

Impact of phenol film grammage on selected mechanical properties of plywood

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Abstract: *Impact of phenol film grammage on chosen mechanical properties of plywood.* For the purpose of this research several plywood samples with a thickness of 15 mm were produced and coated, in industrial conditions, with 5 different variants of phenol films varying in terms of grammage (40/120 g/m², 60/145 g/m², 60/167 g/m², 80/220 g/m², 2 × 80/220 g/m²). Finished plywood was tested for abrasion resistance, MOR, MOE and density. It was concluded that higher grammage of phenol film increases wear resistance and final density of plywood. Plywood coated with two-layer phenol film with grammage of 80/220 g/m² had 4 times higher rate of abrasion resistance in comparison with plywood coated with phenol film with surface density of 40/120 g/m². Coating plywood surface with phenol films generally decreases MOR values, in comparison with uncoated plywood. In terms of MOE, there were no evidence of conclusive relation, despite statistically significant differences between each variant.

Keywords: phenol film grammage, plywood, mechanical properties

INTRODUCTION

Despite of many new wood materials being developed, plywood is still a valuable material used across many industries. The best arguments for the fact are plywood production statistics. According to Food and Agriculture Organization of United Nations (FAO) (<http://www.fao.org/faostat>) data, during last 10 years plywood total production volume has increased by 80% and amounted to over 163 million m³. In the same time in Europe, plywood production volume increased by 40%, and in 2018 it amounted to almost 10 million m³. In 2018, Poland's annual production volume was approximately on the level of 555 000 m³, which gives it 14th place globally and 3rd place in Europe. Moreover, according to the FAO data, in 2018 over 362 300 m³ of softwood and hardwood plywood was exported from Poland and over 373 600 m³ was imported to the country. Based on European Panel Federation (EPF) data, in 2018 plywood was used in various industries: furniture – 30%, construction – 39%, transport – 14%, packaging – 9%, other – 8% (<https://europanel.org>).

Plywood popularity is mainly related to its durability parameters, which derives from layered structure and cross-grain composition of adjacent veneers (Baldwin 1995, Curry and Hearmon 1967, Okuma 1976, Parczewski *et al.* 1969, Sellers 1985, Starecki 1991, Niemz 1993, Thoemen *et al.* 2010). Just like other wood-base materials, plywood could pose some limitations related to its surface resistance while exposed to external factors (moisture, UV radiation, mechanical damage). The resistance can be improved by applying appropriate finishing materials on the surface or special chemical substances (Sellers 1985, FFIF 2002, Borysiuk *et al.* 2005, Borysiuk *et al.* 2006, Borysiuk and Jabłoński 2003, Borysiuk and Nowak 2006, Kurowska and Borysiuk 2010). Borysiuk *et al.* (2017) stated that finishing plywood surface with resin-based coatings (urea-formaldehyde and phenol-formaldehyde) can reduce water and vapour absorption and increase wear resistance. However, authors did not conclude how applying the mentioned finishing solutions can influence plywood mechanical properties. Nonetheless, in their research Saroj *et al.* (2019) stated that fibre glass, generated on plywood surface and impregnated with epoxy resin, can improve durability parameters and reduce moisture penetration.

On the other hand, Biblis and Carino (2000) checked impact of the fibre glass impregnated with epoxy resin on pine plywood properties. They noted that applying the mentioned coating positively influenced MOR and MOE properties, especially in regards to plywood with cross-grain composition. What is more, applying epoxy resin-based and polyvinyl acetate coating, reinforced with basalt fibre, can also improve plywood mechanical properties (Kramár and Král 2019, Kramár *et al.* 2020). However, it should be mentioned that in both cases authors applied coating only on one side of the board. The majority of research conducted on finding new ways to reinforce plywood using fibre materials is based on applying reinforcing material in bonds between each veneer (Borysiuk *et al.* 2012, Bal *et al.* 2015, Liu and Guan 2019, Auriga *et al.* 2020). It is also possible to improve durability parameters using preliminary compressed veneers (Bekhta and Marutzky 2007, Bekhta *et al.* 2009, Bekhta *et al.* 2012, Gaff and Gašparík 2015).

