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Selected properties of MDF boards bonded with various fractions of recycled HDPE particles

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Abstract: *Selected properties of MDF boards bonded with various fractions of recycled HDPE particles*. The substitution of non-renewable, formaldehyde-based amine wood binders in the wood-based composites industry is one of the main directions of trials and research. On the other hand, a bigger effort should be put into carbon capture and storage (CCS) activity, especially in the case of oil-based plastics, to extend their life in the products. The aim of the research was to use waste high-density polyethylene (HDPE) in MDF panels and determine their selected properties, including modulus of elasticity in bending, bending strength, internal bond, thickness swelling, water absorption, screw withdrawal resistance, density profile when referred to the fraction of used HDPE. The panels were created in laboratory conditions with a 50% weight content of HDPE particles of different fractions (<1 mm, <2 mm, <4 mm, and a mixed fraction containing 25% of each fraction and unsorted waste). The results show that the highest strength and modulus of elasticity were obtained for panels with plastic fractions below 1 mm. This fraction also achieved the lowest results for water absorption and thickness swelling. The fraction of the used plastic has no significant effect on screw withdrawal resistance. The negative impact of using larger fractions in the board is noticeable, however, for the mixed fraction, the results are similar to the finest fraction in terms of the internal bond, thickness swelling, and water absorption. The addition of HDPE can have a beneficial effect on the parameters of MDF panels. It is possible to create fibreboards from wasted plastic, store carbon dioxide in them, and upcycle them. In the discussed panels, the only binder for wood fibres was HDPE, so panels should not emit formaldehyde from the binder.

Keywords: plastic, MDF, HDPE, fiberboard

INTRODUCTION

Fiberboards are produced from compressed wood fibers. There are four main types of fiberboards based on their density: LDF 450-650 kg/m³, MDF 650-700 kg/m³, HDF 700-900 kg/m³, and THDF 900-1050 kg/m³. Fiberboards are mainly used for manufacturing kitchen countertops and furniture. Typically, formaldehyde-based resins are used in the production of these panels: UF (urea formaldehyde), MUF (melamine-urea formaldehyde), and PF (phenol formaldehyde). Formaldehyde is a toxic substance to humans and can be emitted into the environment. People living near MDF board factories are the most vulnerable to its effects (Shamlou and Safa 2021)).

To reduce formaldehyde emissions and improve panel properties, alternative binders other than formaldehyde-based resins can be used. One example of such a binder is HDPE, which was used in the creation of WPC (wood plastic composite) panels in another research (Borysiuk and Auriga 2022). The study demonstrated that HDF panels can be effectively replaced with WPC panels, especially under conditions of high humidity. The best results were obtained for composites with a content of 40-50% lignocellulosic particles.

HDPE film was also used as a binder in poplar plywood subjected to tensile strength testing. HDPE proved to be an excellent binding material in plywood (Chang et al. 2016).

HDPE plastic is commonly used in the production of bottles, containers, pipes, and caps. Only 30% of this plastic is recycled, while the rest is either sent to landfills or incinerated in waste-to-energy plants. Unfortunately, plastic can take hundreds of years to decompose, and incineration even in specialized facilities leads to the emission of carbon dioxide into the atmosphere.

HDPE plastic exhibits high resistance to chemical agents (which is why it is used for bottles and containers for chemical substances) and has high strength. Its melting temperature is relatively low at 125 °C. These properties make it a suitable material for use as a binder in MDF panels. Panels with the addition of HDPE plastic would not emit formaldehyde into the environment, positively contributing to carbon storage, and have the potential to improve board properties.

Furthermore, panels with the addition of HDPE could be a good way to store plastic. There are a lot of research searching worms (Shaji et al. 2022), mushrooms or bacteria (Sivan et al. 2011) which can decompose plastic. There is no efficient way for decomposing plastic on large-scale nowadays, so plastic could wait in our furniture for better days.

Post-consumer HDPE plastic can have the same or even better mechanical properties in WPC composites than virgin HDPE. Plastic wastes can be used to produce stable and strong WPCs (Adhikary et al. 2008).

This study aims to determine the properties of MDF panels with the addition of various fractions of high-density polyethylene obtained from waste as a substitute for formaldehyde-based wood binders. On the other hand, an important role of such panels is also to store carbon derived from plastic (carbon capture and storage (CCS) activity, especially in the case of oil-based plastics, to extend their life in the products).

