INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN, 2/2023 (24): 70–77

EFFECT OF HYDROLYSIS REGIME ON STIFFNESS AND DEFORMATION AT BENDING OF RECYCLED MEDIUM-DENSITY FIBREBOARDS (rMDF)

Christian Panchev, Viktor Savov
University of Forestry, Sofia, Bulgaria
e-mail: christian_panchev@ltu.bg; victor_savov@ltu.bg

ABSTRACT

Recycling Medium-Density Fiberboard panels is a significant challenge and is not a widespread industry practice. Given the reduced costs, the methods for recycling this material with hydrothermal hydrolysis of the resins are more promising than those with acid hydrolysis. Despite the considerable amount of research on the topic, the effect of the hydrolysis regime on the stiffness and deformation at the bending load of recycled MDF panels (rMDF) remains limited.

In the present work was conducted a study on the effect of hydrothermal hydrolysis regime, with a variation in temperature from 121°C (saturated steam pressure 0.2 MPa) to 134° (saturated steam pressure 0.3 MPa) and the hydrolysis time from 30 min to 60 min on the stiffness and deformation behaviour of rMDF. It was found that the stiffness of the panels was not significantly affected by the hydrolysis regime, but the rMDF had about ten per cent less stiffness than the control panel from natural fibres. It was determined that the optimal hydrolysis regime is at 121° and has a processing time of 30 minutes. Concerning the investigated rMDF characteristics, the panels are not recommended to be composed entirely of recycled fibres.

Key words: recycled Medium-Density Fibreboards (rMDF), hydrothermal hydrolysis, stiffness, bending deformation.

INTRODUCTION

Globally, the production of fibreboards is the second largest wood-based panel production after that of veneer and plywood (FAO). Medium-Density Fibreboard (MDF) panels are increasingly displacing particleboards in many fields of application (Hui, W. et al. 2014). On the other hand, the goal of the European Commission is that by 2030, up to 80% of the raw material for wood-based panels will be composed of recycled wood. In addition, in many EU countries, it is forbidden to dispose of wood-based panels in general landfills (Irle, M. et al. 2019). According to Irle, M. et al., by five years, about 40% of the MDFs produced end their life cycle (Irle, M. et al. 2019). Considering that the total amount of MDF made globally for 2022 was 111 million.m^3 (FAO), we will have 44.4 million m^3 of waste material in 2027. The recycling of MDF panels presents a significant challenge, and unlike the recycling of particleboards, it is not a widespread manufacturing practice (Ihnát, V. et al. 2017; Antov, P. and Savov, V. 2019; Iždinský, J. et al. 2020; Sala, C. M. and Kowaluk, Gr. 2020). That is mainly due to the cutting of fibres during recycling and spherical fibre structures present in recycled MDF (rMDF). Because of that, preliminary preparation of the material should be carried out with hydrolysis of the resin (Lubis, M. A. R. et al. 2018; Bütün Buschalsky, F.Y. et al. 2021). The main type of resin used in the production of MDF is urea-formaldehyde (UF) resin, which has practically no resistance to hydrolysis (Mantanis, G. I. et al. 2017; Hagel, S. and

Saake, B. 2020; Hagel, S. et al. 2021). Hydrolysis can be chemical (acidic), hydrothermal or using electrolysis (Moezzipour, B. et al. 2017; Moezzipour, B. et al. 2018; Lubis, M. A. R et al. 2021). Electrolysis gives excellent results but is generally expensive, making it difficult for industrial applications. With acid hydrolysis, the process is accelerated significantly. Still, the method is more costly due to the use of chemical reagents. Another disadvantage of chemical hydrolysis is the possibility of affecting the hemicelluloses. Hydrothermal hydrolysis is characterized by extended processing time, but this method is relatively cheap and does not affect the main wood components.

Despite the considerable amount of research on the recycling of MDF panels, data on the stiffness of rMDF and its bending deformation behaviour are limited. These material characteristics are of primary importance regarding applicability to structural elements (Simeonova, R. et al. 2015; Jivkov, V. et al. 2021; Petrova, B. et al. 2023).

The present study aims to determine the stiffness and deformation at the bending of rMDF fabricated from fibres recycled at different hydrolysis regimes.

