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Róbert Németh, Paula Molnárné Posch, Sándor Molnár, Miklós Bak

PERFORMANCE EVALUATION OF STRIP PARQUET FLOORING PANELS AFTER LONG-TERM, IN-SERVICE EXPOSURE

Due to its extraordinary hardness, decorative appearance and possible small dimensions, black locust wood is assumed to be an excellent material for strip parquet flooring. The favourable colour changes achieved by controlled steam treatment further increased the utilization potential of this material. Flooring was installed on a student dormitory stair landing in heavy use. Due to the flooring's very high exposure, 5 years was considered a long enough period to compare the different face layer materials during in-service test. Oil was used as a coating to avoid the remarkable protecting effect of hard film-forming varnishes (acrylic, etc.) against abrasion. Besides the flooring turning grey (all face layers no matter what treatment), only some delamination occurred at certain places after five years in service. The laboratory test results for abrasion resistance, dimensional changes and deformation were analysed. Additionally, the Brinell-Mörath hardness after indoor service and the abrasion due to indoor service were analysed. In terms of abrasion resistance, dimensional changes and deformation, no essential differences were found between the oil-treated and untreated black locust wood on the one hand, and the control oak specimen on the other. Long-term tests showed that, after 5 years in service, the Brinell-Mörath-hardness decreased considerably for all the tested materials. The type of section and the presence of wide rays influenced the roughness and the waviness of the surface after indoor service.

Keywords: strip parquet flooring, black locust, steaming, Brinell-hardness, abrasion resistance, indoor service test, dimensional stability

Róbert Németh (*robert.nemeth@skk.nyme.hu*), Paula Molnárné Posch (*pposch@fmk.nyme.hu*), Sándor Molnár (*sandor.molnar@skk.nyme.hu*), Miklós Bak (*miklos.bak@skk.nyme.hu*), Simonyi Karoly Faculty of Engineering, Wood Sciences and Applied Arts, University of West Hungary, Sopron, Hungary

Introduction

In recent years, oak (*Quercus petraea* and *Quercus robur*) has been the most popular wood species used for the face layer in European parquet production [FEP 2009], but increasing demand can only be met with the growing use of other wood species. For this reason, it is possible to utilise wood species which are used mostly as firewood due to their smaller dimensions or lower yield (large ratio of wood defects), but which provide the necessary technical parameters for parquet production. Smaller log diameter is not a big problem in the field of parquet production, because of the small dimensions of parquet friezes. Furthermore, wood defects can easily be removed using technology. According to the criteria of hardness and abrasion resistance, the following wood species are suitable for parquet production: hornbeam (*Carpinus betulus*), turkey oak (*Quercus cerris*) [Todaro 2012] and black locust (*Robinia pseudoacacia*). An investigation of the different production technologies of oak face layers from the point of view of cost found that raw material costs amount to 80–85% of the total costs [Orłowski, Walichnowski 2013]. This result clearly shows the importance of the selection of the raw material.

The wood species used for flooring face layers have to comply with several technical criteria. Besides high abrasion resistance and hardness, colour homogeneity is also a criterion. Furthermore, from the point of view of utilization, dimensional stability is another important property. In terms of the abovementioned criteria, black locust corresponds to all but one, namely the colour homogeneity. However, this property can be improved with steaming [Dianiskova et al. 2008; Tolvaj et al. 2009; Tolvaj et. al. 2010]. Compared to oak, black locust has a higher density (690 kg/m^3 for oak, 770 kg/m^3 for black locust), higher abrasion resistance and a similar hardness (34 MPa Brinell hardness for both oak and black locust, perpendicular to the grain). In addition, the shrinkage/swelling of black locust is smaller than that of oak (13.35% volumetric swelling for oak and 11.4–12.2% volumetric swelling for black locust) [Molnár, Bariska 2005]. In the case of the wood species used in parquet production, it is important to know the expected hardness, abrasion resistance and the extent of the deformations, because from this information it is possible to predict the resistance to footprints and the applicability [Castro, Zanuttini 2004].

Heat treatment usually decreases the mechanical properties of the wood material, because of degradation of the main cell-wall components [Esteves, Perreira 2009]. However, in some cases, an increase in compression strength was reported [Fojutowski et al. 2009]. The effect of steaming and heat treatment on hardness has been tested using several treatment types and wood species, and the results have differed depending on the parameters used. A reduction in hardness has mostly been reported by the authors. Standfest and Zimmer [2008] investigated the effect of three different heat treatment schedules on the hardness of beech and ash wood. Compared to the untreated samples, only the most intensive treatment resulted in a decrease in hardness in radial and tangential directions. However, there was an increase in hardness parallel to the grain. Similarly, in the case of beech, Stanzl-Tschegg et al. [2009] also reported an increase in hardness parallel to the grain as a result of heat treatment. Gunduz et al. [2009] investigated the Brinell hardness of heat-treated hornbeam (*Carpinus betulus*) after an intensive heat treatment (12 hours at 210°C). The hardness decreased in the tangential direction, radial direction and parallel to the grain, 55%, 54% and 38%, respectively. Varga and van der Zee [2008] reported that steaming (at 92°C for 3–20 h, at 100°C for 7.5 h and at 108°C for 3–20 h) decreased the Jankahardness of four hardwood species, proportional to the temperature and time.

