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THE SOY FLOUR AS AN EXTENDER FOR UF AND MUF ADHESIVES IN BIRCH PLYWOOD PRODUCTION

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ABSTRACT

Formaldehyde emission still remains a major disadvantage of widely applied formaldehyde-containing amino resins such as UF (urea-formaldehyde) resin and MUF (melamine-urea-formaldehyde) resin. The compositions of adhesives for plywood manufacturing have to contain a proper extenders in order to adjust their viscosity. Thus, the aim of the study was to investigate the effect of protein-rich soy flour (SF) as the extender for adhesives. The composition of flours and their ability to absorb the formaldehyde were determined. Properties of liquid resins such as gel time, viscosity, pH and solid content were investigated. The possible chemical interaction between the extenders and resins were assessed with the use of FTIR spectroscopy. Plywood panels manufactured using UF and MUF adhesives with the soy flour introduced as the extender in various concentrations were tested in terms of shear strength and formaldehyde release. Studies have shown that soy flour has a favorable composition and formaldehyde-scavenging ability. The addition of SF affected resins properties such as viscosity and gel time but showed no influence on their pH and solid content. FTIR analysis has not explained the chemical interaction between resin and extender. The application of soy flour in the concentration of 15% for UF resin and 10% for MUF resin allowed to produce plywood characterized by improved bonding quality and decreased formaldehyde emission.

KEYWORDS: Amino resins, soy flour, extender, plywood.

INTRODUCTION

The start of innovative wood composites production had a major effect on wood utilization by its fragmentation to a particles and bonding them together. In addition to the suitable use of scarce raw material, the developed boards were characterized by a properties that were not available from solid wood. Since then, wood-based panels such as plywood, medium- and high density fiberboards became more popular and as their global production increases, the consumption of wood adhesives also increases (Bekhta et al. 2020, Kawalerczyk et al. 2019a). Because of that, there are many ongoing studies concerning the invention of new adhesives or the refinement of the already existing ones (Frihart 2015).

Nowadays the amino resins such as urea-formaldehyde (UF) and melamine-urea-formaldehyde (MUF) are the main adhesives used in the industry for the preparation of wood-based materials (Lei and Frazier 2015). UF resins have gained a wide applications mostly due to their good adhesion to wood, fast curing and low cost (Costa et al. 2013). On the other hand, MUF resins are characterized by a higher moisture resistance which allows to extend the possible applications and include the panels intended for kitchen, floor and structural use (Mirski et al. 2020a). However, the common disadvantage of these resins is the release of formaldehyde (HCHO) from the finished boards, especially those for indoor applications (Antov et al. 2020a, Mirski et al. 2020b).

The effective way to reduce the harmful emissions from plywood is to select a suitable extender for the adhesive (Kawalerczyk et al. 2020b). The compositions of the adhesive mixture in plywood manufacturing have to contain the additives called the fillers or the extenders in order to adjust their viscosity (Chen and Yan 2018, Dukarska and Czarnecki 2016). Many studies have been carried out in order to find a new proteinaceous filling substances for plywood manufacturing. Hogger et al. (2020b) investigated the possibility to introduce wheat flour, wheat starch and wheat protein in various concentrations to PF (phenol-formaldehyde) and UF resin. Studies have shown that the amount of the extender added was determined by the increase in viscosity. The extenders had no major effect on pH values, curing behavior and the course of FTIR (Fourier transform infrared spectroscopy) spectra. Moreover, the properties of plywood containing the various wheat extenders were investigated. It was concluded that the wheat flour and wheat starch can be applied as a suitable filling substances for UF and PF adhesives. However, the amount of wheat protein added was limited by the viscosity of the mixtures to 30% for both resins. The type of extender had no significant effect on the formaldehyde emission (Hogger et al. 2020a). Waage et al. (1991) added up to 40% pecan shell flour and 33% wheat flour to PF resin and determined the influence on its curing properties by thermal analysis (dynamic mechanical thermal analysis and differential scanning calorimetry). The obtained results indicated no significant changes of the extender on the curing process. Ding et al. (2013) added the wheat flour, wheat starch mixed with gluten and maize powder to the UF resin. The strength properties of bond layer between the veneers was not affected by the type of additive. Moreover, it was found that the gluten addition resulted in the highest increase of the viscosity values. Ong et al. (2018) tested the possibility to apply the palm kernel meal (PKM) and palm shell (PS) to the composition of MUF adhesive. Authors optimized the extenders concentration in the range from 13 to 18% where the decrease in formaldehyde emission was at a minimum at 18% and the shear strength increase was at a maximum at 13%. Babcock and Smith (1947) investigated the possibility of using corn gluten and soybean meal as the vegetable proteinaceous extenders for phenolic adhesive in plywood production. Formulas including resin and protein materials in the ratio of 6:4 was characterized by the rapid curing time and the strength properties which meet the requirements for the exterior plywood. Hojilla-Evangelista (2013) studied the application of wet-milled corn germ protein as the extender for phenolic resin. Investigations have shown that the best properties of plywood panels were achieved with the corn germ protein extract included in the adhesive compositions. Taghiyari et al. (2020) conducted the research on the use of soy flour and a micron-sized wollastonite as the fillers for UF resin. On the basis of the results it was found that 10% of soy flour and 5% of wollastonite in the adhesive formulation provided plywood with the lowest formaldehyde emission and the most optimal mechanical and physical properties.