MATERIALS AND METHODS

For the study, industrially produced from Kronospan Bulgaria EOOD (Veliko Tarnovo, Bulgaria), MDF panels were recycled by hydrothermal hydrolysis. The hydrolysis was carried out at temperatures of 121°C and 134°C hydrolysis, and the processing times were 30, 45 and 60 min. Hydrothermal hydrolysis was performed on a TS 14 B+ autoclave (Cixi Tonsor Medical Instrument 146 Co., Ltd., Ningbo, Zhejiang, China).

Six panels were fabricated from recycled under different regimes of hydrothermal hydrolysis fibres, and a control panel from the industrial pulp was also manufactured (Table 1).

Table 1: Experimental plan

Panel Type	Target density ρ, kg.m^{-3}	Hydrolysis temperature T, °C	Hydrolysis time τ, min
A	780	121	30
B	780	121	45
C	780	121	60
D	780	134	30
E	780	134	45
F	780	134	60
REF	780	0	0

The Asplund thermomechanical method was used to fabricate the industrial pulp using a Defibrator L56 (Valmet, Stockholm, Sweden) at Kronospan Bulgaria EOOD (Veliko Tarnovo, Bulgaria). The pulp was from mixed wood raw materials - 40% hardwoods (beech and Turkish oak) and 60% softwoods (spruce and pine). The fibres from the industrial pulp have a moisture content (MC) of 11%, and the recycled ones were with 10% MC. Precisely because of the significant content of hardwood and to increase the compression ratio, the target density of the panels was chosen to be 780 kg.m^{-3}.

The adhesive system comprised 90% urea-formaldehyde (UF) resin and 10% melamine-formaldehyde (MF) resin. The addition of MF resin is mainly aimed at improving the waterproof properties of the panels and partially improving their mechanical properties. Both binders are prepared to a solution with a concentration of 50%. The UF resin had a molar ratio of 1.0 and a dynamic viscosity of 23.76 ± 0.52 MPa.s. The MF resin had a molar ratio of 1.76 and a dynamic viscosity of 21±0.76 MPa.s. As a hardener, ammonium sulfate was used in a content of 1% relative to the dry resin. Ammonium sulfate was introduced into the adhesive system as a solution with a concentration of 30%. As a waterproof substance, wax (paraffin emulsion) was used in a content of 1% relative to dry fibres. The wax emulsion was added at a concentration of 50%.

The fibres were glued in a laboratory blender with needle-shaped blades (prototype, University of Forestry, BG). The blender had a rotation speed of 850 rpm. The adhesive solutions and wax emulsion were sprayed through a 1.5 mm nozzle.

The hot-pressing process was done using a laboratory hydraulic press (PMC ST 100, Italy). The hot-pressing temperature was 175°C, and the press factor was 30 s.mm^{-1}.

The four-stage pressing regime was applied: In the first stage, the pressure was increased to 4 MPa (15% of the press cycle); in the second stage, it was decreased to 1.2 MPa (15% of the press time); in the third stage, the pressure was 0.8 MPa (60% of the press time). The fourth pressing period was at a pressure of 1.5 MPa (10% of the press time). The press factor applied was 30 s.mm^{-1}.

The properties of the rMDF panels were determined by the relevant European Norms (EN 310:1999; EN 323:2001). The mechanical properties were determined by a universal testing machine, WDW – 50E, manufactured by the HST company, China, 2022.

The stiffness at bending, S_t, of MDF panels was determined by the Yosifov-Delin formula (Yosifov, N. and Delin, S. 2014):

$$\boldsymbol{S_t = I_y . E_m}, \text{ N.mm}^2, \quad \textbf{(1)}$$

where I_y is the areal moment of inertia, mm^4;

E_m – modulus of elasticity at bending, N.mm^{-2}.

In turn, the area moment of inertia for the specific case, moment of inertia for a test sample with a rectangular cross-section relative to an axis of symmetry parallel to its side, is calculated by the formula:

$$\boldsymbol{I_y = \frac{b.t^3}{12}}, \text{ mm}^4, \quad \textbf{(2)}$$

where b is the width of the specimen, mm;

t – thickness of the specimen, mm.

RESULTS AND ANALYSIS

The density of the laboratory-produced MDF panels varied from 776 kg.m^{-3} to 797 kg.m^{-3}. The values of that property are very close to the target density, with a maximum difference of 2.7% or significantly below the statistical error of 5%. Therefore, it can be assumed that the panels have the same density, and this main characteristic of the materials will not affect the other properties of MDF panels.