Dimensional stability is highly dependent on the water uptake. Źivkovic et al. [2008] investigated flooring elements made of heat-treated beech and ash wood. They stated that in terms of wood-water relations, the EMC was reduced by 50%, causing a 60% decrease in volumetric shrinking. Surface treatment with oils and waxes further improved the hygroscopic properties. Dimensional stability is particularly important in such places where the climatic conditions change continuously. The most common example of this is the difference between the winter and summer conditions in indoor living environments (in general 20–30% relative humidity (RH) in winter and 60–80% RH in summer). However, in community buildings, for example, where the door is frequently opened and closed, the climatic conditions change much faster and more often, thus the climatic exposure of the wooden flooring is higher. Deformations in wooden floorings especially appear in drier periods, however, the construction layout of the flooring product, the method of installation, and the environmental conditions of the building also play an important role [Drerup et al. 2012].

The overall aim of this study was to investigate the behaviour of black locust strip parquet face layers during and following indoor service and in laboratory conditions, with different face layers (untreated for the control group, light and dark steamed black locust, and oak (*Quercus robur*) for comparison) and using a hard natural oil surface treatment. Oak was involved in the test, because it is a widely used as a flooring face layer. The surface treatment was the same for all the surface layers during the indoor test in order to reduce the influence of coatings on surface wear and to control their influence on abrasion. Regarding very high exposure, 5 years was considered a long enough period to compare the different face layer materials during the in-service test.

The main question initiating this research was whether oak top layers could be replaced by black locust (control, light steamed, or dark steamed). Technical parameters, such as abrasion resistance and surface hardness, and their change due to steaming and the in-service test, were analysed in depth. Another important question of the investigation was whether the black locust top layers could withstand moisture-induced stresses (delamination, deformations) at least to the same extent as oak. On the other hand, as it was an in-service test, it was considered useful from a practical point of view to include observations concerning visible colour changes during the service as additional information in the article.

Materials and methods

The material for this investigation was supplied courtesy of Drava Parkett Kft., Barcs, Hungary. The flooring material was processed and coated on one of the company's regular production lines. Fig. 1. shows the three-ply structure of the flooring. Steaming of the black locust face layers was carried out in an industrial scale steaming chamber at atmospheric pressure and at two different temperatures. The temperatures were 85°C (light steamed) and 95°C (dark steamed), with the same heat holding duration of 48 hours. A 24 hour heating period was used before the heat holding, and a 24 hour cooling period thereafter. The surface treatment during the indoor service was a primer layer of transparent oil (35–40 g/m^2) with a top layer of transparent highsolid oil (25–30 g/m^2). The oil was manufactured by Waterlox Coating Corporation. The oil was used as a coating to avoid the remarkable protecting effect of hard film forming varnishes (acrylic, etc.) against abrasion. Four different face layers were investigated, namely: oak (O), natural (unsteamed) black locust (N), light steamed black locust (L) and dark steamed black locust (D). The core and bottom layer of the flooring material were made of spruce (*Picea abies*).

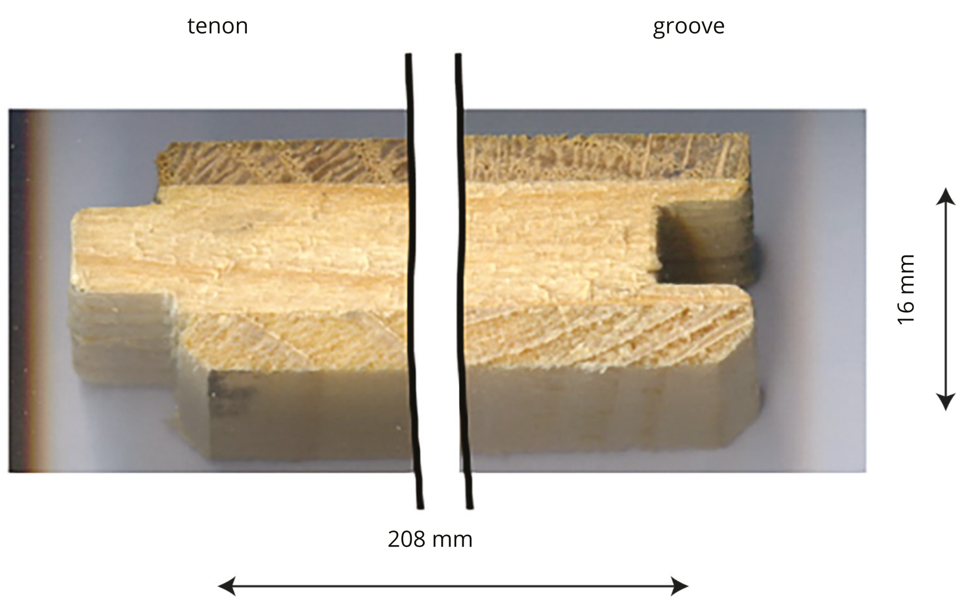

Fig. 1. The cross sectional structure of the flooring

Physical properties of the uncoated floorings (laboratory tests)
Abrasion resistance and Brinell-Mörath hardness

An investigation of the abrasion behaviour of the four different types of flooring panels was carried out according to standard ASTM D 4060-95 (Taber Method). The samples were conditioned (T = 20°C, φ = 65%) in a climatic chamber. The specimen dimensions were 100 × 100 mm, and the number of samples was 30 pieces for each floor type. The tests were carried out by measuring weight loss and thickness loss (at four points) after 400 rotations of the Taber abrasion device, both on the oil treated and untreated (non-oiled) floorings, according to the standard mentioned above.

The Brinell-Mörath hardness was investigated according to standard EN 1534:2011. The samples were climatized to standard climate (T = 20°C, φ = 65%) in a climatic chamber. The specimen dimensions were 50 × 50 × 16 mm, and there were 30 samples for each floor type. Tests were carried out by measuring the indentation depth.

