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ORIGINAL ARTICLE

Selection of materials with entropy-topsis by considering technological properties of impregnated wood

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Abstract

In this study, the hybrid Entropy-TOPSIS method is applied to the problem of selecting an optimal impregnation material with maximum performance requirements. Swelling, shrinkage, bending strength, modulus of elasticity, compressive strength and shock strength values were used to rank the impregnation materials. Barite, boric acid, borax and their mixture were used to impregnation material. The impregnation materials used in the study generally increased the physical and mechanical properties of the spruce specimens, except swelling. The impregnation materials reduced the swelling of the specimens. According to the entropy method, the most important factor affecting the success of the impregnation process was the modulus of elasticity. According to the TOPSIS method, the most successful impregnation material was a mixture of barite and boric acid. Moreover, the proposed method was compared with other Multi-Criteria Decision-Making (MCDM) approaches and it can be used to ranking of impregnation materials with reliable accuracy.

Keywords: *TOPSIS, entropy, decision making, impregnation.*

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1. Introduction

Wood material is used in many industries such as paper and cellulose, board, furniture because of its light weight, its easy to process, its resistance to mechanical and physical impacts, its good electrical and thermal insulation, its renewable. Dimensions and volume of wood material change due to the fact that it is a hygroscopic material. In addition, it may burn and it be destroyed by biotic and abiotic factors. It is not possible to completely eliminate the undesirable properties of wood. However, the wood can be protected by impregnating the wood with suitable impregnation materials[1-3].

Today, boron compounds as an impregnation material are considered one of the safest chemicals. Boron compounds are seen as the most important impregnation material of the future because they are less toxic than other heavy metal containing impregnation materials. Moreover, they have advantages such as eco-friendly, low cost, easy penetration into the wood depending on the steeping time, high performance against biological pests. Boric acid and borax, which are boron compounds and used as impregnation in the study, are the most common fire retardants in wood protection[4-8].

Barite, which is used as an impregnation material in this study, is the main source of barium. Barite is used as both a cost-reducing and functional filling material in the paint, paper, glass and ceramic industries. It has advantages such as insulation against sound and radiation, very good chemical resistance, resistance to weather conditions and UV, stability against high pressure and heat, easy and inexpensive production from various sources. Also, powdered barite particles are easily dispersed in water and oil[9,10].

In order to determine whether the impregnation material is successful, it is necessary to evaluate more than one criterion at the same time, instead of evaluating the physical and mechanical properties (criteria) of the wood material one by one. This process can be possible with multi-criteria decision making (MCDM) methods. MCDM techniques are techniques that select and classify among alternatives by evaluating factors[11]. There are various MCDM techniques used in the literature. In some studies, MCDM techniques have been used alone or in combination[12-19]. In this research, two-stage hybrid MDCM technique, which is formed by combining entropy and technique for order preference by similarity to ideal solution (TOPSIS) methods, was used. In multi-criteria decision making techniques, the weights of the criteria are of great importance. In the entropy method, the weight of each criterion is calculated based on the observation values. The low entropy value of the criterion indicates that the criterion is important and the weight value is high[20-22]. The TOPSIS is the most used of the MCDM methods due to its good performance in different fields. TOPSIS is used to rank alternatives. TOPSIS allows direct application on the obtained data and the method needs very little subjective input. Moreover, this method has advantages such as simple and understandable, computationally efficient, and ability to measure the relative performance of alternatives in a simple mathematical form[23,24].

There are many studies on the effect of impregnation materials on the physical and mechanical properties of wood. There are no studies on the effect of impregnation materials on the properties of wood using multi-criteria decision making methods. In this study, it has been tried to determine which impregnation material is more successful in the effect of impregnation materials on the physical and mechanical properties of wood. To achieve this objective, Entropy and TOPSIS methods, which are one of the multi-criteria decision-making methods and are used the most in practice, were implemented.

2. Materials and Methods

2.1 Wood material

Spruce (*Picea orientalis* Link.) wood obtained from Artvin region of Turkey was used as wooden material.

2.2 Impregnation material

Barite, boric acid, borax and their mixture (1:1; weight/weight or 1:1:1; weight/weight/weight) was used in the impregnation process as 1.00% aqueous solutions.

