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Use of Dead Oak Wood in Furniture Products

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Abstract. Today, furniture made of wood, on which the openings of insect passageways are visible, is popular. Artificially creating such holes on healthy wood does not meet the aesthetic needs of consumers. Considering the annual increase of 8-10 thousand hectares in drying oak stands in Ukraine and, accordingly, the cost of deadwood reduced by almost 50%, it is proposed to use it after proper treatment to destroy pests for the manufacture of furniture products. An analysis of wood disinfection methods was carried out, which transformed over time from non-toxic substances and processing methods – oil, tar, resin, storage in salt water, charring to modern ones using harmful chemical compounds – pentachlorophenol, alkaline chloride, sodium fluorosilicates, tars, DDT, etc. Analysis of available methods for exterminating timber pests allowed distinguishing antiseptics, fumigation, ultra-high frequency current treatment and thermal modification. The purpose of this study was to determine the method of disinfection of sawn goods made from deadwood oak for further use in furniture products. Theoretical and experimental methods were used to achieve this purpose. The scientific originality of this study lies in the application of the fuzzy logic method to select the priority method of wood disinfection, which lies in decomposition of the problem into simpler components and step-by-step prioritisation of the evaluated components using paired comparisons. For alternative options to achieve the purpose, the following criteria were applied: efficiency, environmental friendliness, industrial manufacturability, durability of the result. The corresponding calculations performed, confirmed by the required consistency index, showed the priority of the method of thermal modification of wood. Experimental studies of heat treatment with the proposed modes of deadwood oak with existing pests, namely *Xyleborus dispar* (*Xyleborus dispar*), were carried out. The study determined the possibility of using the action of hot temperatures ($t > 110^{\circ}\text{C}$) for complete sterilisation of deadwood oak. The result of practical application of this eco-safe method for the manufacture of tabletops has shown its effectiveness and can be useful for furniture makers

Keywords: pests, disinfection methods, thermal modification, thermomodified wood tabletop

Introduction

Modern designers try to bring naturalness and environmental friendliness to the interior, while solid wood still is the always used material. In the modern-day European furniture market, there is a considerable demand for “vintage” furniture, which shows the holes of insect passages [1]. Tables made of deadwood oak affected by timber pests are popular for use both in the interiors of private and public premises, as well as in the open air [2]. The presence of insects in deadwood can be traced by the presence of powder on the surface of wood, which is a product of the vital activity

of not only mature pests, but also deposited pupae. Despite this, such wood has an advantage since the price for it is almost 2 times less than for healthy wood [3]. This is relevant for Ukraine, as the volume of deadwood has considerably increased, and over the past 7-8 years it has grown from 8% to 18%. Today, drying covers an area of forests of more than 35 thousand hectares [4]. The cause of drying out of forests can be damage by timber pests that weaken the wood.

Usually, insects affect the sapwood part of tree species. They attack construction wood, lumber, and furniture.

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Adult insects have a length of 2.5 to 5.0 mm. Their shapes are usually elongated and cylindrical, and their colour ranges from reddish-brown to deep brown or black. Their life cycle averages 1-3 years, but females lay their eggs in wood. Larvae form tunnels in both conifers and hardwoods. They can digest cellulose and hemicellulose and break down cell wall carbohydrates, starch, and sugars in the cell contents [5; 6]. The result of their activity is the gradual loss of wood's physical and mechanical properties, which considerably reduces the possibility of using it for products used both outdoors and in internal house structures, etc. It also significantly reduces the time of use of wood products [7].

Organisms (fungi, insects) that destroy wood have been with humanity for many years and have caused great disasters, so finding ways to get rid of them has always been natural. The first chemical conservation measures included cleaning with oil, tar, or resin, storage in salt water, charring, etc. [7]. Later, they began to use pentachlorophenol, alkaline chloride, sodium fluorosilicates, boric acid, potassium dichromate, sodium dichromate, tars, DDT, gaseous pesticides (fumigants, for example, bromomethane and monophosphane) and others [7-9]. However, some of them (pentachlorophenol, alkali chloride, sodium fluorosilicates, DDT, gaseous pesticides, etc.) were banned for use due to health concerns [8].