The variation in the stiffness of the MDF panels depending on the hydrolysis regime is presented in Figure 1.

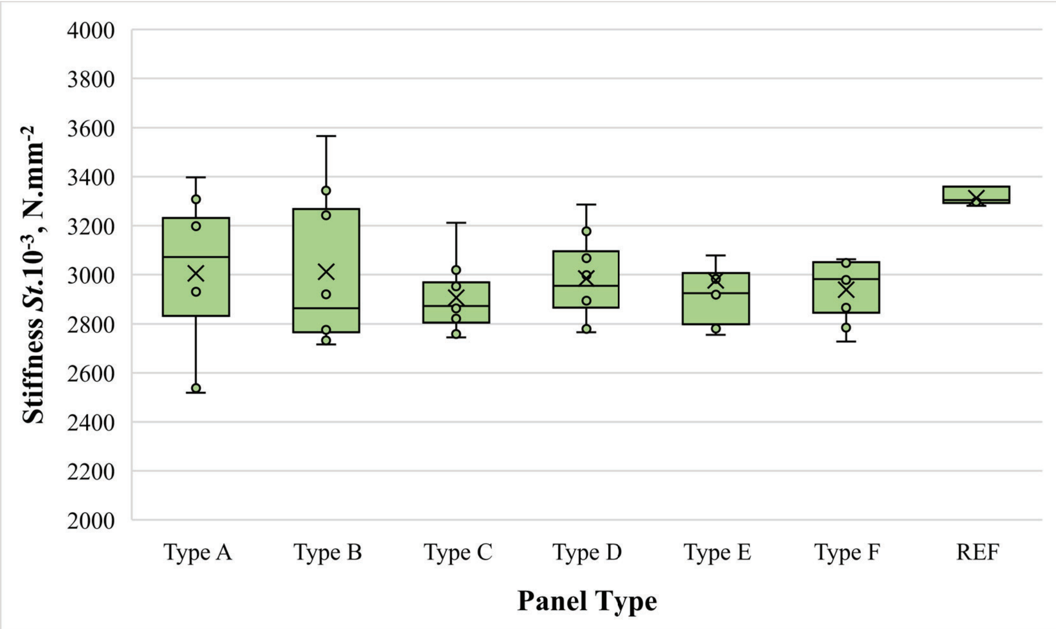
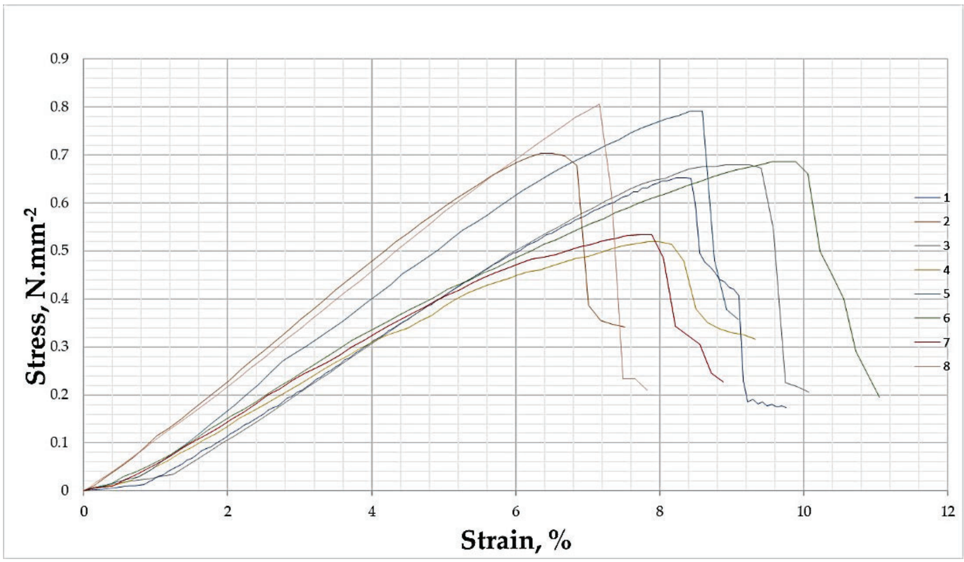
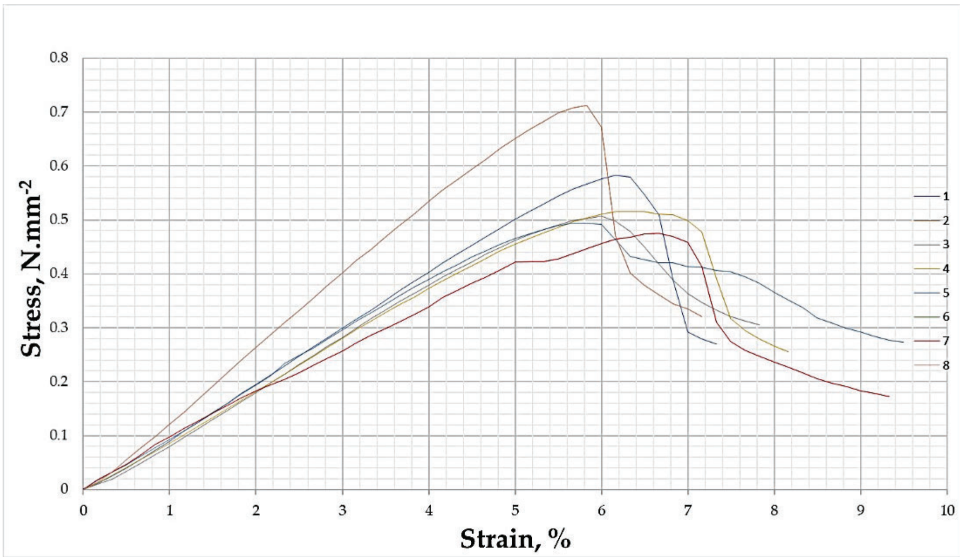


