrast, plywood seems to have lost more mass at the veneer level. Although MDF was the densest material after processing, its original uniform structure and the observed decrease in density likely affected its ability to conduct heat. Fig. 2 shows changes of thermal conductivity of materials referring to thermal modification regimes.

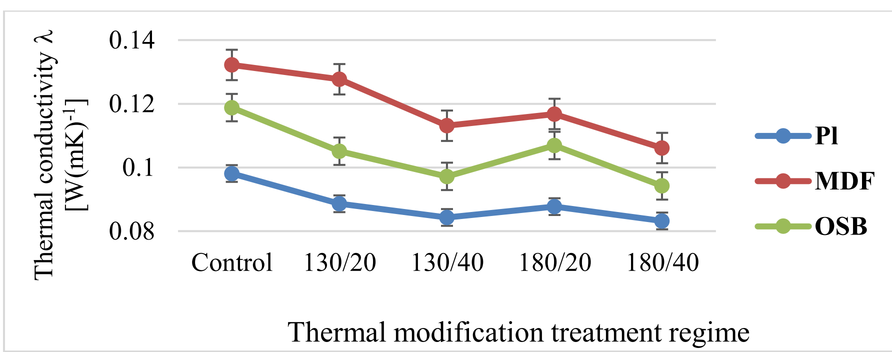

Fig. 2: Thermal conductivity λ in relation to material type and thermal modification regime.

It appears that all modification regimes reduced the panels' thermal conductivity λ compared to the control group. Lower λ-values indicate improved insulating behaviour. For plywood, the reduction ranged from 9.68% to 15.19%; for MDF, from 3.40% to 19.74%; and for OSB, from 10.02% to 20.71%. The largest overall improvement was therefore recorded for OSB under the 180°C/40 min regime, while plywood showed the most restrained variation across treatments and thus the greatest relative stability. The response was not strictly monotonic for all materials. In both plywood and OSB, the 180°C/20 min treatment produced a slightly higher λ-value than the 130°C/40 min regime, and MDF followed a similar pattern. This suggests that the panels' thermal behaviour was influenced not only by the set treatment temperature but also by how heat exposure affected the movement of moisture, the creation of microvoids, internal bonding, and structural changes. Intermediate treatment stages may therefore reflect a temporary balance between degradation and consolidation processes within the composite structure.

The observed material differences align with previous studies on thermally modified wood-based products. OSB's structure, made of discrete strands, already has voids and interfaces that hinder heat transfer; this effect might be enhanced by thermal treatment. MDF, despite its initial density and uniformity, shows significant changes as the fiber network and adhesive bonds are altered. In contrast, plywood, with its continuous layered structure, tends to show more modest changes in thermal behaviour (Glass & Zelinka 2021; Saeed et al. 2022; Bahar et al. 2023).

Tab. 2 presents the results of three-factors analysis of variance (ANOVA) of the thermal conductivity for unmodified and thermally modified of three types of materials, referring to different temperatures and duration of treatment. The ANOVA results confirm that thermal conductivity λ was influenced by a combination of product structure and treatment regime. Material type produced by far the strongest effect (F = 1058.57, p = 0.001), underscoring the importance of inherent panel architecture, density and porosity in governing heat flow. Treatment time also had a substantial effect (F = 293.76, p = 0.001) and was more influential than temperature alone (F = 43.71, p = 0.001), which suggests that the duration of exposure played a particularly important role in driving the structural changes that modified thermal behaviour.

Tab. 2: Three-factor ANOVA for thermal conductivity λ.

Factor	Sum of squares	df	Mean square	Fisher's F-test	Significance (p < 0,05)
Material	0.017970	2	0.008985	1058.57	0.001
Temperature	0.000371	1	0.000371	43.71	0.001
Time	0.002493	1	0.002493	293.76	0.001
Material × Temperature	0.000444	2	0.000222	26.13	0.001
Material × Time	0.000361	2	0.000181	21.28	0.001
Temperature × Time	0.000001	1	0.000001	0.12	0.731
Material × Temperature × Time	0.000095	2	0.000048	5.58	0.005
Error	0.000917	108	0.000008	-	-

The interaction between temperature and time was not statistically significant (p = 0.731). Within the tested range, this indicates that the main effects of temperature and duration acted largely independently rather than synergistically. By contrast, the material × temperature and material × time interactions were both significant, as was the three-way interaction. These findings show that the same thermal schedule did not affect all panel products in the same way. Instead, the final outcome depended on how each material's internal organization responded to both the severity and the duration of heating.

Tab. 3 presents the comparative results (Duncan test) of the influence of modification temperature and time duration on the thermal conductivity of materials. The Duncan test complements the ANOVA by separating the results into distinct statistical groups. For both temperature and treatment time, control samples formed the group with the highest mean λ-value, intermediate treatment levels occupied the middle group, and the most intensive conditions produced the lowest mean λ-values. This pattern supports the interpretation that thermal modification progressively improved insulation performance as treatment severity increased, even though the response remained product specific (Esteves & Pereira 2009).

Tab. 3: Duncan's multiple range test for modification temperature and treatment time.

Variable	Applied value	Number of measurements	Thermal conductivity λ (W/mK)	Group
Temperature (°C)	Control	30	0.114	A
	130	60	0.108	B
	180	60	0.104	C
Time (min)	Control	30	0.114	A
	20	60	0.108	B
	40	60	0.104	C

From an applied perspective, the findings suggest that thermal treatment schedules should be selected according to the intended balance between stability and insulation improvement. Plywood is a good choice when stable thermal properties are important. OSB offers the most significant improvement in insulation. In contrast, MDF might be particularly useful when a strong response to controlled changes is needed. At the same time, because the study was limited to two temperatures and two exposure times under atmospheric-pressure conditions, caution is warranted when extrapolating the results to more severe industrial treatment schedules.

CONCLUSIONS

Thermal modification resulted in significant alterations to the density and thermal conductivity (λ) of every wood composite panel assessed, thereby validating the premise that heat exposure affects not only the chemical composition but also the internal mechanisms governing heat transfer. A uniform reduction in density was observed across all treatment conditions. Under the most intensive treatment (180°C/40 min), plywood exhibited the greatest proportional reduction (19.6%), followed by OSB (11.5%) and MDF (10.5%). These decreases align with the evaporation of volatile substances, the breakdown of wood components sensitive to heat, and the resultant increase in porosity. The treated materials exhibited lower heat transfer compared to the control samples, indicating better insulation. OSB showed the most significant improvement, with its λ value decreasing from 10.02% to 20.71%. Conversely, plywood exhibited the most stable performance across the different treatment regimes, with λ reductions ranging from 9.68% to 15.19%. In contrast, MDF showed a pronounce response to the more intense treatment conditions, with its λ value decreasing by up to 19.74%. Statistical analysis showed that the type of material was the main factor affecting heat transfer. Treatment duration had a greater impact than temperature. However, the interaction between temperature and treatment duration was not statistically significant. Significant interactions involving material type confirmed that each panel product responded differently to the same thermal schedule.

The findings generally support using thermal modification to improve the thermal properties of wood composite panels. On the other hand, the best treatment method should be tailored to each specific product type, rather than using a single method for all panel materials.

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