Material Characterization with the Fuzzy Theory of Particleboards Bonded by Urea Formaldehyde with Nanofillers

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This study investigated the material characterization with the fuzzy theory of particleboards bonded by urea formaldehyde with nanofillers including nanofibrillated cellulose (NFC) and titanium dioxide (TiO_2). The density, water absorption, thickness swelling, and mechanical tests (which included flexure and internal bonding strength tests) were considered. The fuzzy sets theory addressed the ambiguity and subjectivity of language using triangular fuzzy numbers to assess the interests of decision maker's (DMs). The addition of nanofillers slightly decreased water absorption values due to possible good interactions between nanofillers and urea formaldehyde. Thickness swelling ranged from 0.4 to 17.5%, and water absorption ranged from 0.4 to 10.7% compared to the control sample. The physical properties of the samples were generally improved by urea formaldehyde with NFC/TiO_2, and the densities of the test panels were found to be similar. The modulus of rupture of the panels with urea formaldehyde with nanofillers were under the EN 312 standard's requirements, and the highest flexural strength and flexural modulus of elasticity were 11.1 and 1.3 GPa, respectively. Internal bond values were between 0.55 and 0.89 MPa. According to EDAS method rankings, 2C2T-8 was the best material, followed by 2C1T-8 and 2C-8. The samples coded with Control-4 and Control-8 were the lowest-performing materials.

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INTRODUCTION

Alternative lignocellulosic materials have started to replace solid wood due to a lack of raw materials in the forest products industry. Wood composites such as particleboards, fiberboards, plywood, and oriented strand boards are valuable and user-friendly resources in the forest products sector (Istek *et al.* 2012; Ayrilmis *et al*. 2012; Kelleci *et al.* 2022; Baharuddin *et al*. 2023). The high demand for the materials has resulted in a progressively growing interest. A noticeable increase has occurred in the demand for lignocellulosic raw materials in the production of particleboards. Consequently, there has been increased utilization of diverse lignocellulosic raw materials in the manufacturing of particleboards (Istek *et al.* 2013; Mantanis *et al*. 2018; Solt *et al*. 2019).

Nanofibrillated cellulose (NFC), obtained from renewable resources, has attracted significant attention within the scientific community due to numerous materials possessing desirable attributes (Aydemir *et al.* 2011, Lavoine and Bergström 2017; Antonini *et al*. 2019). NFC has received more attention recently due to its vast potential and fascinating features (Yi *et al*. 2020; Aydemir and Gardner 2020, 2022; Riseh *et al*. 2023; Jin *et al*. 2023). This attention stems from its environmentally friendly nature, high durability, and commendable absorbent properties. The NFC products, encompassing both hydrophilic and hydrophobic attributes in their chemical composition, are derived by converting cellulose pulp into fibrillated material. Furthermore, owing to the abundant presence of hydroxyl groups in their structure, NFC can be subjected to diverse modifications to ensure compatibility across a spectrum of applications. As a result, they find utility as reinforcing fillers, contributing to the advancement of polymeric materials (Salajkova *et. al*. 2012; Abitbol *et al*. 2014). According to Kargarzadeh *et al*. (2017), there are advantages to using nanocellulose as a reinforcement in resins used to make wood panel boards, including improved mechanical and physical properties and reduced formaldehyde emissions. The resin strength was improved when NFC at various loading ratios was introduced to urea formaldehyde (UF) resin according to Vineeth *et al*. (2019). Additionally, low quantities of NFC enhanced characteristics such as elastic modulus, bending strength, and bonding quality (Kawalerczyk *et al*. 2021). The usage of cellulose micro- and nanofibrils as filling agents for wood resins in the particleboard has increased recently (Iglesias *et al*. 2021).