Figure 1: Stiffness of fibreboard panels

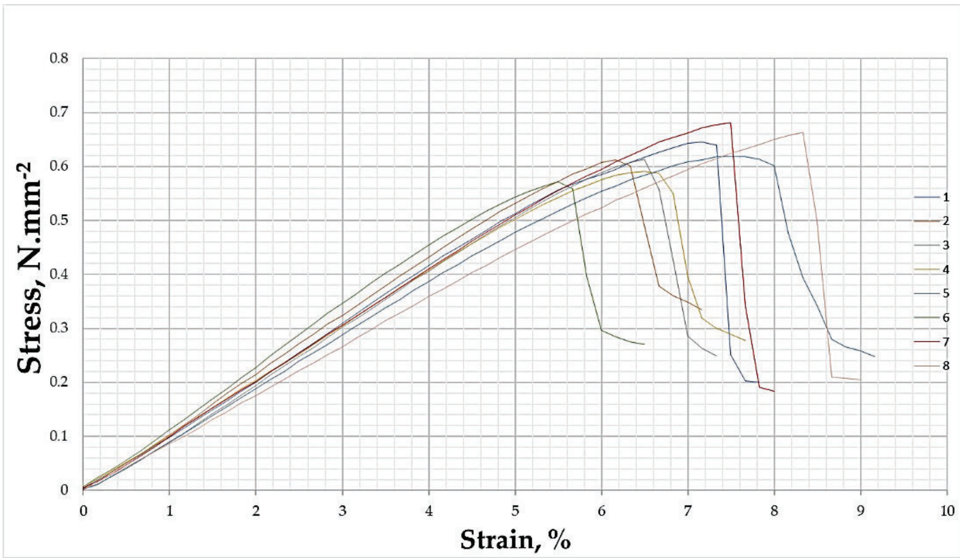
The stiffness of rMDF panels varies from $2906*10^3$ to $3012*10^3$ N.mm^{-2}. At that property, the difference between individual rMDF panels is only 3.6%. Therefore, in terms of their stiffness, the panels are unaffected by the hydrolysis regime. That suggests that the optimal hydrolysis regime is at 121°C and has a processing time of 30 minutes. The stiffness of fabricated MDF from industrial pulp is $3311*10^3$ or 10% higher than that of rMDF panels. The data suggest that the panels from recycled raw material retain their stiffness to a significant extent. That could be explained by the unchanged composition of the fibres recycled by hydrothermal hydrolysis (Savov, V. et al. 2023).

