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SURFACE PROPERTIES OF A MEDIUM DENSITY FIBREBOARD EVALUATED FROM THE VIEWPOINT OF ITS SURFACE TREATMENT

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ABSTRACT

The paper is focused on the study and analysis of specified surface properties of medium density fibreboards (MDF). The primary purpose was to acquire data expressing the surface properties of these materials. The study results related to the morphology of the MDF surface show structural differences between the MDF surfaces and the core layers. The surface layer with the thickness from 1 to 2 mm, consisted of fine wood fibres impregnated with the glue and paraffin. In the inspected MDF boards, this surface layer in interaction with the pressing technology, induced lower roughness and clearly higher resistance to water and against non-polar liquids. The MDF surfaces also showed low surface free energy with dominating dispersion component. In the case of applying the film-forming substances, this may result in uneven spreading of the substances across and their poorer adhesion to the MDF surface.

Key words: MDF, morphology, roughness, wetting, surface free energy.

INTRODUCTION

Medium Density Fibreboards (MDFs) are made up of fibres of lignin-cellulose materials with a density range of 400–850 kg·m^{-3} (VOJTA *et al.* 20018). The final board density however, mostly ranges from 690–750 kg·m^{-3} (GUL *et al*. 2017)**.** The main MDF component is modified fibres from coniferous or broadleaved woody plants. The second one is glue. The glue type and properties define the product performance under mechanical and moisture loading. Therefore, the properties of glues used at MDF production are extremely important (ŠTEFKA 2006, REINPRECHT 2016, UNER and OLGUN 2017). The third component is a group of secondary, facilitating chemical assistant substances such as hydrophobic and protective substances (fire retarders, fungicides) and similar, modifying purposely the MDF performance.

Today, MDFs are the leading primary material for manufacturing kitchen and bathroom furniture, mainly the doors. Under these circumstances, the MDFs may be exposed to a rather high ambient air humidity, or even be in direct contact with liquid water (de CADEMARTORI e*t al*. 2015). That's why the MDFs are supplemented with hydrophobic and fungicidal agents.

The most commonly used hydrophobic medium is paraffin, but there are possible alternative hydrophobization modes for MDF treatment (DE CADEMARTORI *et al*. 2018). The hydrophobization degree of wood materials supplemented with paraffin and the degree of their performance modification depend on the paraffin amount, type and form, as well as on the

application mode of this substance into the material (ŠTEFKA 2002, ROFFAEL *et al*. 2005, GARAI *et al*. 2005, TORKAMAN 2008, CAI *et al*. 2016, KÚDELA 2019). Paraffin reduces the sorption capacity of food fibres, and, consequently, the thickness swelling of the boards concerned. On the other hand, an excessive paraffin amount may cause problems concerning surface treatment with coating materials or with gluing foils or veneers (LIPTÁKOVÁ and KÚDELA 1997, AYRILMIS and WINANDY 2009, KÚDELA 2019). Hydrophobization of agglomerated materials, MDFs included, with paraffin, weakens their surface wetting and lowers their surface free energy, which has also been confirmed by LIPTÁKOVÁ and KÚDELA (1997). According the last cited work, the surface energy of all the tested agglomerated materials with dominant disperse component was significantly lower compared to the corresponding native wood with dominant polar component. This is in accord with (de CADEMARTORI *et al*. 2015, CAI *et al*. 2016, KÚDELA 2019).

The study of surface treatment defects in hard fibreboards (KÚDELA 2019) revealed that the spots with more paraffin did not achieve the required desiccation degree. This had negative impact on applying the additional layers, especially in the case of automatized manufacturing lines. These spots exhibited impaired adhesion between the coating and the substrate. The result was many additional defects, including outlook defects (orange peel, bordered spots, coat cracking after drying, and similar). There was even been observed paraffin penetration throughout the prime coating into the second layer applied.