Improvements occurred with the incorporation of NFC into the resin such as urea-formaldehyde and melamine-urea-formaldehyde in a study completed by Veigel *et al*. (2012). Urea formaldehyde, a synthetic resin, finds extensive application in the particleboard sector owing to its affordability, user-friendliness, and certain advantageous characteristics over alternative bonding agents (Kalaycıoğlu and Özen 2012; Solt *et al*. 2019; Baharuddin *et al*. 2023; Yalçın 2023). In the literature review, the physical and mechanical properties of particleboard prepared by using the resin with the presence of NFC was investigated. However, the dimensional stability and water absorption (WA) of the boards generally did not meet the minimum requirement for general purposes (Amini *et al.* 2017). Therefore, in this study, titanium dioxide (TiO_2) nanofillers were planned to be used in the improvement of the dimensional stability and WA of the panels. Titanium dioxide has the advantages of being non-toxic, chemically inert, affordable, and corrosion resistant; it has a high refractive index, UV filtering capacity, and high hardness in polymeric materials (Deka and Maji 2011). Bardak *et al*. (2018) found that the bonding strength of UF resin with nano-TiO_2 is much higher in all moisture contents than that of neat UF resin. The intricate and diverse structure of composite materials has given rise to various methodologies in research. In this study, the fuzzy logic approach was employed for decision-making and optimization within the intricate and uncertain conditions that characterize the design and production of composite materials. This approach will enhance the acquisition of sturdier and more effective outcomes by tackling the uncertainties inherent in the design and production processes of composite materials.

EXPERIMENTAL

Materials

Raw materials including red pine (*Pinus brutia*) wood chips and UF resin (solid content was 65 wt%) were supplied from a panel plant. In the hardening of the UF resin, ammonium chloride (solid content was 20% wt.) was used. The reinforcing materials including TiO_2 and NFC were provided by MKnano Inc. (Ontario, Canada) and the University of Maine (Orono, ME, USA), respectively. The size of TiO_2 and NFC was 15 to 40 nm (the particle size) and 20 nm/1 µm (diameter/length), and both materials were obtained by mechanical refining, and their purity was 98%.

Methods

In the study, 10% glue was used, and red pine chips were used. In the production stage, nanocellulose was added to the urea-formaldehyde glue in the specified amounts to obtain a homogeneous mixture and mixed for 10 minutes. After a homogeneous mixture, titanium dioxide was added in the specified amounts. The mixing of the whole formulation was continued for 15 minutes at 1500 rpm until a homogeneous mixture was formed. Then the hardener was added and the mixture was continued for another 5 minutes and the mixture was applied to the chips. Particleboards were produced with dimensions of 400 x 400 x 10 mm^3 and a pressure of 20 N/mm^2. Pressing temperature was maintained between 140 and 160 °C, and press times were set between 4 and 8 min. To investigate the impact of TiO_2 on hardening, various pressing times were selected. The sample codes, NFC and TiO_2 proportions percentages (%) with pressure time (min) are given in Table 1.

Table 1. Experimental Design

Samples	NFC (%)	TiO_2 (%)	Pressure Time (min)	Samples	NFC (%)	TiO_2 (%)	Pressure Time (min)
1C1T-4	0.4	0.4	4	1C1T-8	0.4	0.4	8
1C2T-4	0.4	0.8	4	1C2T-8	0.4	0.8	8
1C4T-4	0.4	1.6	4	1C4T-8	0.4	1.6	8
2C1T-4	0.8	0.4	4	2C1T-8	0.8	0.4	8
2C2T-4	0.8	0.8	4	2C2T-8	0.8	0.8	8
2C4T-4	0.8	1.6	4	2C4T-8	0.8	1.6	8
1C-4	0.4	0	4	1C-8	0.4	0	8
2C-4	0.8	0	4	2C-8	0.8	0	8
Control-4	0	0	4	Control-8	0	0	8

Physical and Mechanical Properties

Test samples were prepared by following TS EN 325 (1999) and TS EN 326-1 (1999), and ten replicates were used for each test. Before physical and mechanical tests, every test sample was conditioned for two weeks at 20 ± 2 °C and 65 ± 5% relative humidity. The physical tests including density, WA, thickness swelling (TS), and the mechanical tests including the internal bond strength, modulus of rupture (MOR), and modulus of elasticity in bending (MOE) were conducted by using the TS EN 323 (1999), TS EN 317 (1999), TS EN 319 (1999), and TS EN 310 (1999) standards, respectively.