The deformation behaviour during the bending load of the MDF panels is presented in Figure 2.

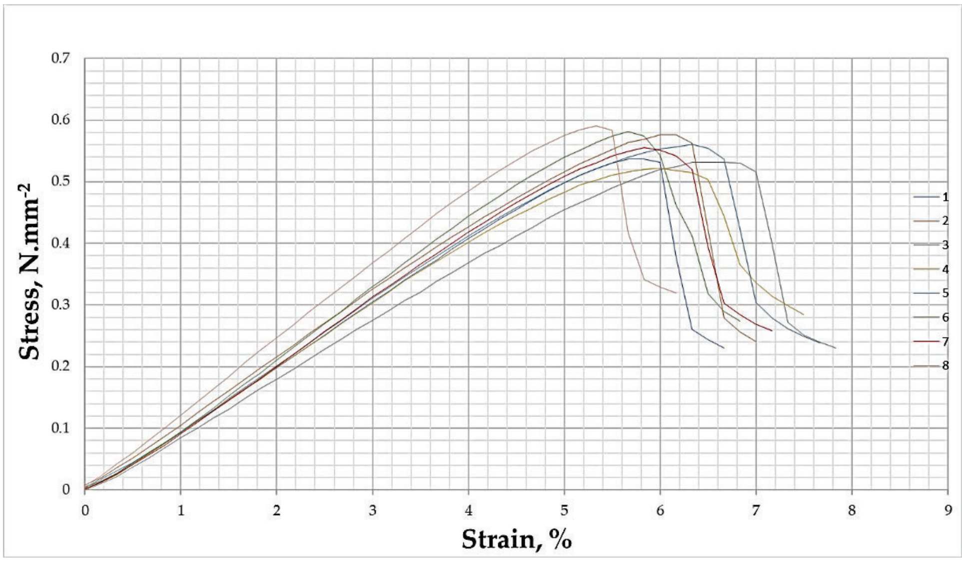
A) 


Stress, N.mm-2
Strain, %
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10
1
2
3
4
5
6
7
8

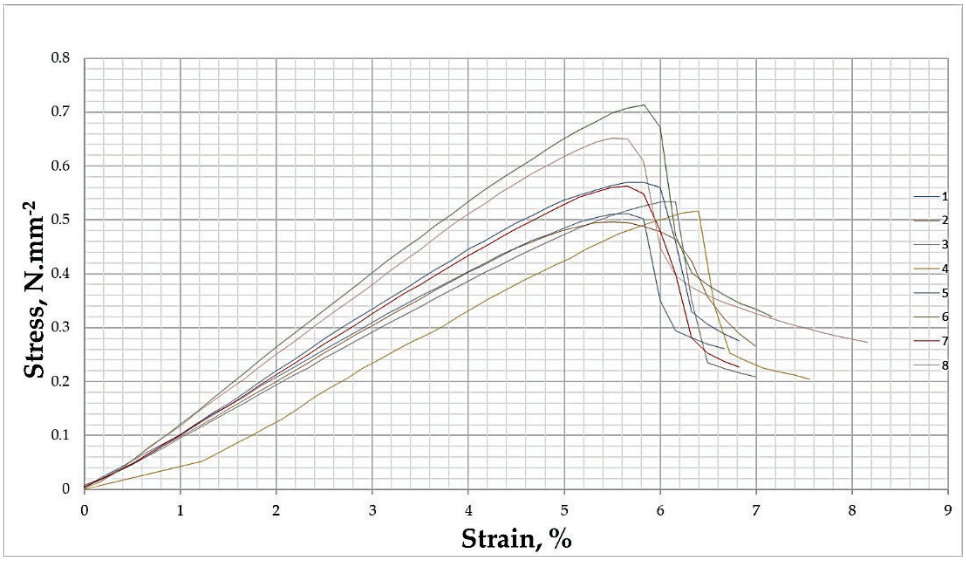
B)


Stress, N.mm-2
Strain, %
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10
1
2
3
4
5
6
7
8

