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THERMOPLASTIC PLYWOOD AND IT'S DRAWBACK WHEN MODERATELY HEATED

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ABSTRACT

GradaTM is new plywood which contains the thermoplastic adhesive. There are so far two material versions 1000 and 2000 which have wide potential in production of wooden products with new perspective of manufacturing. This paper investigates possibilities of including GradaTM material and its versions in skateboard production. Bending strengths at the moderate heat up of this material are presented, specifically at 30, 40°C for both material versions. All increased temperatures are compared to the room temperature (20°C). Mechanical properties that were obtained from the test are modulus of elasticity, modulus of rapture, and stroke strain. The results show the undesirable level of changes present in both versions however version 1000 acts significantly better than 2000.

KEYWORDS: Plywood, thermoplastic plywood, skateboard, mechanical properties, moderate heating.

INTRODUCTION

Plywood is a versatile product that can combine an attractive surface appearance with superior performance under hazardous conditions whilst retaining comparatively high strength to weight ratios (Réh 2013). Regarding composition it is a laminated composite structure where three or more veneers are across each other, connected by a bonded joint. The need for an odd number of veneers is caused by the fact that wood is an anisotropic material, i.e. it has different properties in three main directions, longitudinal, radial and tangential (Irle and Barbu 2010). The classification of plywood is based on manufacturing, species, surface appearance, application field, conditions, glue type etc. (Irle et al. 2013). Plywood allowed the creation of flowing and curving forms. Technology enabled new process for molding and manipulating these building materials, allowing designers to step away from squares and rectangles and explore a more fluid approach to design (Barbu et al. 2014). This paper is focused on hot melts adhesives (HMAs) used in GradaTM thermoplastic plywood construction manufactured by UPM.

HMAs are spread onto substrates in the melt followed by solidification after cooling oppose to thermosetting resins which form polymers that are cross-linked during cure and they are insoluble which means they do not soften on heating. Often refer to a polymer of lower molecular weight and viscosity than most thermoplastics such as poly (ethylene–co–vinyl acetate) (EVA), polyolefins, polyamides, and polyester has been basis of HMAs (Shih and Hamed 1997). These thermoplastics of 100 % solid materials melt in the temperature range from 65 to 180°C although most HMAs melt at about 79°C and they are usually applied at much higher temperatures, from 150 to 290°C (Ebnesajjad 2015).

HMAs main application is general packaging (case and cartoon sealing and assembly), bag manufacturing, book and magazine binding, pressure sensitive tape and label applications, disposables, etc. However, new types of HMAs have appeared in gluing and processing of wood as well (Kajaks et al. 2009; Rolando 1998). Mainly wood composites such as plywood are the concern of using HMAs in this study.

Skateboard industry processes considerable large amount of veneers gluing them into plywood based products where HMAs could be used as a new approach to the manufacturing process. Furthermore except of simplifying the production it is also desirable to replace conventional thermosetting glues based on phenol–formaldehyde, amino–formaldehyde, melamine–formaldehyde as well as epoxy and urethane resins. Formaldehyde is a human carcinogenic. Ecological claims on decreasing emissions of dangerous volatile products from wood composite materials manufacture have been increasing. Therefore many investigators are challenged to solve this problem (Grinbergs et al. 2010; Kajaks et al. 2012).

The idea of this research was to determine a suitability of thermoplastic plywood produced of two versions of thermoplastic adhesive for skateboard industry by testing bending strength at levels of increased temperature 30 and 40°C. Skateboard decks primarily require stiffness and right amount of springiness. The results show if there are some descent in these properties at above mentioned temperature which may occur during the use of these products or not.

MATERIAL AND METHODS

Birch (*Betula pendula* Roth.) commercially recognized as Finnish birch was main wood species which all plywood for the experiment was made from. Used veneers in plywood were rotary cut glued together in a typical cross bonded construction by means of thermally activated foil with nominal thickness of 10 mm. Plywood was made by UPM-Kymmene Wood Oy enterprise at Jyväskylä plywood mill, Finland and it was used as an experimental material which is commercially known as product named UPM GradaTM. The undergoing experimental material is the latest version marked as UPM GradaTM 2000 and its previous version GradaTM 1000. UPM GradaTM is the first application of the new technology based on special adhesive film which allows the plywood to be formed after production. The UPM GradaTM with its two versions 1000 and 2000 is designed specifically for the manufacturing of form pressed components. The initial average moisture content (determined by thermos-gravimetric method) in plywood of version 1000 was 5.36 % whereas in plywood of version 2000 was 4.5-5.0 % and subsequently collective average for density was determined for both versions 640.48 kg.m^{-3}.