For MDF surface treatment with coating materials and for gluing thin foils, MDF surface morphology is important as well, because this feature affects the final product's surface outlook. The material morphology is evaluated based on their roughness and waviness. MDF morphology is determined by the fibre structure and processing, MDF manufacturing technology as well as by the mode of the mechanical treatment of the MDF surface. MDF surfaces are machined by sanding or milling. The ground surface morphology is first of all the result of the grain size. The surface morphology in milled surfaces is backed-up by multiple factors (the milling machine quality, number of knives, shifting speed, rotation speed and others). – (SINN *et al*. 2005, LIN *et al.* 2006, AKBULUT and KOC 2006, AYRILMIS *et al*. 2010, JARUSOMBUTI *et al*. 2010, SÜTCÜ and KARAGÖZ 2012, SEDLECKÝ 2017, KMINIAK *et al*. (2020).

It follows that the MDF surface properties follow from a number of factors (wood species, wood fibre type and size, amounts of ingredients, pressing conditions, surface treatment mode, moisture content, and similar). Key important is wood fibre type and its interactions with the other factors (AKBULUT and KOC 2006).

The surface treatment of these materials is supposed to guarantee good spreading of the applied film-forming substances (coating materials and glues) and forming a compact, decorative protective layer or a stable glued joint after their hardening. KÚDELA and LIPTÁKOVÁ (2006), KÚDELA (2019) demonstrate that the phenomena at the interface between wood or agglomerated materials and film-forming substances in both liquid and solid phase are very complex. The hardening of film-forming materials on the substrate surface is accompanied with physical and chemical phenomena inducing changes in the solid coating (glue) chemical structure. This is, on its turn, reflected on their surface free energy values and on the values of their cohesion and adhesion to the substrate (LIPTÁKOVÁ and KÚDELA 2002, KÚDELA and LIPTÁKOVÁ 2006, AYRILMIS and WINANDY 2009, SLABEJOVÁ *et al*. 2016, SLABEJOVÁ and ŠMIDRIAKOVÁ 2018). From this viewpoint it is important to know the discussed MDF surface properties as well as the properties of the used film-forming material (KÚDELA and LIPTÁKOVÁ 2006, KÚDELA 2012).

To obtain an as much as possible comprehensive idea about the investigated MDF surface, it is necessary to know a number of its properties (morphology, chemical and thermodynamic properties, etc.). It is also obligatory to recognize the effects of a range of

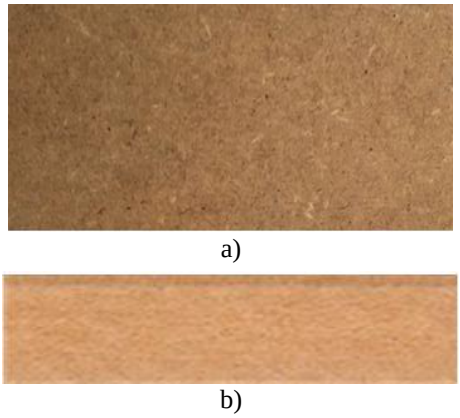
factors on the MDF surface properties. For these reasons, the study of MDF surface properties and on the interactions occurring at the interface MDF – film-forming material is an up-to-date subject, from the viewpoint of improving the surface treatment quality of these materials with coating substances, as well as from the viewpoint of prolonging the correct performance of the glued joint.

The objective of this paper was experimental measuring and evaluation of specific surface properties of commercially produced MDFs, with the aim to assembly data important for these boards´ surface treatment. MDF surface morphology was evaluated from anatomical and physical viewpoint; through values of roughness and waviness, MDF surface wetting with polar and non-polar liquids. There were also determined the surface free energy and its impact on the final MDF surface treatment quality.

MATERIAL AND METHODS

Experimental material

Surface properties were investigated in raw MDFs produced commercially by the manufacturing company DH Decor Ltd. Humpolec, the Czech Republic, and supplied for manufacturing furniture doors. The tested boards were five, selected randomly. From each board, there were cut four specimens, with surface dimensions of 50 × 100 mm. The specimen thickness was 18 mm (Fig. 1.). There were together 20 sp. The specimens were examined for their density, roughness, waviness, surface wetting with water and diiodomethane, surface free energy with distinguished the polar and disperse component.



a)

b)

Fig. 1 MDF test specimen: a) board surface structure, b) lateral view with detectable darker top layer.

Determining of MDF density and assessment of MDF surface morphology

The density was determined on specimens demonstrated in (Fig. 1). Each specimen was weighed with a precision of 0.01g and measured (all three dimensions) with a precision of 0.01 mm. Then surface layers thick of 1.5–2 mm were sawn from the upper and lower surface. The density was determined separately for the two surface layers and the core.

