

Evaluation of essential properties of impregnating agents for preserving wood by AHP method in fuzzy environment

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Abstract: In this study, the essential properties of the impregnating agents for preserving wood were evaluated using analytic hierarchy process (AHP) method in fuzzy environment. Firstly, an AHP has been established and a questionnaire has been prepared of all criteria mentioned in the process. The questionnaire questions were answered by experts in the field. The answers were transformed into fuzzy numbers and all responses were evaluated in accordance with Buckley method. Fuzzy and normalized weights of all major and sub-criteria were calculated. According to the calculations made using this method, the first expected property impregnating agents for preserving wood was found to be the effectiveness parameter. It was followed by the eco-friendly, economic, permanent and reliable main criteria. The expected properties from an impregnation agent may vary according to the classes use and used wood commodity. This study showed that the fuzzy AHP method can be used in the impregnation industry as well as many engineering disciplines.

Keywords: Analytic hierarchy process, Expected/essential properties, Fuzzy environment, Wood preservatives

Odun koruma emprenye maddelerinden istenilen özelliklerin bulanık ortamda AHP metodu ile değerlendirilmesi

Özet: Bu çalışmada, odun koruma emprenye maddelerinden istenilen özellikler bulanık ortamda analitik hiyerarşi süreci (AHP) yöntemi kullanılarak değerlendirilmiştir. Öncelikle bir AHP kurulmuş ve süreçte belirtilen tüm kriterler hakkında bir anket hazırlanmıştır. Anket soruları bu alandaki uzmanlar tarafından cevaplandırılmıştır. Cevaplar bulanık sayılara dönüştürülmüş ve tüm cevaplar Buckley yöntemine göre değerlendirilmiştir. Tüm ana ve alt kriterlerin bulanık ve normalize ağırlıkları hesaplanmıştır. Bu yöntem kullanılarak yapılan hesaplamalara göre, emprenye ahşap koruyucusundan beklenen ilk özellik etkililik parametresidir. Bunu çevre dostu, ekonomik, kalıcı ve güvenilir ana kriterleri izlemiştir. Bir emprenye maddesinden beklenen özellikler, kullanılan ve kullanılan ahşap eşya sınıflarına göre değişebilir. Bu çalışma, bulanık AHP yönteminin emprenye endüstrisinde ve birçok mühendislik disiplininde kullanılabilirliğini göstermiştir.

Anahtar kelimeler: Analitik hiyerarşi süreci, Beklenen/temel özellikler, Bulanık ortam, Odun koruyucu

1. Introduction

Wood is one of the most common materials people have used for centuries. Wood, which is a biological material, can be degraded by micro and macro organism and abiotic factors (Eriksson et al., 2012). Wood and wood-based products need to be protected against these factors in order to provide a reliable level of service. The most common application is to impregnate the wood with protective chemicals in order to protect it against above mentioned factors (McIntyre and Eakin, 1984). Therefore, wood preservation differs from the surface treatments. While the surface treatment includes the application of protective processes by surface treatments of the wood material, the vacuum - pressure impregnation determine various chemicals into the wood structure for protecting wood against biotic and abiotic factors.

Since wood has been used in human life, numerous methods have been tried for wood preservation. Wood preservation methods and materials have been still

extensively investigated by many researchers. For example, Onuorah (2000) studied the anti-fungal properties of heartwood extracts of two very durable tropical hardwood species *Milicia excelsa* and *Erythrophleum suaveolens* and noted that high level concentration of extracts can be used as wood-preservative. Goktas et al., (2007) have been reported that poisonous *Sternbergia candidum* extracts with high level concentrations could be used as effective wood preservative. Eller et al., (2010) investigated efficiency of critical fluid and ethanol extracts of *Juniperus virginiana* against subterranean termites and wood-rot fungi and the researchers reported that extracts of the studied plant is a safe and renewable source for wood protection. Some researchers also were noticed the usage possibilities of nanoparticles such as silica nanoparticles (Giudice and Pereyra, 2010), titanium dioxide (De Filpo et al., 2013), nano-sized boron nitride (BN) (Kizilirmak et al., 2018) and silver nanoparticles (Can et al., 2019) in the wood preservation industry. Dong et al. (2016) used the rosin impregnation to improve the physical and mechanical

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properties of poplar wood. Var and Ozkan (2018) studied the effects of the leaves of quince tree, pomegranate and walnut fruit shells' dye and natural mineral water treatment on some physical properties of poplar wood and they recommended this technique as a natural wood protection way.