MATERIALS AND METHODS

The raw materials listed below were used to make the tested MDF panels:

- Pine (*Pinus sylvestris* L.) and spruce (*Picea abies* L.) industrial fibers (IKEA Industry Poland sp. z o. o. brand Orla, Poland). The moisture content of the fibers was 4%.

- Four fractions of shredded HDPE plastic from bottle caps, containers and bottles: below 1 mm, below 2 mm and below 4 mm and mixed fraction made of 25% of each fraction and of unsorted waste.

There were made of 4 different HDF panel types, each with a 50% of weight content of coniferous wood fibers. The 4 names of produced panels refer to the HDPE fraction used (<1 mm, <2 mm, <4 mm and a mix). Each board had a different fraction of HDPE plastic but they were made with the same parameters of pressing. Fibres were mixed with fractions of plastic and pressed (AKE, Mariannelund, Sweden) under a pressure of 2.5 MPa and temperature of 180 °C for 10 min, then cooled at room temperature.

The produced MDF panels had dimensions 320 x 320 mm^2 and a nominal thickness of 3 mm and their density was aimed at 800 kg/m^3. Before the tests, the panels were stored at 20 °C and 65% relative humidity (RH) for 7 days.

Properties of the panels were determined in accordance with European Standards: density (EN 323 1993), modulus of rupture (MOR) and modulus of elasticity (MOE) (EN 310 1993), internal bond (IB) (EN 319 1993), screw withdrawal resistance (SWR) (EN 320 2011), water absorption (WA) and thickness swelling (TS) after 2 and 24 h of immersion (EN 317 1993). No less than 10 samples per every panel type were used to complete the mentioned tests. To evaluate the density profiles, the samples were cut into 50 mm x 50 mm test specimens (3 samples per every panel type; after initial evaluation of results, one representative profile has been used for final evaluation). The density profile was measured on a Grecon DA-X measuring instrument (Alfeld, Germany) with direct scanning X-ray densitometry across the panel thickness with an incremental step of 0.02 mm.

All the mechanical tests were performed on a computer-controlled universal testing machine (Research and Development Centre for Wood-Based Panels Sp. z o.o. Czarna Woda, Poland).

Analysis of variance (ANOVA) and t-tests calculations were used to test (α=0.05) for significant differences between factors and levels using the IBM SPSS statistic base (IBM, SPSS 20, Armonk, NY, USA).

RESULTS AND DISCUSSION

The density of the boards ranges from 780 kg/m^3 to 820 kg/m^3 (2.5% of density variation from nominal density). The best results for modulus of rupture 25.4 N/mm^2 (Fig. 1) and modulus of elasticity 1417 N/mm^2 (Fig. 2) are for fractions below 1 mm. Unfortunately, there are no significant differences between results but a fraction below 1 mm has the smallest error bars so the structure of this panel is more homogeneous. When referring the achieved results of MOR to the specific European standard (EN 622-5 2009), it should be concluded, that only <1 mm and <4 mm tested panels meet the requirements (min. 23 N/mm^2). Since there is no requirement for minimum MOE for panels of a nominal thickness of 3 mm, the achieved results have been compared to the nearest thickness mentioned in the European standard. The minimum MOE value for 4-6 mm thick MDF panels is 2700 N/mm^2. That means none of the tested panels meets this requirement. The only statistically significant difference between the mean values of MOR and MOE has been found for <1 mm panels when referred to <2 mm panels.

According to Song et al. (2015), the main factor influencing the bending properties of HDPE-lignocellulosic composite is the content of lignocellulosic material. However, since in the research evaluated here, the wood fibers – HDPE ratio was constant, the conclusion of Song et al. (2015) can not be applied here. There is also research, which indicates that the factor influencing the strength of the HDPE-wood fiber interface can be the wood specie (Gaugler et al. 2019).