MDF surface morphology was assessed with the aid of light microscopy. The appliance used was a microscope Leica MZ 9.5, equipped with a camera Leica EC 3. From the physical viewpoint, the MDF surface was evaluated based on roughness and waviness, measured with a profile-meter „Surfcom 130A“ supplemented with an evaluation unit and a software equipment.

Roughness and waviness were measured on each specimen two times, at two different spots. Altogether, there were completed 40 measurements. There were scanned MDF surface

profiles. The roughness evaluation was done in the following way: After filtering away waviness from the measured profile, there was obtained the roughness profile curve. This curve was transferred onto the base line. Then the roughness was filtered away from the curve. The final result was the waviness profile. The traversing length consisted of the start-up length, five sampling lengths (cutoff) and the run-off length. The start up and run-off of the measuring equipment served for the elimination of vibrations possible to generate during starting and stopping the measuring eqipment. The sampling length was chosen from the interval 0.025–8 mm based on preliminary measured values of roughness parameters *R*a and *Rz*. In the case of MDF, the sampling length was 2.5 mm and the total evaluation length l_n was 5 × sampling length, making together 12.5 mm. The surface roughness and waviness were evaluated based on parameters: arithmetic mean deviation – *Ra, (Wa),* maximum height of the assessed profile within a sampling length – *Rz,* maximum height of the assessed profile within a traversing length – *Rt,* (*Wt)* and mean distance between the valley – *RSm,* (*WSm)* (EN ISO 4287).

MDF surface wetting with liquids and determining of surface free energy

MDF surface resistance to liquids was tested with two liquids differing in polarity– redistilled water and diiodomethane. The two liquids were chosen following KÚDELA (2014). Diiodomethane is a non-polar liquid with the non-polar surface free energy component higher than the disperse component of wood. The second liquid – redistilled water represents polar-non-polar liquids with the polar surface free energy component higher than the polar component of wood. The parameters for the two liquids can be found in Kúdela *et al*. 2020).

The MDF wetting process, associated with the measuring contact angle values as far as the complete drop soaking into the substrate was realised with using a goniometer Krüss DSA30 Standard (Krüss, Germany). The drop with a volume of 0.0018 ml, after having reached the MDF surface, wetted the surface and spread over it. The time course of the drop profile during the wetting was scanned with a camera. The scanning frequency was one second. The drop shape analysis was made and the contact angles were determined with using the circle method. Simultaneously, there was measured the drop diameter *d* (Kúdela *at al.* 2020). The contact angle value θ_0 was determined at the beginning of the wetting process, this means immediately after the drop had reached the board surface. Based on the time-dependent variation of the parameter *d* (drop diameter), the moment of conversion of the contact angle from advancing to receding one was identified. The contact angle measured at this moment was considered as „equilibrium" contact angle – θ_e. The contact angle values θ_0 and equilibrium contact angle values θ_e served for calculation of the contact angle values θ_w for an ideally smooth surface. The calculation followed the methods designed by LIPTÁKOVÁ and KÚDELA (1994). On each test specimen, contact angles were measured at two different spots.

The MDF wetting was investigated with using two wetting liquids; consequently, the wood surface free energy was calculated separately from wetting with water and wetting with diiodomethane, following the adjusted equation proposed originally by NEUMANN *et. al*. (1974); the disperse and polar components γ_S^d and γ_S^p of this energy were calculated according to KLOUBEK (1974).

