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Influence of water glass on selected properties of particleboard

Wpływ szkła wodnego na wybrane właściwości płyt wiórowych

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Abstract

The study aimed to determine the properties of particleboards impregnated with water glass. Three variants of surface impregnation were examined: one, two, and three layers of water glass. Flammability of the impregnated boards was tested by the single flame method and selected mechanical and physical properties of the boards (MOR, MOE, IB, density and density profile, water absorption, and thickness swelling after soaking in water) were determined. The reference material was non-impregnated particleboard. Obtained results revealed that the surface impregnation with water glass improved the fire resistance of the particleboard. At the application of 93 g/m^2 water glass, the boards demonstrated a statistically significant improvement in mechanical properties. However, impregnation deteriorated boards' resistance to moisture.

Streszczenie

W ramach badań przedstawiono właściwości płyt wiórowych impregnowanych powierzchniowo szkłem wodnym. Zastosowano 3 warianty impregnacji powierzchniowej: jedną, dwiema i trzema warstwami szkła wodnego. Dla zaimpregnowanych płyt zbadano palność metodą pojedynczego płomienia oraz oznaczono ich wybrane właściwości mechaniczne i fizyczne (MOR, MOE, IB, gęstość i profil gęstości, nasiąkliwość i spęcznienie na grubość po moczeniu w wodzie). Jako wariant kontrolny zbadano płyty wiórowe nieimpregnowane. Stwierdzono, że impregnacja powierzchniowa płyt wiórowych szkłem wodnym poprawia ich odporność na działanie ognia. Przy naniesieniu 93 g/m^2 płyty impregnowane powierzchniowo szkłem wodnym wykazują istotną statystycznie poprawę właściwości mechanicznych. Płyty impregnowane wykazywały obniżenie odporności na działanie wilgoci.

Keywords: water glass, particleboard, combustibility, surface impregnation

Słowa kluczowe: szkło wodne, palność, płyta wiórowa, impregnacja powierzchniowa

Introduction

Particleboards are one of the basic materials used to build furniture and same like wood are classified as combustible materials. In accordance with the classification of products in the field of reaction to fire, contained in the PN-EN 13501-1: 2019-02 standard, industrially produced furniture particleboards are generally classified as class D - s2, d0 (easily ignitable material with medium smoke emission and no flaming droplets and debris). There are also special-purpose particleboards on the market with increased fire resistance, classified as class B - s2, d0, i.e. for non-flammable materials with an average amount of smoke and no flaming droplets and waste (Prüfinstitut Hoch 2020). However, it should be noted that the number of this type of boards in the total production of particleboards is relatively small (Thoemen et al. 2010). There are three main methods of applying flame retardants:

- as an additive to chips or glue during the panel manufacturing process. Chemical agents applied in this way include, among others: boron compounds (Thoemen et al. 2010, Boruszewski et al. 2011, Pedieu et al. 2012, Terzi 2018), sodium chloride and calcium carbonate (Yusof et al. 2020), ammonium polyphosphate (Grexa et al. 2003), colemanite (Terzi 2018);
- using additional raw materials that reduce flammability, such as gypsum (Lee et al. 2011), cement (Saval et al. 2014), vermiculite (Kozlowski et al. 1999), mineral wool (Mamiński et al. 2009, Mamiński et al. 2011), expanded graphite (Chun et al. 2020);
- surface application of flame retardants, eg calcite with the addition of boron compounds (Özdemir and Tutuş 2016), expanded graphite (Grexa et al. 2003).

In the first two cases, the introduction of flame retardant measures takes place at the stage of production of the panels, which precludes the use of these methods to insulate the panels produced earlier. Additionally, materials reducing the flammability applied inside the panels, may negatively affect their physical and mechanical properties and lower the durability of the protected elements (Grexa et al. 2003). These types of problems can be avoided by applying surface protection of the boards, especially when using ecological chemicals.