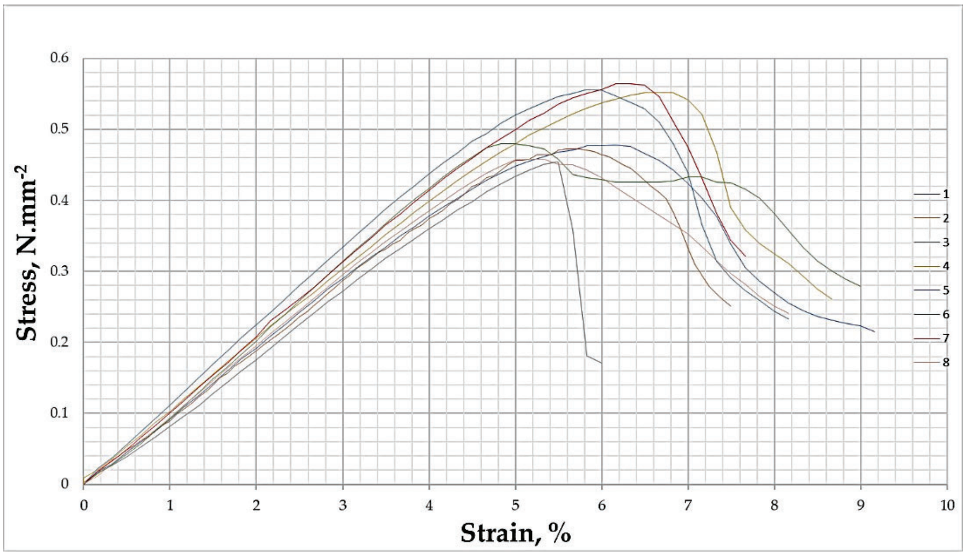
C)


Stress, N.mm-2
Strain, %
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9
1
2
3
4
5
6
7
8

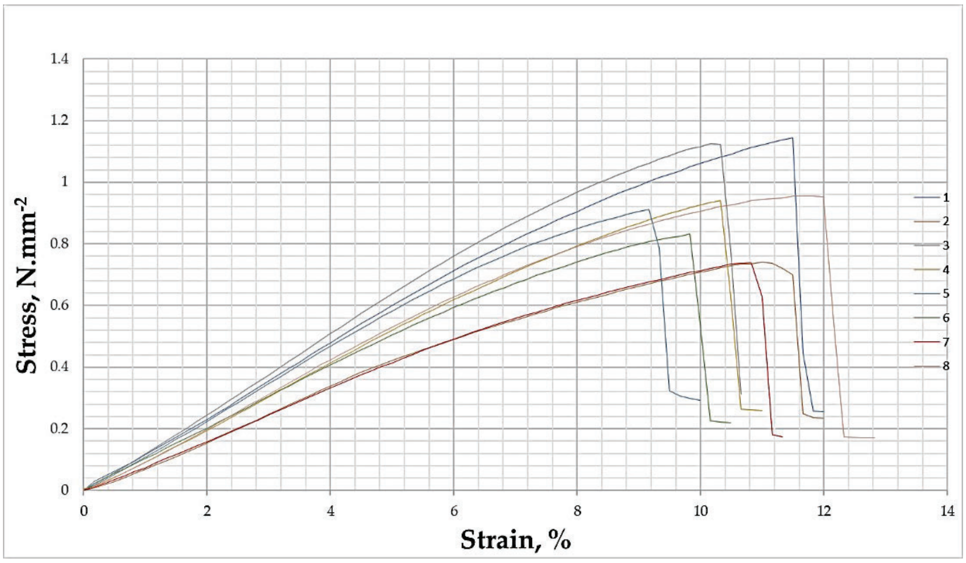
D)



E)



F)



REF)

Figure 2: Deformation at the bending load of fiberboard panels
A) Panel type A; B) Panel type B; C) Panel type C; D) Panel type D; E) Panel type E; F) Panel type F; G) REF

When analyzing the Stress-Strain curves, it is found that the panels with recycled fibres take the stress of up to 0.9 $N.mm^{-2}$ before their failure. The control panel fabricated from natural fibrec can take maximum stress up to 1.2 $N.mm^{-2}$ before failure. That is, the maximum stress of the control MDF is 33% higher than that of the Type A panel from recycled fibres. This rMDF panel has the highest ultimate stress resistance of all the fibreboard panels produced with recycled fibres. The Type F panels break at the lowest stress – an average of 0.5 $N.mm^{-2}$. This panel type has a 1.8 times lower load capacity than the Type A panel. That leads to a conclusion about the negative effect of increased hydrolysis temperature and processing time on the properties of recycled fibreboards.