RESULTS AND DISCUSSION

MDF surface density and morphology

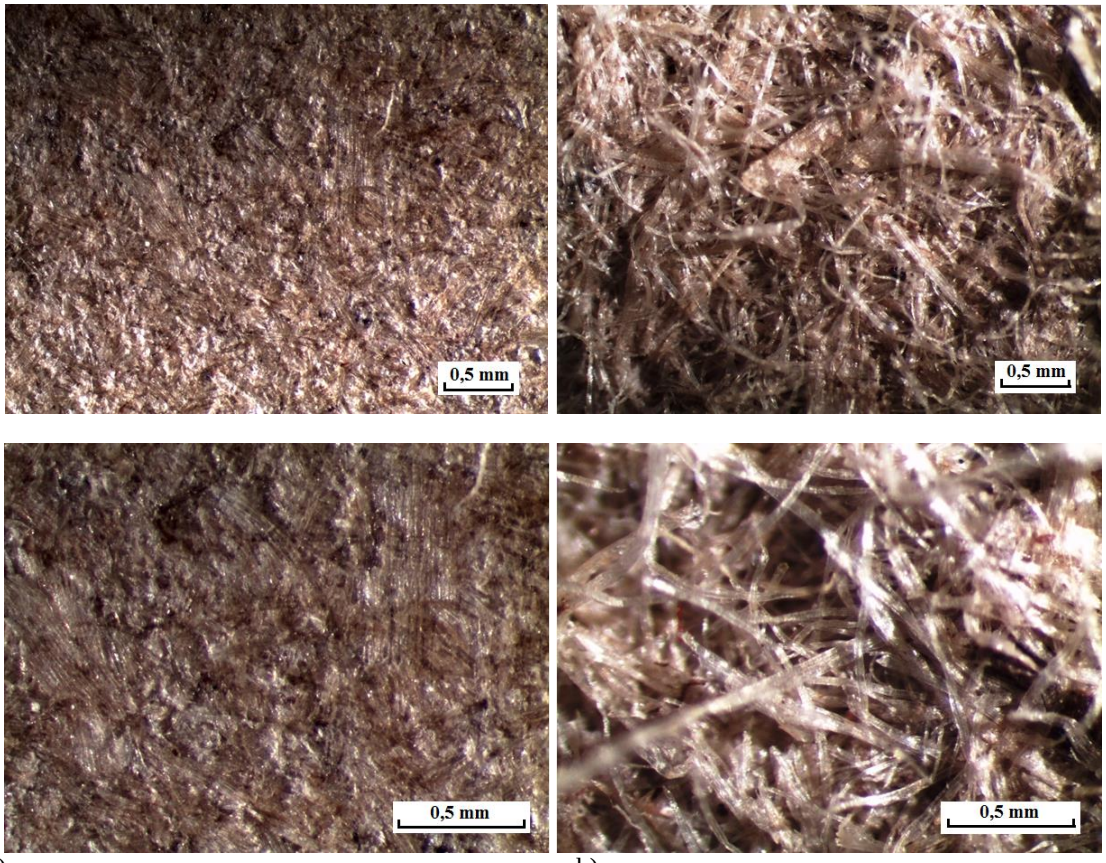
The visual observations of the board lateral surfaces as well as microscopic observations of the board structure in its surface layer and in its core layer resulted in finding that the fibre

fraction varied across the board cross section. There was confirmed that the MDF producer is using finer fibre fraction for the upper surface cover layer, with the aim to obtain smoother surface. After the pressing, this layer was thick from 1.5 to 2 mm, visible as a narrow darker band on the lateral board surface (Fig. 1b). The average density values for the whole boards and for their upper and core layers are in Table 1. The results confirm that the density across the cross section varied. The upper layer average density was evidently higher than the density of the medium layer (Table 1). In certain cases, the first attained even the values of hard fibre boards. AKBULUT and KOÇ (2006) report MDF density profiles demonstrating the lowest density in the board core, and the highest density on the board surface. The higher density of the surface consisting of fine fibre fraction was also reflected on this surface morphology. Under a 32 and a 60-ply magnification, the very fine particles on the MDF surface are not possible to specify with sufficient precision. The very fine wood particles and wood dust are impregnated with glue and paraffine (Fig. 2a). Under the same magnification, entire wood fibres in core layers were distinctly visible (Fig. 2b).

Tab. 1 Basic statistical characteristics for MDF density.

Basic statistical characteristics	Whole MDF	Surface layer	Core layer
$\bar{x}$ [kg·m^{-3}]	760	889	714
s [kg·m^{-3}]	30	46	15
n	20	20	20

$\bar{x}$ – average, s – standard deviation, n – sample size; the symbols are valid for all the tables



a) b)

Fig. 2 MDF structure a) surface layer , b) core layer.