This study is a continuation of the research concerning the incorporation of various flour types into the adhesives applied in the plywood manufacturing process. The following five types of flours were investigated as the potential UF resin extenders: hemp, rye, coconut, pumpkin and rice. The outcomes showed that the influence on viscosity and gel time varied depending on the introduced flour type. Moreover, the plywood panels were tested in terms of shear strength, modulus of elasticity and modulus of rupture. The best results were noted in variants containing the rye and pumpkin flour. The values of formaldehyde emission indicated that the hemp flour can be also used as a formaldehyde scavenger (Kawalerczyk et al. 2019b). However, the hemp flour addition resulted in the decrease of UF glue line strength and the plywood mechanical properties. Thus, Authors conducted the studies aimed to adjust the amount of introduced extender in order to achieve a proper viscosity level and to confirm the effect on lowering the harmful emissions from MUF adhesives. The addition of hemp flour to MUF resin in the concentrations of 20% and 25% led to obtain the equally good properties of the manufactured panels with the formaldehyde emission lowered by up to 26% when compared to reference plywood (Kawalerczyk et al. 2020c). Since the advantageous effect was probably related to the high protein content Authors decided to investigate how the addition of soy flour affects the plywood properties.

The soy flour has been used in wood glues for decades (Zhang et al. 2017). According to Vnučec et al. (2017) the application of soy in wood bonding is a reasonable choice due to its high production volume and the small use of soy meal-based products for human food consumption. Moreover, the low cost, high protein content and easy processing are listed among its the most important advantages. There are many ongoing studies on using soy products in the formulation of formaldehyde-free wood adhesives containing also e.g. glyoxal (Amaral-Labat et al. 2008), polyepoxide resins (Huang et al. 2012), polyamidoamine (Gui et al. 2013) also for plywood manufacturing (Huang and Li 2008, Li et al. 2014). However, a low water-resistance can be still a limiting factor for some applications.

In summary, the production of amino resins is expected to increase further especially in the developing regions (Gonçalves et al. 2018). However, since the formaldehyde is classified as the carcinogenic and mutagenic substance it is very important to continue the research on the reduction of the adverse emissions. Moreover, both the global production of plywood and the availability of soy products are also constantly growing. Thus, the aim of this study was to determine the possibility to apply soy flour as the extender for UF and MUF adhesives in the production of plywood characterized by good mechanical properties and significantly lowered formaldehyde emission.

MATERIAL AND METHODS

Materials

A commercially available UF and MUF resins with a properties presented in Tab. 1 were purchased from the market. Ammonium nitrate (20 wt%) was applied as a hardener for the adhesives. Both the soy flour and the rye flour (used for comparison purpose) were obtained from the market. Plywood was prepared with the use of birch (Betula L.) veneer sheets with the average density of 570 kg·m^{-3}, average thickness of 1.4 mm, moisture content 4 ± 1% and the dimensions of 320 × 320 mm.

Tab. 1: Properties of adhesives.

Property	UF	MUF
Viscosity (mPa × s)	1211	981
Solid content (%)	69	67
pH	8.1	9.6
Gel time at 100°C (s)	65	68

Determining the compositions of flours

The purchased flours were subjected to a basic composition analysis. The investigations involved the water content based on EN ISO 712 (2012) and the share of following compounds: crude protein content according to Kjeldahl method EN ISO 5983-1 (2006), the content of mineral compounds in the form of ash according to EN ISO 2171 (2010), total fat content according to EN ISO 6492 (2005) and carbohydrates content according to EN ISO 6865 (2002).