Fuzzy Set Theory

To express observation or judgment, language is frequently either subjective, confusing, insufficient, or all three. Probability and statistics have long considered such ambiguity and subjectivity (Govindan *et al.* 2013). The concept of a linguistic variable is employed to offer a rough description of a situation that is either too intricate or inaccurate to be explained using conventional quantitative language, given that words are less precise than numerical values (Herrera and Herrera-Viedma 2000). In other words, it may be a challenging but crucial endeavor to conquer the world of language with the army of mathematics. Zadeh (1965, 1976) developed the fuzzy sets theory to carry out this task. Bellman and Zadeh (1970) proposed using fuzzy numbers to tackle Multi-Criteria Decision Making (MCDM) problems to establish the Fuzzy Multi-Criteria Decision Making FMCDM approach. Triangular fuzzy numbers (TFNs) are used in this study to assess the interests of decision maker's DMs. Triangular fuzzy numbers are favored because they are straightforward to calculate and have a straightforward structure.

Fuzzy AHP

The Analytic Hierarchy Process AHP approach employs a pairwise comparison with a nine-point scale to determine the weights of the chosen criteria. This method compares the selection criteria at each level to estimate the priorities. Although this method produces clear and simple answers, it does not give decision-makers precise data. Assessments are typically based on prior experience, knowledge gained over time, and individual judgment. A redesigned approach is needed when problem complexity rises and the need for exact answers increases. Complex decision-making problems might not be accurately solved by the traditional AHP method. Fuzzy AHP (FAHP) (Chang 1996) is a cutting-edge method that uses hierarchical structure analysis and fuzzy set theory for alternative selection. In this method, decision-makers rate the significance of each consideration in terms of a number (Singh *et al*. 2020). It is first important to compile group decisions. When applying the AHP, geometric mean techniques are frequently used to aggregate group decisions (Davies 1994). The fuzzy AHP was applied as describing by Chang (1996) and Singh *et al*. (2020).

Evaluation Based on Distance from Average Solution (EDAS) Method

The EDAS method is an MCDM approach developed by Keshavarz *et al*. (2015). It determines the distances of the alternatives to the mean values in the criteria. Unlike other methods such as Similarity to Ideal Solution (TOPSIS), Multi-Criteria Decision Analysis Method (VIKOR), and Process Capability (CP) which calculate distances from the ideal or anti-ideal solution, EDAS calculates the positive distance from the average (PDA) and the negative distance from the average (NDA) (Keshavarz *et al*. 2015; Kundakcı 2019).

RESULTS AND DISCUSSION

Physical and Mechanical Properties

Table 2 presents the density (*D*, g/cm^3), water absorption (WA, %), thickness swelling (TS, %), modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB). The samples were submerged in water for a day to measure the TS and WA. The moisture content (MC %) decreased in a ratio ranging from 0.1% to 10% with the presence of the nanofillers, as seen in Fig. 1 (a), and the WA decreased with adding the nanofillers due to more homogeneous cross section and smaller pore volume of the board structure. Although the addition of nanoscale cellulosic fillers might lead to a small rise in the water absorption values due to the hydrophilic nature of nanocellulose (Khanjanzadeh *et al*. 2019), both MC and WA improved at small percentages with adding nanofillers. The use of metallic oxide nanofillers has the potential to raise the heat transfer inside the panels as presented by Silva *et al*. (2019), and Taghiyari and Moradiyan (2014). However, the issue with NFCs in several thermoset resins is their tendency to easily agglomerate due to hydrogen bonding. This results in poor dispersion of NFC fillers within the polymer composite (Morita *et al.* 2021). As a result, the adding of TiO_2 increased the heat transfer in the samples, and as a result, all of the water relationships in the panels generally improved according to the WA and TS results. Similar results about the improvements on the physical properties with enhanced heat transfer in the particleboards by helping several nanofillers were found by Silva *et al.* (2019), Taghiyari *et al.* 2022, and Choupani Chaydarreh *et al*. 2023.