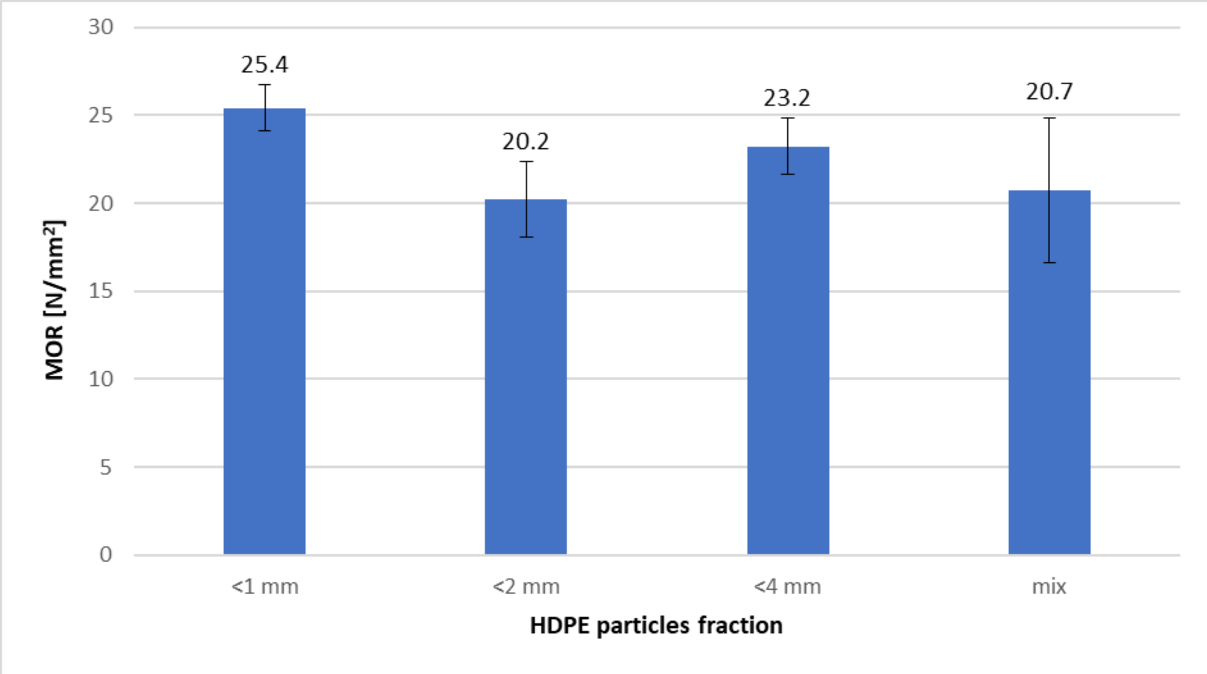

Fig. 1 Modulus of rupture of MDF panels with HDPE

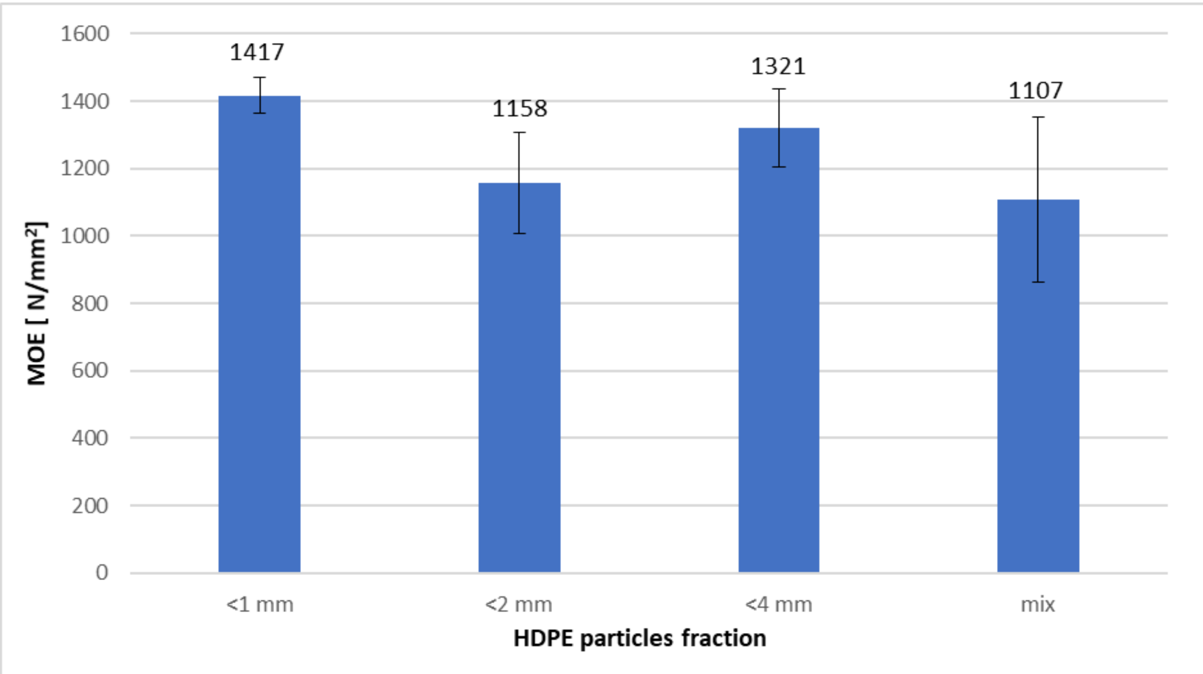

Fig. 2 Modulus of elasticity of MDF panels with HDPE

The values of internal bond (Fig. 3) differ more than in MOE or MOR. The biggest strength is for mixed fractions and then below 1 mm. In the case of mixed panels, the highest internal bond can be caused by bigger pieces of plastic which bound more fibers while melting. Still, a fraction below 1 mm has the smallest error bars, which can be recognized as the highest uniformity of the panel's internal structure. The worst result is for a fraction below 4 mm. In deduction not also bigger pieces of plastic are needed to get the best results for internal bonds but also the smallest fraction. The only statistically significant difference between the mean values of internal bond has been found for <1 mm panels when referred to <4 mm panels. When referring the achieved results of the internal bond to the specific European standard requirements (EN 622-5 2009), it should be concluded, that all the tested panels meet the requirements (min. 0.65 N/mm^2).