2.3 Preparation of test specimens

Test specimens were cut in dimensions of 20 x 20 x 360 mm according to TS EN 2474 (1976) standards for tests of bending strength perpendicular to the grain and modulus of elasticity in the bending[25]. Test specimens were cut in dimensions of 20 x 20 x 30 mm according to TS 2595 (1977) standards for tests of compression strength parallel to the grain[26]. Test specimens were cut in dimensions of 20 x 20 x 300 mm according to TS 2477 (1976) standards for tests of shock strength[27]. A total of 210 test specimens, 70 of which were test specimens, were used for each test.

2.4 Impregnation method

Impregnation process of the samples was carried out according to ASTM D 1413-76 (1976) standards[28]. In the impregnation process, the pre-vacuum equivalent to 60 cm of Hg was applied at 60 minute. Then, the samples were dipped in the barite, boric acid, borax, and their mixture solution at atmospheric pressure for 60 minute. After impregnation process, the impregnated specimens were kept at the temperature of 103 ± 2°C until fully dry. The amounts of retention (kg.m-3) were calculated by the following Formula 1[29]. The impregnation test setup was shown in Figure 1.

$$R = \frac{GxC}{V} x10^3 \quad (1)$$

$$G = T_2 - T_1$$

Where:

G : the amount of solution absorbed by test specimen;

T_1: weight of test specimen before impregnation (g);

T_2: weight of test specimen after impregnation (g);

V: volume of test specimen (cm^3);

C: the solution concentration as percentage.

2.5 Determination of physical and mechanical properties of test specimens

Shrinkage and swelling ratios of test samples were determined according to TS 4083, 4084, 4085 and 4086 standards[30-33].

The bending strength and modulus of elasticity tests were carried out in accordance with the principles of TS 2474 (1976)[25].

The compression strength parallel to grain test was determined according to the TS 2595 (1977) standard[26].

The shock strength test was performed according to the TS 2477 (1977) standard[27].

2.6 Determination of alternatives and criterion and implication of criterion

The symbolizations of the impregnation materials (alternatives) used in this study are given as:

Alternative-1 (A-1): non-impregnated material

Alternative-2 (A-2): barite-impregnated material

Alternative-3 (A-3): boric acid-impregnated material

Alternative-4 (A-4): borax acid-impregnated material

Alternative-5 (A-5): barite and boric acid mixture-impregnated material

Alternative-6 (A-6): barite and borax mixture-impregnated material

Alternative-7 (A-7): barite, boric acid and borax mixture-impregnated material

The evaluated physical (shrinkage, swelling) and mechanical (bending strength, modulus of elasticity, compressive strength, shock strength) properties were taken as a criterion in the ranking process of the impregnation materials. The implications of the selected criterion are given as:

Figure 1. Impregnation test setup.

Criterion-1 (C-1): Shrinkage (Volume-%, Lower-is-better)

Criterion-2 (C-2): Swelling (Volume-%, Lower-is-better)

Criterion-3 (C-3): Bending strength ($N.mm^{-2}$, Higher-is-better)

Criterion-4 (C-4): Modulus of elasticity ($N.mm^{-2}$, Higher-is-better)

Criterion-5 (C-5): Compressive strength ($N.mm^{-2}$, Higher-is-better)

Criterion-6 (C-6): Shock strength ($N.mm^{-2}$, Higher-is-better)

2.7 Overview of the integrated entropy-TOPSIS method

In this study, a hybrid Entropy-TOPSIS technique was used to rank the best alternatives of impregnated materials. The architecture of the hybrid Entropy-TOPSIS approach was presented in Figure 2. The process is concerned with determining the attribute weight using the Entropy and the best alternatives using the TOPSIS method.

Entropy, one of the most used methods for weight calculation, was proposed by Shannon and Weaver[34] and formulated using probability theory. The steps of the entropy method are listed below[21,35];

Step 1: Creating the decision matrix

The decision matrix consists of the alternatives and the evaluation criteria.

Step 2: Normalization of the decision matrix

The data was subjected to normalization using Formula 2.

$$p_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \tag{2}$$

Where: a_{ij} is the benefit value, and p_{ij} is the normalized value.