Deformation and dimensional changes associated with changes in relative humidity

Calculation of the dimensional stability and deformations was done in accordance with the requirements of standard EN 318. The dimensions measured at control conditions (RH = 65% and T = 20°C) served as base values to which the percentage changes were calculated. The two exposure conditions were: RH = 33%; T = 20°C and RH = 84%; T = 20°C. According to the standard, one cycle was completed with both exposure conditions. Dimensional changes were measured at 33% and 84% relative humidity and related to the dimensions recorded at 65%, in case of each oak, natural black locust, dark and light steamed black locust. Increases in width (IW) and in length (IL) were defined by equations (1) and (2):

$$IW_{33\%/84\%} = \frac{W_{33\%/84\%} - W_{65\%}}{W_{65\%}} \cdot 100\% \tag{1}$$

$$IL_{33\%/84\%} = \frac{L_{33\%/84\%} - L_{65\%}}{L_{65\%}} \cdot 100\% \tag{2}$$

where: $IW_{33\%/84\%}$ – increase in width due to changing the RH from 65% to 33% or from 65% to 84%, respectively
$IL_{33\%/84\%}$ – increase in length due to changing the RH from 65% to 33% or from 65% to 84%, respectively
$W_{33\%65\%/84\%}$ – width of the specimen at the respective RH levels
$L_{33\%65\%/84\%}$ – length of the specimen at the respective RH levels

Deformations were measured at 33% and 84% relative humidity, and related to the dimensions recorded at 65%, in case of each oak, natural black locust, dark and light steamed black locust.The curvature values lengthwise (C-L) and across the width (C-W) of the panels were determined. The length and width of the panels were 850 mm and 208 mm, respectively. 6 samples were investigated from each face layer type. The height of the bow was measured using callipers. Positive and negative curvature values indicated convex or concave shapes, respectively.

The distribution normality of the data was verified and statistical significance tests (t-probe, ANOVA) were conducted for the effect of steaming and oiling.

Indoor service test

The mezzanine of the dormitory of the University of West Hungary was chosen for the in-service testing. This area is under very heavy traffic, as about 300 students live in the dormitory and use the stairs frequently. Figs. 2 and 3 demonstrate the location and set-up of the in-service flooring experiments. The area of the flooring was 12.25 m^2 (3 m^2 of each of the four types). Fig. 2 shows the layout and the main walking directions.

Although the staircase is heated during winter, the entrance door is usually open. During rainy and snowy weather, the floor is exposed to more moisture. Wear was expected to be very high due to the gravel access roads and fashion shoes with rough soles. It was advised that hot water without detergents should be used for cleaning. In this investigation, the oak and black locust layers were tested under the same use conditions. However, a detailed description of conditions (such as number and weight of people walking through the area, amount and size of abrasive elements present on shoes and the test surface, and the moisture content in the upper thin layer (range of abrasive elements), etc.) was not recorded, with the assumption that the same conditions were valid for all four different top layers.

As changes in colour and moisture content during service were not recorded (only observed), no correlations between the colour variation or moisture content, and the exactly measured data were investigated or are discussed in this paper. This information is only discussed to give additional information from a practical point of view concerning visible colour changes and cracks during service.

The four different top layers (D, L, N and O) were placed next to each other forming a section in order to have them exposed to similar wear. For identification of the lamellae of the surface layers, the letters a, b and c were used. The numbers 1 to 12 show the position of the elements in the row (fig. 2) Prior to installation, the characteristics of the top-layer lamellae were assessed and recorded. These attributes included the dimensions, grain orientations and visible defects. The floor was laid down on October 20, 1998. Visual observations were recorded every three months.

The Brinell-Mörath hardness was tested on all the floor types after the indoor service period. Before testing the hardness, the samples were climatized to normal climate (T = 20°C, φ = 65%). The abrasion caused during the 5 years of indoor service was also evaluated. The flooring elements were climatized after exposure to normal climate (T = 20°C, φ = 65%), and the thickness at the non-abraded edges and at the abraded middle section (second, third and fourth sections) was measured after reaching the equilibrium moisture content (EMC). The difference between the abraded and non-abraded thickness was the abrasion of the face layer after exposure. A test area with dimensions of 2500 × 120 mm, located in the middle of the floor section was chosen for the above investigations. This area involved sections 2, 3, and 4, and represented all four types of flooring, as indicated in fig. 2. Fig. 3 shows the flooring installed at the testing area.

Since an exact and detailed record of the in-service test for five years would hardly have been possible, it was logical to compare the laboratory method (Taber) and the in-service test.