Wood impregnation can be made with different systems and many different impregnation materials. Among the impregnation solutions, water-soluble impregnation agents are the most common used for the protection of wood. The impregnation agent used to protect wood must have some properties. Although these properties vary according to the area of use, it is possible to determine the characteristic properties which are desired and expected from an impregnation agent. To know what are the desired and expected properties from an impregnation substance will be contributed to the both the researchers who are researching new impregnation materials and industrialists interested in introducing new products in the market.

Analytic Hierarchy Process (AHP) is one of the multi-criteria decision making methods developed by Thomas L. Saaty in the 1980s (Saaty, 1980). Based on pairwise comparisons in human nature, AHP evaluates how important, preferred or dominant these pairwise comparisons and options are compared to each other. This method for determining the best option is frequently used in the solution of complex decision problems due to its ease of use and considering both quantitative and qualitative factors (Imren et al., 2016). In classical AHP, decision makers use the real values while making evaluations, while Fuzzy AHP (FAHP) can make easier evaluation using fuzzy numbers or linguistic variables (Gurgen et al., 2019).

The aim of this study is to evaluate the expected performance properties from impregnating agents for preserving wood using analytic hierarchy process (AHP) method in fuzzy environment. In the study, the fuzzy AHP method developed by Buckley, (1985) was applied. This method consists of several steps. First of all, the experts evaluated each main and sub-criterion involved in the predetermined analytical hierarchy process by pairwise comparison and expressed the importance of each criterion in linguistic terms.

2. Material and methods

The method of this study is analytical hierarchy process. 5 experts which were academicians working in the field of wood preservation answered the AHP pairwise comparisons in this study. The experts have been studied over 20 years wood protection science field. When preparing the process, the required properties of the wood impregnation substance were divided into main and sub-criteria. The main and sub-criteria used in the study was given in Figure 1.

The linguistic expressions and fuzzy significance scale were given in Table 1.

Table 1. Linguistic expressions and corresponding triangular fuzzy numbers

Description	Triangular fuzzy numbers	Contrast triangular fuzzy numbers
Equally important	(1,1,1)	(1/1, 1/1, 1/1)
Moderately more important	(1,3,5)	(1/5, 1/3, 1/1)
Strongly more important	(3,5,7)	(1/7, 1/5, 1/3)
Very strongly more important	(5,7,9)	(1/9, 1/7, 1/5)
Demonstratively more important	(7,9,9)	(1/9, 1/9, 1/7)

The fuzzy decision matrix was obtained after the data collected from the experts as follows;

$$\tilde{C}^k = [c_{ij}]_{n \times n} = \begin{bmatrix} 1 & \tilde{c}_{12} & \tilde{c}_{13} & \dots & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \tilde{c}_{23} & \dots & \tilde{c}_{2n} \\ \cdot & \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \cdot & \dots & \cdot \\ \tilde{c}_{n1} & \tilde{c}_{n2} & \tilde{c}_{n3} & \dots & 1 \end{bmatrix} \quad (1)$$

$k=1, 2, \dots, p$
 $i, j=1, 2, \dots, n$

where, \tilde{C}^k is fuzzy decision matrix that represents the importance degrees of criteria given kth expert, p is the number of experts, n is the number of criteria. c_{ij} indicates the fuzzy comparison value of criterion i to creation j . In this study, the geometric mean method was used to gather the answers of the experts. The aggregated result matrix is as follows.

