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Impact of conditions of use on selected properties of HDF

Wpływ warunków użytkowania na wybrane właściwości płyt HDF

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Abstract

As part of the work, the influence of air temperature and relative humidity on selected properties of HDF boards was examined. Industrial HDF boards with a thickness of 2.5 mm and a density of 820 kg/m^3 were used for the tests, which were subjected to seven-day air conditioning at temperatures from -20°C to 50°C (in steps of 10°C) at 55% relative humidity and at 40°C at 20% and 80% relative humidity. For the tested boards, the following were determined: density and density profile, MOR and MOE, IB, thickness swelling and water absorption after 24 hours of soaking in water. It has been shown that the increase in air-conditioning temperature has an ambiguous effect on the MOR and MOE values of the tested HDF boards. In the temperature range from -20°C to 10°C, the strength values generally decreased, while further increasing the air conditioning temperature (above 10°C) increased the MOR and MOE values. On the other hand, in correlation to IB, an increase in air-conditioning temperature generally increases the strength of HDF boards. An increase in relative air humidity from 55% to 80% causes a decrease in the MOR and MOE values, while an increase in relative air humidity from 20% to 55% causes an increase in the IB value of conditioned HDF boards. In the case of physical properties, it was shown that an increase in the air-conditioning temperature translates into an increase in the thickness swelling value and water absorption of HDF boards. On the other hand, an increase in relative air humidity causes a decrease in the value of swelling and water absorption of HDF boards.

Streszczenie

W ramach pracy zbadano wpływ temperatury i wilgotności względnej powietrza na wybrane właściwości płyt HDF. Do badań wykorzystano przemysłowe płyty HDF o grubości 2,5 mm i gęstości 820 kg/m^3, które poddano siedmiodniowej klimatyzacji w temperaturach od -20°C do 50°C (z odstopniowaniem co 10°C) przy wilgotności względnej powietrza 55% oraz w temperaturze 40°C przy wilgotności względnej powietrza 20% i 80%. Dla badanych płyt oznaczono: gęstość i profil gęstości, MOR oraz MOE, IB, spęcznienie na grubość i nasiąkliwość po 24 h moczeniu w wodzie. Wykazano, że wzrost temperatury klimatyzacji wpływa niejednoznacznie na wartości MOR i MOE badanych płyt HDF. W przedziale temperatur od -20°C do 10°C wartości wytrzymałości na ogół ulegały obniżeniu zaś dalsze zwiększanie temperatury klimatyzacji (powyżej 10°C) wpłynęło na wzrost wartości MOR i MOE. Z kolei w odniesieniu do IB wzrost temperatury klimatyzacji powoduje na ogół wzrost wytrzymałości płyt HDF. Wzrost wilgotności względnej powietrza z 55% do 80% powoduje spadek wartości MOR i MOE, zaś wzrost wilgotności względnej powietrza z 20% do 55% powoduje wzrost wartości IB klimatyzowanych płyt HDF. W przypadku właściwości fizycznych wykazano, że wzrostem temperatury klimatyzacji przekłada się na wzrost wartości spęcznienia na grubość oraz nasiąkliwości płyt HDF. Z kolei wzrost wilgotności względnej powietrza powoduje spadek wartości spęcznienia oraz nasiąkliwości płyt HDF.

Keywords: HDF, air relative humidity, temperature, mechanical properties, MOR, MOE, IB

Słowa kluczowe: płyta HDF, wilgotność względna powietrza, temperatura, właściwości mechaniczne, MOR, MOE, IB

Introduction

Dry-formed fibreboards (MDF, HDF) are currently one of the basic materials used in the furniture industry. During storage and use of finished products, these materials may be exposed to changing environmental conditions. It is generally assumed that in summer the average relative humidity of air in living quarters is about 40%, while in autumn it increases to about 75%. On the other hand, the temperature of the rooms, depending on their function, should be in the range of 16-24°C for living rooms and 12-14°C for utility rooms (https://www.instalacjebudowlane.pl). It should be added here, that the conditions (relative air humidity, temperature) prevailing in rooms, especially in warehouses, often differ from those assumed as optimal during the year. Therefore, the humidity of objects made of lignocellulosic materials used or stored there ranges from approx. 5% in winter to approx. 19% in summer (Kozakiewicz and Matejak, 2016).