Step 3: Calculating the entropy value

The entropy value (e_j) was calculated according to Formula 3. The e_j value takes a value between 0 and 1. The k value was the inverse of the natural logarithm of the total number of alternatives ($k = 1 / \ln(m)$).

$$e_j = -k \sum_{i=1}^{m} p_{ij} Inp_{ij} \tag{3}$$

Where: p_{ij} is the normalized value, e_j is the entropy value and k is the entropy coefficient.

Step 4: Calculation of weight value

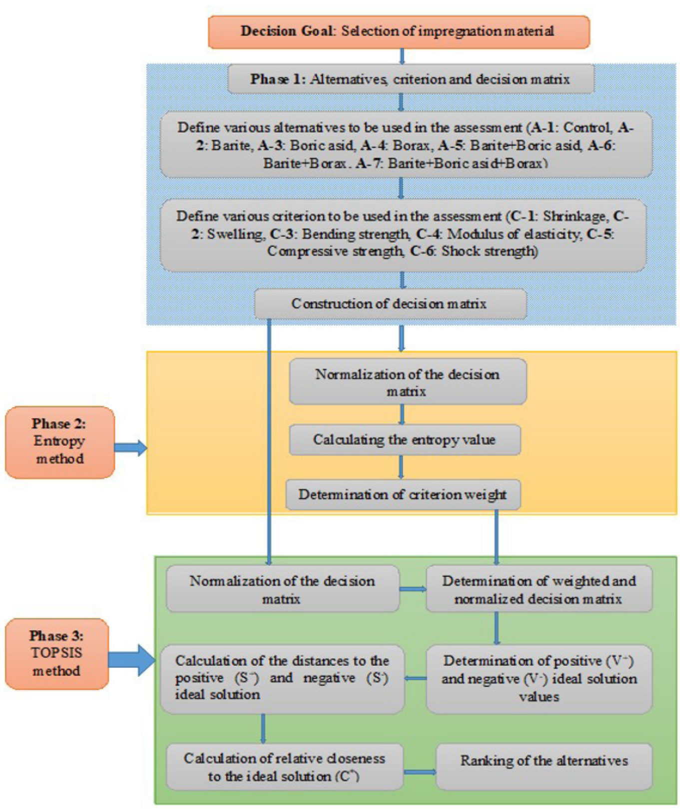

Figure 2. Architecture of the hybrid entropy-TOPSIS approach.

The weight value (w_j) is calculated via Formula 4.

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}\left(1-e_j\right)} \quad (4)$$

Where: e_j is the entropy value, w_j is weight value.

The TOPSIS method was first proposed by Hwang and Yoon[36] and developed by Yoon[37] and Hwang et al.[38]. The basic principle of the TOPSIS method is to choose the alternative closest to the positive ideal solution and the farthest from the negative ideal solution. This method consists of 6 steps. The stage of creating the decision matrix is explained in the steps of the entropy method, and the other steps are listed below[39];

Step 2: Normalization of the decision matrix

The data was subjected to normalization using Formula 5.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (5)$$

Where: r_{ij} is normalized value.

Step 3: Creation of weighted and normalized decision matrix

The weighted and normalized decision matrix is formed via Formula 6.

$$V_{ij} = r_{ij} \times w_j \quad (6)$$

Where: V_{ij} is weighted normalized value, is weighted normalized value, w_j is weight value.

Step 4: Determination of positive (V^+) and negative (V^-) ideal solution values

V^+ and V^- values are determined using weighted-normalized values. Formulas 7 and 8 are used to calculate the V^+ and V^- values.

$$V^+ = \left\{\left(\sum_{i}^{max} v_{ij} \,/\, j \in J\right), \left(\sum_{i}^{min} v_{ij} \,/\, j \in J'\right) / \, i = 1,2\ldots N\right\} \quad (7)$$

$$V^- = \left\{\left(\sum_{i}^{min} v_{ij} \,/\, j \in J\right), \left(\sum_{i}^{max} v_{ij} \,/\, j \in J'\right) / \, i = 1,2\ldots N\right\} \quad (8)$$

Where: J is the maximization value, J' is the minimization value

Step 5: Calculation of the distances to the positive (S^+) and negative (S^-) ideal solution

Using Formulas 9 and 10, distances to the positive and negative ideal solution are calculated.