Table 2. Physical and Mechanical Results and their Statistical Analysis

Sample-s	MC (%)	Density (g/cm³)	WA (%)	TS (%)	MOE (GPa)	MOR (MPa)	IB (MPa)
Control -4	10.4 (±0.4)	0.688 (±0.1)	101.2 (±10.7)	29.7 (±4.1)	0.8 (±0.1)	7.2 (±0.9)	0.55 (±0.1)
1C-4	10.3 (±0.5)	0.732 (±0.1)	94.3 (±6.7)	28.7 (±3.7)	1.1 (±0.2)	8.8 (±0.7)	0.68 (±0.1)
2C-4	10.3 (±0.3)	0.739 (±0.0)	94.8 (±4.7)	28.5 (±5.5)	1.2 (±0.2)	9.7 (±1)	0.80 (±0.0)
1C1T-4	10.4 (±0.3)	0.709 (±0.1)	96.4 (±16.2)	24.5 (±1.8)	0.9 (±0.1)	7.6 (±1.2)	0.60 (±0.1)
1C2T-4	9.7 (±0.5)	0.727 (±0.0)	93.0 (±9.0)	25.0 (±2.2)	0.9 (±0.1)	7.2 (±1.5)	0.59 (±0.1)
1C4T-4	9.8 (±0.4)	0.731 (±0.1)	99.6 (±11.4)	25.6 (±2.0)	1.0 (±0.2)	7.3 (±1.3)	0.57 (±0.1)
2C1T-4	9.6 (±0.2)	0.74 (±0.1)	98.1 (±11.2)	26.1 (±3.6)	1.1 (±0.3)	9.1 (±1.1)	0.72 (±0.1)
2C2T-4	10.1 (±0.2)	0.758 (±0.0)	90.9 (±9.0)	25.4 (±5.5)	0.9 (±0.1)	7.2 (±1.4)	0.58 (±0.0)
2C4T-4	9.7 (±0.8)	0.765 (±0.0)	99.6 (±8.3)	27.5 (±2.7)	0.9 (±0.1)	8.7 (±1.3)	0.59 (±0.1)
Control -8	9.2 (±0.6)	0.735 (±0.1)	98.0 (±12.9)	28.2 (±3.8)	0.9 (±0.1)	7.5 (±1.2)	0.60 (±0.1)
1C-8	8.9 (±0.5)	0.779 (±0.1)	90.4 (±11.8)	27.7 (±3.8)	1.1 (±0.2)	9.4 (±1.4)	0.75 (±0.1)
2C-8	9.2 (±0.3)	0.789 (±0.1)	94.0 (±8.8)	27.5 (±3.0)	1.1 (±0.1)	11.1 (±1.6)	0.89 (±0.1)
1C1T-8	8.9 (±0.3)	0.747 (±0.1)	97.6 (±7.3)	25.4 (±2.0)	1.0 (±0.2)	8.2 (±1.2)	0.65 (±0.0)
1C2T-8	8.3 (±0.6)	0.779 (±0.0)	93.8 (±4.7)	26.0 (±5.7)	1.1 (±0.2)	9.7 (±1)	0.78 (±0.1)
1C4T-8	8.6 (±0.6)	0.789 (±0.0)	92.7 (±4.6)	27.3 (±5.5)	1.1 (±0.1)	9.6 (±1.2)	0.77 (±0.0)
2C1T-8	8.7 (±0.5)	0.793 (±0.1)	89.4 (±12.3)	28.1 (±3.0)	1.2 (±0.2)	10.2 (±1.4)	0.82 (±0.1)
2C2T-8	8.9 (±0.5)	0.798 (±0.1)	87.5 (±3.5)	28.0 (±4.8)	1.3 (±0.2)	9.9 (±1.9)	0.84 (±0.0)
2C4T-8	8.7 (±0.3)	0.801 (±0.1)	97.0 (±7.6)	28.1 (±2.8)	1.0 (±0.1)	7.8 (±1.4)	0.66 (±0.1)

Adding NFC to resins, *e.g.* urea-formaldehyde and melamine-urea-formaldehyde, improves their elastic modulus, bending strength, and bonding quality. In parallel to WA ratios (Fig. 1 (d)), the thickness swelling values were calculated to improve at ratios ranging from 0.3% to 18% as seen in Fig. 1 (c). Water absorption and TS decreased while the pressure time rose from 4 to 8 h. In the literature review, after being submerged for 24 h, the WA and TS values of the boards increased due to numerous hydroxyl groups on the surface of cellulose nanofiber boost and a result of the weak interaction between particle-resin (Cui *et al*. 2015; Khanjanzadeh *et al*. 2019), but the good interaction and adhesion among the wood particles inside the panels provided lower water absorption and thickness swelling (Nazerian *et al*. 2016; Yılmazer *et al*. 2023). Moreover, water absorption and thickness swelling of the board samples were found to be affected by the presence of nano-sized cellulose.