GradaTM 2000 in comparison to its previous version UPM GradaTM 1000 is more reactive to the exposure of heat which allows formability already at 95°C instead of 130°C binding version 1000. According to the enterprise thus pressing process is made more efficient and safes energy required for the process. The enterprise also states for the entire brand name that the plywood is absolutely free of formaldehyde or other harmful compounds which fulfills the EN 13986 E1 (2004) and the CARB No Added Formaldehyde emission classes. Veneer sheets are bonded with moisture resistant bonding (EN 314-2/ class 3, 2014). The face veneer quality complies with EN 635 (2009), BB (III) classification.

The mechanical testing in this experiment represents three-point bending. Tests were carried out according to the standards EN 310 (1998) and EN 319 (1995). In total in version 2000 for three-point bending was used 39 test pieces divided into 4 categories 20°C, 20 crosswise, 30, 40°C. The same principle of division for version 1000 except number of test pieces increased to 55 pieces. Due to nature of experiment of testing at moderately increased temperature a certain test pieces modification was required.

In case of three-point bending test, the test pieces were modified with 1 cm thick StyrofoamTM glued to the top and bottom of the pieces to preserve accumulated heat while conditioned in the oven for one hour. In addition the precaution taken by StyrofoamTM insulation, a radiating heating device was placed behind the supports of testing machine to secure higher temperature around the perimeter of testing parts. Each test piece was wired with 4 heat measuring probes to observe temperature reduction from the point of taking individual piece from the oven till the end of the test. Average time was recorded approximately within 60 seconds.

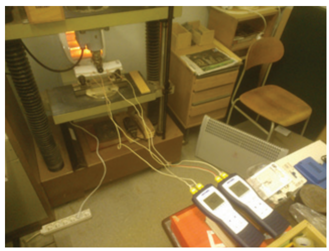

Fig. 1: Three-point bending test and its performance.

The set-up of the test describes Fig. 1. Temperature measurement was initiated when the probes were placed under the StyrofoamTM and it was recorded, the same process occurred after the rupture. The reduction was counted in percentage between initial and final average temperature which resulted into 1 % reduction for test pieces that fall into 30°C category and 3 % for pieces that fall into 40°C category.

Detailed data figures are shown in Tab. 1.

Tab. 1: Reduction of temperature in the moments of inserting probes and rupture.

Start						Finish					
Catg.	T1	T2	T3	T4	Average	T1	T2	T3	T4	Average	Reduction (%)
30°C	30.50	30.50	30.21	30.25	30.37	30.02	30.26	29.75	30.21	30.6	1.00
40°C	41.41	41.46	41.37	41.46	41.43	40.09	40.13	40.28	40.22	40.18	3.1

RESULTS AND DISCUSSION

By determining bending properties and tensile strength perpendicular to the surface of moderately heated thermoplastic plywood, the following mechanical properties were obtained.

Tab. 2: Three point bending of moderately heated thermoplastic birch plywood of GRADA 2000.

20°C	MOE (N·mm^{-2})	MOR (N·mm^{-2})	AB (%)	20°C crosswise	MOE (N·mm^{-2})	MOR (N·mm^{-2})	AB (%)
Mean	7835.7	77.60	1.47	Mean	6288	79.54	1.95
SD	129.2	4.30	0.14	SD	176.14	3.45	0.16
SE	40.86	1.40	0.04	SE	58.71	1.15	0.05
Minimum	7607.4	68.10	1.27	Minimum	6049.8	75.07	1.71
Maximum	8000.9	81.90	1.64	Maximum	6520.3	85.81	2.15
N	10	10	10	N	9	9	9
30°C	**MOE (N·mm^{-2})**	**MOR (N·mm^{-2})**	**AB (%)**	**40°C**	**MOE (N·mm^{-2})**	**MOR (N·mm^{-2})**	**AB (%)**
Mean	3933	76.2	1.89	Mean	3995.7	62.10	1.51
SD	505.2	3.8	0.09	SD	431.4	7.40	0.20
SE	159.77	1.19	0.03	SE	136.42	2.35	0.06
Minimum	3039.6	66.7	1.78	Minimum	3169.1	49.40	1.29
Maximum	4609.6	78.55	2.13	Maximum	4722.2	72.20	1.91
N	10	10	10	N	10	10	10

Tab. 3: Three point bending of moderately heated thermoplastic birch plywood of GRADA 1000.