Both in the case of solid wood and wood-based panels, an increase in material moisture results in a decrease in their strength parameters. Bekhta and Niemz (2009) showed that with an increase in relative air humidity from 35% to 95%, a decrease in the MOR and MOE values of conditioned MDF boards by about 65% was observed (Bekhta and Niemz, 2009).

The authors also found that the highest decrease in strength parameters was observed for air-conditioned panels in the range of relative air humidity from 65% to 95%. Similar results were previously obtained by Popper *et al.* (2001) who conditioned 16 mm thick MDF boards in air with a relative humidity of 0% to 93%. In the range of relative air humidity from 0% to 11%, the authors noted an increase in strength parameters (MOR, MOE) of air-conditioned boards by approx. 17%, further increase in the relative humidity of the air to 93% resulted in a decrease in the strength parameters of the air-conditioned panels by approx. 50%. Sala *et al.* (2020), examining MDF boards (thickness 5 mm, 780 kg/m^3) and HDF boards (thickness 1.9 mm, 820 kg/m^3) found that boards conditioned in air with a relative humidity of 33% are characterized by similar MOR values and higher values MOE compared to panels conditioned at 0% relative humidity. The authors also showed that boards conditioned at a relative air humidity of 97% were characterized by a decrease in strength parameters by approx. 70% in the case of MDF and approx. 80% in the case of HDF.

The increase in air-conditioning temperature also has a negative impact on the properties of wood based materials. Bekhta *et al.* (2003) found that temperature changes from +20°C to +140°C (with steps of 20°C) with a 1.0-hour exposure time of MDF boards (thickness 19 mm, 763 kg/m^3) to a given temperature reduce the MOR value by up to 37%. The observed changes were linear. On the other hand, Sonderegger and Niemz (2006) studied MDF boards with a thickness of 16 and 18 mm and a density of 749 and 759 kg/m^3, respectively, exposed to temperatures from -20°C to +60°C. The authors found that lowering the temperature from +20°C to -20°C increased the MOR value by 18.5% and MOE by 17.5% of the tested panels. On the other hand, increasing the air-conditioning temperature of the panels from 20°C to 60$^{°C}$ resulted in a decrease in the strength value by approx. 33% in the case of MOR and 40.5% in the case of MOE. Ayrilmis *et al.* (2010) examining the mechanical properties of wood materials, including MDF boards, subjected to a temperature range of -30°C to +30°C (with steps of 10°C) for 48 hours, found a decrease in their strength, with the largest changes recorded in the temperature range from -10°C to + 10°C. Kulman *et al.* 2015 conducted strength tests of MDF boards with a thickness of 10 and 16 mm and a density of 770 kg/m^3 to 870 kg/m^3 subjected to air conditioning at the following temperatures: 20°C, 40°C, 60°C, 80°C and relative air humidity of 65%. The authors found that for every 10°C the temperature increases, MOE decreases by approx. 200 N/mm^2 and MOR by approx. 3-5 N/mm^2. Sydor and Pałubicki (2019) found that HDF boards subjected to short-term exposure to temperatures up to 250°C were characterized by high shape stability (much greater than thin plywood).

As a result of improper operating conditions of products made with the use of HDF boards, their technical and structural value may decrease. In general, it should also be stated that there are few current, comprehensive studies of HDF boards in terms of changes in mechanical properties depending on the temperature and relative humidity of the air during air conditioning.

Aim and scope of work

The aim of this study was to evaluate the influence of changes in relative humidity and temperature on selected properties of HDF boards. Most of the research carried out in this area concerns MDF boards. In the studies carried out so far, the authors have generally used a short time of exposing the boards to raised temperature. The conducted research should extend and complete the information available in the literature so far on the impact of changes in relative air humidity and temperature on dry-formed fibreboards.

The scope of work included air conditioning of the panels for 7 days at temperatures from -20°C to 50°C (with 10°C steps) at 55% relative humidity and at 40°C at 20% and 80% relative humidity.

Materials and Methods

An industrially produced HDF board with a thickness of 2.5 mm and a density of 820 kg/m^3 was used for the tests. The board is made of pine fibers glued with MUF resin with 5% melamine content. The degree of sizing was 10%.