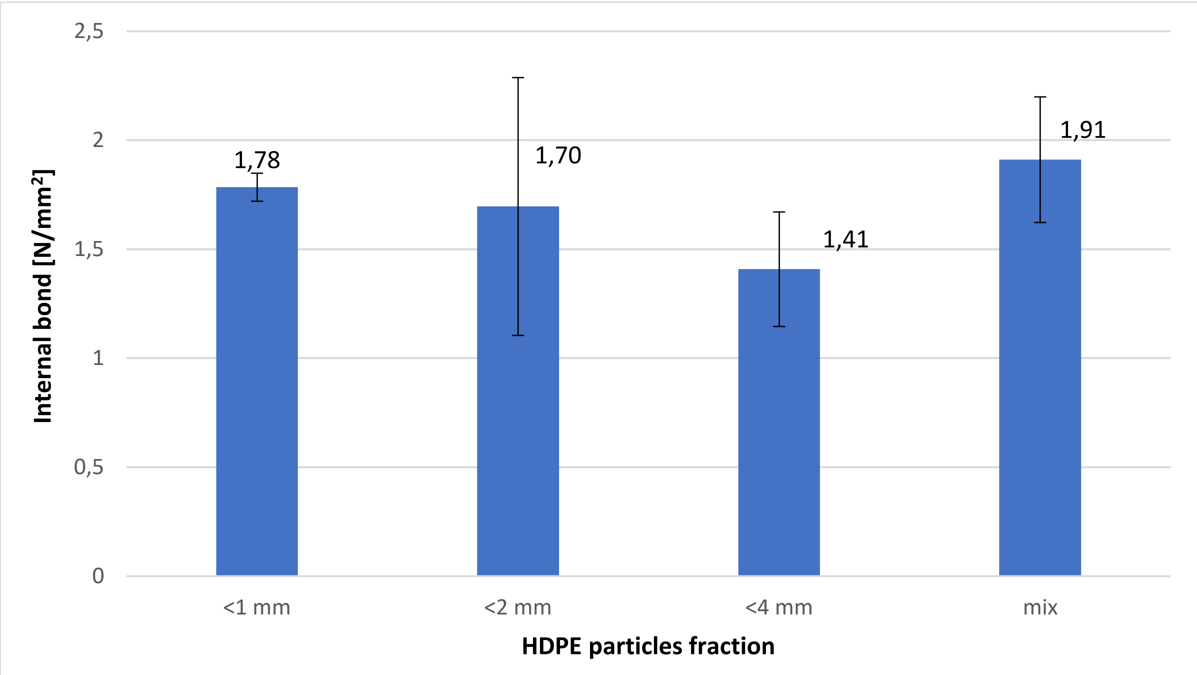

Fig. 3 Internal bond of tested MDF panels with HDPE

However, recycled thermoplastic materials, such as HDPE, are hard to distinguish and recover from the waste, due to their physical properties, these can lead to producing the value-added materials, which can be successfully applied in composites (Sormunen and Kärki 2019). This is among other due to good mechanical properties, for example, internal bond. Also, it should be mentioned, that the internal bond was not influenced by the density profile of the tested panels. This conclusion is similar to the results achieved when testing high-density fiberboards bonded with bio-based adhesives (Gumowska and Kowaluk 2023).

For screw withdrawal resistance (Fig. 4) results are practically the same. The fraction of plastic may have not an impact on this test. There were no statistically significant differences found for mean values of screw withdrawal resistance. The achieved results are much higher than SWR values for HDF panels with recycled textile fibers (Suchorab et al. 2023). However, if the density of the panel would be higher, the SWR values can grow significantly (Wronka and Kowaluk 2019).