Water glass is the common name for aqueous solutions of sodium silicates, potassium silicates or a mixture of sodium silicates and potassium silicates (Jansson et al. 2015). From an ecological point of view, these are harmless compounds (Ogłaza 2010). However, they are characterized by high alkalinity that requires appropriate PPE when working with them. In industrial conditions, sodium water glass is most often used, among others: for water treatment, in the production of cleaning agents, as a corrosion inhibitor, for stabilizing crude oil, for extinguishing fires, as a component of drying agents, as a component of molding masses, as an additive to cement, for soil stabilization (Koźlak 2008, 2009). Water glass can also be used to bond lignocellulosic particles in the production of insulation boards (Richter 1993). Slimak and Slimak (2000) proposed the use of sodium water glass as an effective and ecological alternative to impregnants protecting wood against the action of moisture and biological degradation, as well as against the action of fire. However, the product the authors developed under the trade name TimberSIL (https://materialyinzynierskie.pl/) turned out to be ineffective in terms of the impact of external conditions, and the elements made of it were biologically degraded (Thompson 2015). Koźlak (2008) pointed to the possibility of using water glass for surface impregnation of wood as an effective method of limiting its flammability. In turn, Gawłowski et al. (2017) described the use of water glass to impregnate PET fibers as an effective way to increase their resistance to ignition, slow down the combustion process and eliminate the droplet effect. The authors also pointed to the low cost and ease of such a process.

The research carried out so far leads to a hypothesis that water glass can be used to impregnate particleboards.

Aim and scope of work

The aim of the work was to investigate the effect of surface impregnation with water glass on the flammability and selected physical and mechanical properties of particleboards. As part of the research, surface impregnation of particleboards with water glass was carried out in three variants of coverage: one, two and three layers. Flammability of the impregnated boards was tested by the single flame method and their selected physical and mechanical properties (MOR, MOE, IB, density and density profile, water absorption and thickness swelling after soaking in water) were determined. The analysis of the examined properties was performed with reference to non-impregnated boards.

Materials and Methods

As part of the research, an industrially manufactured three-layer particleboard with a thickness of 15 mm, average density 580 kg/m^3 and moisture 6.5% was used. Samples made of this board on both sides were surface impregnated with a 40% aqueous solution of sodium silicate (Dragon Poland Sp z o.o., Sp. K.). It is a colorless viscous liquid with a density
of 1.4 kg/dm^3. Four variants of impregnated boards were prepared:

- Variant 0 - no impregnation - a control variant,
- Variant 1 - one layer - application of 32.9 g/m^2,

- Variant 2 - two layers - application of 71.2 g/m^2,
- Variant 3 - three layers - application of 93.0 g/m^2.

The surface impregnation was carried out by applying undiluted water glass to the surfaces of the samples with a brush. Subsequent impregnation layers were applied after the previous layer was dust-free. The impregnated boards were left to dry in the ambient conditions (temperature approx. 20°C, humidity above 65%) for 7 days. The impregnated boards were subjected to the following tests:

- the flammability test was carried out using the single flame method in accordance with PN-EN ISO 11925-2: 2004. The exposure time to the flame was 60 seconds. The following measurements were recorded: whether the sample ignited, how long the burning was sustained, whether the flame reached a height of 150 mm and the time required to achieve it;
- density and density profile - using Laboratory Density Analyzer DAX GreCon. Density measurement was performed every 0.02 mm at the measurement speed of 0.05 mm/s;
- modulus of rupture (MOR) and modulus of elasticity (MOE) - in accordance with PN-EN 310: 1994;
- internal bond (IB) - in accordance with PN-EN 319: 1999;
- thickness swelling (TS) and water absorption (WA) after 2h and 24h of soaking in water - in accordance with PN-EN 317: 1999.

In the case of the density and flammability tests, 3 samples were used for each variant. In the case of the remaining studies, 10 samples were used for each variant. The statistical analysis of the obtained results was carried out in the Statistica13. In order to compare the obtained results, a one-way analysis of variance was performed and the significance of differences in individual values was determined based on the Tukey's test.

Results and Discussion

The results of the board flammability test are presented in Table 1 and Fig. 1. In the case of two samples of the control panels (variant 0), the fire sustained after removing the burner, and the third sample was strongly charred. As a result of combustion, the flame reached the height of 150 mm after 146 and 200 seconds, respectively. As for variants I, II and III, none of the panels impregnated with water glass on the surface did not sustain combustion. The boards impregnated with one layer (variant I) charred in the place of direct flame exposure, and above, they discolored gray. In the case of boards covered with two and three layers of water glass (variants II and III, respectively), only slight charring of the samples was noted. These boards turned light gray in the area of the flame with a visible white coating. The color changes visible on the surface of the boards (white deposit) are related to the water glass polymerization process as a result of the temperature (Slimak and Slimak 2000). The results of the flammability test indicate an increase in the resistance of water glass impregnated boards to fire in two ways - by creating a barrier between the particleboard and the flame and by using a part of the energy supplied by the flame for the polymerization process.