The boards were subjected to air conditioning under the following conditions - a total of 10 air conditioning variants:

I. conditioned boards at temperatures: -20°C, -10°C, 0°C, 10°C, 20°C, 30°C, 40°C, 50°C and 55% relative humidity for 7 days,

II. boards conditioned at 40°C and relative air humidity of 20% and 80% for 7 days.

The air-conditioning conditions were selected based on previously conducted research (Borysiuk and Nurczyk, 2018; Borysiuk and Furmanik, 2019; Borysiuk *et al.*, 2019). After air-conditioning, the following were tested for individual batches of panels:

- density profile - using the DAX GreCon profiler, 3 samples of 50×50×18 mm for each finish variant, measurement speed 0.05 mm/s, measurement accuracy 0.02 mm;
- modulus of rapture (MOR) and static modulus of elasticity (MOE) - based on the PN-EN 310:1994 standard, 10 samples for each variant;
- internal bound in the direction perpendicular to the plane of the board (IB) - based on PN-EN 319:1999, 10 samples for each variant;
- thickness swelling and water absorption after 2 h and 24 h of immersion in water - based on the PN-EN 317:1999 standard, 10 samples for each variant.

The tests should be carried out each time immediately after the end of the air-conditioning process, taking into account only the technical time needed to prepare the samples.

The statistical analysis of the obtained results was carried out in the Statistica 13.1 program. The Tukey test was used to determine the significance of differences between the obtained results (with $\alpha = 0.05$).

Results and Discussion

The average density of the boards used in the study was 823 kg/m^3. In Figures 1 and 2 show the density profiles obtained for the samples after individual air-conditioning cycles. All the tested boards were characterized by a typical “U-shaped” course of density profiles (Thoemen, Irle and Sernek, 2010). Differences in density profiles for samples conditioned at -20°C to 50°C result from differences in the thickness of the individual samples. It can be stated that the air-conditioning temperature does not affect the course of the density profiles of HDF boards.

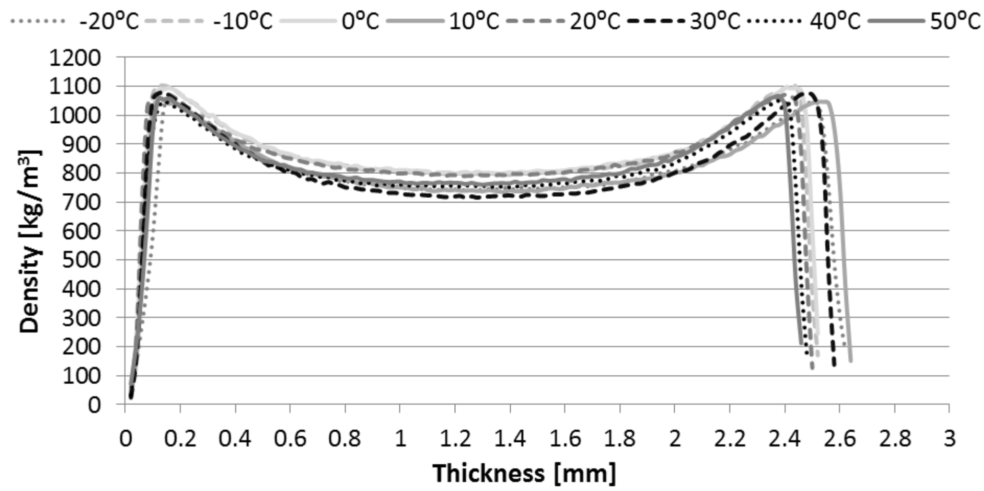

Fig. 1. Exemplary density profiles of tested panel variants conditioned at different temperatures
Rys. 1. Przykładowe profile gęstości badanych wariantów płyt klimatyzowanych w różnych temperaturach

Boards conditioned at 40°C and 80% relative humidity have an average density of 830 kg/m^3, while the average density of the samples after air conditioning at 20% relative humidity was 807 kg/m^3. These differences result from the increase in the weight of the samples caused by the increase in the moisture content in the samples conditioned in increased relative air humidity.

