The Relationship between the Impact Resistance, Sound Emittance and the Hardness of Wooden Floorings

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Abstract: - Due to the simplicity, the short measurement time and the direct application in practice, dynamic methods are becoming important to determine the hardness of various flooring types. In this regards, the study focused on determining the dynamic impact resistance of several wooden floorings including the analysis of the sound emittance. Significant correlation between density and hardness of wooden floorings has been confirmed. Additionally, the average sound pressure was positively related with the density and wood hardness, whereas maximum sound pressure was the same at all tested wood species. A more homogeneous frequency spectrum of emitted sound in the range of up to 5 kHz is achieved with less dense wooden floorings.

Key-Words: Wooden floorings, Impact resistance, Sound emittance, Sound pressure, Brinell hardness, Density

1 Introduction

Hardness and density are considered to be among the most important technical properties of floorings [1-3], and largely determine their wear and impact resistance. Various materials for flooring applications are used, depending on the purpose and the desired mechanical, physical and decorative properties of the flooring.

Wooden floorings are among the more frequent types of lining in the living quarters. Various wood species and wood composites are used, where the characteristics of the linings are also influenced by the types of underlayment, like concrete slabs or wood frame constructions [4]. Wood hardness is typical determined by static methods of Brinell and Janka [5]. Hardness could also be estimated nondestructively, because as several authors have reported, appears to be linearly correlated to density [6, 7].

Recently, research on dynamic methods for determining the hardness of wooden floorings has also begun. The advantages of dynamic methods are primarily in the shorter measurement time and the application directly at the sites of use of floorings [8]. In this regard, research has been conducted on using of dynamic indenting [9] and dynamic impact resistance [10].

The purpose of this research is to improve the applicability of dynamic methods for determining the hardness of materials by introducing their vibro-acoustic properties. For this purpose, the dynamic impact resistance method also included measurement of the emitted sound, which according to several studies is influenced by surface hardness and structural properties of tested material [4, 11]. The aim of this study was to analyze emitted sound characteristics at dynamic impact resistance of various wood species for the purpose of the determination of the hardness of wooden floorings.

2 Material and Methods

Five groups of samples, with 30 solid wooden flooring boards (20 × 50 × 300 mm) per wood species, were prepared by random sampling from flooring company warehouse. We used wood of spruce (*Picea abies*), larch (*Larix decidua*), beech (*Fagus sylvatica*), oak (*Quercus* spp.) and ash (*Fraxinus excelsior*).

2.1 Determination of wood density and Brinell hardness

Selected specimens reached equilibrium weight after 1-month laboratory conditioning at 20 °C and, 50 % RH, to determine the wood density. The modified Brinell hardness testing method (HB) was applied on every specimen, using ZwickRoell Z005 device according EN 1534 standard procedure (Fig. 1). Due to better correlation between wood density and HB [5, 7, 12] measurement the depth (h) instead of mean diameter (d) of the indentation of the steel ball was used (1) (Fig. 1).

$$HB = \frac{F}{\pi \times D \times h} \tag{1}$$

HB – Brinell hardness [N/mm^2],
F – force of 1 kN, sustained for 25 s,
D – diameter of steel ball (D = 10 mm),
h – indentation depth [mm].

2.1 Dynamic impact resistance of wood and impact sound measurement

The specimens were mounted by 2 flat grippers to concrete foundation. The free fall of steel ball (m = 110 g; Φ = 35 mm) from 1.5 m height was used afterwards to determine dynamic impact resistance of wooden flooring. In this test, the potential energy of steel ball at the impact, which was induced close to HB measurement, caused irreversible plastic deformation, i.e. indentation in the wooden flooring surface layer (Fig. 1). The impact sound was recorded at the moment of impaction of steel ball with wood surface by microphone PCB 130D20 and NI-9234 DAQ-card, at 51 kHz sampling frequency.

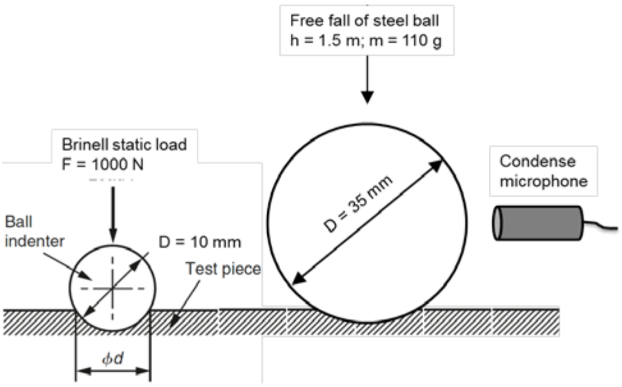

Figure 1 Experimentation setup for Brinell hardness (left) and dynamic impact resistance determination (right)

The LabView software was used afterwards to analyze the sound signal of the collision. We determined maximum sound pressure (P_{max}) at the moment of the collision of a ball with a surface. The average sound pressure (P_{eq}) was determined additionally from the exponential decayed signal of the emitted sound (2). The Fast Fourier Transformation (FFT) was used to analyze the emitted sound in frequency domain space.

$$P_{eq} = 10 \log_{10} \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} \left(\frac{p(t)}{p_0} \right)^2 dt \qquad (2)$$

P_{eq} – average sound pressure [dB]
t_1, t_2 – time interval limits (Δt = 150 ms)
$p(t)$ – momentary sound pressure [Pa]
p_0 – reference sound pressure (p_0 = 20 μPa)

3 Results and discussion

3.1 Wood density and Brinell hardness of wooden flooring

The density of spruce and larch wood was as expected lower comparing to higher dense hardwood species, i.e. beech, oak and ash (Tab. 1). The trend of differences in density was also confirmed in the hardness of these wood species. The variability in density measurements was up to 7 times less than in hardness measurements.