20°C	MOE (N·mm^{-2})	MOR (N·mm^{-2})	AB (%)	20°C crosswise	MOE (N·mm^{-2})	MOR (N·mm^{-2})	AB (%)
Mean	8947.8	85.3	1.22	Mean	4155.57	60.1	1.94
SD	422.98	8.21	0.16	SD	389.66	6.69	0.30
SE	109.21	2.12	0.04	SE	87.13	1.50	0.07
Minimum	8222.40	73.18	0.93	Minimum	3372.99	42.10	1.09
Maximum	9639.83	100.02	1.51	Maximum	4972.38	66.90	2.51
N	15	15	15	N	20	20	20
30°C	**MOE (N·mm^{-2})**	**MOR (N·mm^{-2})**	**AB (%)**	**40°C**	**MOE (N·mm^{-2})**	**MOR (N·mm^{-2})**	**AB (%)**
Mean	7652.28	76.55	1.55	Mean	7651.55	80.45	1.46
SD	930.53	11.10	0.20	SD	753.05	9.42	0.16
SE	240.26	2.87	0.05	SE	194.44	2.43	0.04
Minimum	6238.69	55.37	1.15	Minimum	6080.48	64.22	1.16
Maximum	9131.75	87.61	1.88	Maximum	8510.66	94.37	1.71
N	15	15	15	N	15	15	15

MOR - modulus of rupture, AB – stroke strain, SD - standard deviation, SE – standard error, N - sample size.

According to the presented results there is a significant difference between unheated samples and those exposed to moderate heating; specifically at heating to 30 and 40°C. Values of modulus of elasticity and bending rigidity of version 1000 and 2000 are presented in Tabs. 2 and 3. Version 2000 of temperatures 30 and 40°C reached only average of around 4 000 N.mm^{-2} (t-test there is not significant difference between 30 and 40°C $p = 0.768$) whereas at 20°C the average was 7 835.7 N.mm^{-2} which is approximately 49 % reduction of rigidity at 30 and 40°C (Figs. 2 and 3).

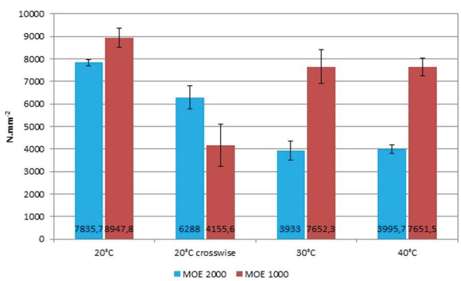

Fig. 2: Modulus of elasticity MOE of version 1000 and 2000.

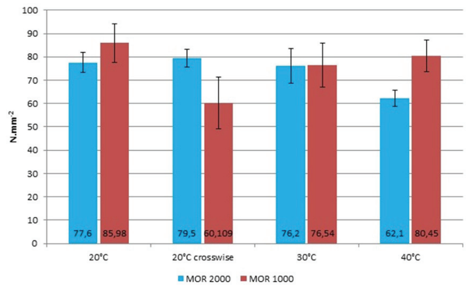

Fig. 3: Modulus of rapture MOR of version 1000 and 2000.

Looking to the version 1000 where the average of MOE at 30 and 40°C is around 7 652 N·mm^{-2} (t-test there is not significant difference between 30 and 40°C p = 0.49) whereas at 20°C the average was 8 947.8 N·mm^{-2} which is approximately 14.5 % reduction of rigidity at 30 and 40°C.

Such reduction in strength is explained by nature of hot melts adhesives and their drawback that the compositions tend to be temperature sensitive. In other words the bonding mass tends to lose bond strength as the temperature of the bonding mass and the substrate is increased (Markevka et al. 1988).