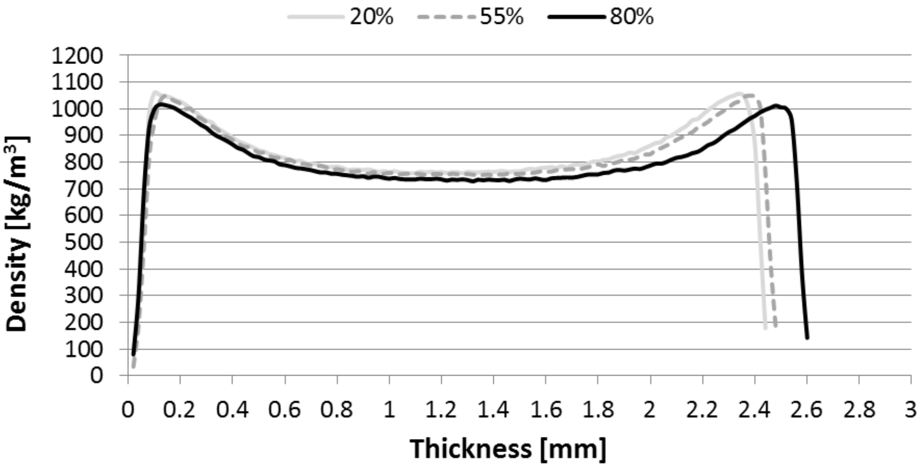

Fig. 2. Exemplary density profiles of tested panel variants conditioned at 40°C with different relative air humidity
Rys. 2. Przykładowe profile gęstości badanych wariantów płyt klimatyzowanych w temperaturze 40°C przy różnej wilgotności względnej powietrza

The results of the MOR and MOE measurements are shown in Fig. 3, 4, 5 and 6. With regard to all tested variants of air conditioning, it should be stated that both the temperature and relative humidity of the air had a statistically significant effect on the obtained values of panel strength. Considering the influence of temperature, it should be stated that in the temperature range from -20°C to 10°C, the strength values generally decreased by about 14% for MOR and 15% for MOE. Further increasing the air-conditioning temperature from 10°C to 30°C resulted in an increase in the MOR and MOE values by approx. 35%. Air conditioning of boards at temperatures above 30°C translated into a slight - statistically insignificant decrease in strength parameters. Studies of MDF boards carried out by other authors (Bekhta, Łecka and Morze, 2003; Ayrilmis, Buyuksari and As, 2010) indicated a decrease in the strength parameters of the boards with increasing air conditioning temperature. It should be noted, that the studies carried out so far have generally concerned boards with significantly greater thickness. the samples used in this study, due to their thickness of 2.5 mm, absorbed the ambient temperature much faster by heating or cooling respectively. An increase in the air-conditioning temperature above 20°C could also reduce the humidity of the samples, and thus increase their stiffness.

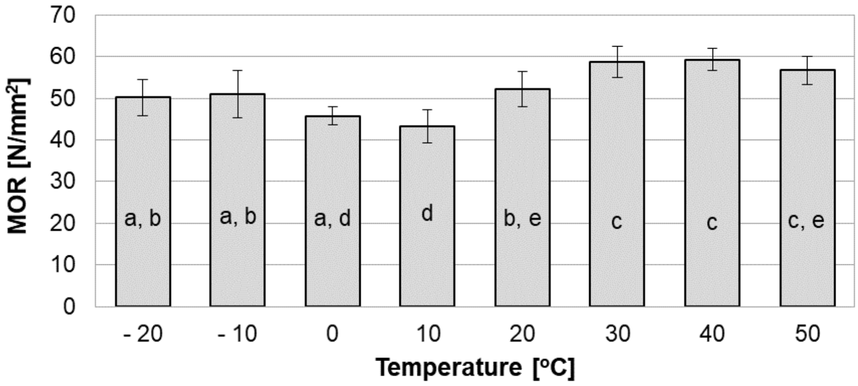

Fig 3. MOR values of tested panels conditioned at different temperatures (a, b, c, d, e - homogeneous groups)
Rys. 3. Wartości MOR badanych płyt klimatyzowanych w różnych temperaturach (a, b, c, d, e - grupy jednorodne)