The above described fine fibre fraction impregnated with glue and paraffin, in interaction with the pressing technology, determined the MDF surface geometry. This geometry was quantified though roughness and waviness parameters. A representative roughness and waviness profile for MDF surface is in Fig. 3.

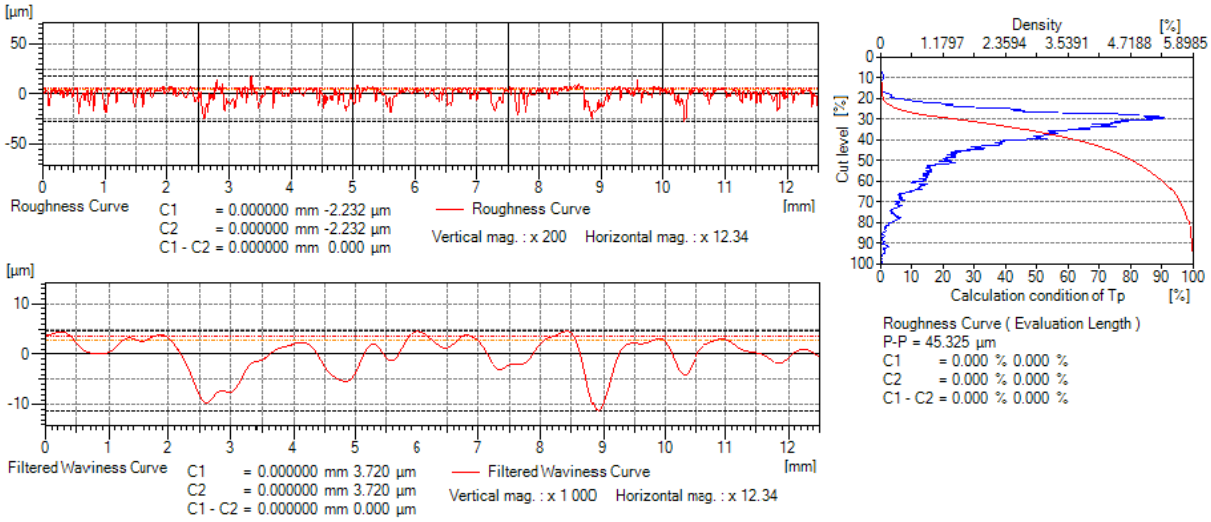


Fig. 3 Roughess and waviness profile of MDF surface.

All the measured roughness and waviness profiles were evaluated trough roughness parameters *Ra*, *Rz*, *Rt* and *RSm* and waviness parameters *Wa*, *Wt*, *WSm*. The average values of these parameters, together with other statistic characteristics are in Table 2. Logically, we may suppose that higher MDF surface density will be associated with lower surface roughness. An example of using two surfaces with different properties is production of milled furniture doors.

Tab. 2 Basic statistic characteristics for roughness and waviness parameters.

Basic statistical characteristics	Roughness parameters				Wavines parameters		
	Ra	*Rz*	*Rt*	*RSm*	*Wa*	*Wt*	*WSm*
$\bar{x}$ [µm]	4.29	32.31	42.03	223.19	2.20	13.77	2618.67
s [µm]	0.77	5.02	9.16	31.65	0.50	3.36	982.98
v [%]	18.04	15.55	21.80	14.18	22.54	24.38	37.54
n	40	40	40	40	40	40	40

The roughness parameter values we measured in MDFs are in accordance with the values reported by AYRILMIS and WINANDY (2009), AYRILMIS *et al.* (2010) for MDFs subject to appropriate thermal treatment or to final sanding with a paper with a grain size of 120. In our case, the average value of the mean arithmetic deviation *Ra* was from 2 to 3 times lower than the value reported for various milled MDF surfaces by KMINIAK *et al.* (2020). This implies that more distinct roughness is to consider in the case of milled surfaces common in furniture doors production.

The obtained roughness parameters were compared with the corresponding parameter values for spruce and beech – the two wood species most commonly used for MDF production in our region. The comparison showed that the MDF roughness was more distinct than the roughness of the milled surfaces of the two original wood species along the grain. The MDF roughness and waviness parameter values were the same as the corresponding parameter values recognized for tangential surfaces of the two wood species milled perpendicular to the grain direction (KÚDELA *et al.* 2018).