Today, the most common methods of sterilisation are steam treatment, gamma radiation, and ultra-high frequency current, which are recommended by the European standards EN 113-1 (2021) [10] and EN 113-2 (2021) [11]. The use of gamma radiation, despite the positive effect, requires the use of expensive equipment – a neutron accelerator. Microwave insecticide is also costly, being used for disinfection of finished wood products during restoration [12; 13].

Thermal sterilisation is used worldwide and is currently the most practical and environmentally friendly treatment for pest control in solid wood. The international phytosanitary standard for wood packaging material requires heating the wood to $t=56^{\circ}\text{C}$ for at least 30 minutes. For complete sterilisation of wood, higher temperatures are used – $t>110^{\circ}\text{C}$ [14].

Heat treatment of wood has become quite popular over the past twenty years [15], although it is still being developed as an industrial process to improve some wood properties (shape stability, durability, light sensitivity, etc.). The first heat treatment studies concerned the determination of equilibrium humidity, dimensional stability, durability, and mechanical properties [16]. In the future, a decrease in weight, hygroscopicity, colour change over the cross-section were identified [17; 18], chemical transformations of the wood structure, and an increase in its biological stability [19; 20]. This has encouraged the use of thermally modified wood in non-structural products that can be used outdoors or in products that come into contact with water, such as sinks, bathtubs, and kitchen tabletops [21; 22].

In Ukraine, the following methods are mainly used for pest control: fumigation, antiseptics, which involve toxic substances that are harmful not only to insects, but also to processing personnel, and possibly to users of products treated in this way [23]. For local extermination of insects in finished products, a microwave insecticide is used that generates ultra-high frequency current (microwave) [23]. In case of preparing wood raw materials for the manufacture of furniture, the use of the above methods is questionable, since its manufacturability is complicated, and therefore it

is relevant to determine the method of wood disinfection that is harmless to manufacturers and consumers.

The purpose of this study was to determine a rational way to exterminate pests in sawn timbers made from deadwood oak.

Materials and Methods

Among the common methods of pest control in Ukraine, it was necessary to choose a priority one. For this purpose, one of the methods of fuzzy logic is used – the hierarchy analysis method (HAM), which lies in decomposing the problem into simpler components and gradually prioritising the evaluated components using paired comparisons [24].

The application of HAM includes defining the purpose, alternative options for achieving the purpose, and criteria for evaluating the quality of alternatives. In the case under study, the purpose is to choose a priority method of wood disinfection; the following methods of disinfection are chosen as alternatives: A_1 – fumigation, A_2 – antiseptic, A_3 – microwave exposure, and A_4 – thermal modification of wood (TMW); as criteria: Cr_1 – efficiency, Cr_2 – environmental friendliness, Cr_3 – industrial manufacturability, Cr_4 – durability of the result.

After determining the priorities of all elements of the hierarchy using the method of paired comparisons using the Saati scale [25] and synthesising global priorities of alternatives, by linear convolution of priorities of elements and hierarchies, judgments are verified for consistency and decisions are made based on the results obtained. In this case, the matrix of paired comparisons (MPC) of criteria is built relative to the purpose, and the MPC of alternatives will be relative to each criterion. In the case under study, there were four MPC alternatives.

The geometric average is calculated for each matrix, G_i , and local priority, LPr_n , for each row of the matrix:

$$G_i(a_{i1}, a_{i2}, \dots, a_{is}) = (a_{i1} * a_{i2} * \dots * a_{is})^{\frac{1}{s}} \quad (1)$$

where i is the matrix row number; s is the number of elements in the i^{th} row of the matrix;

$$a_{i1} = w_1/w_1; a_{i2} = w_1/w_2; \dots a_{is} = w_1/w_s \quad (2)$$

w is the accepted numerical value on the Saati scale.

$$LPr_n = \frac{[(w_n/w_1)(w_n/w_2) \dots (w_n/w_n)]}{(G_1 + G_2 + \dots + G_n)} \quad (3)$$

where n is the row number of the MPC.