$$S^+ = \left\{\sqrt{\Sigma\left(v_{ij} - v_j^+\right)^2}\right\}, i = 1,2\ldots.N \quad (9)$$

$$S^- = \left\{\sqrt{\Sigma\left(v_{ij} - v_j^-\right)^2}\right\}, i = 1,2\ldots.N \quad (10)$$

Step 6: Calculation of relative closeness to the ideal solution (C^*) and ranking of alternatives

S^+ and S^- values are used to calculate the relative closeness of each alternative to the ideal solution. The relative closeness of each alternative to the ideal solution is calculated using Equation 11. Alternatives are ranked so that the alternative with the higher C^* value is in the first place.

$$C^* = \frac{s_i^-}{s_i^- + s_i^+} \quad (11)$$

3. Results and Discussions

Properties of the materials used in the impregnation process were given in Table 1. According to Table 1, there was no important change in the pH value and density of the solutions before and after the impregnation.

Table 2 shows the effects of different chemicals (barite, boric acid, borax) on the physical (shrinkage and swelling ratios) and mechanical (bending strength, modulus of elasticity, compressive strength, and shock strength) properties of spruce wood. While the impregnation process generally increased the shrinkage ratio of spruce wood, it decreased the swelling ratio of the wood. Compared to the control (alternative A-1), the shrinkage ratios of the test specimens treated with boric

Table 1. Properties of impregnation materials.

Impregnation material	Solution Concentration (%)	Solvent	Retention ($kg.m^{-3}$)	pH		Density	
				BI	AI	BI	AI
Barite	1	DW	22.3	6.86	6.88	0.952	0.952
Boric acid (Ba)	1	DW	12.47	6.01	6.01	0.962	0.962
Borax (Bx)	1	DW	25.33	6.89	6.9	0.949	0.949
Barite + Ba	1	DW	16.9	7.53	7.53	1.001	1.001
Barite + Bx	1	DW	20.6	5.97	5.96	0.945	0.945
Barite + Ba + Bx	1	DW	60.33	7.73	7.74	0.952	0.952

DW: Distilled water; BI: Before impregnation; AI: After impregnation.

Table 2. Experimental data of the alternatives.

Impregnation material	C-1: Shrinkage (%)	C-2: Swelling (%)	C-3: Bending Strength (N.mm^{-2})	C-4: Modulus of Elasticity (N.mm^{-2})	C-5: Compressive Strength (N.mm^{-2})	C-6: Shock Strength (Kpm.cm^{-2})
A-1: Control	11.35	11.16	54.98	6183	32.43	0.27
A-2: Barite	11.68	10.25	59.63	7346	42.87	0.35
A-3: Boric acid (Ba)	10.94	9.91	70.43	6883	44.18	0.24
A-4: Borax (Bx)	12.91	9.95	79.11	9160	45.18	0.29
A-5: Barite + Ba	11.89	10.27	75.27	9696	46.22	0.34
A-6: Barite + Bx	12.48	9.36	66.97	8450	47.74	0.35
A-7: Barite + Ba + Bx	10.14	9.32	69.73	7293	36.59	0.34

acid (alternative A-3) and the mixture of barite, boric acid and borax (alternative A-7) were decreased by 3.6% and 10.7%, respectively. The highest shrinkage was obtained after the test specimens were impregnated with borax (alternative A-4) and the ratio of increase was 13.7% compared to the control. The alternative A-7 (Barite + Ba + Bx) had the lowest swelling (9.32%). Compared to the control, the swelling ratio of the test specimens treated with the mixture of barite, boric acid and borax (alternative A-7) were decreased by 16.5%. The control group (alternative A-1) had the highest swelling (11.16%). Baysal et al.[40] stated that water absorption levels of aqueous solutions of Ba+Bx were much higher than that of control specimens. Baraúna et al.[41] reported that boron compounds at different concentrations (4% and 8%) significantly influenced tangential, radial and volumetric shrinkage of eucalyptus wood.