Table 1. Flammability test results
Tabela 1. Wyniki badania palności

Variant	Sample	Flame sustantion	Time needed to reach flame of 150 mm [s]	Obervation
0	1	Yes	200	carbonization on the surface, the specimen was extinguished after the flame reached a height of 150 mm
	2	Yes	146	
	3	No	-	carbonization at and above the direct flame application spot
I	1	No	-	carbonization at the spot of direct flame application, above it a gray discoloration
	2	No	-	
	3	No	-	carbonization at the spot of direct flame application, a gray discoloration above it, visible a white deposit
II	1	No	-	slight carbonization at the spot of direct flame application, a light gray discoloration above it, visible a white deposit
	2	No	-	
	3	No	-	
III	1	No	-	slight carbonization at the spot of direct flame application, a light gray discoloration above it, visible a white deposit
	2	No	-	
	3	No	-	

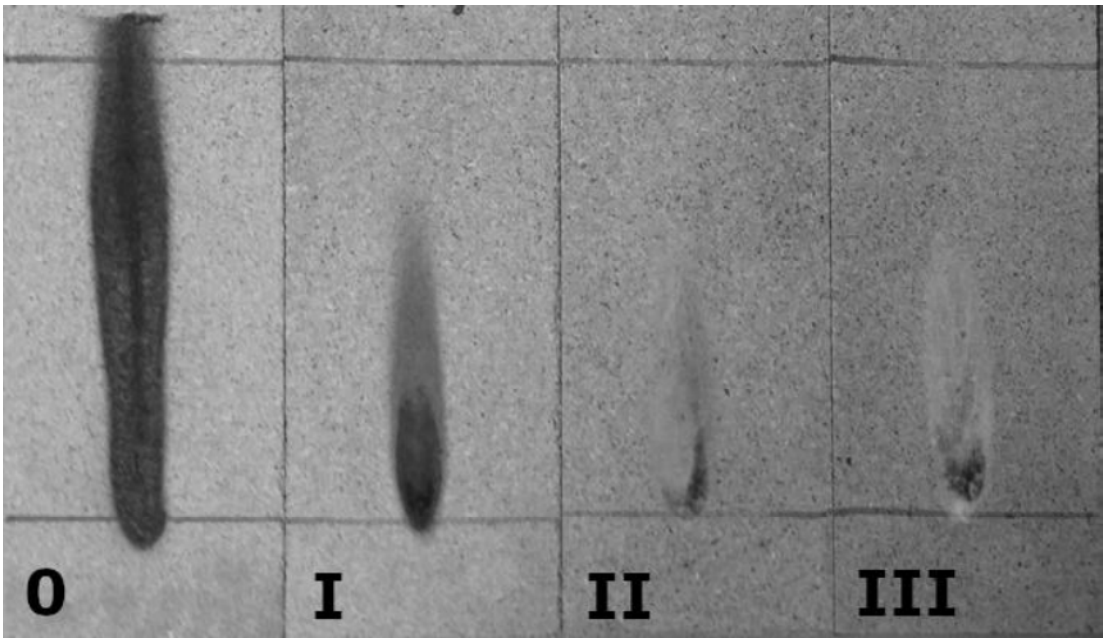


Fig. 1. Image of samples characteristic for a given variant after the flammability test
Rys. 1. Obraz próbek charakterystycznych dla danego wariantu po badaniu palności

The surface impregnation of particleboards did not significantly affect their average density. The tested boards were characterized by an average density in the range of 571-586 kg/m^3. It is generally assumed that the differences in density not exceeding 10% should not statistically significantly affect the properties of the tested boards (İstek and Sıradağ 2013) The effect of the surface impregnation of the boards was noted on the courses of the density profiles of individual variants (Fig. 2). The increase in the amount of water glass applied to the surface of the panel translated into an increase in the density of the surface layers of the panels up to approx. 0.2 mm thick (Fig. 3). When applying approx. 93.0 g/m^2 of water glass (variant III), the density of the subsurface layers increased almost 3 times in relation to the density of the subsurface layers of the control variant. It is worth noting here that the course of the density profile clearly correlates with the basic mechanical properties of particle boards such as MOR, MOE or IB (Wong et al. 1999, Niemz 2003, Treusch et al. 2004).