It is common to apply phenol films or plastic coatings for technical plywood, used mainly in construction industry (Kuusipalo 2001, FFIF 2002, Kurowska and Borysiuk 2010, Fierek *et al.* 2013). The aforementioned coatings provide high resistance to external factors, simultaneously maintaining primary resistance parameters of plywood. For better moisture penetration resistance of phenol film coating it is preferable to additionally modify its surface with silanes before impregnating papers with PF resin. (Wang *et al.* 2014). Moreover, to provide anti-skidding surface producers commonly use phenol films with grid pattern, which is obtain by pressing process. Despite better wear resistance, plywood is also characterized with improved friction ratio (Fierek *et al.* 2013, Sachek and Mezrin 2020). Phenol films used as coating can have grammage from 120 g/m² to 460 g/m², depending on the intended use (FFIF 2002, <http://www.sklejka.pl>, <http://www.sklejkaorzechowo.pl>, <https://biaform.com.pl>, <https://sklejkapaged.pl>, <https://sklejkapaged.pl>). The final value of phenol films grammage depends on base paper grammage and amount of applied phenol-formaldehyde resin. Grammage of Kraft paper, used in phenol film amounts to a range of 40 g/m² up to 100 g/m² (<http://phenolicpaper.com>). In materials containing specifications for plywood finished with phenol films producers commonly include information about its surface resistance to abrasion. It is common to relate higher film grammage with higher wear resistance (FFIF 2002).

An analysis of research conducted up to this day showed no information about how phenol film influences mechanical properties of film-faced plywood.

MATERIALS AND METHODS

For the purpose of this research, 11-layer birch plywood with nominal thickness of 15 mm was produced. The plywood characterized with standard perpendicular grain composition in adjacent layers. Plywood gluing process was performed using a bonding compound, based on phenol-formaldehyde (PF) resin. Moreover, the plywood was coated on both sides with phenol films with grammage of (description: paper grammage / grammage paper impregnated with resin):

- 40/120 g/m²,
- 60/145 g/m²,
- 60/167 g/m²,
- 80/220 g/m²,
- 2 x 80/220 g/m².

Pressing process of phenol films was performed in industrial conditions, with following technological parameters: time – 450–540 s (depending on phenol film grammage), temperature – 135–140 °C, unit pressure – 1.6 MPa.

After finishing, the plywood with phenol film coating was air-conditioned in climatic chamber, according to PN-EN ISO 291:2010 standard, for 72 hours in temperature of $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$ and relative air moisture of $50\% \pm 5\%$.

A wear resistance test of the phenol film-faced plywood was conducted in accordance with PN-EN 438-2+A1:2019-01 standard. The test was performed using a Taber S-42 (TABER[®] Industries, USA) unit, equipped with self-adhesive abrasive belts with 12.7 mm of width and 160 mm of length and $70\text{ g/m}^2 - 100\text{ g/m}^2$ of grammage. Tested samples had dimensions of 100 mm x 100 mm x 15 mm. 3 samples were tested for each variant. During testing, the samples were rotated with a speed of 58–62 rpm. The abrasive belts were changed after every 200 revolutions. Samples' surfaces had been examined after every 100 revolutions. After noticing first signs of wear, the examinations were conducted after every 50 revolutions.

MOR and MOE tests were conducted in accordance with PN-EN 310:1994 standard. The tested samples had dimensions of 350 mm x 50 mm x 15 mm and were manufactured in two different structure types: cross and longwise grain composition in external layers. Plywood without phenol film coating was used as reference the material. 50 samples were tested for each type and variant. The examination was carried out using a Zwick Roell Z010 (ZwickRoell GmbH & Co. KG, Germany) universal testing machine.

A statistical analysis of the results was carried out in TIBCO SoftwareInc (2017), Statistica (data analysis software system), version 13. Analyses of variance (ANOVA) were used to test ($\alpha=0.05$) for significant differences between factors. A comparison of the means was performed using Tukey test, with $\alpha=0.05$.

RESULTS AND DISCUSSION

The results from surface abrasion resistance tests for the film-faced plywood are presented on fig. 1. It can be generally stated that phenol film grammage has a significant impact on abrasion resistance.