Determining the ability of flours to absorb the formaldehyde

In order to determine the ability of flours to absorb the formaldehyde an 0.1 M aqueous solution of formaldehyde was prepared. In order to prepare 0.1 M formaldehyde solution 5 drops of concentrated sulphuric acid were mixed with 100 ml of 15% formaldehyde solution and then refluxed for 15 min to depolymerize the paraformaldehyde. The solution after cooling was neutralized with NaOH to pH 7 and diluted with distilled water. Then, an appropriate amount of flour was added to this solution. After that, the prepared water-formaldehyde solutions of flours were kept in laboratory oven for 3 hours at 65°C. The obtained solution was filtered and the content of formaldehyde was investigated with the use of sodium sulfite titrimetric method. 25 ml of 0.1 M Na_2SO_3 and 2 ml of 0.1 M NaOH were added to a 10 ml aliquot of the formaldehyde-containing filtrate. The titration was performed with 0.05 M HCl solution (phenolphthalein as an indicator). A control test was carried out with the same procedure excluding the formaldehyde. Moreover, the analysis of formaldehyde solution incubated for 3 hours at 65°C without flours was also performed. The analysis involved three repetitions for each solution (Bekhta et al. 2019, 2021).

Adhesive preparation

The amounts of introduced additives such as flours and hardener were adjusted depending on the variant (Tab. 2). The amount of introduced extender has been adjusted based on the viscosity of purchased resins. Both experimental and reference variants were mixed manually until the proper homogenization was achieved.

Tab. 2: Compositions of adhesive mixtures.

Variant label	Resin type	Quantity (pbw* per 100 g of solid resin)			
		Soy flour	Rye flour	Water	Hardener
UF-R	UF	0	20	10	2
UF-15	UF	15	0	10	2
UF-20	UF	20	0	10	2
UF-25	UF	25	0	10	2
MUF-R	MUF	0	15	10	2
MUF-10	MUF	10	0	10	2
MUF-15	MUF	15	0	10	2
MUF-25	MUF	20	0	10	2

*- pbw means parts by weight.

FTIR analysis

The FTIR analysis was performed in order to assess a chemical interactions between the extenders and resins. The flour-filled adhesive mixtures were cured in the laboratory oven at 120°C and 140°C in case of UF and MUF resins, respectively. After that it was grinded with the use of laboratory mill and sieved in order to obtain a dimensional fraction of 0.125 × 0.125 mm^2. The cured adhesive in the form of powder was mixed with KBr at a 1/200 mg ratio. Spectra was registered with the use of Nicolet iS5 spectrophotometer with Fourier transform within a range of 500 to 4000 cm^{-1} at a resolution of 4 cm^{-1}, registering 16 scans. The same preparations were completed for pure adhesives without any extender.

Determining the properties of adhesive mixtures

A viscosity is an essential parameter in plywood manufacturing process (Kawalerczyk et al. 2021). Thus, the effect of the adhesive composition on the viscosity of prepared mixtures was investigated right after the resin preparation with the use of Brookfield DV-II + pro viscometer. Moreover, the following properties listed by Gonçalves et al. (2019) among the commonly used industrial indicators for adhesives such as pH, solid content and gel time at 100°C were determined according to relevant standards: EN 1242 (2011), EN 827 (2005) and PN-C-8952-3 (1996), respectively.

Plywood manufacturing and testing

In order to manufacture a three-layered plywood the UF and MUF adhesives were applied on the surface of the external veneer sheets in the amount of 170 $g \cdot m^{-2}$. The veneers glued with UF resin were pressed at 120°C and unit and 1.4 MPa for 4 min. In case of variants containing MUF resin pressing process was conducted at 140°C for 4 min with the unit pressure of 1.3 MPa. The manufactured panels were tested in terms of formaldehyde emission using a flask methods according to EN 717-3 (1996) initially and after 8 weeks of samples conditioning at an ambient room temperature. In order to determine a bonding quality of plywood the shear strength test was carried out according to EN 314-1 (2004). Plywood glued with UF adhesive was tested in dry state and after soaking in water (20 ± 3°C) for 24 hours. Panels bonded with MUF adhesive were tested after 24 hours of soaking in water and after pretreatment consisting of boiling in water for 6 h and cooling in water for 1 hour at 20 ± 3°C which was briefly called boiling when describing the results. The determination of formaldehyde emission involved 5 samples from each variant and shear strength involved 12 samples from each variant. The obtained results were subjected to a multivariate statistical analysis ANOVA. Moreover, in order to distinguish homogeneous groups the Tukey test on a significance level of α = 0.05 was performed using Statistica 13.0 software.

RESULTS AND DISCUSSION

The results of flour compositions determinations are summarized in Tab. 3. On the basis of presented outcomes it can be concluded that the soy flour was characterized by significantly higher proteins content than rye flour.

Tab. 3: The composition of flours.