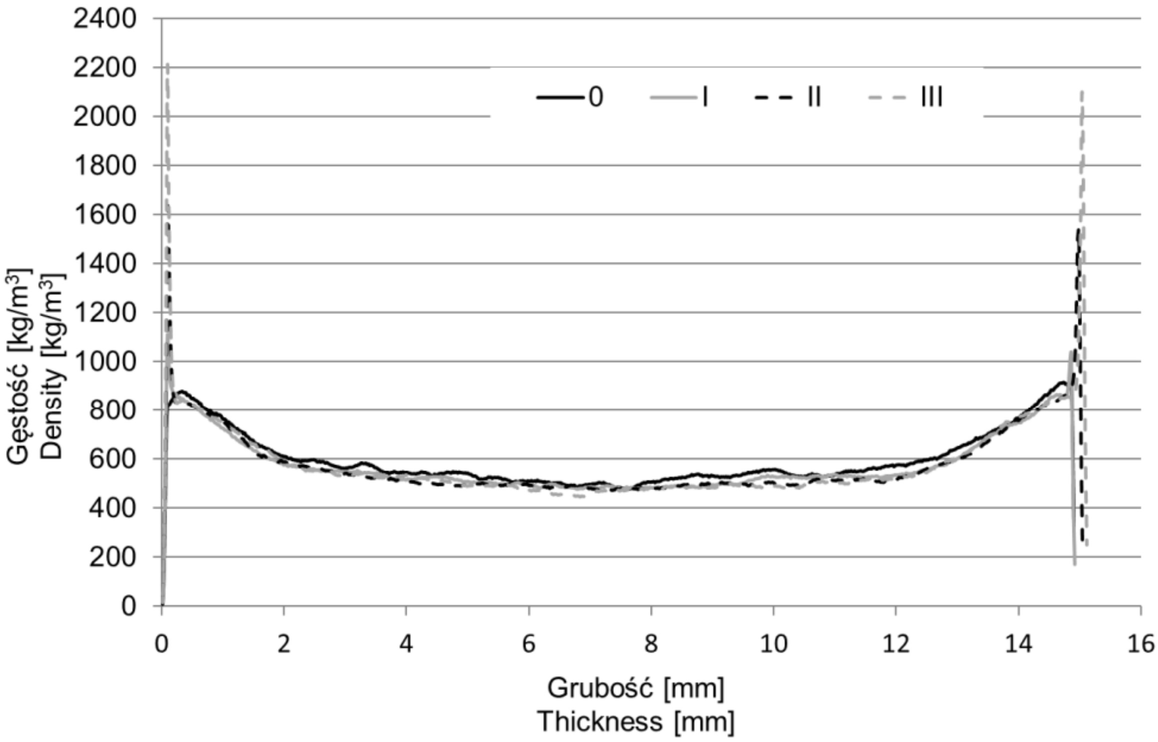


Fig. 2. Density profiles of tested boards
Rys. 2. Profile