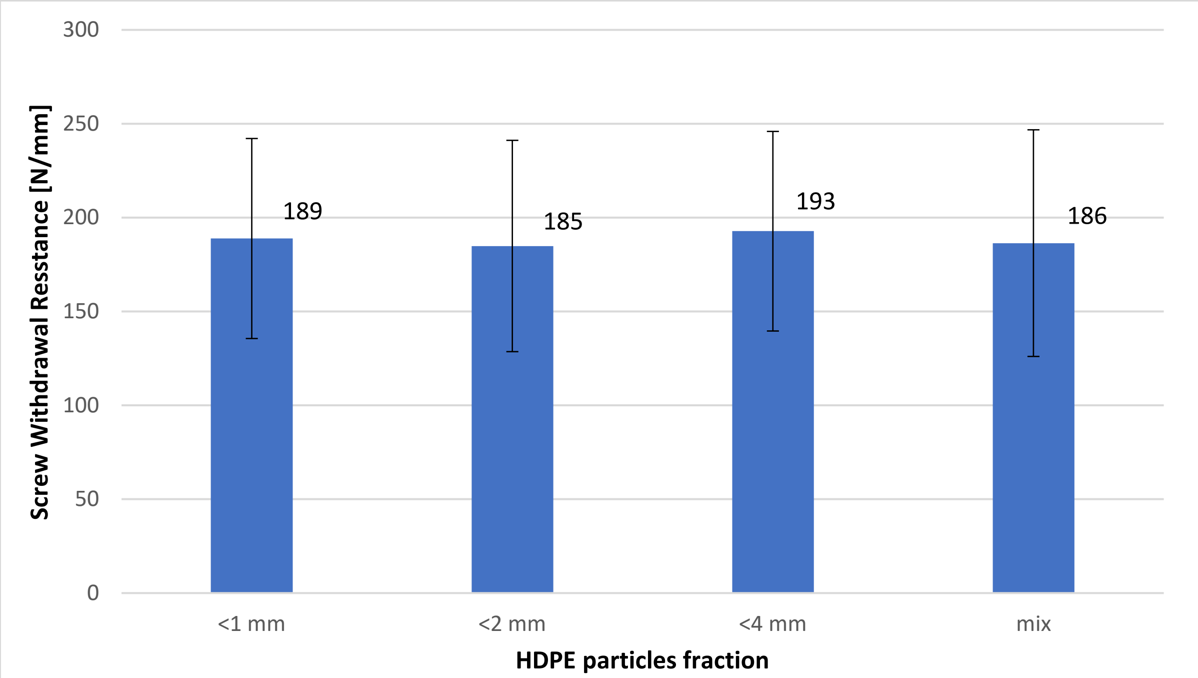

Fig. 4 Screw withdrawal resistance of MDF panels with HDPE

Values for thickness swelling (Fig. 5) and for water absorption (Fig. 6) were measured after 2 h and 24 h of samples soaking in the water. The lowest results of both tests were for panels with HDPE fractions below 1 mm. It can be caused by the homogeneity of these panels. With the growing size of HDPE binder seems to be more spaces filled by wood fibers only, which are able to uptake water more intensively. However, panels with mixed fractions have similar values to the panels with the smallest HDPE fraction in the case of water absorption. When referring the achieved results of the thickness swelling to the specific European standard (EN 622-5 2009), it should be concluded, that all the tested panels meet the requirements for MDF panels (max 35% after 24 h of soaking in water).