On the contrary behavior of modulus of rupture had noticeably different character whereas version 2000 had at 20°C the average value of modulus of rapture 77.6 N·mm^{-2}, at 30°C it was 76.2 N·mm^{-2} which is in reduction of strength only 1.8 %. According to the t – test there is not significant difference p = 0.440. Interestingly groups of samples heated to 40°C were already reduced in average down to 62.1 N·mm^{-2} which equals to 20 % of strength weakening. Version 1000 behaves slightly different as version 2000 when temperature is raised to 30°C. The average is 76.55 N·mm^{-2} reduced by 10.25 % when compared to the average 85.3 N·mm^{-2} at 20°C. When comparing groups of 30 and 40°C according to the t – test there is no significant difference p = 0.154 however there is very small statistical difference between groups 40 and 20°C p = 0.0488 and likely between the whole group of 20, 30 and 40°C ANOVA p = 0.0354. Results show that as far as the version 2000 is concerned its rigidity does not go equally with the strength of tested material. In other words the strength of the material does not undergo changes until the temperature is raised over 30°C. As far as the rigidity is concerned, the significant changes occur already before temperature reaches 30°C. Reduction in percentage between the groups can be seen in Tab. 4.

Tab. 4: Reduction in MOE, MOR and increase in AB.

Parameter	Version	Φ 20°C	Φ 20°C cross (%)	Φ 30°C (%)	Φ 40°C (%)
MOE	2000	7835.7 N·mm^{-2}	-20	-49	-49
	1000	8947.8 N·mm^{-2}	-53.55	-14.48	-14.48
MOR	2000	77.6 N·mm^{-2}	+2.5	-1.80	-2.0
	1000	85.3 N·mm^{-2}	-29.54	-10.25	-5.6
AB	2000	1.47 %	+32.65	+28.57	+2.72
	1000	1.22 %	+59.00	+27.00	+19.67

The similar sequence in this case is increase of border fiber prolongation meaning higher flexibility was observed. The average value of AB in group of 20°C was 1.47 % and in the group of 30°C it was 1.89 % in group of 40°C it was 1.51 % which increases up to 28.6 % and 3 % of comparing group respectively. There is no clear explanation why group of 40°C illogically retreats back to the comparable group in these 2 parameters and there is not statistical back up of significant difference when t – test calculated p = 0.624.

As far as the version 1000 is concerned and its border fiber prolongation there was a similar increase in flexibility when heated. However the behavior was slightly different than at version 2000. The average value of AB in group of 20°C was 1.22 % and in the group of 30°C it was 1.55 % in group of 40°C it was 1.46 % which increases up to 27 % and 19.7 % of comparing group respectively. The same but significantly milder retraction was again detected with the group of 40° meaning that prolongation diminishes when reaching higher temperature at this particular range which could be only explained within the adhesive itself. When comparing groups of 30 and 40°C according to the t – test there is no significant difference between these 2 groups p = 0.1.

Regarding the comparability of versions, version 1000 fares better with prolongation consistency as well as with the undergoing changes in this parameter. It concerns groups 20, 30 while at the group of 40°C according to ANOVA there is not significant difference p = 0.52. Parameter AB can be seen in Fig. 4.

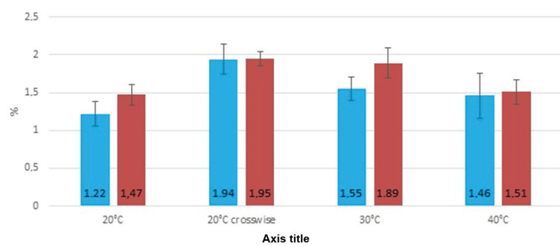

Fig. 4: Fiber prolongation (strain stroke) AB of version 1000 and 2000.

For a general view of both versions we also stated comparisons between lengthwise and crosswise samples of both versions only at standard room temperature. The observation results as expected where version 2000 and its crosswise group of samples had in comparison with group of lengthwise samples 20 % reduction in MOE, not significant increase in MOR only 2.5 % p = 0.301, 30 % reduction in MOR and increase in flexibility AB 32 %. The version 1000 had the similar trend of decrease in all the properties as version 2000. Up to 54 % reduction in MOE, nearly 30 % weakening in MOR and expected considerable increase in AB 59 %. The results corresponded to the order layout of plywood where more layers with crosswise fibers are in the structure than in other comparable group.