gęstości badanych płyt

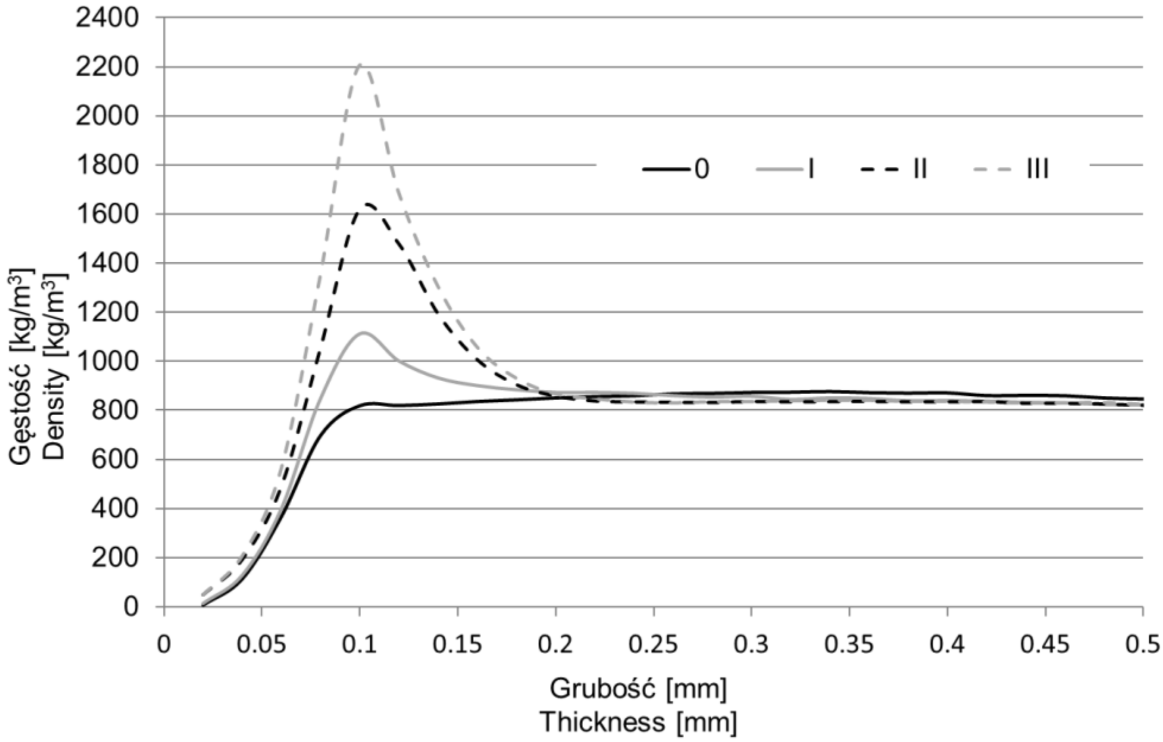
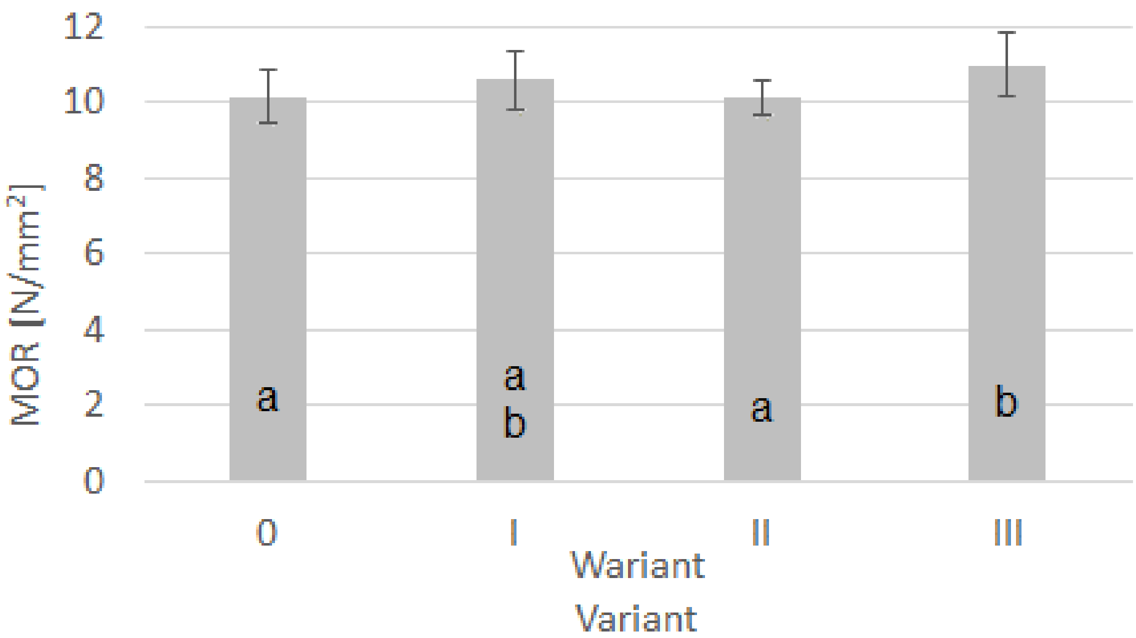