$$\tilde{C} = \begin{bmatrix} 1 & \tilde{c}_{12} & \tilde{c}_{13} & \dots & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \tilde{c}_{23} & \dots & \tilde{c}_{2n} \\ \cdot & \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \cdot & \dots & \cdot \\ \tilde{c}_{n1} & \tilde{c}_{n2} & \tilde{c}_{n3} & \dots & 1 \end{bmatrix} \quad (2)$$

where \tilde{C} is the aggregated pairwise comparison matrix. After the aggregated pairwise comparison matrix is obtained, the calculation of the criteria weights is performed. Fuzzy weight matrix is determined by Buckley's method as below;

$$\tilde{r}_i = (\tilde{c}_{i1} \otimes \tilde{c}_{i2} \otimes \dots \otimes \tilde{c}_{in})^{1/n} \quad (3)$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_i + \tilde{r}_i + \dots + \tilde{r}_i)^{-1} \quad (4)$$

where \tilde{r}_i is the geometric mean of the fuzzy comparison value of criterion i to each criterion, \tilde{w}_i is the fuzzy weight of the i th criterion. At last stage, defuzzification and normalization operations are applied. In this study, centroid method is used in order to convert the fuzzy weight into crisp value. Centroid method is defined as below,

$$w_i = \frac{w_l + w_m + w_u}{3} \quad (5)$$

where w_i is the crisp value of the i th criteria. w_l , w_m , w_u that represent triangular fuzzy numbers indicates the lower bound the middle value and the upper bound, respectively. These values should be normalized to be more understandable and comparable. The normalization process is performed as follows,