Type of flour	Percentage content of the components (%)				
	Water	Proteins	Ash	Fat	Carbohydrates
Rye flour	14.39 ± 0.36	12.53 ± 0.32	1.51 ± 0.09	1.54 ± 0.10	70.36 ± 0.47
Soy flour	6.49 ± 0.86	50.71 ± 0.31	7.33 ± 0.10	1.25 ± 0.04	34.22 ± 0.48

The high protein content is a favorable feature for the extender and it indicates that the soy flour can be possibly applied as a bio-based scavenger. The proteins in soy flour contains many potentially reactive side-chain amino acid groups (Fan et al. 2011). The numerous groups occurring in amino acids, proteins and peptides demonstrate the ability to undergo the addition and condensation reactions with HCHO (French and Edsall 1945). The formaldehyde reacts with amino and thiol groups and methylol derivatives are formed. Subsequently the part of methylol adducts are dehydrated and the Schiff-bases are formed which consequently allows the further type of cross-linking reactions with other amino acid residues (Hoffman et al. 2015, Metz et al. 2004). Fig. 1 shows the results of investigations regarding the ability of flours to absorb the formaldehyde.

Studies have shown that probably due to the higher protein content the soy flour absorbed the formaldehyde more efficiently when compared to the rye flour. The higher flours content in the solution was, the more noticeable the tendency was. It probably resulted from the increased amount of protein introduced with the soy flour. Similar effects were observed in the investigations concerning the addition of a bark particles and sludge to the formaldehyde solutions. Moreover, the application of these substances as fillers in the adhesive compositions resulted in a decreased HCHO emissions from plywood bonded with UF resin (Bekhta et al. 2019, 2021).

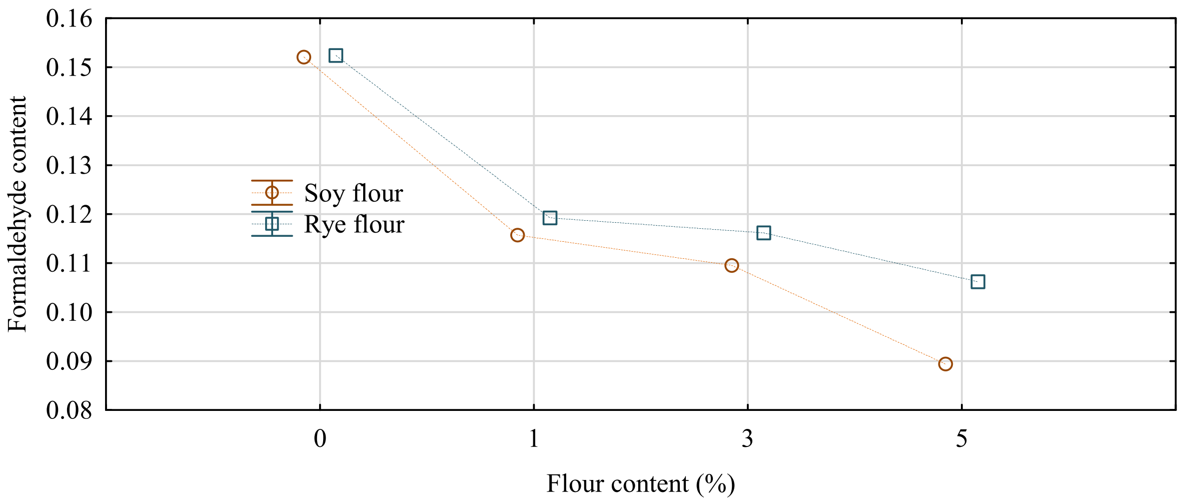


Fig. 1: Formaldehyde content in the aqueous solution of formaldehyde with soy and rye flour.

The FTIR spectra of UF resin, UF resin with the rye flour and the soy flour as extenders are presented in Fig. 2. Since the course of the spectra of adhesives containing the soy flour in various concentrations were the same only one variant was presented. The broadband observed in the 3390 cm^{-1} range was corresponded to the O-H and N-H groups (Ghahri et al. 2018). Two peaks in the 2970 cm^{-1} and 2890 cm^{-1} were attributed to C-H symmetric and asymmetric stretching of CH_2 and CH_3 groups, respectively (Ghahri et al. 2018, Wang et al. 2008). The bands at 1650 cm^{-1}, 1540 cm^{-1} were assigned to C=O stretching and N-H bending bands in amide I and II (Su et al. 2010, Zhang et al. 2017). Moreover, a peak at 1240 cm^{-1} was also observed and it was corresponded to C-N stretching and N-H bending vibrations of amide III (Ghahri et al. 2018). The above-mentioned bands were considered constant across the all adhesive formulations. Additionally, in case of introducing soy and rye flour as the extenders, an overlapping of the bands from the resin components and the components of filling materials, mainly proteins and carbohydrates, were observed.