The achieved results of water absorption are comparable to the results of Hosseinaei et al. (2012), who tested the WPC materials produced from wood treaded by hemicellulose extraction. The good resistance to water of the wood fiber panels produced with HDPE as a binder has been also confirmed by Ekpunobi et al. (2013).

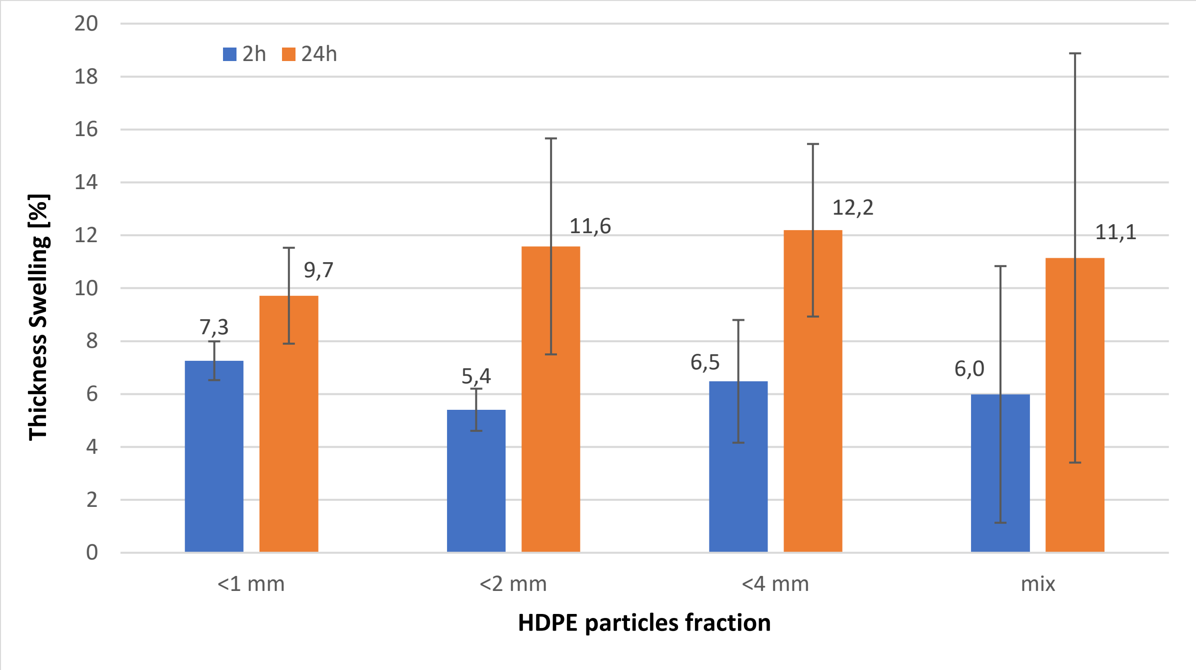

Fig. 5 Thickness swelling of MDF panels with HDPE

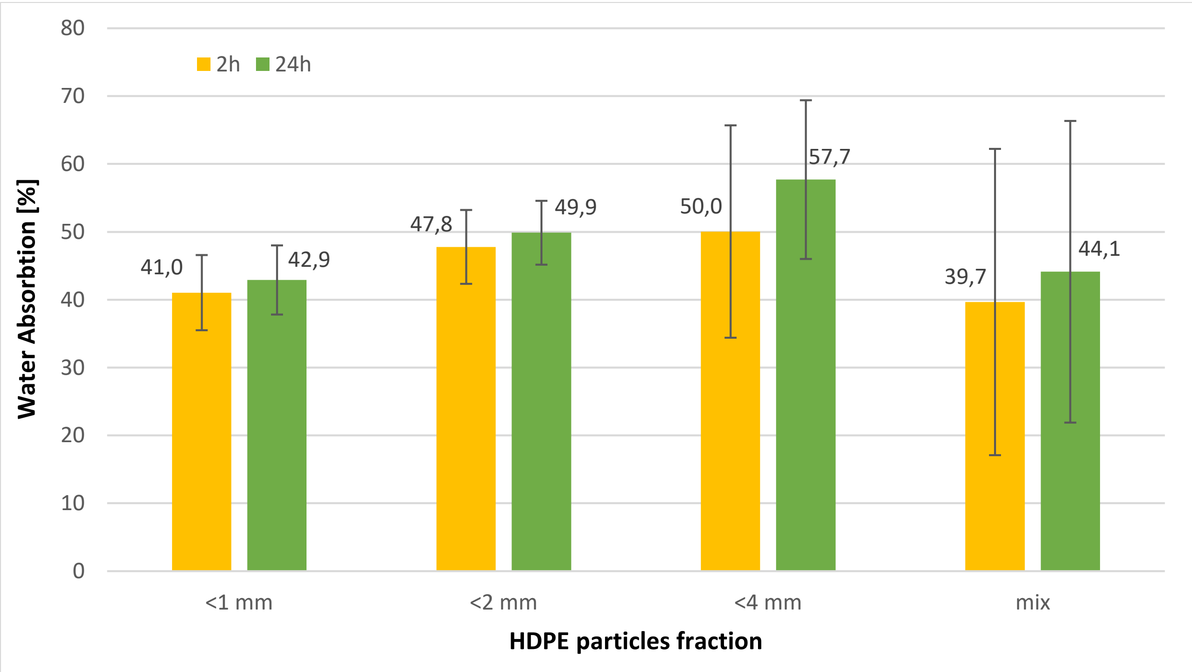

Fig. 6 Water absorption of MDF panels with HDPE

The density profiles of the tested panels of various fractions of HDPE particles used as a binder are presented in Fig. 7. The finest fraction (<1 mm) had the most similar density profile to the regular MDF board (Sala et al. 2020). Unevenness in the density profile in other samples is caused by a higher density of HDPE particles. It can be concluded, that the density profile of the tested MDF panels is uneven and random. It can be also said, that the thickness of the samples slightly raise with the size of the HDPE particles fraction raise. This can be caused by the random, manual distribution of the polymer particles when mixing with wood fibers during mat forming. During that process, a single, larger HDPE particle can create agglomerates, which can result in a higher local thickness of the panel.