When Table 2 showing the mechanical properties of alternatives was examined, the impregnation materials used in the study generally increase the bending strength, modulus of elasticity, compressive strength and shock strength of spruce wood. Compared with the control (alternative A-1) test specimens (0.27 Kpm.cm^{-2}), only the shock strength of the test specimens treated with boric acid (alternative A-3) was low (0.24 Kpm.cm^{-2}). The highest bending strength determined was in the test specimens treated with borax (alternative A-4). The alternative A-6 (test specimens treated with mixture of barite and boric acid) had highest modulus of elasticity (9696 N.mm^{-2}). The highest compressive strength was in the alternative A-5 (test specimens treated with mixture of barite and borax). The shock strength of wood specimens treated with barite and a mixture of barite and boric acid (alternatives A-2 and A-6) were the highest (0.35 Kpm.cm^{-2}).

These findings are similar to other studies; for example, LeVan and Winandy[42] reported that Bx has an increasing effect on bending strength in scotch pine and beech wood specimens. Keskin et al.[43] stated that Borax increases the mechanical properties of Rowan wood and boric acid decreases only bending strength of Rowan wood. Perçin et al.[44] reported that borax slightly increases the bending strength, modulus of elasticity and compressive strength parallel to the grain of the oak wood specimens, and boric acid slightly decreases the bending strength and modulus of elasticity of the wood specimens. In addition, they said that boric acid slightly increases the compressive strength parallel to the grain of the oak wood. Tan et al.[45] investigated the effects of barite on the bending strength, modulus of elasticity and shock strength of scotch pine and eastern beech woods. They found that the barite material increases the bending strength, modulus of elasticity and shock strength. Sen et al.[6] stated that the compressive strength parallel to the grain of Scotch pine test samples impregnated with boric acid, borax and a mixture of boric acid and borax had higher than untreated test specimens. In addition, they found that that boric acid increased the elastic modulus of scotch pine wood, even at different concentrations and compared to the control group, the bending strength of the test specimens impregnated with boron compounds is generally low. Wang et al.[7] detected that the bending strength and modulus of elasticity of Chinese fir wood treated with BA+BX (2% boric acid + 4% borax) to compared untreated Chinese fir wood were higher.

Table 3. Entropy and weight values.

Criteria	Entropy (e_j)	Weight (w_j)
C-1	0.9986	0.0707
C-2	0.9991	0.0423
C-3	0.9966	0.1706
C-4	0.9942	0.2866
C-5	0.9960	0.1996
C-6	0.9954	0.2303

For recommending the best impregnation material, the results of the evaluated properties were analyzed using the combined Entropy-TOPSIS methodology. As seen in Table 2, the decision matrix consists of seven alternatives and six criteria. Generally, the criteria (tests) in this study are used to determine whether the wood material is suitable for the place of use. Kaymakci and Bayram[46] used the same criteria (tests) to measure the success of the heat treatment and to determine the optimum parameters.

To rank the alternatives, the weights of the criteria must first be calculated. The weight values of the criteria were determined using the Entropy method. After the decision matrix was created to determine the weight values of the criteria, the data were normalized via Formula 2. After normalization, the entropy value of each criterion and the weight value of each criterion via Formulas 3 and 4 were determined, respectively (Table 3).

According to calculations, the order of criterion weight was obtained as C-4 (0.2866) > C-6 (0.2303) > C-5 (0.1996) > C-3 (0.1706) > C-1 (0.0707) > C-2 (0.0423). Therefore, the impregnation treatment may have the greatest effect on the modulus of elasticity of the wood. The effect of the impregnation treatment on the swelling and shrinkage of the wood was quite low. It is seen that there is no significant difference between the importance levels of the mechanical properties.

After the calculation of weights via Entropy method, the ranking of the test samples was determined using the TOPSIS method. In the TOPSIS method, the decision matrix (Table 2) used in entropy method was used. Firstly, the decision matrix was normalized via Formula 5. The matrix formed by the normalized data was given in Table 4.

Then, the weighting normalized decision matrix were obtained (Table 5). To get this matrix, the normalized data were multiplied by the weight values of the criteria.

By using weighted normalization matrix values, positive-ideal solution (V^+) and negative-ideal solution (V^-) values were obtained. Positive-ideal solution ($V^{+)}$ values were determined by choosing the highest value from each criterion (column) value, and negative-ideal solution (V^-) values were determined by choosing the lowest value. The positive and negative ideal solution values were given in Table 6. The assessed criteria play a decisive role in determining the positive ideal solution and negative ideal solution. The implications of the selected criterion in section 2 are specified. For example, lower experimental values are desirable for criteria like shrinkage, swelling, whereas higher values are desirable for bending strength, elastic modulus, compressive strength, shock strength.