On average, the pre-failure strain of the control panel was 12%÷14%, while that of the rMDFs was between 6% and 8%. Accordingly, the stress-strain ratio was 0.79 for the control panel and only about 0.1 for the fibreboards from recycled fibres.

CONCLUSIONS

As a result of the study, it was established that the panels fabricated from recycled fibres through hydrothermal hydrolysis retain their stiffness to a significant extent. In relation to this property, only a ten per cent drop was recorded compared to the control panel fabricated from industrial pulp. No significant effect of the hydrolysis regime at the selected process parameters on the stiffness of rMDF panels was found.

Regarding the bending deformation, it was found that increasing the hydrolysis time and especially the hydrolysis temperature leads to a decrease in the load-carrying capacity of the panels. It was found that panels fabricated from recycled fibres have between 1.33 and 2.2 times lower load capacity than those made from natural fibres.

Therefore, as the main conclusions and contribution of the research, it should be stated that a hydrolysis regime with a temperature of 121°C and a processing time of 30 minutes was found to be optimal regarding the stiffness and bending deformation of the panels. It was also established that it is not advisable that MDF panels be entirely composed of recycled fibres.

ACKNOWLEDGEMENTS

This research was supported by Project No. НИС-Б-1215/04.2022 "Properties and application of innovative biocomposite materials in furniture manufacturing" carried out at the University of Forestry, Sofia, Bulgaria.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

Antov, P., Savov, V. 2019. Possibilities for Manufacturing Eco-friendly Medium Density Fibreboards from Recycled Fibres – a Review. Proceedings of 30th International Conference on Wood Science and Technology - ICWST 2019 "Implementation of wood science in woodworking sector" & 70th Anniversary of Drvna industrija Journal, 12th – 13th December, Zagreb, Croatia, pp. 18–24.

Bütün Buschalsky, F.Y., Mai, C. 2021. Repeated thermo-hydrolytic disintegration of medium density fibreboards (MDF) for the production of new MDF. Eur. J. Wood Prod. 79, pp. 1451–1459 (2021). DOI: 10.1007/s00107-021-01739-6.

Hagel, S., Saake, B. 2020. Fractionation of Waste MDF by Steam Refining. Molecules, 25, 2165. DOI: 10.3390/molecules25092165.

Hagel, S., Joy, J., Cicala, G., Saake, B. 2021. Recycling of Waste MDF by Steam Refining: Evaluation of Fiber and Paper Strength Properties. Waste and Biomass Valorization, 12, pp. 5701–5713. DOI: /10.1007/s12649-021-01391-4.

Hui, W., Xiang-Ming, W., Alpha, B., Jun, S. 2014. Recycling wood composite panels: characterizing recycled materials. BioResources.

IHNÁT, V.; LÜBKE, H.; RUSS, A.; BORŮVKA, V. 2017. Waste agglomerated wood materials as a secondary raw material for chipboards and fibreboards. Part I. preparation and characterization of wood chips in terms of their reuse, Wood Research.

IRLE, M., PRIVAT, F., COURER, L., BELLONCLE, CH., BONNIN. E., CHATALA, B. 2019. Advanced recycling of post-consumer solid wood and MDF. Wood Materials Science and Engineering, 14(1), pp. 19–23.
DOI: 10.1080/17480272.2018.1427144.

IŽDINSKÝ, J., VIDHOLDOVÁ, Z., REINPRECHT, L. 2020. Particleboards from Recycled Wood. Forests 11, 1166; DOI: 10.3390/f11111166.

JIVKOV, V., SIMEONOVA, R., ANTOV, P., MARINOVA, A., PETROVA, B., KRISTAK, L. 2021. Structural Application of Lightweight Panels Made of Waste Cardboard and Beech Veneer. Materials MDPI, 14, 5064. DOI: 10.3390/ma14175064.

LUBIS, M. A. R., HONG, M. K., PARK, B. D., LEE, S. M. 2018. Effects of recycled fiber content on the properties of medium density fiberboard. European Journal of Wood and Wood Products, DOI: 10.1007/s00107-018-1326-8.