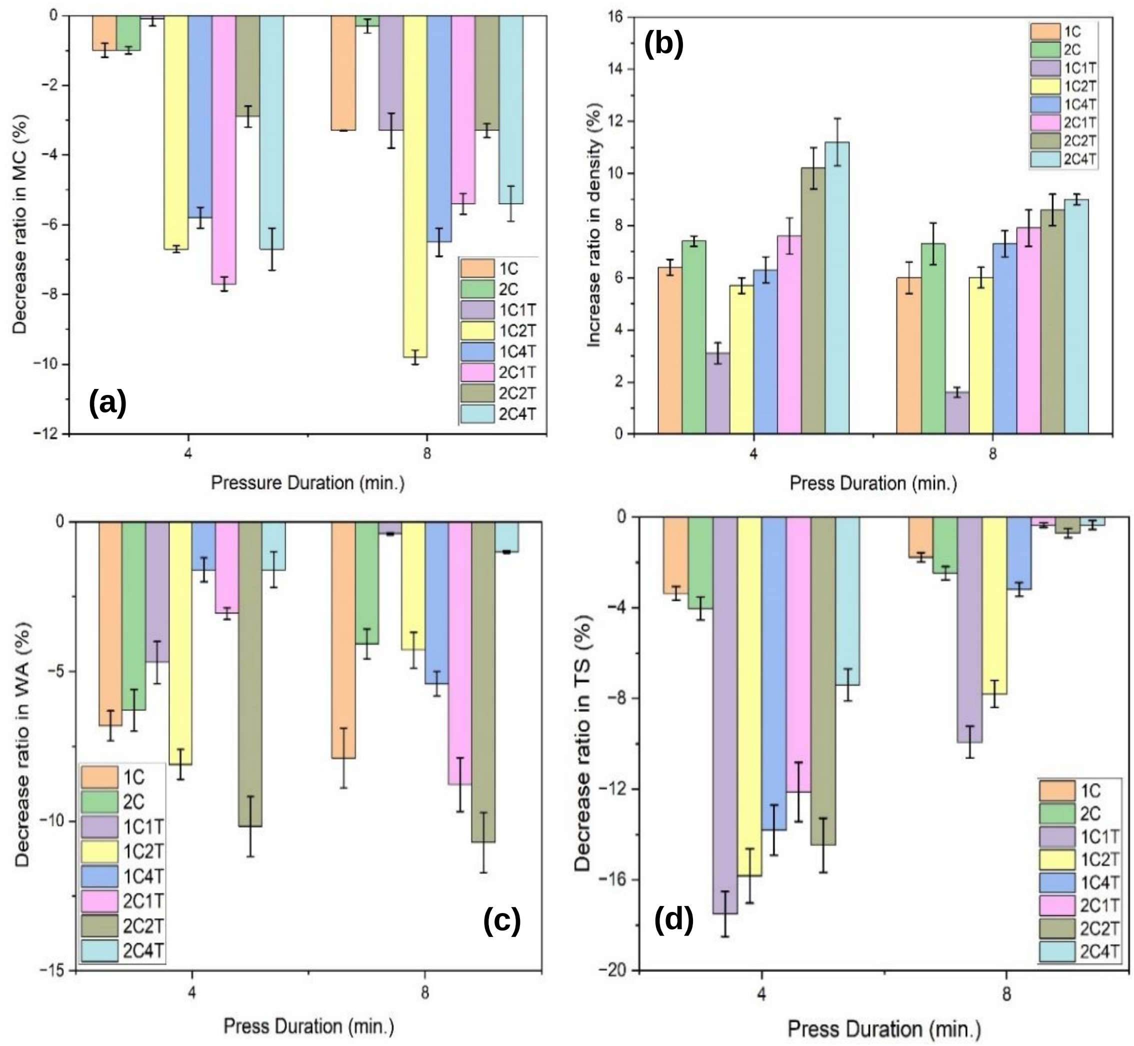

Fig. 1. Press duration of MC (a), density (b), WA (c) and TS (d) of the panels according to control samples