CONCLUSIONS

Based on the analysis of bending properties of moderately heated thermoplastic birch plywood under the trademark GradaTM versions 1000 and 2000 the following can be concluded:

- Mechanical properties were negatively affected when the samples were moderately heated mainly concerning version 2000 which is more thermally reactive than version 1000.
- MOR of version 2000 at 30°C did not show significant reduction in comparison with

comparing group of 20 however at 40°C the reduction was already significant.
- MOE of version 2000 at 30 and 40°C did not show significant differences in stiffness between these two groups however in comparison with the group of 20°C the decrease of rigidity was profound.
- MOR of version 1000 was very similar in all tested groups.
- MOE of version 1000 was already affected reducing MOE about 14.5 % which is considerably less in comparison with 48 % at the version 2000.
- All these changes with high probability are caused due to sensitivity of glue compounds toward increased temperature even if its way below glass transition point.
- Although version 1000 is not suitable for normal skateboard decks manufacturing, in the sector of longboard manufacturing it could be applicable mainly in a sense of skipping production stages and thus accelerating the whole manufacturing process.
- Future research should lead to stabilize reactivity of glue compounds when it is sufficiently under the glass transition point.

The obtained results show that the version 2000 saves energy consumption and time even if positively reacts at lower temperature. It negatively affects mechanical properties when temperature stabilization becomes problematic at the moderately increased temperature. It would be recommended to use only version 1000 which is significantly more stable even if the temperature is moderately raised mainly when it is exposed to the natural conditions of summer season. Both versions straggle to retain stiffness for which it would most likely be rejected by skateboard companies, however for longboard industry there might be the applicability for a reason of having a variety of products with different stiffness requirements.

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REFERENCES

1. Barbu, M.C., Réh, R., Irle, M., 2014: Wood-based composites. In: Research developments in wood engineering and technology (ed. Aguilera A and Davim JP). Pp 1-47, IGI Global, Hershey.
2. Ebnesajjad, S., 2015: Characteristics of adhesive materials. Handbook of Adhesives and Surface Preparation. Pp 137-183, Elsevier Inc.
3. Grinbergs, U., Kajaks, J., Reihmane, S., 2010: Usage of ecologically perspective adhesives for wood bonding, Scientific Journal of Riga, Technical university, Material Science & Applied Chemistry (22): 114-117.
4. Irle, M., Barbu, M.C., 2010: Wood-based panel technology, Wood-based panels. An introduction for specialists. Pp. 1-94, Brunel University Press, London.
5. Irle, M., Barbu, M.C., Réh, R., Bergland, L., Rowell, R.M., 2013: Wood composites. In : Handbook of wood chemistry and wood composites, Second Edition. Pp 321-411, CRC Press, Taylor & Francis Group, Boca Raton.

6. Kajaks, J.A., Bakradze, G.G., Viksne, A.V., Reihmane, S.A., Kalnins, M.M., Krutohvostov, R., 2009: The use of polyolefins-based hot melts for wood bonding. Mechanics of Composite Materials 45(6): 643-650.
7. Kajaks, J., Reihmane, S., Grinbergs, U., Kalnins, K., 2012: Use of innovative environmentally friendly adhesives for wood veneer bonding. In: Proceedings of the Estonian Academy of Sciences 61(3): 207-211.
8. Markevka, V.C., Mackey, S.J., Bunnelle, W.L., 1988: Thermally stable hot melt moisture-cure polyurethane adhesive composition. Patent US4775719 A.
9. Réh, R., 2013: Plywood panels and decorative veneers. Dollis, s.r.o., Bratislava, 144 pp.
10. Rolando, T.E., 1998: Solvent-free adhesives. Rapra review reports, Report 101, 9(5): 16-20.
11. Shih, H.H., Hamed, G.R., 1997: Peel adhesion and viscoelasticity of poly(ethylene-co-vinyl acetate)-based hot melt adhesives. II. The influence of wax. Journal of Applied Polymer Science 63(3): 333-342.

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