MDF surface wetting and surface free energy

The tested MDF surface exhibited resistance to water, which has also been approved with the measured contact angle values. In all the cases, the contact angle values at the moment where the liquid drop reached the substrate surface were higher than 90°, ranging from 110 to 135°, with an average value of 129°. It follows that the surfaces treated in this way were almost wetting resistant. The spreading rate of the liquid drop over the surface was very slow. The contact angle values had dropped under 90° as late as after 10 to 17 minutes. The contact angle values at the moment of drop application, after one minute and after two minutes of MDF wetting, together with other statistic variables are in Table 3.

Tab. 3 Time-dependent contact angle values θ for MDF wetted with water and diiodomethane.

Basic statistical characteristics	Contact angle θ for wetting with water			Contact angle θ for wetting with diiodomethane		
	θ_0	θ_{60}	θ_{120}	θ_0	θ_{60}	θ_{120}
$\bar{x}$ [°]	129	123	120	89	83	81
s [°]	4.8	7.4	9.6	9.4	11.6	4.6
n	40	40	40	40	40	40

The lower index corresponds to the time (0, 60, 120 seconds) of the contact angle measurement.

High MDF surface resistance to wetting was also confirmed for diiodomethane. Also in this case, the contact angle values at the moment of the drop application were relatively high, ranging from 73 to 106°. The average contact angle values together with other statistical characteristics are in Table 3. Diiodomethane also exhibited a low spreading rate over the MDF substrate surface. After two minutes of wetting, the average contact angle had been reduced to 81° which represents only 8° reduction.

The wetting process with wetting liquids was scrutinised up to the complete drop spreading over and soaking into the substrate. In the case of water, this time was rather variable, lasting from 18 to 30 min. The equilibrium contact angle time was somewhat shorter, but not always possible do determine unambiguously. In the case of diiodomethane, even 42 minutes were not enough for drop spreading and soaking. As diiodomethane is a non-polar liquid, better wetting was expected on the background of interactions between unsaturated non-polar forces occurring at the beginning of the wetting process, mostly immediately after the diiodomethane touching the substrate KÚDELA (2014). The contact angle values varying with time are in Fig. 4. In the case of water, all the contact angle values at the moment of application were higher compared to diiodomethane, but to the end, the water spreading over the substrate surface was faster.

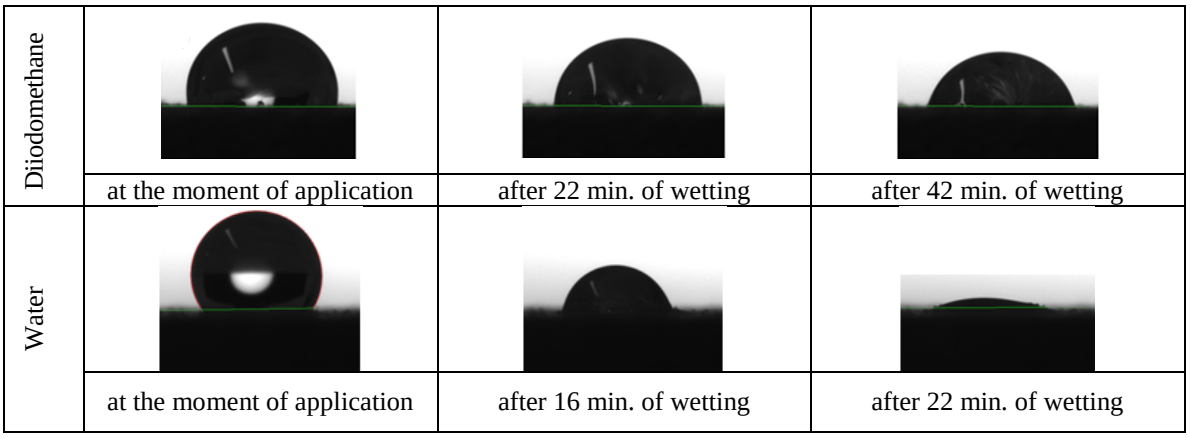


Fig. 4 Wetting-time-dependent profiles of water and diiodomethane drop.