As can be seen in Fig. 1 (b), the change in density increased with both nanofillers, and the change in density values at 4 min. of the pressure time were found to be higher than those at 8 min. The range of MOR values was 7.2 to 11.1 MPa, and MOR increased with the presence of NFC, as presented in Fig. 2 (a). Therefore, MOR values of experimental samples did not provide 12.5 MPa for general-purpose particleboards by EN 312 (2012). Additionally, the Control-4 type boards had the lowest MOE value of 0.8 GPa and the maximum MOE value of 1.3 GPa in 2C2T-8 type sample, and the added NFC had a positive effect on the MOE, as shown in Fig. 2 (b). The MOE values fell short of the required minimum mechanical property of 1.6 GPa. The internal bond strength values of the boards are given in Fig. 2 (c). The highest and lowest IB values were changed between 0.89 and 0.60 MPa while staying under pressure for 8 min, respectively. However, the values of the samples which were produced under 4 min pressure, were found between 0.80 and 0.55 MPa internal bond strength values. Generally, the increment of density on samples caused by the internal bond increases. Likewise, the decrement of density on test samples decreased the IB values.

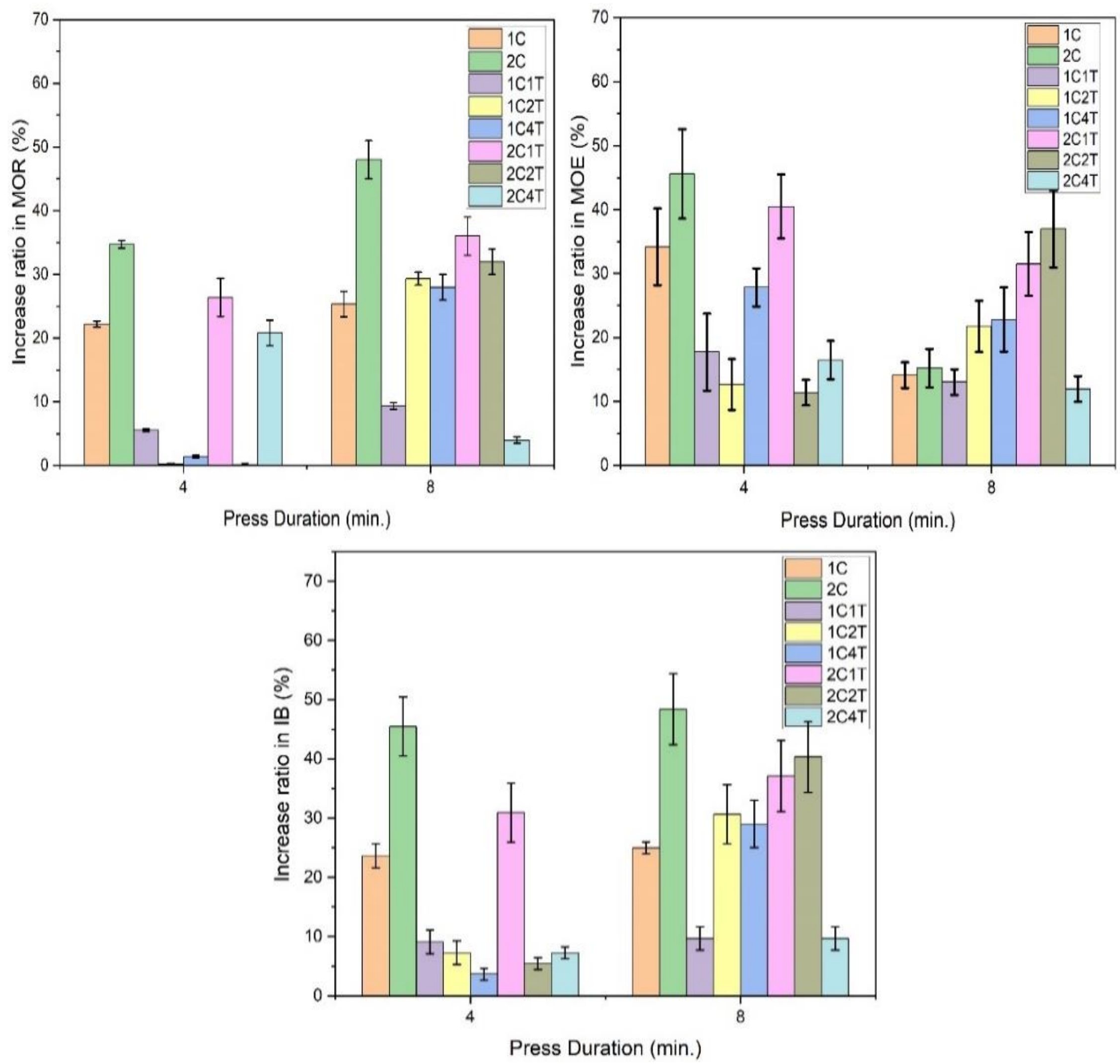

Fig. 2. Press duration of MOR, MOE and IB of the panels according to control samples

Determination of Criterion Weights with Fuzzy Theory

Expert opinions were first taken to calculate the weights using the FAHP method. The opinions were obtained from 12 academicians who are experts in this field for weight calculation. Tables 3 and 4 show the merged expert opinions for the calculation of criteria weights and optimization characteristics for the material selection problem. The criteria weights calculated by the FAHP method are given in Table 4. The table also includes Fuzzy weights, crisp weights, and the desired optimization characteristics for the criteria.