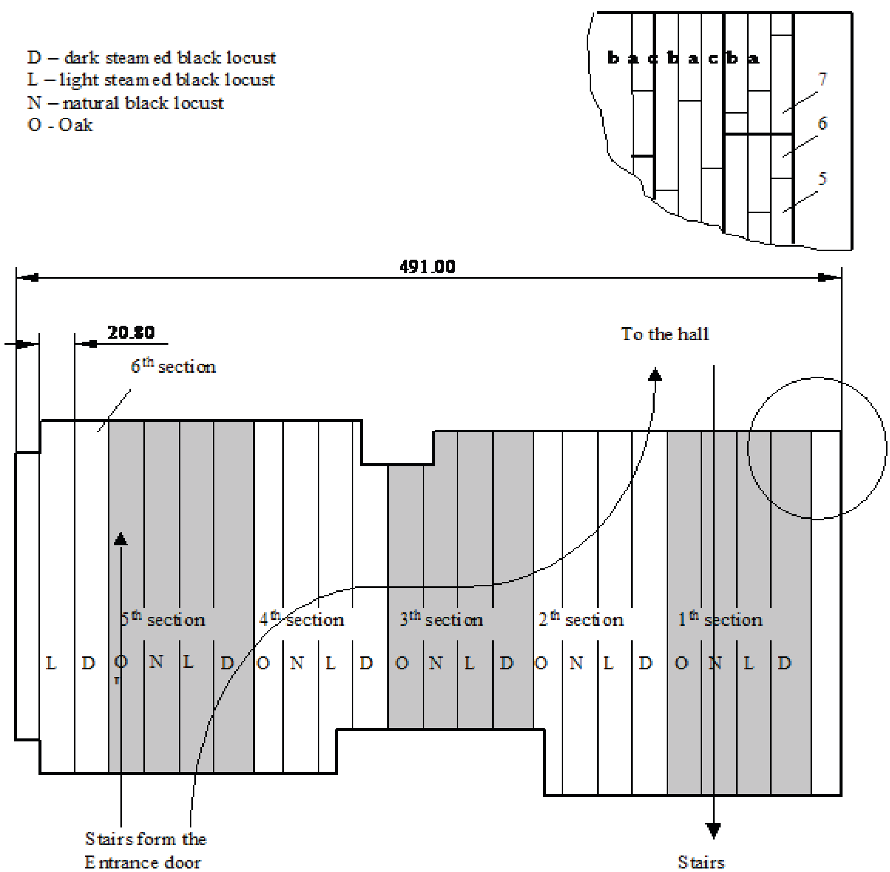

Fig. 2. Pre-fab flooring layout for indoor service

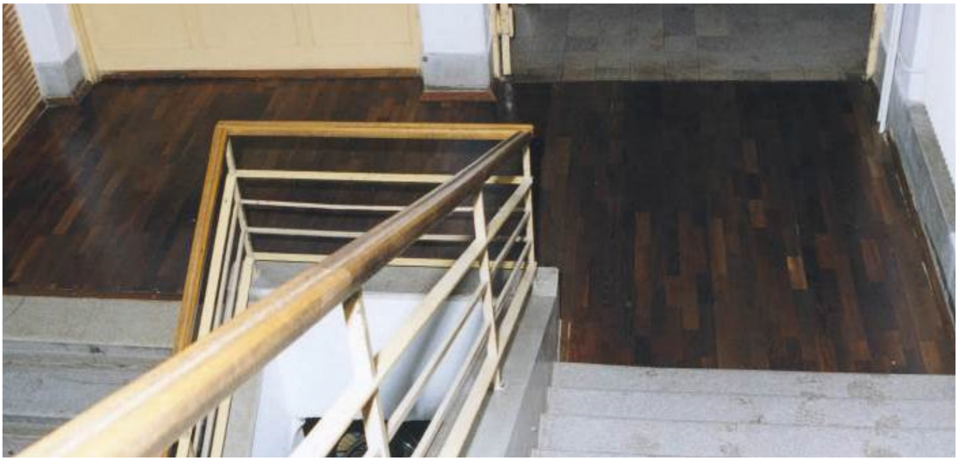

Fig. 3. The appearance of the floor after installation

Results and discussion

Laboratory tests – Abrasion resistance

Fig. 4 illustrates the results of the abrasion tests in terms of weight loss and thickness reduction for oak as well as natural, light and dark steamed black locust. To show the effect of the surface treatment (oil) on the abrasion resistance, the results before and after finishing are also shown. The distribution normality of the data was verified, and, in order to show the effect of the steaming and oiling, statistical significance tests were conducted in each case.

Comparing the results of the floorings without oiling, it was found that the wear of the dark steamed specimens, as expressed in thickness loss, was slightly higher (0.154 mm) than that of the oak (0.136 mm) and of the natural (0.149 mm) and light steamed black locust (0.143 mm). The abrasion expressed in weight loss showed higher values for the light steamed black locust (0.641g) when compared to the oak (0.574 g), the natural black locust (0.565 g), and to the dark steamed black locust (0.575 g) (fig. 4).

Compared to the floorings without surface treatment, oiling caused some decrease in abrasion resistance in terms of both thickness (+9.3%) and weight loss (+9.2%) only for the natural black locust (fig. 4.). The effect of oiling on the thickness loss (+18.4%) of the oak and the weight loss (−33.1%) of the light steamed black locust was also found to be significant. On the other hand, the abrasion resistance also increased slightly in the latter case. The effect of oiling on the dark steamed black locust was not statistically significant, but different when determined using the method based on weight loss (−5.2%) or thickness loss (+8.7%). As there is no plausible explanation why oiling of the wood surface should effect the abrasion resistance, the noted differences may be explained by differences in the density or in the anatomical direction of the respective substrates. This was an expected result of the random sampling, which caused high variability in the density and the anatomical direction of the face-layers in the samples. This simulates the real circumstances.