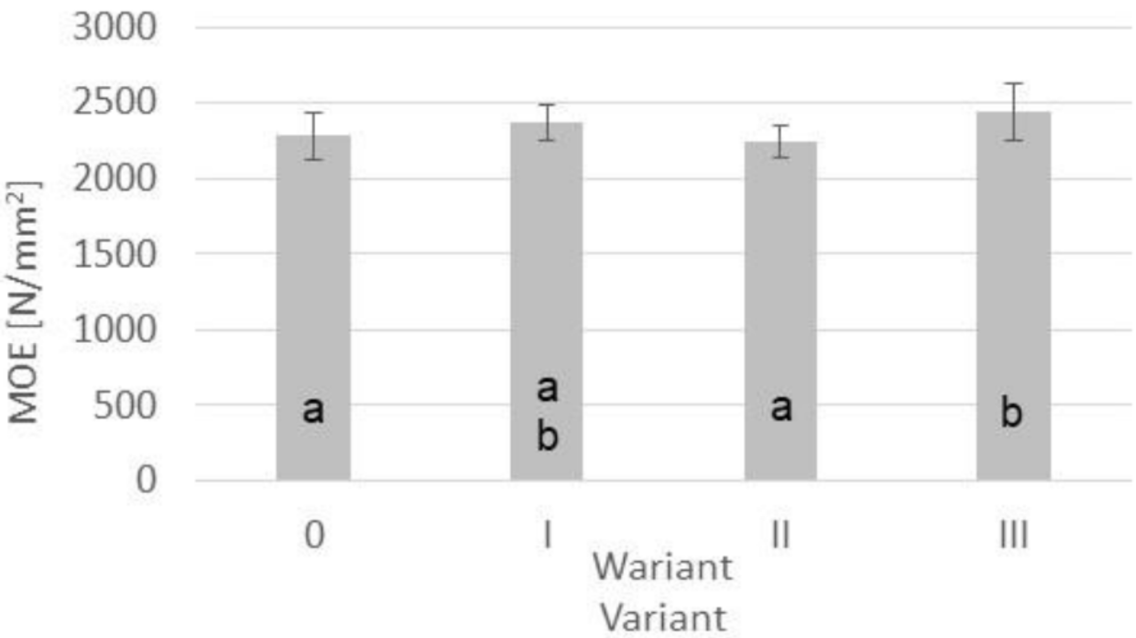
Fig. 3. Density distribution in the subsurface layers of the tested panel variants
Rys. 3. Rozkład gęstości w warstwach przypowierzchniowych badanych wariantów płyt

The results of the boards' strength tests are presented in Figures 4, 5 and 6. The analysis of variance showed a statistically significant influence of the surface impregnation of the boards on their strength properties. However, a statistically significant increase in the strength values of surface impregnated panels compared to non-impregnated panels was visible only when applied about 93 g/m^2 (variant III). It is worth noting here that similar relationships have been observed when the surface of the boards was covered with a melamine film, in general, it improved boards' elastic properties (Nemli et al. 2005, Nemli and Çolakoğlu 2005, Borysiuk et al. 2019). Moreover, it should be marked, that the impregnation used was only superficial. The observed differences in the IB values (Fig. 6), although statistically significant, could result from the different structure of the board, and not from its surface modification.



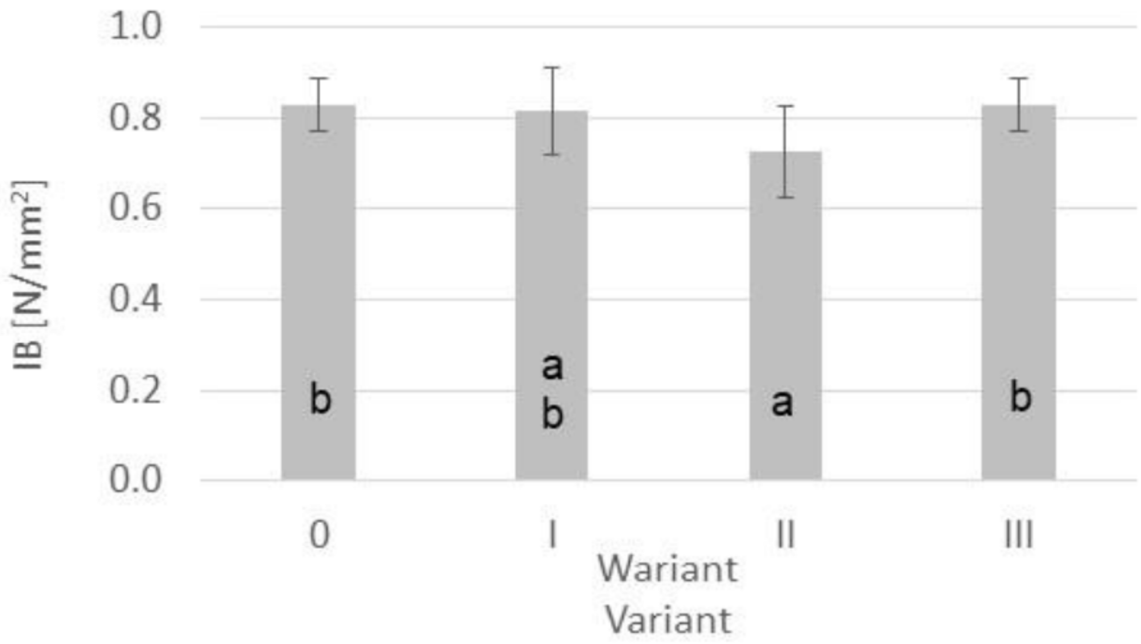
abc - homogeneous groups determined using Tukey's test
abc - grupy homogeniczne wyznaczone przy wykorzystaniu testu Tukeya