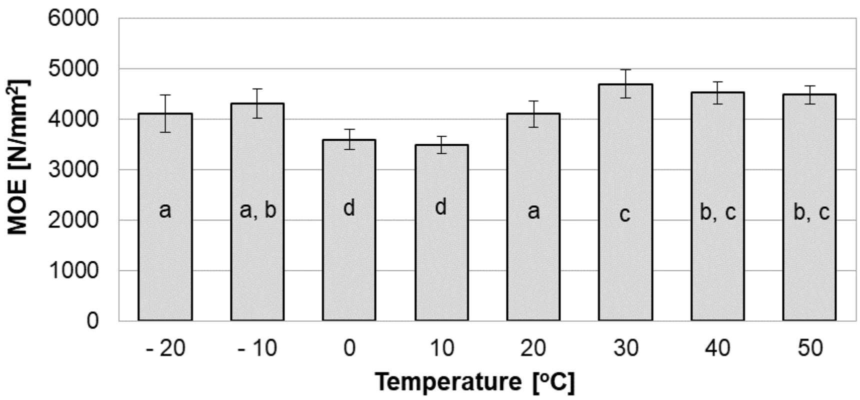

Fig. 4. MOE values of tested panels conditioned at different temperatures (a, b, c, d - homogeneous groups)
Rys. 4. Wartości MOE badanych płyt klimatyzowanych w różnych temperaturach (a, b, c, d - grupy jednorodne)

The increase in relative air humidity to 80% during the conditioning of HDF boards generally resulted in a decrease in the MOR and MOE values. It should be noted, that a statistically significant maximum decrease in the strength parameters of the panels was noted when the relative humidity of the air changed from 55% to 80% (Fig. 5 and 6). It was 19% for MOR and 24% for MOE, respectively. The obtained relationships are consistent with the data available in the literature (Popper *et al.*, 2001; Bekhta and Niemz, 2009; Sala *et al.*, 2020). It is worth adding here that the authors usually give higher ranges of decrease in the value of strength parameters. However, this is most likely due to different air conditioning conditions (temperature, relative air humidity) carried out as part of individual tests and panel parameters.

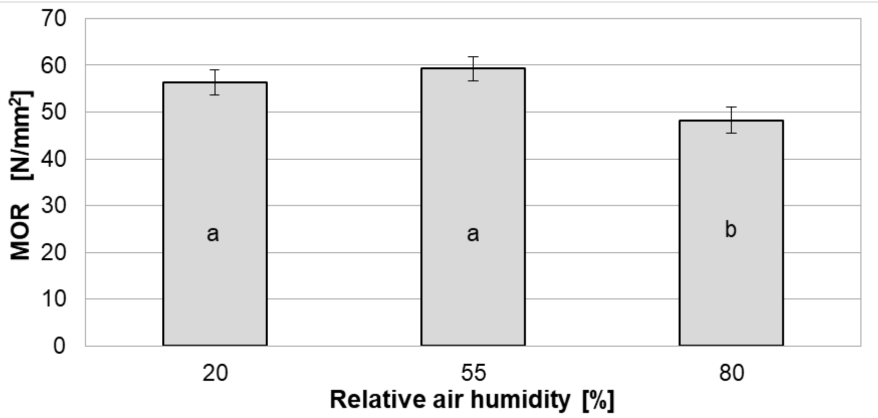

Fig. 5. MOR values of the tested panels conditioned at 40°C with different relative air humidity (a, b - homogeneous groups)
Rys. 5. Wartości MOR badanych płyt klimatyzowanych w temperaturze 40°C przy różnej wilgotności względnej powietrza (a, b - grupy jednorodne)

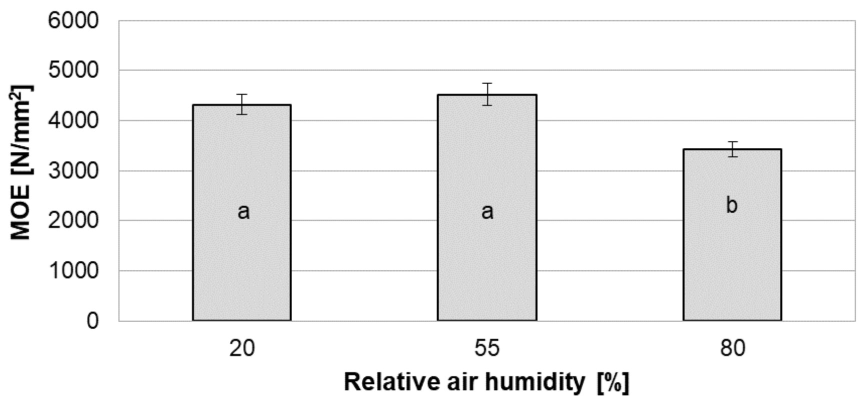

Fig. 6. MOE values of the tested panels conditioned at 40°C with different relative air humidity (a, b - homogeneous groups)
Rys. 6. Wartości MOE badanych płyt klimatyzowanych w temperaturze 40°C przy różnej wilgotności względnej powietrza (a, b - grupy jednorodne)

In Fig. 7 and 8 show the results of the perpendicular tensile strength test of the air-conditioned panels. The increase in the air-conditioning temperature generally resulted in an increase in the IB value of the conditioned HDF boards. In all variants, the plates were characterized by high variability of results (coefficient of variation from 16% to 32%).