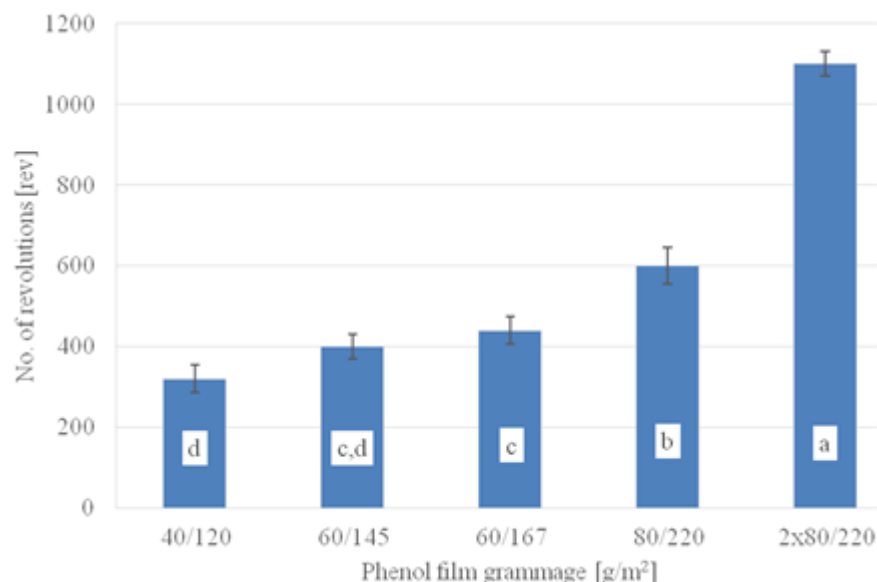


Figure 1. Surface abrasion tests results for phenol film-faced plywood (a, b, c, d – homogeneous groups by Tukey test)

Applying the phenol film with a high grammage improves plywood resistance to mechanical damages (Sellers 1985, Baldwin 1995, FFIF 2002, Pilato 2010). Coatings based on two layers of phenol films with a grammage of $80/220\text{ g/m}^2$ provide approximately 4 times

higher abrasion resistance in comparison with coatings based on phenol films with a grammage of 40/120 m². Similar relation between higher resin content and improved abrasion resistance was noted by Nemli and Usta (2004), who tested melamine films. It should be also mentioned that resistance to abrasion at 1000 revolutions allows to compare these coatings to HPL and CPL laminates, which are characterized by a very high wear resistance rate (<https://www.egger.com>).

Table 1. Results from MOR, MOE and plywood density research

Variant	MOR (N/mm ²)			
	Longwise		Transversely	
	Average	St. Dev.	Average	St. Dev.
No coating	79.9 ^a	11.3	71.3 ^{de}	10.3
40/120	69.5 ^{def}	4.9	65.4 ^{fg}	6.7
60/145	73.5 ^{bcd}	5.9	63.3 ^g	6.7
60/167	79.0 ^a	6.7	76.2 ^{abc}	6.3
80/220	77.2 ^{ab}	8.1	72.2 ^{cde}	4.0
2x80/220	70.8 ^{de}	5.4	67.9 ^{efg}	7.8
Variant	MOE (N/mm ²)			
	Longwise		Transversely	
	Average	St. Dev.	Average	St. Dev.
No coating	8564 ^{bc}	667	7480 ^e	924
40/120	8385 ^{bcd}	368	7499 ^e	418
60/145	9047 ^a	476	6794 ^f	532
60/167	8241 ^{cd}	494	8999 ^a	371
80/220	8174 ^d	241	8538 ^{bc}	363
2x80/220	8660 ^b	534	8388 ^{bcd}	307
Variant	Density (kg/m ³)			
	Longwise		Transversely	
	Average	St. Dev.	Average	St. Dev.
No coating	715 ^d	18	706 ^e	16
40/120	741 ^{ab}	7	730 ^c	13
60/145	739 ^{ab}	8	739 ^{ab}	10
60/167	737 ^b	8	729 ^c	9
80/220	716 ^d	10	729 ^c	8
2x80/220	743 ^{ab}	12	746 ^a	9

a, b, c, d, e, f – homogeneous groups by Tukey test

Tabela 2. ANOVA for selected factors affecting MOR, MOE and density of plywood

Factor	MOR		MOE		Density	
	p	X [%]	p	X [%]	p	X [%]
test direction	0,0000	10.26	0,0000	12.10	0,0275	0.39
phenol film grammage	0,0000	20.12	0,0000	12.26	0,0000	46.02
Test direction * phenol film grammage	0,0005	2.57	0,0000	38.21	0,0000	6.65
Error		67.05		37.44		46.94

p – significant with $\alpha=0.05$; X – percentage of contribution

The resistance test results for plywood and their grammage are presented in table 1. Table 2 shows the analysis of different factor variations (phenol film grammage, test direction), how they interact with each other with regard to MOR, MOE and the density of finished plywood. It can be generally stated that both, phenol film grammage and test direction have statistically significant impact on the examined plywood parameters. With regard to MOR, applying phenol films, in general, caused a reduction in the resistance values