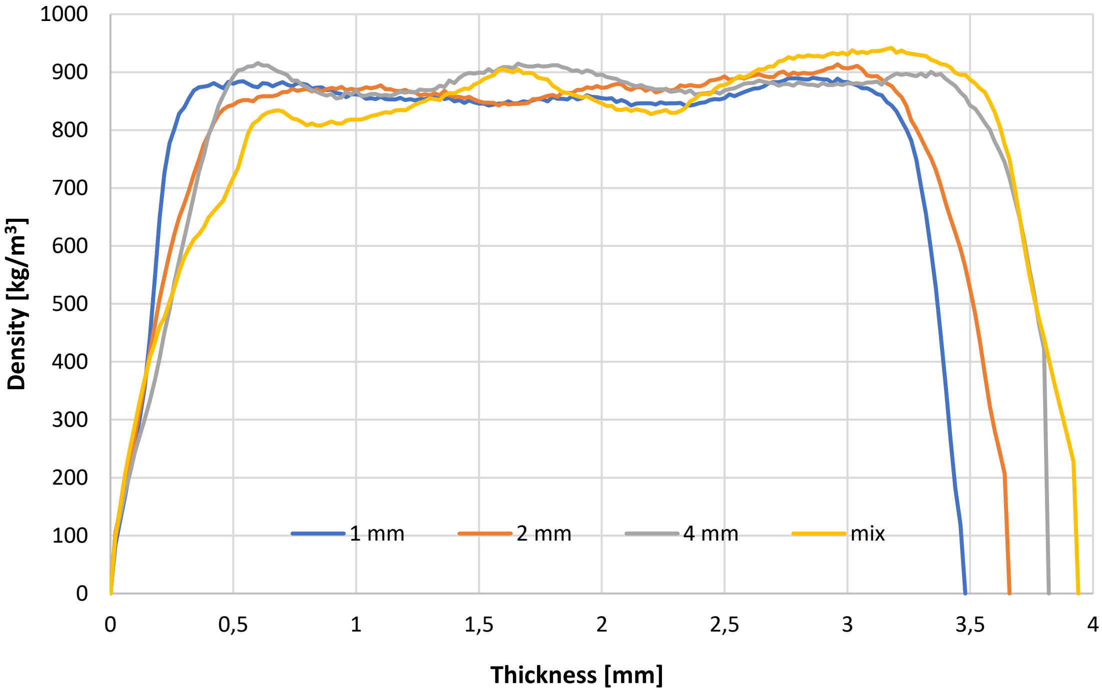

Fig. 7 Density profile of MDF panels with HDPE

CONCLUSION

On the basis of the completed research on the influence of various fractions of recycled HDPE particles on the selected properties of MDF panels, and after analysis of the results, the following conclusions can be drawn:

- The highest bending strength and modulus of elasticity were obtained for panels with plastic fractions below 1 mm.
- All the tested panels meet the European standard for MDF when referred to the internal bond requirements.
- Panels with the addition of the finest fraction (<1 mm) are more homogeneous. That was seen in the uniform density profile of the panels, as well as in the high repeatability of the results (small standard deviation values).
- HDPE fractions below 1 mm had the lowest results for water absorption and thickness swelling.
- The HDPE fraction has no significant effect on screw withdrawal resistance.
- For the mixed fraction, the results are similar to the finest fraction in terms of the internal bond, thickness swelling, and water absorption.

The addition of HDPE can have a beneficial effect on the parameters of MDF panels. It is possible to create fiberboards from wasted plastic, store carbon dioxide in them, and upcycle them. In the discussed panels, the only binder for wood fibers was HDPE, so panels should not emit formaldehyde from the binder. In the future panels with HDPE plastic could be fully decomposed.

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Streszczenie: *Wybrane właściwości płyt MDF klejonych różnymi frakcjami cząstek HDPE pochodzących z recyklingu.* Zastąpienie nieodnawialnych, aminowych spoiw do drewna na bazie formaldehydu w przemyśle kompozytów drewnopochodnych jest jednym z głównych kierunków prób i badań. Z drugiej strony należy włożyć większy wysiłek w działania związane z wychwytywaniem i składowaniem dwutlenku węgla (CCS), zwłaszcza w przypadku tworzyw ropopochodnych, aby wydłużyć ich żywotność w produktach. Celem badań było wykorzystanie odpadowego polietylenu o wysokiej gęstości (HDPE) w płytach MDF i określenie ich wybranych właściwości, w tym modułu sprężystości przy zginaniu, wytrzymałości na zginanie, wytrzymałości na rozciąganie prostopadłe, spęcznienia na grubość, nasiąkliwości, oporu przy osiowym wyciąganiu wkręta, profilu gęstości w odniesieniu do do frakcji zużytego HDPE. Płyty powstały w warunkach laboratoryjnych z 50% wagową zawartością cząstek HDPE o różnych frakcjach (<1 mm, <2 mm, <4 mm oraz frakcja mieszana zawierająca po 25% każdej frakcji oraz odpady niesortowane). Z przeprowadzonych badań wynika, że największą wytrzymałość i moduł sprężystości uzyskano dla płyt o udziale tworzywa sztucznego poniżej 1 mm. Frakcja ta uzyskała również najniższe wyniki pod względem nasiąkliwości i spęcznienia na grubość. Frakcja zastosowanego tworzywa sztucznego nie ma istotnego wpływu na opór przy osiowym wyciąganiu wkręta. Negatywny wpływ stosowania większych frakcji w płytach jest zauważalny, jednak dla frakcji mieszanej wyniki są zbliżone do frakcji najdrobniejszej pod względem wytrzymałości na rozciąganie prostopadłe, spęcznienia na grubość i nasiąkliwości. Dodatek HDPE może korzystnie wpłynąć na parametry płyt MDF. Ze zużytego plastiku można tworzyć płyty pilśniowe, magazynować w nich dwutlenek węgla i poddawać je recyklingowi. W omawianych płytach jedynym spoiwem do włókien drzewnych był HDPE, więc płyty nie powinny wydzielać formaldehydu ze spoiwa.

Słowa kluczowe: tworzywo sztuczne, MDF, HDPE, płyta pilśniowa

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