The steaming and oiling had a noticeable combined effect on the abrasion resistance. The wear of the natural black locust with oiling was significantly higher than that of the oiled, light steamed black locust for both thickness and weight loss (21.6 and 33.1%, respectively, see fig. 4). In the case of the dark steamed locust, the oiling only caused a statistically significant increase in the abrasion resistance in terms of the thickness loss (11.6%). However, there was a large difference between the light steamed and dark steamed black locust face layers in terms of abrasion (in both *mm* and *g*). The light steamed back locust also showed lower abrasion values with and without oiling. This may be explained by the chemical changes during steaming [Fengel, Wegener 1989; Todaro et al. 2013]. Steaming reduces the equilibrium moisture content (EMC) of wood, which increases the mechanical properties at a specified climate [Yilgor et al. 2001]. However, with an increase in temperature, chemical changes will reach a level where the reduced EMC will have a smaller increasing effect on the mechanical properties than the reducing effect of the chemical changes (thermal degradation of the cell wall structure). Middle lamellae are sensitive to heat [Boonstra et al. 2006], therefore a higher steaming temperature causes critical degradation from the point of view of the abrasion resistance. As explained previously, differences in density and anatomical direction are also likely to account for this trend.

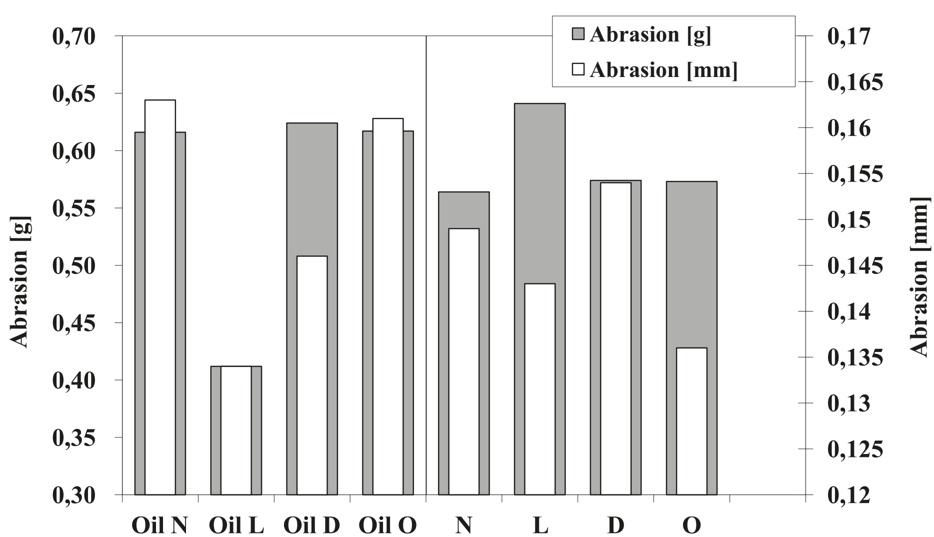

Fig. 4. Mean abrasion values by treatment and measurement method

Laboratory tests – Dimensional changes and deformation

Fig. 5 and 6 show the results of the dimensional and form stability changes measured at 33% and 84% relative humidity compared to the dimensions recorded at 65%. Fig. 5 shows the curvature values lengthwise (C-L) and across the width (C-W).

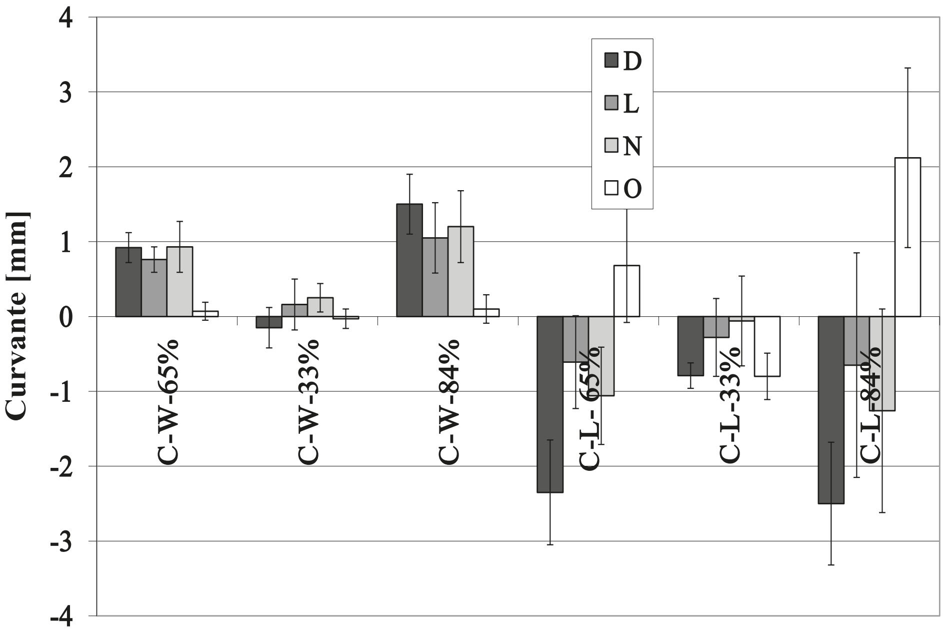

Fig. 5. Mean curvature values lengthwise and across the width at 65%, 35%, 84% RH (positive values: convex curvature; negative values: concave curvature)

The deformation (warp/bow/cup) of specimens with the black locust face layer was found to be smallest at RH 33%. This relative humidity was close to the value of RH 42% which generally characterises an in-door environment and corresponds to the approx. 8% equilibrium moisture content of black locust wood at 20ºC. The specimens with the dark steamed black locust face layer had the largest deformation compared to the other wood types. The oak was proven the most stable face layer material in terms of deformation in different climatic conditions.

Compared to the values found in literature, the dimensional changes in the pre-fab flooring elements were much smaller than those of solid wood, probably due to the mechanical constraints of the three-ply structure [Molnár, Bariska 2005] (fig. 6) The fact that after changing the relative humidity from 33% to 84% the samples did not even recover their original dimensions in width at 65% RH, seems to confirm this assumption.