Table 3. Aggregated Fuzzy Expert Opinions for Criterion Weights

Criteria	MC (%)	Density (g/cm³)	WA (%)	TS (%)	MOE (GPa)	MOR (MPa)	IB (MPa)
MC (%)	(1,1,1)	(0.7,0.9,1.1)	(0.3,0.4,0.5)	(0.5,0.6,0.7)	(0.3,0.4,0.5)	(0.3,0.4,0.5)	(0.3,0.5,0.6)
Density (g/cm³)	(0.9,1.2,1.5)	(1,1,1)	(1,1.4,1.8)	(1,1.3,1.7)	(0.9,1.2,1.6)	(0.7,0.9,1.2)	(0.4,0.6,0.8)
WA (%)	(2.2,2.6,3.2)	(0.6,0.7,1)	(1,1,1)	(0.8,0.9,1.2)	(1.4,1.7,2)	(1.8,2.1,2.5)	(1.6,2.1,2.6)
TS (%)	(1.4,1.7,2.1)	(0.6,0.8,1)	(0.9,1.1,1.3)	(1,1,1)	(0.6,0.8,1)	(1.3,1.6,1.9)	(1.3,1.7,2.1)
MOE (GPa)	(2.1,2.8,3.5)	(0.6,0.8,1.1)	(0.5,0.6,0.7)	(1,1.3,1.6)	(1,1,1)	(1.3,1.6,2)	(1.1,1.3,1.6)
MOR (MPa)	(1.9,2.5,3.2)	(0.8,1.1,1.5)	(0.4,0.5,0.6)	(0.5,0.6,0.8)	(0.5,0.6,0.8)	(1,1,1)	(0.5,0.6,0.7)
IB (MPa)	(1.7,2.2,2.9)	(1.3,1.8,2.3)	(0.4,0.5,0.6)	(0.5,0.6,0.8)	(0.6,0.8,0.9)	(1.4,1.8,2.2)	(1,1,1)

Table 4. Criteria Weights and Optimization Characteristics

Criteria	Fuzzy Weights	Crisp Weights	Weights	Optimum
MC (%) (C1)	(0.05,0.071,0.106)	0.0757	0.0717	Min.
Density (g/cm^3) (C2)	(0.085,0.134,0.208)	0.1421	0.1345	Max
Water Absorption (%) (C3)	(0.135,0.199,0.295)	0.2097	0.1984	Min.
Thickness Swelling (%) (C4)	(0.102,0.151,0.226)	0.1596	0.1510	Min.
MOE (GPa) (C5)	(0.11,0.167,0.252)	0.1764	0.1669	Max
MOR (MPa) (C6)	(0.081,0.124,0.187)	0.1308	0.1238	Max
IB (MPa) (C7)	(0.101,0.153,0.233)	0.1625	0.1538	Max

Expert opinion was obtained from 12 academicians who are experts in this field for weight calculation. In the criteria weights, it is generally observed that the criteria have proportionally close weights to each other. However, water absorption criterion has the highest importance level with a weight value of 0.198, while MC criterion has the lowest importance level with 0.072.