Based on the works LIPTÁKOVÁ and KÚDELA (1997), CAI *et al*. (2016) and KÚDELA (2019) we may suppose that the principal cause resulting in high MDF surface resistance to wetting with liquids is paraffin admixed into the MDFs. The second important factor possibly backing-up lower wetting performance is the impact of pressing temperature, acting for a short time, but at high values. ANDOR (2018) demonstrates a substantial wood surface hydrophobization as the result of thermal treatment at a temperature of 180°C. The last cited work implies that after grinding, the surface hydrophobic performance was reduced significantly. This was also observed for MDFs (AYRILMIS *et al*. 2010). If the paraffin amount in the fibre board is higher, the paraffin may melt due to heat generated during grinding and, in this way, increase the MDF surface hydrophobic efficiency. Subsequently, this has a negative impact on the surface treatment of such surface with certain types of solvent-based coating substances (KÚDELA 2019).

To determine the equilibrium contact angle was tricky, so the surface free energy values were calculated based on the contact values measured at the moment of the drop application, both in the case of water and diiodomethane. The resulting surface free energy values, together with the disperse and polar components derived from the wetting with water and diiodomethane are in Tab. 4. The surface free energy obtained in this way was very low. In both cases, the disperse components were dominant. Similar results for surface free energy in insulation fibreboards have been recognised by CAI *et al*. (2016).

Tab. 4 Surface free energy and its disperse and polar components on MDF surface.

Basic statistical characteristics	Surface free energy and its components derived from wetting with water			Surface free energy and its components derived from wetting with diiodomethane		
	γ_s	γ_s^d	γ_s^p	γ_s	γ_s^d	γ_s^p
$\bar{x}$ [mJ·m^{-2}]	7.35	7.28	0.06	17.86	14.16	3,70
s [mJ·m^{-2}]	2,49	2,41	0.10	4.58	4.55	0.16
n	40	40	40	40	40	40

The calculated MDF surface free energy was lower than the surface energy of coating substances in liquid phase (KÚDELA and LIPTÁKOVÁ 2006, ŠTRBOVÁ 2015). This may cause poor spreading of film-forming materials across MDF surface, and also have a negative impact on the film-forming material adhesion to the MDF surface. If paraffin distribution across the board surface is not uniform, the local surface tension in the film-forming materials may be weakened during the process of these materials application and drying. In this way, the surface tension gradient originates, causing the polymers from the film-forming material to flow from the areas with lower surface tension to the ones in which this tension is higher. This polymer flow is backing up the creation of orange peel and craters (WITTHE 1999, KÚDELA 2019).

As the MDF hydrophobization is necessary for improving their resistance to water, there is an urgent need for an appropriate surface treatment guaranteeing elimination of negative impact of hydrophobization on the surface treatment in these boards. A viable approach seems surface pre-treatment with plasma, prior to the film-forming substances application (de CADEMARTORI *et al*. 2015, KLÍMEK *et al.* 2016).

CONCLUSIONS

Our research objective was to study MDF surface properties from the viewpoint of their surface treatment. The evaluation and analysis of the obtained results allow us to

deduce the following conclusions:

The study of MDF morphology revealed differences in the structure between the MDF surface and core layers. The upper surface layer, thick of 1.5 to 2 mm is composed of fine fibre fraction impregnated with glue and paraffin. The core layer exhibited distinct observable fibrous elements.

The fine wood fibre fraction together with glue and paraffin interacted with wood pressing technology, and in such a way, determined the MDF surface geometry. This altogether resulted in lower roughness, evident from lower values of roughness and waviness parameters.

The tested MDF surfaces manifested high resistance to water and to non-polar liquids. This was documented with the measured contact angle values. In the case of water, the contact angle values at the moment of drop application onto the MDF surface ranged from 110° to 135°; the value range for diiodomethane was from 73° to 106°. MDF surface resistance to liquids was also evident on long time necessary for spreading and soaking the drop into the substrate. This time was several tens of minutes. The main role in the high MDF resistance to liquids has been attributed to paraffin admixed in MDFs.

The MDF surfaces were characterized by a low surface energy with dominant disperse component. The MDF free surface energy was lower than the surface free energy of the film-forming materials. This may cause poor spreading of film-forming materials over the MDF surface, with possible negative impact on film-forming material adhesion to the MDF surface.

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