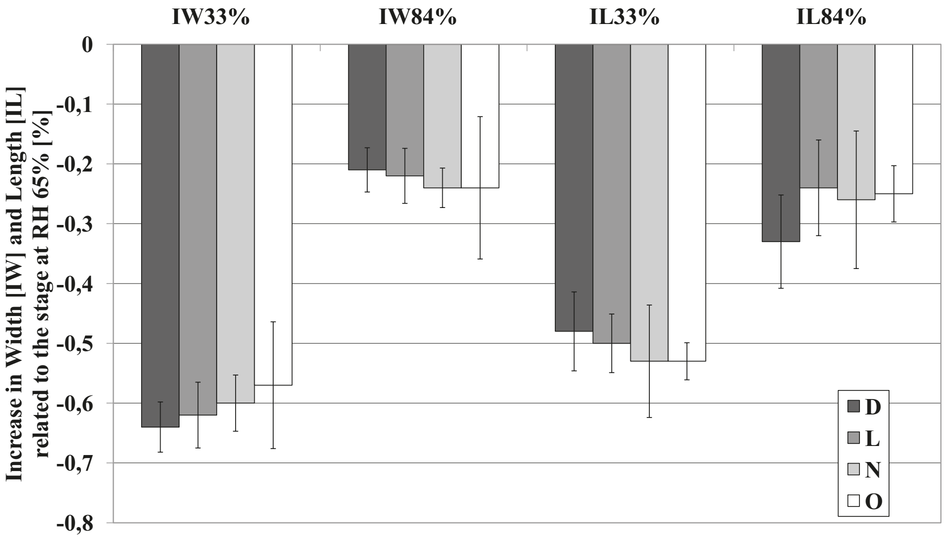

Fig. 6. Mean width and length increase value at 33% and 84% RH levels.

In-service test – Optical observations

Besides the pre- and post-treatment tests described above, regular inspections helped to assess the flooring conditions during the exposure phase of the research. These visual evaluations were scheduled between October, 1998 and June, 2003. The first assessment was carried out after 1 month of service, and it revealed that the appearance of the floor surface had entirely changed. The colour differences had disappeared completely and all the top layers had turned grey (in dry conditions) due to the heavy traffic and regular cleaning with hot water. Following this first observation, no further colour changes were noted. For comparison see fig. 7 a and b.

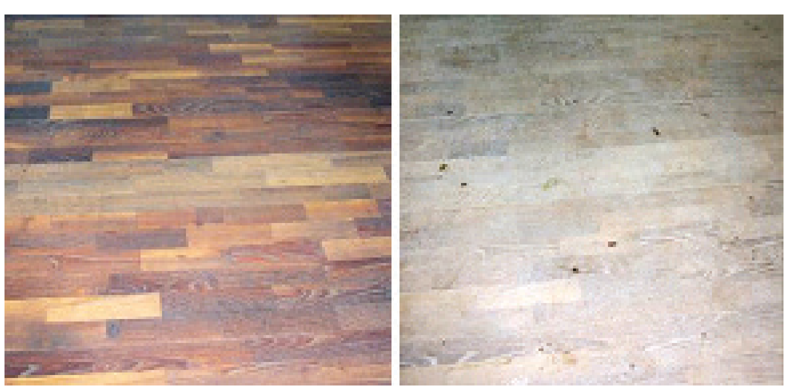

Fig. 7. The original conditions (a) and after exposure (5 year) (b) of the flooring

Wet spots were found along the joints between the lamellae and the elements. The oiling had disappeared after 1 month. After a 3.5 year indoor service period, the top layer became delaminated in 6 places. The location of the failure did not correlate with the wood species and position, and the failure area varied between 20 to 50 cm^2. Insufficient adhesion and cohesion forces, probably due to imperfect gluing, may have caused the latter phenomenon. During the fifth year of exposure, no further significant changes occurred. As the width of the previously measured gaps remained constant throughout the 5 year period, the periodic changes in relative humidity (weather) and exposure to water (cleaning) did not cause any significant movement of the three-ply flooring elements. Fig. 7 shows the original and present conditions (after five years of service).

Laboratory tests after indoor service – Brinell-Mörath hardness and abrasion test

For comparison, the values of hardness measured before the in-service test are also shown in fig. 8. In addition, abrasion after the indoor service was determined (fig. 9). The values resulting from the Taber test are also included for comparison.

After the service period, tests were conducted to show how the indoor service affected the Brinnel-Mörath hardness. As seen in fig. 8., a significant decrease in surface hardness can be observed. Reductions in hardness for the unsteamed, light steamed and dark steamed black locust and the oak were 22.03, 23.08, 32.34 and 18.65%, respectively. Reduced hardness means that abrasion will probably accelerate after five years.