Using weighted normalization matrix values and Formulas 9 and 10, the distance of each alternative (row) from the positive-ideal solution (S^+) and the distance of each alternative from the negative-ideal solution (S^-) were calculated. Finally, the relative closeness (C*) values of each alternative to the ideal solution were obtained via Formula 11. The alternatives (test samples) were ranked so that the alternative with the higher C* value is in the first place and the S^+, S^-, and C* results were given in Table 7 and the ranking of alternatives illustrated in Figure 3.

In this investigation, it was observed that ranking of impregnation materials are in descending order as A-5 >

Table 4. Normalized data obtained with Formula 5.

Alternatives	C-1	C-2	C-3	C-4	C-5	C-6
A-1	0.3679	0.4198	0.3035	0.2941	0.2885	0.3249
A-2	0.3786	0.3856	0.3292	0.3494	0.3814	0.4211
A-3	0.3547	0.3728	0.3888	0.3274	0.3930	0.2888
A-4	0.4185	0.3743	0.4367	0.4357	0.4019	0.3489
A-5	0.4081	0.4125	0.4502	0.4917	0.4348	0.4483
A-6	0.4046	0.3521	0.3697	0.4019	0.4247	0.4211
A-7	0.3287	0.3506	0.3850	0.3469	0.3255	0.4091

Table 5. Weighting normalized data.

Alternatives	C-1	C-2	C-3	C-4	C-5	C-6
A-1	0.0260	0.0178	0.0518	0.0843	0.0576	0.0748
A-2	0.0268	0.0163	0.0562	0.1001	0.0761	0.0970
A-3	0.0251	0.0158	0.0663	0.0938	0.0784	0.0665
A-4	0.0296	0.0158	0.0745	0.1249	0.0802	0.0804
A-5	0.0289	0.0174	0.0768	0.1409	0.0868	0.1032
A-6	0.0286	0.0149	0.0631	0.1152	0.0848	0.0970
A-7	0.0232	0.0148	0.0657	0.0994	0.0650	0.0942

Table 6. Positive (V^+) and negative (V^-) ideal solution values.

	C-1	C-2	C-3	C-4	C-5	C-6
V^+	0.02324	0.014829	0.076812	0.140915	0.086794	0.103244
V^-	0.029589	0.017757	0.051782	0.08428	0.057582	0.066501

Table 7. S^+, S^-, and C* values and ranking of alternatives.

Alternatives	S^+	S^-	C^*	Ranking
A-1	0.074241	0.009049	0.108644	7th
A-2	0.047512	0.03941	0.453399	4th
A-3	0.061249	0.027612	0.310729	6th
A-4	0.02952	0.053585	0.644785	2th
A-5	0.006195	0.077704	0.926159	1th
A-6	0.030381	0.052532	0.633582	3th
A-7	0.049036	0.03596	0.423078	5th

Table 8. Comparison of the proposed method with other MCDM approaches.

Alternatives	Proposed	VIKOR	ARAS	PROMETHEE II	GRA	COPRAS	MOORA
A-1	7	7	7	7	7	7	7
A-2	4	5	5	5	5	5	5
A-3	6	6	6	6	6	6	6
A-4	2	3	3	3	3	3	3
A-5	1	1	1	1	1	1	1
A-6	3	2	2	2	2	2	2
A-7	5	4	4	4	4	4	4

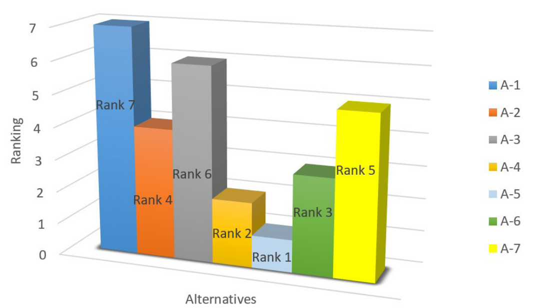

Figure 3. Ranking of impregnation materials.