$$w_i^N = \frac{w_i}{\sum_{i=1}^n w_i} \quad (6)$$

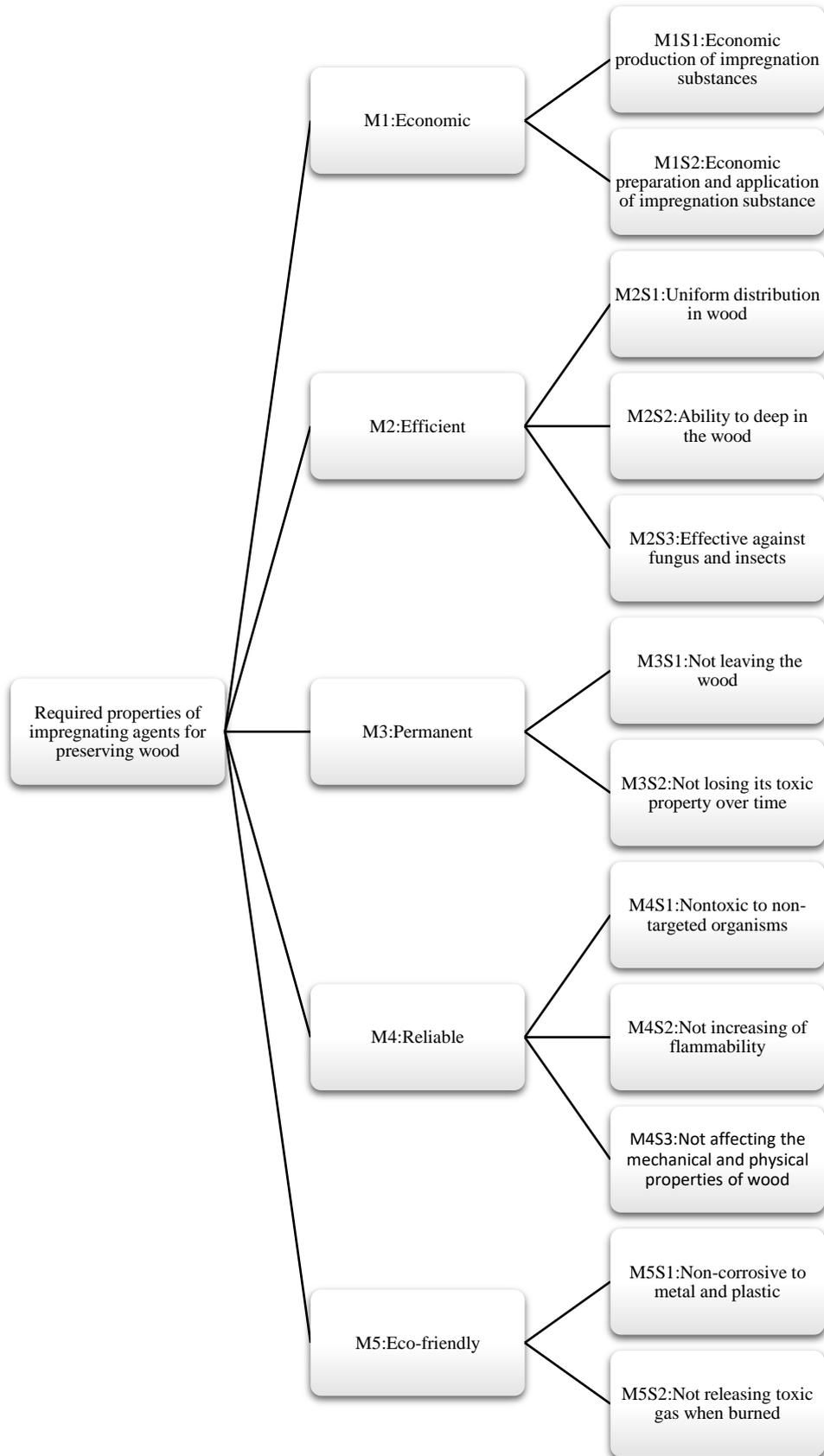


Figure 1. The main and sub-criteria used in the study (M: Main criteria, S: Sub-criteria)

3. Results and discussion

The linguistic expressions given by the experts to the pairwise comparisons in the questionnaire were converted to fuzzy numbers and combined with the geometric mean

method and a single matrix was obtained. The aggregated pairwise comparisons for the main and sub-criteria were given in Table 2-7. The degrees of importance of all main and sub-criteria were given in Table 8 and Figure 2-7.

Table 2. Aggregated pairwise comparisons for the main criteria

	Economic (M1)	Efficient (M2)	Permanent (M3)	Reliable (M4)	Eco-friendly (M5)
M1	(1.000,1.000,1.000)	(0.118,0.128,0.176)	(0.577,0.614,0.668)	(4.217,6.257,8.276)	(0.614,0.826,1.316)
M2	(5.663,7.770,8.451)	(1.000,1.000,1.000)	(2.817,3.873,4.582)	(3.637,4.582,5.196)	(1.404,1.732,2.006)
M3	(1.495,1.626,1.732)	(0.218,0.258,0.354)	(1.000,1.000,1.000)	(0.312,0.438,0.759)	(0.577,0.614,0.668)
M4	(0.120,0.159,0.237)	(0.192,0.218,0.274)	(1.316,2.279,3.201)	(1.000,1.000,1.000)	(0.759,0.880,1.316)
M5	(0.759,1.209,1.626)	(0.498,0.577,0.712)	(1.495,1.626,1.732)	(0.759,1.136,1.316)	(1.000,1.000,1.000)

Table 3. Aggregated pairwise comparisons for the "Economic" sub-criteria

	Economic production of impregnation substances (M1S1)	Economic preparation and application of impregnation substance (M1S2)
M1S1	(1.000,1.000,1.000)	(1.626,2.140,3.000)
M1S2	(0.333,0.467,0.614)	(1.000,1.000,1.000)

Table 4. Aggregated pairwise comparisons for the "efficient" sub-criteria

	Uniform distribution in wood (M2S1)	Ability to deep in the wood (M2S2)	Effective against fungus and insects (M2S3)
M2S1	(1.000,1.000,1.000)	(3.482,4.486,4.879)	(0.192,0.253,0.347)
M2S2	(0.204,0.222,0.287)	(1.000,1.000,1.000)	(0.192,0.192,0.232)
M2S3	(2.877,3.948,5.196)	(4.303,5.196,5.196)	(1.000,1.000,1.000)