Fig. 4. MOR values of tested boards
Rys. 4. Wartości MOR badanych płyt



abc - homogeneous groups determined using Tukey's test
abc - grupy homogeniczne wyznaczone przy wykorzystaniu testu Tukeya

Fig. 5. MOE values of tested boards
Rys. 5. Wartości MOE badanych płyt

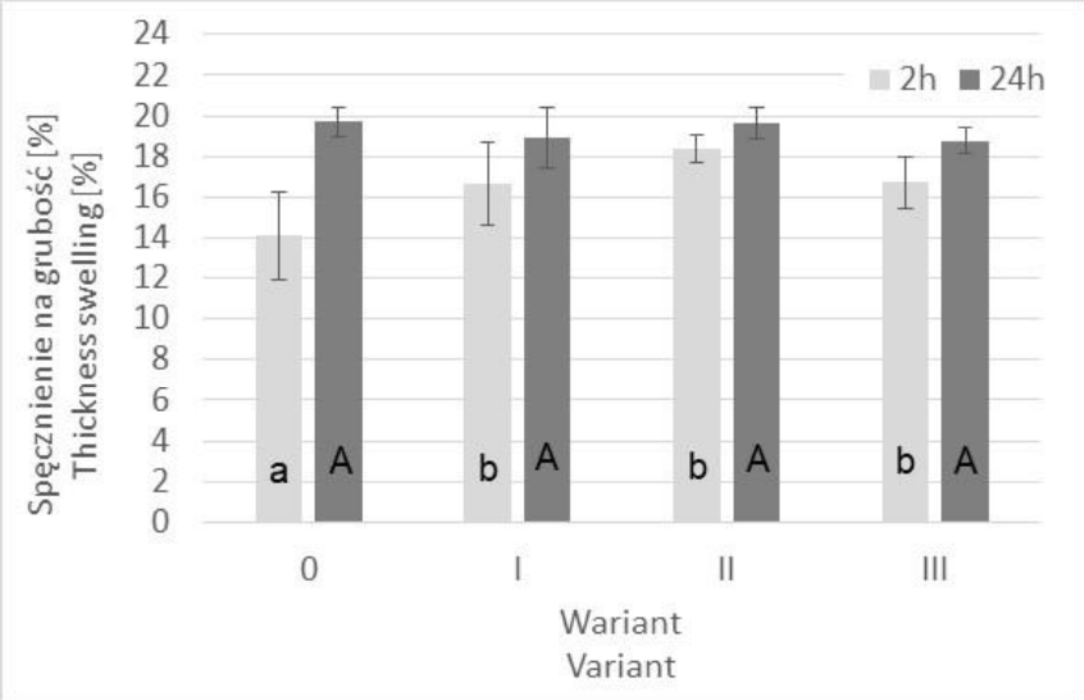


abc - homogeneous groups determined using Tukey's test
abc - grupy homogeniczne wyznaczone przy wykorzystaniu testu Tukeya