LUBIS, M. A. R., MANOHAR, S. Y., LAKSANA, R. P. B., FATRIASARI, W., ISMAYATI, M., FALAH, F., SOLIHAT, N. N., SARI, F. P., HIDAYAT, W. 2021. The Removal of Cured Urea-Formaldehyde Adhesive Towards Sustainable Medium Density Fiberboard Production: A Review. Journal Silva Lestari, 9(1). DOI: 10.23960/jsl1923-44.

MANTANIS, G. I., ATHANASSIADOU, E.T., BARBU, M.C., WIJNENDAELE, K. 2017. Adhesive systems used in the European particleboard, MDF and OSB industries, Wood Materials Science and Engineering, 13 (2), pp. 104–116.
DOI:10.1080/17480272.2017.1396622

MOEZZIPOUR, B., AHMADI, M., ABDOLKHANI, A., DOOSTHOSEINI, K. 2017. Chemical changes of wood fibers after hydrothermal recycling of MDF waste. Journal of Indian Academic of Wood Science 14(2), pp. 133–138. DOI: 10.1007/s13196-017-0198-6.

MOEZZIPOUR, B., ABDOLKHANI, A., DOOST-HOSEINI, K., RAMAZANI, S. A. A., TARMIAN, AS. 2018. Practical properties and formaldehyde emission of medium density fiberboards (MDFs) recycled by electrical method. European Journal of Wood and Wood Products, 76, pp.1287–1294. DOI: 0.1007/s00107-018-1291-2.

PETROVA, B., JIVKOV, V., YAVOROV, N. 2023. Possibilities for Efficient Furniture Construction Made of Thin and Ultra-Thin Materials by Using Mitre Joints. Materials, MDPI, 16, 6855. https://doi.org/10.3390/ma16216855.

SALA, C. M., KOWALUK, GR. 2020. The influence of Defibration Pressure and Fibres drying parameters on the Properties of HDF Made with Recovered Fibres. Annals of Warsaw University of Life Sciences, 111, pp. 143–159.

SAVOV, V., ANTOV, P., PANCHEV, C., LUBIS, M.A.R., LEE, S.H., TAGHIYARI, H.R., TODOROVA, M., PETRIN, S. 2023. Effect of Hydrolysis Regime on the Properties of Fibers Obtained from Recycling Medium-Density Fiberboards. Fibers, MDPI, 11, 64. DOI: 10.3390/fib11070064.

SIMEONOVA, R., MARINOVA, A., JIVKOV, V. 2015. Study of Stiffness Coefficient Under Bending Test of Corner Detachable Joints of Structural Elements Made of Plywood. Innovation in Woodworking Industry and Engineering Design, 1(7), pp. 59–66.

YOSIFOV, N., DELIN, S. 2014. Prognostication of strein-strength characteristics of structural particleboards during countinuos static bending load. Innovation in woodworking industry and engineering design, vol. III, pp. 137–146. ISSN 1314-6149.

EN 310:1999; Wood-Based Panels—Determination of Modulus of Elasticity in Bending and of Bending Strength. European Committee for Standardization (CEN): Brussels, Belgium, 1999.

EN 323:2001; Wood-Based Panels—Determination of Density. European Committee for Standardization (CEN): Brussels, Belgium, 2001.

FAO STAT. Forestry Production and Trade, [online] Available at: https://www.fao.org/faostat/en/#data/FO [Accessed 11. 2023].

UNIVERSITY OF FORESTRY

FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

2/2023

INNO vol. XII Sofia

ISSN 1314-6149
e-ISSN 2367-6663

Indexed with and included in CABI

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

Science Journal
Vol. 12/ p. 1–88
Sofia 2/2023

ISSN 1314-6149
e-ISSN 2367-6663

Edition of
FACULTY OF FOREST INDUSTRY – UNIVERSITY OF FORESTRY – SOFIA

The Scientific Journal is indexed with and included in CABI.

SCIENTIFIC EDITORIAL BOARD

EDITORIAL BOARD

Cover Design: DESISLAVA ANGELOVA

Printed by: INTEL ENTRANCE
Publisher address: UNIVERSITY OF FORESTRY – FACULTY OF FOREST INDUSTRY
Kliment Ohridski Bul., 10, Sofia, 1797, BULGARIA
http://inno.ltu.bg
http://www.scjournal-inno.com/

CONTENTS