Table 5. Aggregated pairwise comparisons for the "Permanent" sub-criteria

	Not leaving the wood (M3S1)	Not losing its toxic property over time (M3S2)
M3S1	(1.000,1.000,1.000)	(2.140,2.590,2.817)
M3S2	(0.354,0.386,0.467)	(1.000,1.000,1.000)

Table 6. Aggregated pairwise comparisons for the "reliable" sub-criteria

	Nontoxic to non-targeted organisms (M4S1)	Not increasing of flammability (M4S2)	Not affecting the mechanical and physical properties of wood (M4S3)
M4S1	(1.000,1.000,1.000)	(2.432,2.817,3.000)	(2.140,2.590,2.817)
M4S2	(0.333,0.354,0.411)	(1.000,1.000,1.000)	(0.222,0.287,0.447)
M4S3	(0.354,0.386,0.467)	(2.236,3.482,4.486)	(1.000,1.000,1.000)

Table 7. Aggregated pairwise comparisons for the "Eco-friendly" sub-criteria

	Non-corrosive to metal and plastic (M5S1)	Not releasing toxic gas when burned (M5S2)
M5S1	(1.000,1.000,1.000)	(0.411,0.508,0.759)
M5S2	(1.316,1.968,2.432)	(1.000,1.000,1.000)

Table 8. The degrees of importance of all main and sub-criteria

Main and sub-criteria	Code	Fuzzy weights	Normalized crisp weights
ECONOMIC	M1	(0.098,0.136,0.210)	0.142
Economic production of impregnation substances	M1S1	(0.506,0.681,0.934)	0.686
Economic preparation and application of impregnation substance	M1S2	(0.229,0.318,0.423)	0.313
EFFICIENT	M2	(0.337,0.489,0.663)	0.476
Uniform distribution in wood	M2S1	(0.190,0.252,0.337)	0.254
Ability to deep in the wood	M2S2	(0.074,0.084,0.114)	0.089
Effective against fungus and insects	M2S3	(0.503,0.662,0.850)	0.656
PERMANENT	M3	(0.079,0.105,0.158)	0.109
Not leaving the wood	M3S1	(0.619,0.721,0.815)	0.714
Not losing its toxic property over time	M3S2	(0.252,0.278,0.331)	0.285
RELIABLE	M4	(0.065,0.096,0.154)	0.101
Nontoxic to non-targeted organisms	M4S1	(0.446,0.552,0.661)	0.543
Not increasing of flammability	M4S2	(0.108,0.133,0.184)	0.139
Not affecting the mechanical and physical properties of wood	M4S3	(0.238,0.314,0.415)	0.317
ECO-FRIENDLY	M5	(0.118,0.172,0.242)	0.170
Non-corrosive to metal and plastic	M5S1	(0.263,0.336,0.487)	0.351
Not releasing toxic gas when burned	M5S2	(0.471,0.663,0.872)	0.648