Fig. 6. IB values of tested boards
Rys. 6. Wartości IB badanych płyt

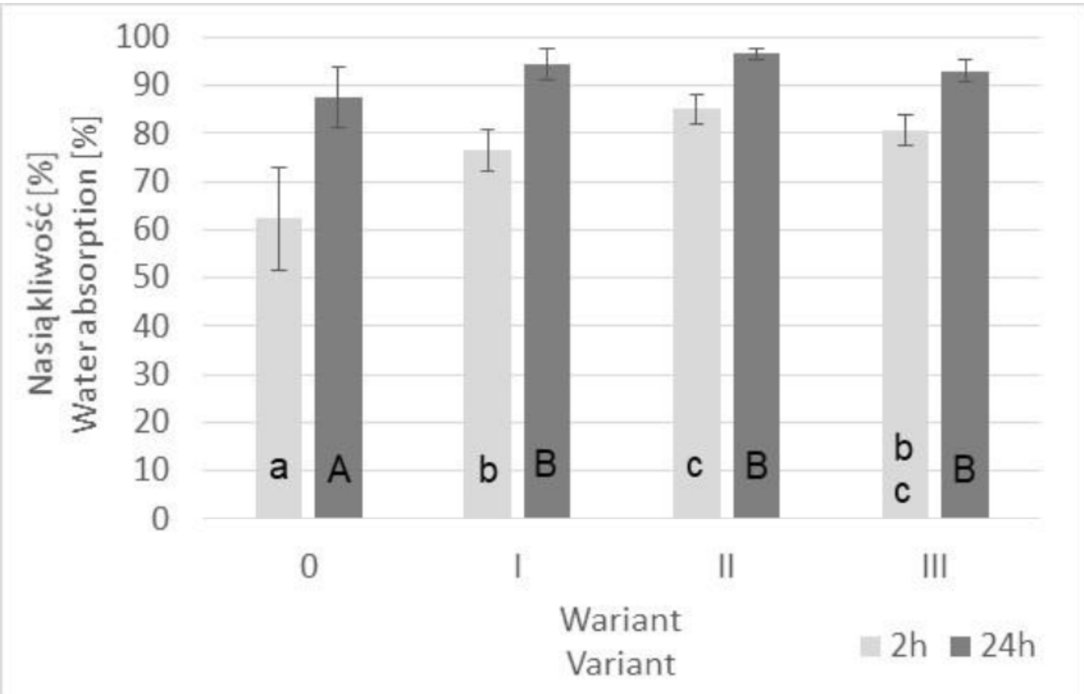
In the case of moisture resistance, the greatest differences were observed in the values of swelling and water absorption after 2 hours of soaking in water. In this range, the swelling and water absorption values of the surface impregnated panels were from 18% to 37% higher compared to the control panels. However, all tested boards impregnated with water glass demonstrated a statistically significant increase in water absorption compared to non-impregnated boards (Fig. 7). This difference was visible both after 2h and 24h of soaking in water. On the other hand, in the case of swelling, a statistically significant differentiation of the results was visible only after 2 h of soaking in water (Fig. 8).

The decrease in the moisture resistance of the boards' surface impregnated with water glass was related to surface enlargement after impregnation (increase in roughness), which could facilitate the penetration of moisture



abc ABC - homogeneous groups determined using Tukey's test
abc ABC - grupy homogeniczne wyznaczone przy wykorzystaniu testu Tukeya

Fig. 7. TS values of tested boards
Rys. 7. Wartości TS badanych płyt



abc ABC - homogeneous groups determined using Tukey's test
abc ABC - grupy homogeniczne wyznaczone przy wykorzystaniu testu Tukeya

Fig. 8. WA values of tested boards
Rys. 8. Wartości WA badanych płyt

Conclusions

Based on the tests of particleboards surface impregnated with water glass, it was found that:

1. Surface impregnation with water glass increases the resistance of the particleboard to fire.
2. The surface impregnation with water glass has a statistically significant effect on the mechanical properties (MOR, MOE) of the particleboard only with the application of about 93 g/m^2.
3. Impregnation with water glass lowers the moisture resistance of the particle board after 2 h exposure to water. In the case of long-term exposure (24 hours), the water absorption value of the impregnated boards significantly increased.

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Wykaz norm

PN-EN 13501-1:2019-02 Klasyfikacja ogniowa wyrobów budowlanych i elementów budynków - Część 1: Klasyfikacja na podstawie badań reakcji na ogień

PN-EN 310:1994 Płyty drewnopochodne - Oznaczenie modułu sprężystości przy zginaniu i wytrzymałości na zginanie

PN-EN 317:1999 Płyty wiórowe i płyty pilśniowe - Oznaczanie spęcznienia na grubość po moczeniu w wodzie

PN-EN 319:1999 Płyty wiórowe i płyty pilśniowe - Oznaczanie wytrzymałości na rozciąganie w kierunku prostopadłym do płaszczyzn płyty

PN-EN ISO 11925-2:2020-09 Badania reakcji na ogień - Zapalność wyrobów poddawanych bezpośredniemu działaniu płomienia - Część 2: Badania przy działaniu pojedynczego płomienia

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