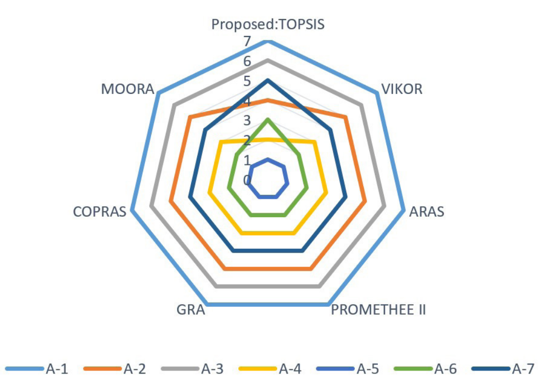

Figure 4. Comparative ranking of proposed entropy-TOPSIS with other methods.

A-4 > A-6 > A-2 > A-7 > A-3 > A-1. It is seen that the C* value of the alternative A-5 (barite and boric acid mixture-impregnation material) is the highest (0.9262), whereas the C* value of the alternative A-1 (non-impregnated material) is the lowest (0.1086).

Furthermore, the ranking results of the proposed entropy-TOPSIS methodology were compared to those of other common MCDM methodologies to validate its applicability. The ranking results obtained by the entropy-TOPSIS approach were compared with VIKOR (Visekriterijumska optimizacija kompromisno resenjemeaning)[47], ARAS (Additive ratio assessment)[48], GRA (Grey relation analysis)[49], PROMETHEE II (Preference ranking organization method for enrichment evaluation II)[50], MOORA (Multiple objective optimization on the basis of ratio analysis)[51], COPRAS (Complex proportional assessment)[52] approaches and ranking results are given in Table 8 and Figure 4. Table 8 demonstrates that the alternative A-5 highest of all other alternatives and the alternative A-1 lowest when solved with all the methods. Therefore, it can be reported that the proposed Entropy-TOPSIS can be used to ranking of impregnation materials with reasonable accuracy.

4. Conclusions

The effects of impregnation materials were investigated relative to the physical and mechanical properties of spruce wood with the Entropy and TOPSIS methods. According to the obtained data, the following results were obtained:

The impregnation process generally increased the shrinkage ratio of the spruce specimens and decreased the swelling ratio of the specimens. The highest shrinkage (12.91%) and swelling (11.16%) ratios were found in borax treated specimens and untreated (control) specimens, respectively. The lowest shrinkage (10.14%) and swelling (9.32%) ratios were found in the specimens treated with a mixture of barite, boric acid and borax.

Compared with the control specimens, it was determined that there was an improvement in the mechanical properties of the test samples treated with the impregnations used in the study. It was obtained that the highest bending strength was in the specimens treated with borax with 79.11 N.mm^{-2}, the highest modulus of elasticity was in the samples treated with a mixture of barite and boric acid with 9696 N.mm^{-2}, and the highest compressive and shock strengths were in the samples treated with a mixture of barite and borax with 47.74 N.mm^{-2} and 0.35 Kpm.cm^{-2}.

The modulus of elasticity emerged as the most important factor affecting the success of the impregnation process. The effect of physical properties (shrinkage and swelling) on the success of the impregnation process was quite low.

According to the TOPSIS method, the best results among the impregnation materials were obtained in the specimens impregnated with barite and boric acid. The worst result was obtained in the non-impregnated specimens.

Moreover, the results of the proposed method proved to be reliable by comparing with other decision making approaches. Therefore, the study shows that the Entropy-TOPSIS method is a robust tool in the selection of impregnation material.

In this study, seven alternatives (barite, boric acid, borax, their mixture and control) and six criteria (shrinkage, swelling, bending strength, modulus of elasticity, compressive strength, and shock strength) were discussed. This is a limitation of the study. More alternatives and criteria may be added to this study.

The MCDM can be recommended as an alternative method for non-destructive, cost-effective and rapid analysis of success of wood materials.

5. Author's Contribution

- **Conceptualization** – Hüseyin Peker; Nadir Ersen; İlker Akyüz.
- **Data curation** – Nadir Ersen.
- **Formal analysis** – Hüseyin Peker; Nadir Ersen.
- **Funding acquisition –** NA.
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