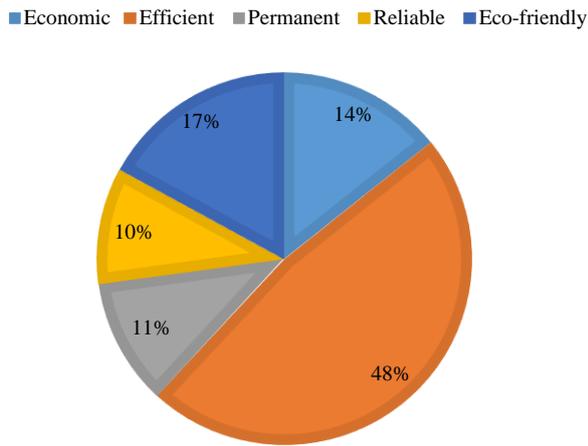


Figure 2. The degrees of importance for main criteria

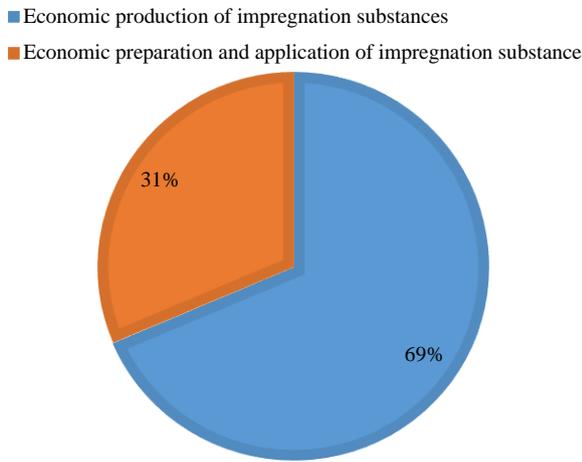


Figure 3. The degrees of importance for 'economic' criteria

Figure 2 depicts the degrees of importance for main criteria. The degrees of main criteria can be listed as efficient > eco-friendly > economic > permanent > reliable. It can be concluded that the first desired property of the impregnation agent is 'efficient'. Impregnation agent is used to give the desired level of service life to the wood according to the place and conditions used. Therefore, an ineffective impregnating agent cannot be used, no matter how cheap and environmental. The most desirable property of the impregnation material which provides the condition of being effective is that it is eco-friendly and economic (cheap) respectively. The one of the most important issues is not to pollute the environment while protecting wood. Because chromated-copper-arsenate (CCA) is inexpensive and effective, it has been used for wood protection in many parts of the world for long years, but is currently restricted and / or banned for environmental reasons (McQueen and Stevens, 1998). The searching for more environmentally friendly impregnation substances has encouraged the researchers to investigate for more natural (plant and / or animal origin) alternative substances (Yang, 2009; Tascioglu et al., 2013; Hsiao et al., 2016; Yildiz et al., 2018).

Figure 3 shows the degrees of importance for economic criteria. According to experts' results, the economic preparation and application of impregnation substance is 2.2 times more important than economic production of impregnation substance. This result does not mean that it is not important that the production of the impregnation material is cheap or expensive. However, it must be cheap for both researchers and industrialists, as an impregnation agent.

Figure 4 illustrates the degrees of importance for efficient criteria. The most important sub-criteria of efficient is effective against fungus and insects with 66% importance level. Fungus and insects are the most commonly struggled wood decay agents in the area of wood protection. Insect-fungal tests are one of the first experiments when a new impregnation material is introduced to the literature (Bultman and Parrish,1979; Jin et al., 2011; Palanti et al., 2012; Rosalina et al., 2016). Researchers firstly test the impregnation agent against fungus-insects, and if the impregnation agent is effective, then they perform other detailed experiments. In the study, the other desired properties were showed uniform distribution on wood and ability to deep in the wood with 25 % and 9% importance degrees, respectively.