It should also be added here that in the case of panels conditioned at temperatures of -20°C, -10°C, 0°C, 10°C and 30°C, the differences in IB values, although visible, are statistically insignificant (the same homogeneous group). The specificity of the test, taking into account the need to glue the linings to the samples using hot melt glue (hot gluing), could also have had some influence on the obtained IB values.

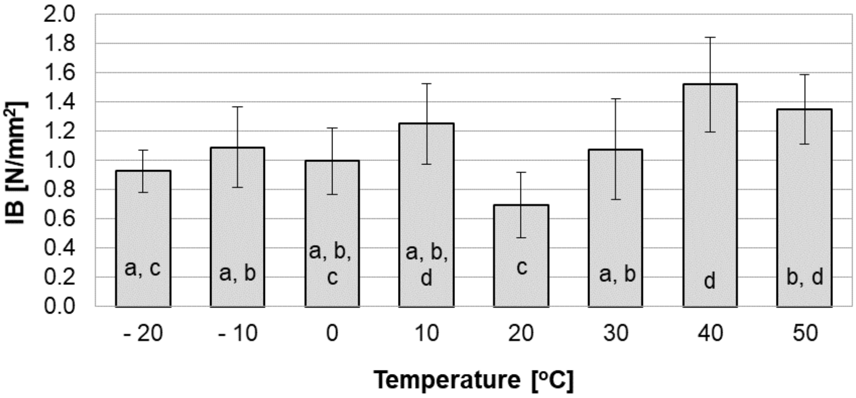

Fig. 7. IB values of tested panels conditioned at different temperatures (a, b, c, d - homogeneous groups)
Rys. 7. Wartości IB badanych płyt klimatyzowanych w różnych temperaturach (a, b, c, d - grupy jednorodne)

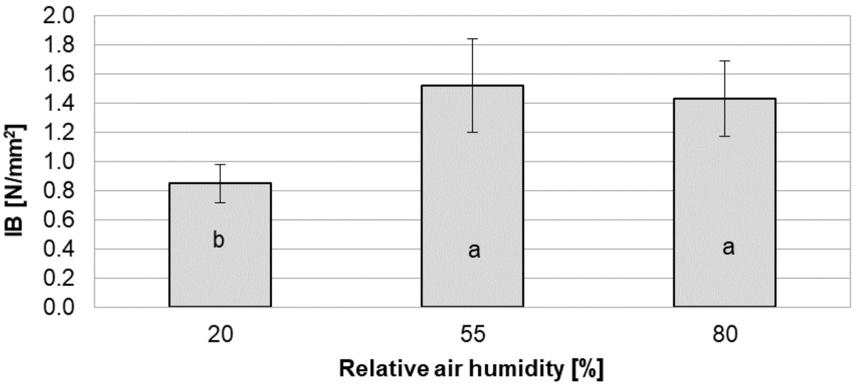

Fig. 8. IB values of the tested panels conditioned at 40°C with different relative air humidity (a, b - homogeneous groups)
Rys. 8. Wartości IB badanych płyt klimatyzowanych w temperaturze 40°C przy różnej wilgotności względnej powietrza (a, b - grupy jednorodne)

When analyzing the change in relative air humidity during air conditioning of HDF boards, it should be stated that it does not have a statistically significant effect on the IB values for relative air humidity of 55% and 80%. Only in the case of air conditioning of the panels in air with a relative humidity of 20%, statistically significantly lower IB values were noted. In general, an increase in the moisture content of HDF boards causes a decrease in the IB value (Magalhães *et al.*, 2021). With regard to the obtained correlation, it is worth noting that the lack of a significant effect of cyclical changes in relative humidity (90%/45%) on the IB values of air-conditioned MDF boards was also demonstrated by Korai *et al.* (2015). It should also be added that the values presented in the literature (Magalhães *et al.*, 2021) refer to boards conditioned at 20°C. In the case of boards conditioned at 40°C, the strength value could be negatively affected by the higher stiffness of the dried fibers, and thus lower elasticity of the entire sample. This could have contributed to their cracking at lower loads.