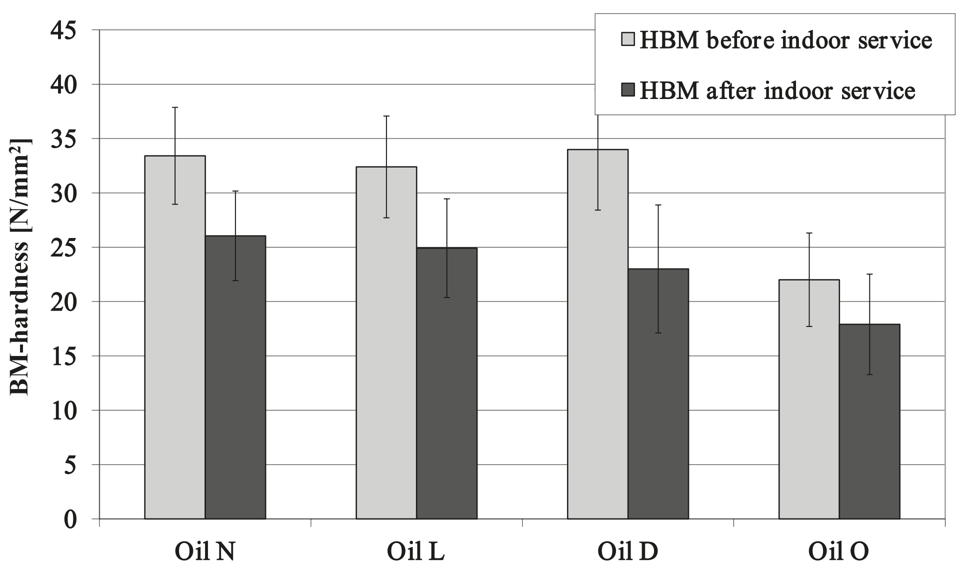

Fig. 8. Brinell-Mörath hardness values before and after indoor service

Investigations of the abrasion after the 5 year service showed that the unsteamed black locust and oak, with respective thickness losses of 0.164 mm and 0.183 mm, were the most stable top layer materials, while the light steamed and dark steamed black locust top layers resulted in the highest abrasion, 0.409 mm and 0.459 mm, respectively (fig. 9). The middle lamellae, which are sensitive to heat, were softened and slightly damaged during the steaming process. This decreased the cohesion between the fibres. This phenomenon is expected to result in increased abrasion in the steamed material.

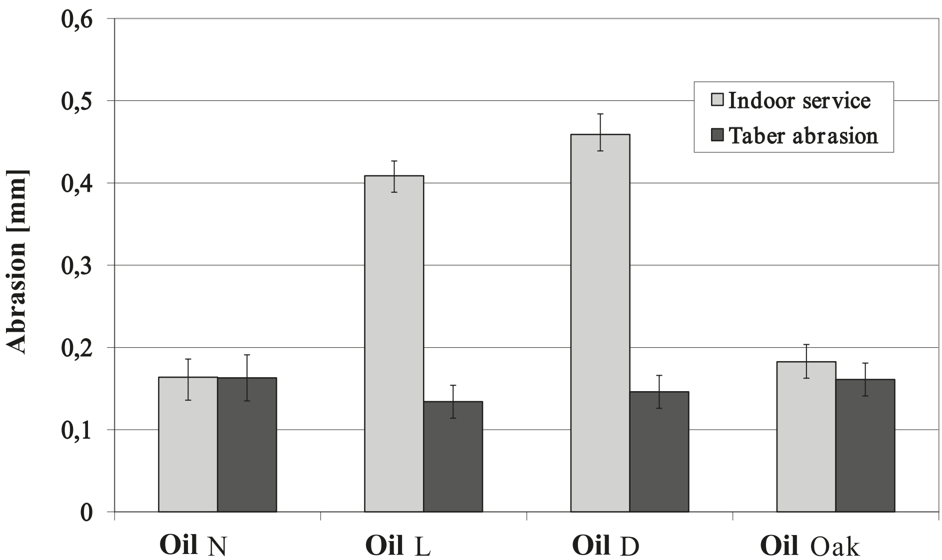

Fig. 9. Abrasion values measured after Taber test and indoor service (5 years)

Laboratory tests after indoor service – Effect of anatomical direction and wide rays on the surface characteristics during indoor service exposure

Due to the indoor exposure, the radial sections became rougher because of the ring porous character, i.e. the large vessels in the early wood (fig. 10 and 11 (a)). The tangential sections shown in fig. 10 and 11 (b) became wavier due to the harder late wood, mostly consisting of fibres.

As shown in fig. 12, the wide rays of the oak were more resistant to abrasion than the fibres. This property contributed to the inhomogeneity of the surface of oak floorings during service. While on tangential surfaces the rays caused roughness, on the radial section they resulted in smooth spots.

After analysing the effect of the anatomical direction on the surface roughness and waviness, it can be concluded that tangential surfaces became rougher, while radial surfaces became wavy after the indoor service. The wide rays of the oak had a special role in forming the surface. On the radial surfaces they kept the surface smooth, while on the tangential surfaces the rays caused roughness after the indoor service.

Fig. 10. Cross sections of black locust lamellae, showing surface roughness on the LR (a) and waviness on the LT (b) anatomical planes

Fig. 11. Cross sections of oak lamellae, showing surface roughness on the LR (a) and waviness on the LT (b) anatomical planes

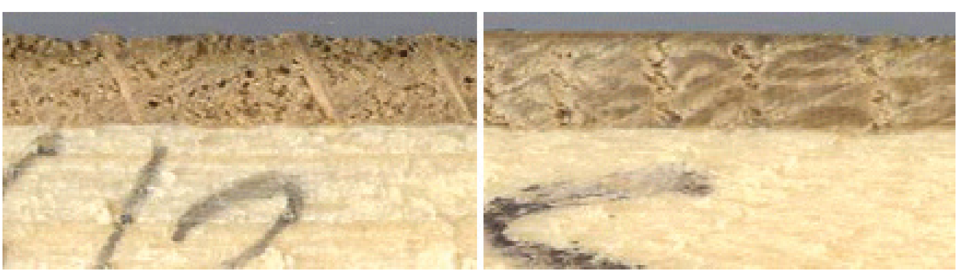

Fig. 12. Cross sections of oak lamellae, showing the effect of wide rays on the surface character of the LR (a) and the LT (b) anatomical planes

Conclusions

1. Under the prevailing conditions – a stair landing in a student dormitory under very heavy traffic – the appearance of the flooring elements changed rapidly, changes clearly visible to the naked eye after a short period. However, the landing did not suffer significant changes in structure or performance.