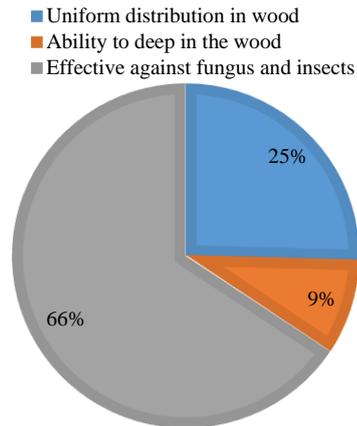


Figure 4. The degrees of importance for 'efficient' criteria

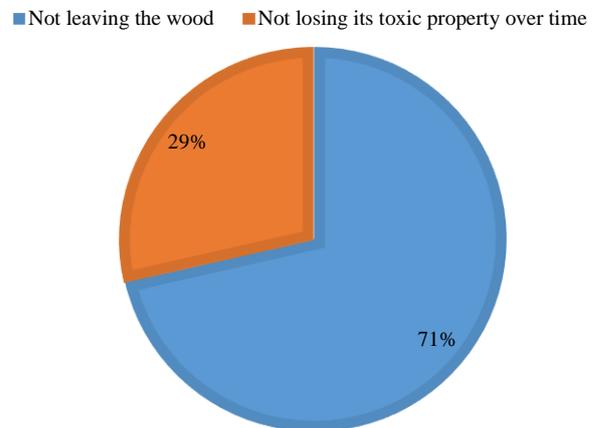


Figure 5. The degrees of importance for 'permanent' criteria

Figure 5 displays the degrees of importance for permanent criteria. The importance of sub-criteria can be listed as not leaving the wood (71%) and not losing its toxic property over time (29%). For example, boron compounds are effective antifungal impregnating agents as well as have a fire-retardant effect. They are also non-toxic to other organisms as having a natural structure (Schubert, 2000; Caldeira, 2010; Tomak et al., 2012). All these properties make boron compounds are excellent wood protection components. But boron and its compounds are leached away from the wood when is outdoor exposed. Therefore, several studies have been conducted to fixation the boron compounds in the wood (Pizzi and Baecker 1996; Obanda et al., 2008; Tomak et al., 2011).

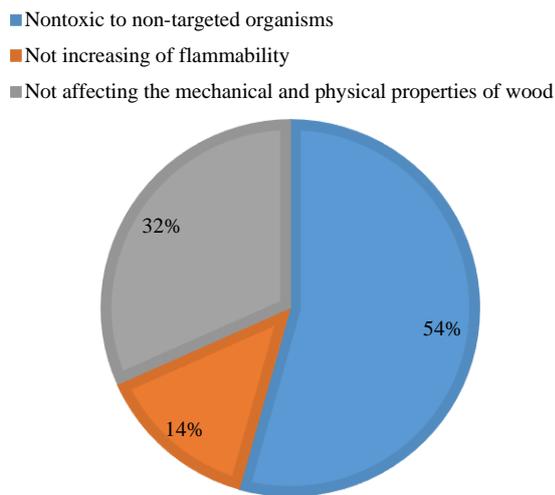


Figure 6. The degrees of importance for 'reliable' criteria

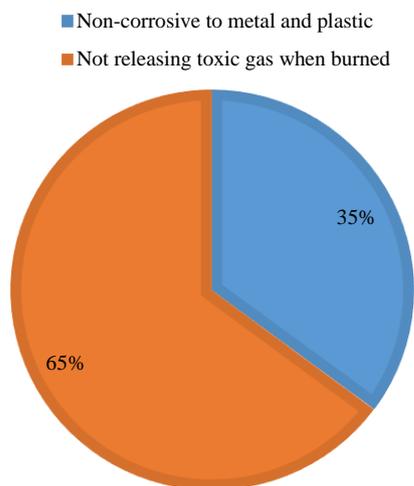


Figure 7. The degrees of importance for 'eco-friendly' criteria

Figure 6 represents the degrees of importance for reliable criteria. Nontoxic to non-targeted organisms were found the most important property among the sub-criteria of reliable criteria. This order of importance was followed by not affecting the mechanical and physical properties of wood and not increasing of flammability of wood, respectively.

Figure 7 demonstrates the degrees of importance for eco-friendly criteria. Not released toxic gas when burned criteria is found approximately 1.9 times more important than non-corrosive to metal and plastic criteria. This property is more important for disposal process than the use of impregnation agent. In addition, it is known that wood is a flammable material. Therefore, when the wood is burned, the release of the impregnating substance from the toxic substance harms both the living health and the environment.

Conclusions

Each impregnation process may vary depending on the impregnation method, the properties of the impregnation agent, the desired protection time, the conditions of use, and the like. The characteristics of wood species are different from each other, and the characteristics of trees of the same species may even vary.

In this study, the desired and expected properties from the impregnation agents were evaluated using fuzzy AHP method. This study was also conducted to demonstrate that fuzzy AHP method can be applied almost all disciplines of engineering. As a result, the desired and expected properties from an impregnation substance can be sorted as effective, by eco-friendly, economic, permanent and reliable main criteria, respectively.

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