in comparison with the uncoated plywood. It amounted to a maximum of 13%, while conducting test longwise grain and 11% while conducting test transversely to grain structure. On the other hand, in regards to particleboards melamine film coating in general improves their resistance (Nemli *et al.* 2005, Nemli and Çolakoğlu 2005, Borysiuk *et al.* 2019). It was also noted that higher phenol film grammage had ambiguous impact on MOR of tested plywood. The reduction of MOR caused by phenol films coatings is related to a low resilience rate of hardened phenol-formaldehyde resin, which is rather stiff, rigid and fragile (Pilato 2010). During the bending test, the maximal tensile and compression stresses (depending on placement) are transferred through layers generated on plywood surface. An analysis of MOR showed that phenol film grammage had twice higher percentage impact on the values (20.12%) than test direction (table 2). However, it should be also noted that the impact of the above-mentioned factors is significantly lower than the impact of factors not included in the research (error = 67.05%).

Taking into consideration MOE, there was ambiguity noted in the impact of phenol films grammage on the analyzed parameter values during the research. Similar changes in the percentage values (approx. 12%) were noted for both the grammage of phenol film and the test direction. Concluding all the checked factors, the highest percentage impact (38.21%) on parameter values was noted for the relation between the phenol film grammage and test direction (table 2). What is also important, significant impact on MOE values had factors not included in the research (error = 37.44%). The highest MOE difference values, depending on phenol films grammage, amounted to 10% while conducting test along the grain and 25% while conducting test transversely to the grain structure. Similarly, to mentioned MOR, the impact of the coating is totally different with regard to particleboards, whose resilience is rather improved along with the application of a melamine films coating (Nemli *et al.* 2005, Nemli and Çolakoğlu 2005, Borysiuk *et al.* 2019).

Concerning plywood density, it can be stated that the application of a phenol film coating generally causes a statistically significant increase of the subject matter parameter. Impact of phenol film grammage is presented percentage-wise and amounted to 46% (table 2). Moreover, taking into consideration MOR and MOE, the impact of factors not included in the research on the final density value was also distinct (error = 46.94%). For phenol film-faced plywood with a grammage of 2x80/220 g/m², the highest noted increase value amounted to 6%. However, the results from the research had not proved that the plywood density value had increased after applying the phenol film with a higher grammage (table 1).

The obtained values for phenol film-faced plywood are comparable to, or even higher than, the average values related to birch plywood with a thickness of 15 mm, manufactured in industrial conditions (<https://sklejkapaged.pl>):

- MOR tested transversely to grain structure – 52 N/mm²;
- MOR tested longwise to grain structure – 60 N/mm²;
- MOE tested transversely to grain structure – 6300 N/mm²;
- MOE tested longwise to grain structure – 7200 N/mm²;
- density rate – 700 kg/m³.

CONCLUSION

Based on the research conducted on birch phenol film faced plywood with various grammage it can be stated that:

1. Application of phenol film coating with higher grammage increases plywood wear resistance.
2. Plywood coated with two-layer phenol film with grammage of 80/220 g/m² have 4 times higher rate of abrasion resistance in comparison with plywood coated with phenol film with grammage of 40/120 g/m².

3. Plywood coated with phenol film is characterized by lower MOR values in comparison with analogous plywood without coating. However, there is inconclusive relation between increase of rate of phenol film grammage and decrease of MOR parameters.
4. Coating plywood surface with phenol films with various grammage inconclusively influences its MOE parameters.
5. Applying phenol films with higher grammage increases the final plywood density rate.

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Streszczenie: *Wpływ gramatury filmów fenolowych na wybrane właściwości mechaniczne sklejek. W ramach badań przemysłowe sklejki brzożowe o grubości 15 mm wykończono w warunkach przemysłowych 5 wariantami filmów fenolowych, zróżnicowanych pod względem gramatury (40/120 g/m², 60/145 g/m², 60/167 g/m², 80/220 g/m², 2 × 80/220 g/m²). Wykończone sklejki poddano badaniom odporności na ścieranie, MOR, MOE i gęstości. Wykazano, że wzrost gramatury filmu fenolowego wpływa na wzrost odporności na ścieranie oraz gęstość sklejek. Sklejki uszlachetnione podwójną warstwą filmu fenolowego o gramaturze 80/220 g/m² wykazują 4 krotnie wyższą odporność ścieranie w porównaniu do sklejek uszlachetnionych filmem fenolowym o gramaturze 40/120 g/m². Pokrycie powierzchni sklejek filmem fenolowym wpływa na ogół na spadek wartości MOR w stosunku do sklejek niewykończonych. W przypadku MOE, pomimo statystycznie istotnych różnic pomiędzy wariantami, nie odnotowano jednoznacznych zależności.*

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