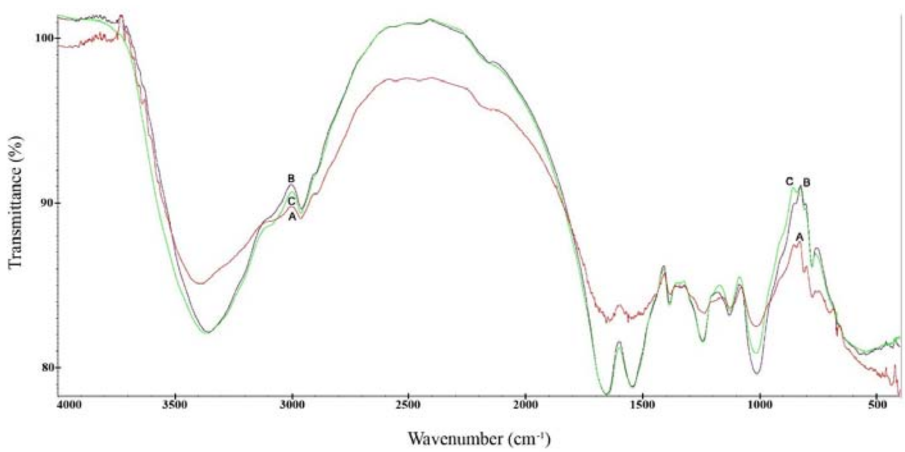


Fig. 2: FTIR spectra of: A – UF resin without any extender, B – variant labeled as UF-20, C – variant labeled as UF-R.

The spectra of both the pure and flour-filled MUF adhesives are presented in Fig. 3. The weak peak at 1657 cm^{-1} was corresponding to the NH_2 band and it occurred for MUF resin (Yuan et al. 2016). Band at 1554 cm^{-1} was detected and according to Luo et al. (2015) this band was caused by secondary amides (-CONH-). The bands from a triazine ring of melamine was occurred at 812 cm^{-1} (Luo et al. 2015, Reimschuessel and McDevitt 1960). Moreover, in the spectra of flour-filled MUF resin, there were bands observed at 1011, 1165 and 1370 cm^{-1}, which could be connected with presence of polysaccharides in soy and rye flours. Many polysaccharides were presented by a specific band in the 1200-1000 cm^{-1} region and dominated by the ring vibrations overlapped with the vibrations of C-OH group and C-O-C glycosidic bond (Kačuráková et al. 2000). In turn, the band at 1370 cm^{-1} can be attributed to bending vibration of C-H and C-O groups of the aromatic rings in polysaccharides (De Rosa et al. 2011). The spectrum marked with A symbol was characterized by higher intensity of these bands, than spectrum labeled as B, which is connected with higher content of polysaccharides in rye flour than in soy flour. The investigations of chemical interaction between the resins and the extenders showed only the presence of flours but based on that, it cannot be unambiguously stated that the chemical reactions occurred. Similar effect was observed in studies concerning the addition of e.g. wheat derivatives and nanocellulose as the filling substances for UF resin (Hogger et al. 2020a, Kawalerczyk et al. 2020b).