2. Based on this experiment, the effect of steaming on the abrasion resistance of the flooring top layers was found to be significant. Oiling significantly increased the abrasion resistance of the steamed specimens, but the obtained differences in abrasion resistance are more likely due to differences in the density and annual ring orientation (radial, tangential) than to the surface treatment. In general, the measured differences between the samples, although sometimes statistically significant, were small from a practical point of view. This is especially true when comparing the abrasion properties of the black locust with those of the oak, as with one method the oak attained superior ratings, while with the other, the black locust performed better.
3. Regarding dimensional changes and deformation, the tests yielded similar results for the oak and the natural black locust, whereas the light steamed black locust performed even better. The dark steamed black locust proved to be inferior to all the other materials.

In summarising the results obtained by this study on flooring element performance, both the in-service and the laboratory tests indicated that the wood density, grain orientation and element structure (three-ply) appear to effect the performance of the floor to a much higher degree than the different structure and treatments of the materials used. The black locust wood definitely proved to be the most suitable for in-door flooring applications.

References

Boonstra M.J., Rijsdijk J.F., Sander C., Kegel E., Tjeerdsma B., Militz H., van Acker J., Stevens M. [2006]: Microstructural and physical aspects of heat treated wood. Part 2. Hardwoods. Maderas. Ciencia y tecnología 8 [3]: 209–218

Castro G., Zanuttini R. [2004]: Multi-laminar wood: Manufacturing process and main physical-mechanical properties. Forest Products Journal 54 [2]: 61–67

Dianiskova M., Babiak M., Tolvaj L. [2008]: Colour homogenisation of cherrywood (*Cerasus avium* l.) and black locust (*Robinia pseudoaccacia* l.) during steaming. Wood Research 53 [4]: 45–58

Drerup M.J., Erdem I., Anthony R.W. [2012]: Trouble under foot – In situ and laboratory investigation of engineered wood flooring. Proceedings of the 6th Congress on Forensic Engineering 2012, 31th October – 3th November, San Francisco, CA, USA

Esteves M.B., Pereira H.M. [2009]: Wood modification by heat treatment: a review. Bioresources 4 [1]: 370–404

Fengel D., Wegener G. [1989]: Wood: Chemistry, Ultrastructure, reactions. Walter de Gruyter, Berlin, Germany

FEP, European Federation of the Parquet Industry [2009]: The European parquet industries in 2008. A challenging year for the European Parquet Sector. pp 1–5

Fojutowski A., Noskowiak A., Kropacz A. [2009]: Physical and mechanical properties and resistance to fungi of Scots pine and birch wood modified thermally and using natural oil. Drewno 52 [181]: 43–62

Gunduz G., Korkut S., Aydemir D., Bekar Í. [2009]: The density, compression strength and surface hardness of heat treated Hornbeam (*Carpinus betulus*) wood. Maderas, Ciencia y Tecnología 11 [1]: 61–70
Molnár S., Bariska M. [2005]: Wood species of Hungary. Szaktudás Kiadó Ház Rt, Budapest.
Orłowski K.A., Walichnowski A. [2013]: Analiza ekonomiczna produkcji warstw licowych podłóg klejonych warstwowo (Economic analysis of upper layer production of engineered floorings). Drewno 56 [189]: 115–126
Standfest G., Zimmer B. [2008]: The surface hardness of thermally treated woods. Poster presentation at 62nd International Convention of the Forest Products Society, 22–24 June, St. Louis, USA
Stanzl-Tschegg S., Beikircher W., Loidl D. [2009]: Comparison of mechanical properties of thermally modified wood at growth ring and cell wall level by means of instrumented indentation tests. Holzforschung 63 [4]: 443–448
Todaro L. [2012]: Effect of steaming treatment on resistance to footprints in Turkey oak wood for flooring. European Journal of Wood and Wood Products 70 [2]: 209–214
Todaro L., **Dichicco P., Moretti N, D'Auria M.** [2013]: Effect of combined steam and heat treatments on extractives and lignin in sapwood and heartwood of turkey oak (*Quercus cerris* L.) wood. Bioresources 8 [2]: 1718–1730
Tolvaj L., Molnár S., Németh R., Varga D. [2010]: Colour modification of black locust depending on steaming parameters. Wood Research 55 [2]: 81–88
Tolvaj L., Németh R., Varga D., Molnár S. [2009]: Colour homogenisation of beech wood by steam treatment. Drewno 52 [181]: 5–18
Varga D., van der Zee M.E. [2008]: Influence of steaming on selected wood properties of four hardwood species. Holz als Roh- und Werkstoff 66 [1]: 11–18
Yilgor N, Unsar O, Kartal N. [2001]: Physical, mechanical, and chemical properties of steamed beech wood. Forest Products Journal 51 [11–12]: 89–93
Źivković V., Prša I., Turkulin H., Sinković T., Jirouš-Rajković V. [2008]: Dimensional stability of heat treated wood floorings. Drvna Industrija 59 [2]: 69–73

List of standards

ASTM D 4060:1995 Standard test method for abrasion resistance of organic coatings by the Taber abraser
EN 1534:2011 Wood flooring – Determination of resistance to indentation – Test method.
EN 318:2002 Wood based panels – Determination of dimensional changes associated with changes in relative humidity

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