To control the consistency of expert assessments, two related characteristics were used – the consistency index (CI) and the consistency ratio (CR):

$$CI = \frac{\lambda_{max} - m}{m - 1} \quad (4)$$

$$CR = \frac{CI}{P_m} \quad (5)$$

where m is the matrix size; P_m is the CI for a positive inverse symmetric matrix of random size estimates $m \times m$; λ_{max} is the maximum eigenvalue of MPC:

$$\lambda \sum a_{1i_1} \sum a_{2i_2} \sum a_{ni_{n_{max}}} \quad (6)$$

where $\sum a_{ji}$ is the sum of the values of the first column of the MPC; G_i is the local priority value of the first line of the MPC.

At $CR < 0.1 \dots 0.2$, the calculations performed are considered satisfactory.

The solution of the multi-criteria ranking problem is presented in the form of a global priority vector (GIPr) of alternatives in relation to the purpose. The GIPr is calculated as follows: each component of this vector constitutes a scalar product of the local priority vector (LPr) of criteria

and a vector comprising local priorities of the alternative to the presented criteria. The largest value of the GIPr vector corresponds to the priority alternative.

For experimental studies, samples of deadwood oak were selected, with signs of the presence of pests – white powder on the surface of boards and insect passages visible to the naked eye (Fig. 1).



Figure 1. Biological damage to samples

It was found that along the entire length of the lumber there were areas of settlement of timber pests. The samples of lumber under study can be attributed to “old deadwood”. Their sapwood part was at the last stage of biological destruction.

To detect the presence of pests in the samples, one of them was split. The resulting sample particles were placed in a microscope Micromed XS 330 microscope with 240x and 1600x magnification – Figure 2. This allowed detecting the insect passages within the wood – Figure 3.

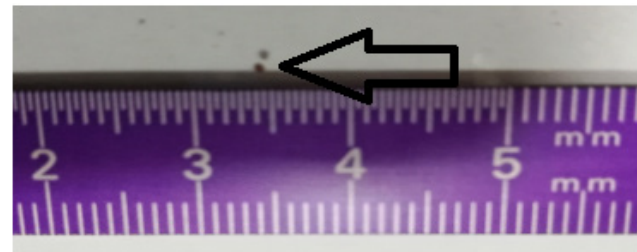


Figure 2. Shredding for the study of biological damage to pieces of lumber and the separation of existing pests



Figure 3. Timber pest passages within the wood

Samples of affected wood were dried in a laboratory convection drying chamber at $t=50^{\circ}\text{C}$ to a final wood moisture content of $W=8\%$. Subsequently, they were placed in a laboratory thermal chamber, where they were treated with the following schedules – Table 1. The applied processing

temperature parameters are consistent with those accepted in industry [15]. A total of 81 samples were examined.

Test samples of oak wood were made from sawn timber from a round log in the Zhytomyr region and had dimensions of $50 \times 180 \times 200 \text{ mm}$.

Table 1. Schedules parameters of thermal modification of oak wood samples

Schedules number	Processing temperature, $^{\circ}\text{C}$	Temperature exposure time, h		
		6	12	24
1	110	9 samples	9 samples	9 samples
2	160	9 samples	9 samples	9 samples
3	220	9 samples	9 samples	9 samples

Results and Discussion

It was established that a *Xyleborus dispar* was present in the oak wood during the initial settlement. This is evidenced by the oblong shape of the horizontal entrance channels in the wood, which have a depth of about 5 centimeters and have

branches for uterine passages (Fig. 4.) extending inside the wood. Furthermore, the presence of darkening of the passages was detected and this is also an inherent feature of this type of pest.



Figure 4. Place of pupation during the pest

Other insect species were also found in the worm-holes of the samples. These were entomophages, mites that feed on larvae and pupae of *Xyleborus dispar* (Fig. 5).