Considering the results of strength tests, it is worth noting that all HDF boards, regardless of the air-conditioning conditions, met the requirements of the PN-EN 622-5:2010 standard (for boards with a thickness of 1.8-2.5 mm, the minimum required values are respectively: MOR - 23 N/mm^2, MOE - 2700 N/mm^2, IB - 0.65 N/mm^2). The obtained test results are also consistent with the results of HDF board tests carried out by other authors (Sala and Kowaluk, 2020; Magalhães *et al.*, 2021).

Table 1 presents the results of the study of thickness swelling and water absorption of HDF boards after immersion for 2 h and 24 h, conditioned at different temperatures and relative air humidity of 55%. In general, an increase in the value of the examined features was found with the increase in air conditioning temperature. This is related to the greater drying of the samples and, consequently, their increased absorbency at higher temperatures. In addition, lower differences in the average values of swelling and water absorption of the samples soaked for 24 hours were noted in relation to the samples soaked for 2 hours.

Table 1. Values of swelling and water absorption of the tested conditioned panels at different temperatures
Tabela 1. Wartości spęcznienia i nasiąkliwości badanych płyt klimatyzowanych w różnych temperaturach

Air conditioning temperature	Thickness swelling				Water absorption			
	2 h		24 h		2 h		24 h	
	Aver.	SD	Aver.	SD	Aver.	SD	Aver.	SD
(°C)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
-20	18.5	1.1	33.4	1.3	24.6	2.1	54.2	3.2
-10	10.0	2.6	31.8	0.9	10.9	1.8	52.7	2.2
0	11.5	0.7	30.8	0.8	17.9	0.6	50.4	1.1
10	14.0	2.8	32.3	3.2	18.2	3.6	50.2	4.3
20	19.9	1.4	33.0	1.3	27.0	1.2	53.2	2.8
30	13.2	3.3	34.1	0.6	12.3	3.3	55.1	2.7
40	15.2	0.7	31.4	0.8	25.5	3.1	58.9	3.4
50	21.1	0.3	34.1	1.1	30.0	4.4	61.0	4.3

Aver. - average, SD - standard deviation

Table 2 presents the results of the study of swelling and water absorption of HDF boards after soaking for 2 h and 24 h, conditioned at 40°C with different relative air humidity. In general, it can be stated that with the increase in relative air humidity, the values of swelling and water absorption decrease (particularly it is visible at 55% and 80% relative air humidity). Lower values of swelling and water absorption of HDF boards result mainly from their initial moistening already at the air-conditioning stage.

Table 2. Values of swelling and water absorption of the tested climatic panels at 40°C and different relative air humidity
Tabela 2. Wartości spęcznienia i nasiąkliwości badanych płyt klimatyzowanych w temperaturze 40°C przy różnej wilgotności względnej powietrza

Relative air humidity	Thickness swelling				Water absorption			
	2 h		24 h		2 h		24 h	
	Aver.	SD	Aver.	SD	Aver.	SD	Aver.	SD
(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
20	17.1	4.0	33.8	2.3	23.9	4.9	58.2	4.2
55	15.2	0.9	31.6	0.7	26.7	2.9	60.2	3.0
80	14.0	2.4	28.5	1.2	17.4	2.6	48.9	2.4

Aver. - average, SD - standard deviation

Conclusions

Based on the conducted air conditioning tests of HDF boards at temperatures from -20°C to 50°C with steps of 10°C at 55% relative humidity and at 40°C at 20%, 55%, 80% relative humidity, it can be draw the following conclusions:

- The air-conditioning conditions do not significantly affect the density and density profile of the tested HDF boards.
- The increase in air-conditioning temperature has an ambiguous effect on the MOR and MOE values of the tested HDF boards. In the temperature range from -20°C to 10°C, the strength values generally decrease, while further increasing the air conditioning temperature (above 10°C) increases the MOR and MOE values.
- An increase in relative air humidity from 55% to 80% causes a decrease in the MOR and MOE values of air-conditioned HDF boards.
- An increase in air-conditioning temperature generally causes an increase in the IB value of HDF boards.
- An increase in relative air humidity from 20% to 55% increases the IB value of conditioned HDF boards.
- As the air-conditioning temperature increases, the value of thickness swelling and water absorption of HDF boards increases.
- An increase in relative air humidity causes a decrease in the value of thickness swelling and water absorption of HDF boards.

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