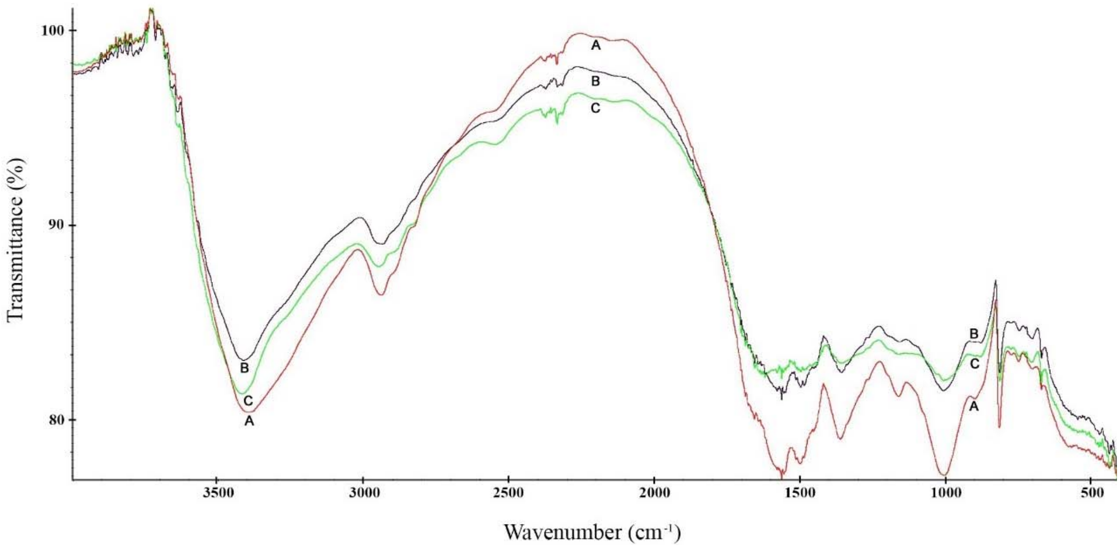


Fig. 3: FTIR spectra of: A – variant labeled as MUF-R, B – variant labeled as MUF-15, C – MUF resin without any extender.

Tab. 4 shows the results of adhesives properties investigations. The outcomes indicate that the type of extender influenced especially such properties as the viscosity and the gel time. Viscosity is an essential parameter in adhesive application during the plywood manufacturing. Too low viscosity results in deterioration of bonding strength because of the excessive resin penetration into the porous veneer surfaces. Consequently, the amount of remaining bonding agent is insufficient to ensure good strength of the glue lines (Kawalerczyk et al. 2020a).

Tab. 4: Properties of adhesive mixtures.

Variant label	Viscosity (mPa×s)	Solid content (%)	pH	Gel time (s)
UF-R	4798 ± 12	71.41 ± 0.09	7.0 ± 0.1	89 ± 2
UF-15	3465 ± 21	69.33 ± 0.11	7.1 ± 0.2	73 ± 1
UF-20	3681 ± 18	71.32 ± 0.04	7.0 ± 0.1	71 ± 2
UF-25	3996 ± 14	72.41 ± 0.07	7.1 ± 0.2	69 ± 2
MUF-R	4661 ± 23	68.19 ± 0.03	7.8 ± 0.1	94 ± 2
MUF-10	3007 ± 18	68.03 ± 0.09	7.7 ± 0.3	85 ± 2
MUF-15	3113 ± 11	68.11 ± 0.02	7.7 ± 0.3	82 ± 1
MUF-25	3519 ± 13	68.49 ± 0.08	7.7 ± 0.1	75 ± 2

The reference variants containing rye flour were characterized by a higher viscosity than the soy flour-filled mixtures. The adhesives mixed with soy flour reached values in the range between the 2000 – 4000 mPa×s assigned to machine application by a glue applicator (Dunky and Niemz 2013). The increased viscosity may be caused by the higher content of carbohydrates. Studies performed by Bekhta et al. (2014) showed that the viscosity of PF adhesive heightened with the increasing amount of starch. The starch is able to absorb the water and swell which leads to intensive rise of viscosity. Studies performed by Hogger et al. (2020b) described a slightly different tendency in case of wheat extenders, however, the rye starch is characterized by a significantly lower gelatinization temperature than the wheat starch (Verwimp et al. 2004). It seems like the type of extenders has not affected the solid content which increased along with the increasing share of filling particles contained in the composition. The pH values reached the similar values regardless of the type of flour. The gel time of MUF adhesive was longer in comparison with UF resin which corresponds with the Zhang et al. (2013) observations on an adverse effect of melamine addition on resin curing behavior. Moreover, the gel time varied depending on the introduced flour. The application of soy flour was beneficial since the curing time was shortened. It can possibly lead to the shortening of pressing time or to the reduction of plywood pressing parameters (Mirski et al. 2011). The gelation process was faster probably due to the higher amount of proteins. The proteins contained in the flour composition shows high reactivity with the methylol groups of amino adhesives which leads to obtain a highly cross-linked polymer structure in the shorter period of time (Fan et al. 2011). Similar effect was observed in case of applying hemp flour characterized by the high proteins content (Kawalerczyk et al. 2020c).

Fig. 4 presents the results of the formaldehyde emission from manufactured plywood panels measured initially and after 8 weeks of storage in an ambient room temperature. The hazardous formaldehyde emission is still a major disadvantage of amino resins especially in the indoor environments since the HCHO was classified as the known human carcinogen (Antov et al. 2020c,b, Réh et al. 2019). As expected, plywood bonded with UF resin was characterized by the higher formaldehyde emission in comparison with panels glued with MUF resin because of the melamine scavenging ability (Dutkiewicz 1984, Paiva et al. 2012). The addition of soy flour had a positive effect and led to a decrease in the amount of formaldehyde emitted from the plywood. The more soy flour was included in the adhesive composition, the less amount of HCHO was emitting from the panels.