According to the calculation performed for (1-6), a matrix of priorities of criteria relative to the purpose and alternatives relative to each of the criteria is constructed using HAM – Table 2.



Figure 5. Entomophages found in wood

Table 2. Matrix of priorities criteria relative to the purpose and alternatives for each criterion

Criteria	Criterion priority	Alternatives			
		A_1	A_2	A_3	A_4
Cr_1	0.038	0.090	0.094	0.069	0.059
Cr_2	0.086	0.121	0.136	0.112	0.055
Cr_3	0.099	0.204	0.186	0.325	0.173
Cr_4	0.777	0.585	0.584	0.494	0.713
Consistency of calculations					
	0.095	0.024	0.191	0.071	0.174

The calculation results are clearly consistent since they are within the required limits of $CR < 0.1 \dots 0.2$. The results

of determining the global priority method of wood disinfection from the accepted alternatives are presented in Table 3.

Table 3. Global priorities of accepted alternatives

Alternatives	A ₁	A ₂	A ₃	A ₄
GIPr	0.489	0.488	0.428	0.578

Therefore, the greatest priority is given to Alternative 4 – thermal treatment of wood, so in experimental studies, the TMW method was used to destroy pests.

As a result of thermal modification of oak wood samples affected by *Xyleborus dispar*, all samples were found to have darkened. This is the result of the decomposition of hemicellulose and lignin [26].

Heat treatment of wood affects the viability of insects, coagulation (denaturation) of proteins essential for the existence of insects occurs. Increase in wood temperature up to $t = 110^\circ\text{C}$ and above caused the death of the *Xyleborus dispar* beetle at all stages, namely eggs, larvae,

pupae, adult insects due to the destruction of the protein inherent in the body [26; 27]. In the case of the presence of other pests in the firewood of both deciduous and coniferous species, namely weevils, bark beetles, etc., according to [28], treatment at $t = 60^\circ\text{C}$ for 60 minutes was sufficient [29]. However, the use of $t \leq 110^\circ\text{C}$ prevents the decomposition of pest-friendly components of the wood structure – hemicellulose, which does not guarantee the viability and reproduction of newly populated pests.

The remains of *Xyleborus dispar* that were detected after thermal treatment with schedules 1 (24 hours) and 2 (12 hours and 24 hours) are presented in Figure 6.

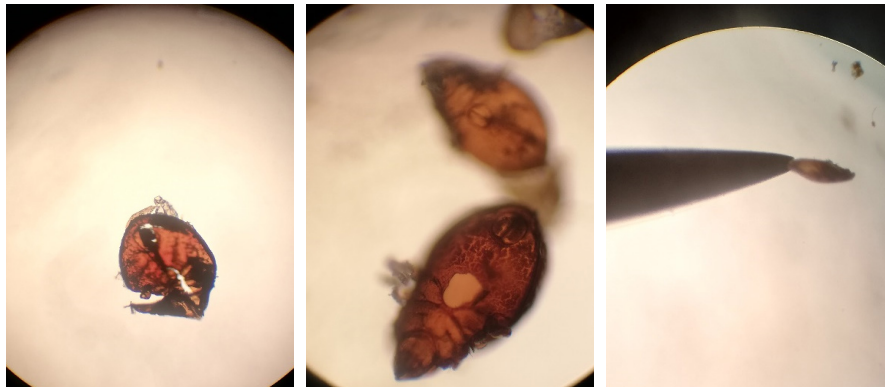


Figure 6. Insect remains found in oak samples after TMW

No insect remains were found in samples treated with schedule 1 (6 h and 12 h) and mode 2 (6 h). The samples treated at $t = 220^\circ\text{C}$ were charred, and therefore were not examined under a microscope for the presence of insect remains. Moreover, such wood can no longer be used for making furniture. The results obtained indicate that thermal modification of sawn timber from deadwood

oak, which is affected by the *Xyleborus dispar*, promotes the extermination of insects. Due to the destruction of hemicellulose at $t > 110^\circ\text{C}$, which is a nutrient for insects, products made of thermal-treated wood will not be attractive to pests during operation [20]. Several tables were made from the oak lumber selected for the study in 2019 (Fig. 7).