Ranking of Particleboards Using the EDAS Method

The decision matrix used in the EDAS method is given in Table 5. The intermediate figures and final rankings calculated using the EDAS method are shown in Table 5. According to EDAS method rankings, 2C2T-8 was the best material, followed by 2C1T-8 and 2C-8. The samples coded with Control-4 and Control-8 were the lowest-performing materials.

Table 5. EDAS Method Outputs

Alternative	SP Values	SN Values	NSP Values	NSN Values	AS Values	Ranking
Control-4	0.0000	0.1387	0.0000	0.0000	0.0000	18
1C-4	0.0077	0.0224	0.0670	0.8385	0.4527	10
2C-4	0.0580	0.0173	0.5064	0.8750	0.6907	6
1C1T-4	0.0144	0.0708	0.1253	0.4895	0.3074	14
1C2T-4	0.0155	0.0734	0.1357	0.4706	0.3031	15
1C4T-4	0.0082	0.0670	0.0717	0.5167	0.2942	16
2C1T-4	0.0304	0.0106	0.2654	0.9238	0.5946	8
2C2T-4	0.0181	0.0752	0.1584	0.4576	0.3080	13
2C4T-4	0.0020	0.0548	0.0174	0.6052	0.3113	12
Control-8	0.0019	0.0717	0.0166	0.4834	0.2500	17
1C-8	0.0440	0.0035	0.3840	0.9748	0.6794	7
2C-8	0.0910	0.0035	0.7948	0.9746	0.8847	3
1C1T-8	0.0149	0.0216	0.1304	0.8446	0.4875	9
1C2T-8	0.0708	0.0000	0.6180	1.0000	0.8090	4
1C4T-8	0.0646	0.0013	0.5638	0.9908	0.7773	5
2C1T-8	0.1029	0.0057	0.8987	0.9587	0.9287	2
2C2T-8	0.1145	0.0052	1.0000	0.9627	0.9813	1
2C4T-8	0.0138	0.0300	0.1204	0.7840	0.4522	11

CONCLUSIONS

1. The addition of nanoscale cellulose to the board constructions showed significant improvements in mechanical characteristics, thickness swelling, and water absorption. Although nanofibrillated cellulose (NFC) has a hydrophilic nature, the good interaction between nanofibrils and resin provided an improvement in water absorption and thickness swelling values. However, it is difficult to achieve the standards for general-purpose particleboards due to hydrophilic nature of NFC. The weak bonding between fibers further contributes to the elevated water uptake observed in the boards.
2. The water resistance of the board samples was not appreciably harmed by the presence of nanofibrillated cellulose. The modulus of elasticity (MOE) and modulus of rupture (MOR) values, however, did not constantly match the required levels, suggesting possible areas for improvement in the mechanical qualities of the boards.

3. Fine-tuning the composition of the boards, such as adjusting the ratio of nanocellulose, could be explored to enhance water resistance while maintaining or improving mechanical properties.
4. Investigating and implementing stronger bonding methods between fibers can contribute to reducing water uptake and improving overall board performance.
5. Exploring variations in manufacturing conditions, such as pressure and duration, may offer insights into achieving optimal internal bond strength and meeting mechanical property standards.
6. Considering the potential benefits of incorporating nanocellulose into resins, further research into developing composite materials with improved bonding quality and enhanced mechanical strength is recommended. These recommendations aim to address the identified challenges and pave the way for the development of particleboards with enhanced properties for diverse applications.

7. With the weights calculated with fuzzy analytical hierarchy process (FAHP), the water absorption criterion was determined as the most important criterion. Thus, the importance levels of the criteria were determined by processing the expert opinions collected linguistically with the help of fuzzy theory. In addition, 2C2T-8 was chosen as the best chipboard in the ranking made by the distance from average solution (EDAS) method. The materials were objectively ranked from the decision matrix created from the results of the experiments conducted with the EDAS method. It may be recommended to use FAHP-EDAS methods in other material selection studies.

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