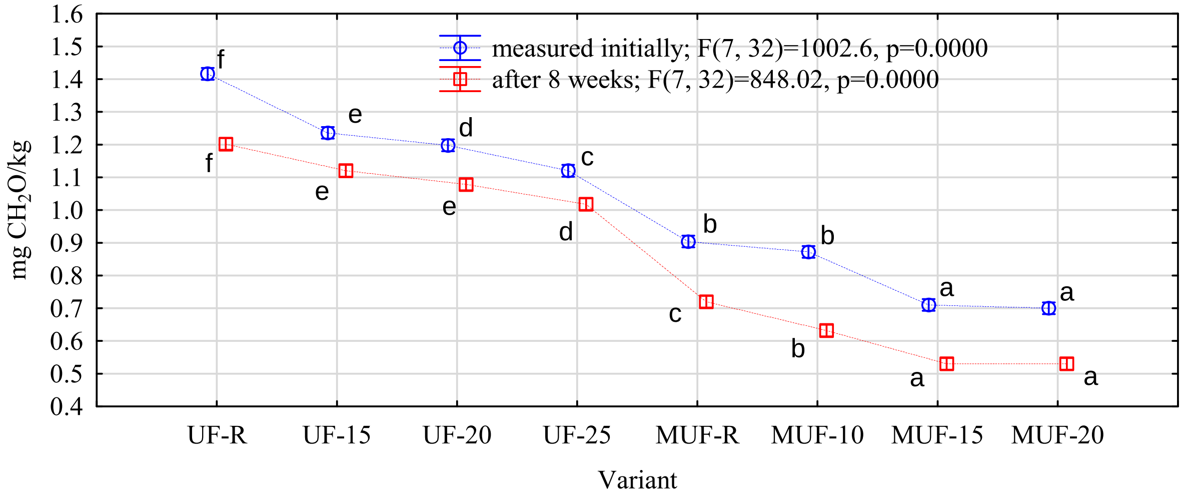
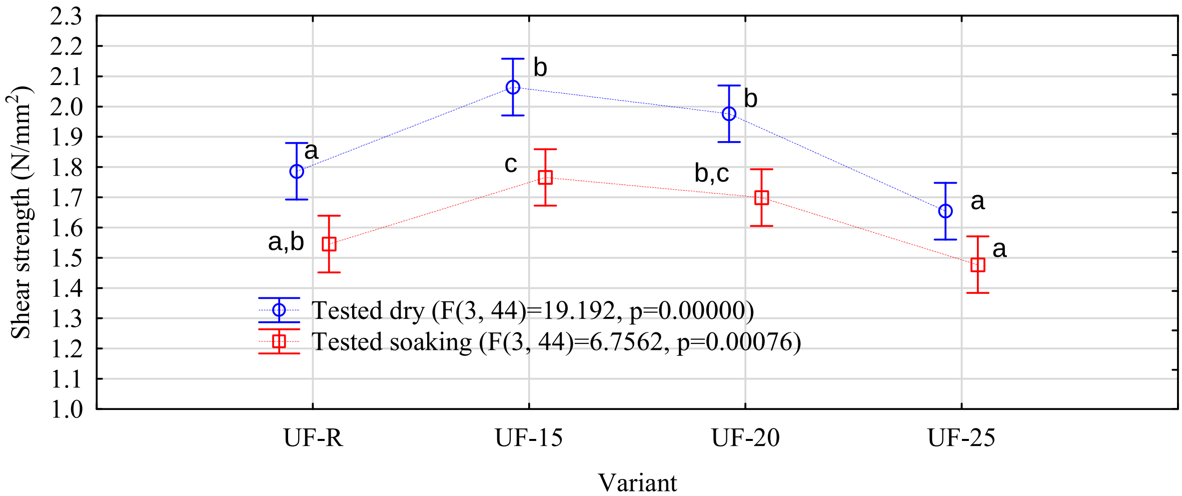
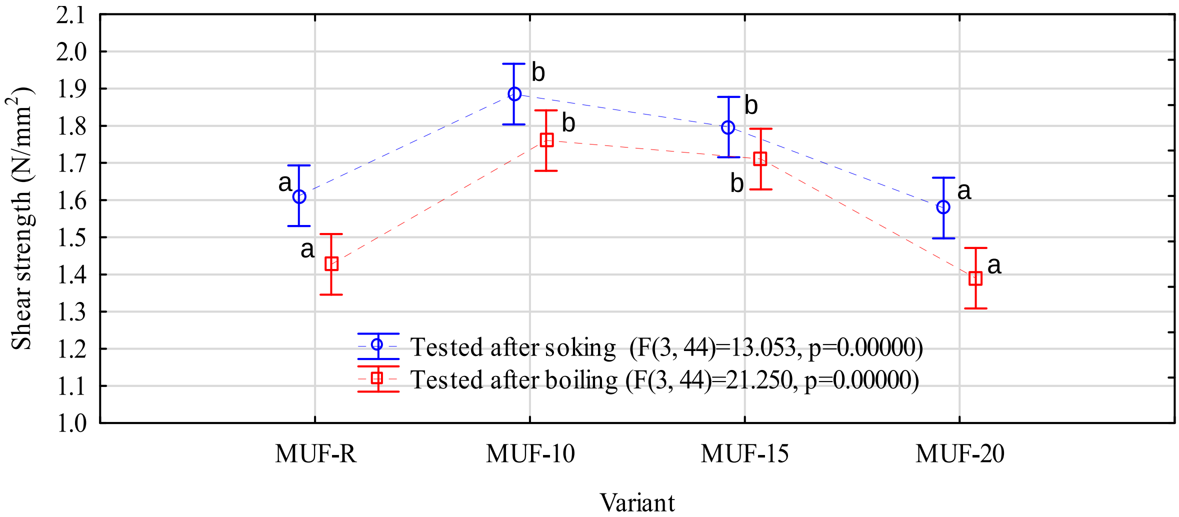