Figure 7. Table made of thermally modified oak wood: a – part of the tabletop that shows the passages of insects; b – general view of the table

These products have been used for almost three years in the open air. During this time, no signs of insect activity were detected, i.e., the presence of powder. Furthermore, the products did not change their shape as a result of both dripping moisture and environmental climate changes. Thus, thermal modification of wood can be recommended for disinfection of deadwood by pests for the manufacture of such modern popular antique furniture.

Conclusions

1. An increase in the amount of deadwood oak affected by pests limits its full use for the manufacture of furniture products. In the wood of ordinary oak originating from the Zhytomyr region, the presence of a slight destruction of the core part formed by the passages of the timber pest – the *Xyleborus dispar* – was revealed.

2. The analysis of methods of wood disinfection allowed identifying the methods common in Ukraine – fumigation, antiseptics, ultra-high frequency current treatment, thermal modification. Using the hierarchy analysis method, an effective ecological method was chosen for the selected methods of pest control – thermal modification of wood, which has successful industrial use.

3. Experimental studies of the influence of the proposed schedule parameters of thermal treatment on the viability of pests proved the possibility of its further use in popular furniture products made of oak wood, which have signs of ageing, but will not be destroyed over time.

4. For the possibility of using disinfected dead-wood thermally modified oak wood in other furniture products, it is necessary to conduct studies of its mechanical properties.

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Використання сухостійної деревини дубу у меблевих виробках

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Анотація. Сьогодні популярними є меблі, виготовлені із деревини, на яких видно отвори ходів комах. Штучне створення таких отворів на здоровій деревині не задовольняє естетичних потреб споживачів. Враховуючи щорічне зростання на 8–10 тис. га в Україні площі деревостанів дубу, що висихає та, відповідно, знижену майже на 50 % вартість сухостійної деревини запропоновано використання її після відповідного оброблення по знищенню шкідників для виготовлення меблевих виробів. Проведено аналіз способів знезараження деревини, які трансформувалися із часом від досить нетоксичних речовин та способів обробки – олії, дьогтю, смоли, зберігання в солоній воді, обвуглювання до сучасних із використанням шкідливих хімічних сполук – пентахлорфенолу, лужного хлориду, натрію фторосилікатів, гудронів, ДДТ тощо. Аналіз доступних способів ліквідації стовбурових шкідників, дозволив виділити антисептування, фумігацію, оброблення струмом надвисокої частоти та термічне модифікування. Метою дослідження є визначення способу знезараження пилопродукції із сухостійної деревини дубу для подальшого використання у меблевих виробках. Для досягнення означеної мети застосовано теоретичний та експериментальний методи. Наукова новизна полягає у застосуванні методу нечіткої логіки для вибору пріоритетного способу знезараження деревини, який полягає у декомпозиції проблеми на більш прості складові частини і поетапному встановленні пріоритетів оцінюваних компонентів з використанням парних порівнянь. Для альтернативних варіантів досягнення цілі були застосовані такі критерії – ефективність, екологічність, промислова технологічність, довговічність результату. Проведені відповідні розрахунки, що підтверджені необхідним індексом узгодженості, показали пріоритет способу термічного модифікування деревини. Проведено експериментальні дослідження термічного оброблення запропонованими режимами сухостійної деревини дубу з наявними шкідниками, а саме непарного західного короїду (*Xyleborus dispar*). Визначено можливість використання дії високих температур ($t > 110$ °C) для повної стерилізації сухостійної деревини дубу. Результат практичного застосування цього еколого безпечного способу для виготовлення стільниць показав його ефективність і може бути корисним для меблевиків

Ключові слова: шкідники, способи знезараження, термічне модифікування, стільниця з термомодифікованої деревини