Fig. 4: Formaldehyde emission from plywood (F(x,y)=z,p where F– Roland Fisher's test method, x– number of degrees of freedom, y – number of tests, z– value of F test, p– probability level).

The emissions measured initially decreased by up to 20% in case of plywood glued with UF resin and up to 22% in case of plywood with MUF resin in variants assuming the highest concentrations of soy flour. The measurements conducted after 8 weeks of storage showed a decrease by up to 15% and 25% for plywood bonded with UF and MUF adhesives, respectively. The application of soy flour led to a significant reduction in formaldehyde emissions because of the proteins molecules which contain many functional groups such as amines and amides. These groups can easily react with HCHO (Xing et al. 2013). Similar effect was observed in studies concerning the addition of protein-rich hemp flour to the UF and MUF adhesives in plywood production (Kawalerczyk et al. 2019b, 2020c).



(A)



(B)

Fig. 5: Shear strength of: (A) plywood bonded with UF resin; (B) plywood bonded with MUF resin (F(x,y)=z,p where F – Roland Fisher's test method, x – number of degrees of freedom, y – number of tests, z – value of F test, p – probability level).

In order to assess the effect of the rye flour replacement with the soy flour on plywood bonding quality, the shear strength test was carried out. The results are presented in Fig. 5. The best results for UF resin were obtained for variant assuming the soy flour application in the concentration of 15%. It resulted in the increase in shear strength by up to 13% for plywood tested in dry conditions and after soaking in water. Further addition of soy flour in the amount of 20% also resulted in the statistically significant improvement. Similar tendency was noted in variants glued with MUF adhesive. The most advantageous effect was obtained for plywood bonded with the mixture containing a 10% of soy flour. The increase of bonding strength was up to 14% and 19% in the tests conducted after soaking and after boiling, respectively.

As expected, plywood glued with the MUF adhesive reached higher values after soaking in comparison with the UF resin due to the increased water resistance resulting from the melamine addition (Zanetti and Pizzi 2003). The improvement in bonding quality was probably caused because of the high content of proteins included in the soy flour composition. According to Wang and Pizzi (1997) a secondary amido groups contained in the protein chain skeleton show a high reactivity with formaldehyde and the methylol groups of resin. The ongoing chemical bonding leads to the intensification of the cross-linking reactions. However, regardless of the adhesive type, the addition of soy flour in maximum concentration led to a slight decrease in plywood bonding quality. The results were comparable with the reference panels and there were no statistically significant changes noted. Too excessive water absorption by the extenders may lead to a lack of water which participates in forming a three-dimensional crosslinking structure of the resin (Réh et al. 2019). Moreover, the introduction of the extenders in that high concentrations can cause a formation of agglomerates. It leads to the weakening of bonding strength due to the stress accumulation in the certain points of glue line.

CONCLUSIONS

The results of investigations concerning the composition of flours and the ability of flours to absorb the formaldehyde indicate that soy flour can be applied to the amino resins as a scavenger reducing the formaldehyde emissions. The course of FTIR spectra revealed mainly functional groups of adhesives and the presence of proteinaceous extenders but the analysis has not explained the chemical interaction between the flour and the polymer. The replacement of rye flour with the soy flour affected the viscosity values and led to the acceleration of gel time. The type of extender has not influenced the solid content and the pH values. The introduction of soy flour to the UF and MUF adhesive compositions resulted in manufacturing plywood characterized by improved bonding quality and reduced formaldehyde emission.

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