Table 1 Mean density and Brinell hardness of tested wooden floorings (CV – Coef. of variation)

	Brinell hardness		Density	
Wood species	Mean [N/mm^2]	CV %	Mean [kg/m^3]	CV %
SPRUCE	11.2	17.5	436	5.2
LARCH	23.3	23.5	562	3.3
BEECH	28.8	17.1	701	8.5
OAK	25.9	17.3	629	7.1
ASH	29.3	15.0	684	10.2

The wood hardness has been found in many studies in statistically significant linear correlation with the wood density [7, 13]. However, this study show, that hardness is not dependent exclusively on wood density but also on structural properties of wood species (Fig. 2). Spruce and larch in this regard exhibited the greatest Brinell hardness, in relation to the wood density, specifically greater comparing to hardwoods.

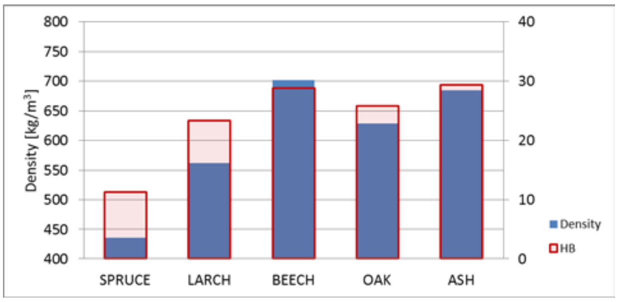

Figure 2 The trend of mean Brinell hardness and density of tested wood species

Some literature found better correlation between hardness and wood density using exponential and power models. This was also confirmed in this study (Fig. 3), where the power model parameters were comparable with the literature [12, 14].

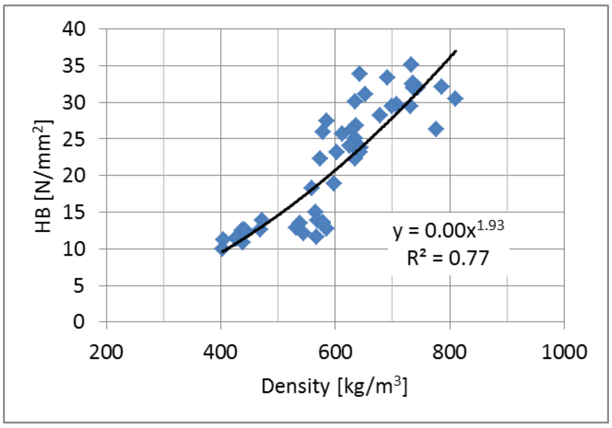

Figure 3 Dependence of Brinell hardness of wood and density of wood florings

The results are in agreement with the founding of sinking effect at the indentation of steel ball in the wood structure during Brinell hardness testing [7]. This effect due to elasto-mechanics of the surrounding wood tissue causes less plastic deformation, i.e. greater hardness at lower wood species, like spruce.

3.2 Relationship between the impact sound and hardness of wooden floorings

The maximum sound pressure (P_{max}), measured at the moment of collision, has been found to be independent of the tested wooden flooring (Fig. 4). The maximum sound pressure emitted by collision was 41.8 dB ($CV\%$ = 0.69).

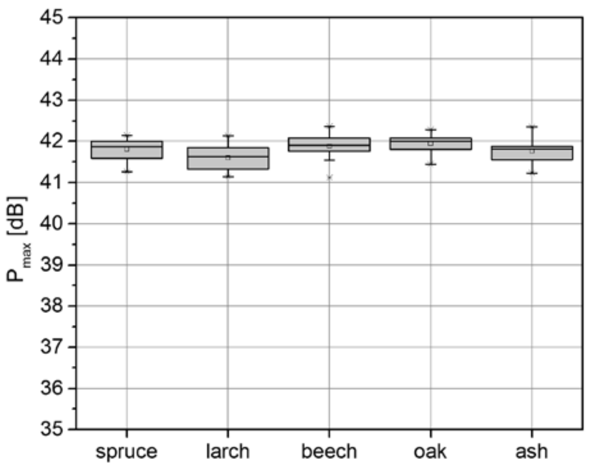

Figure 4 The emitted maximum sound pressure at testing of different wooden floorings

This result shows that the maximum sound pressure depends largely on the kinetic energy of the impact of the steel ball and only partly from the mechanical properties of the surface of the specimens. The differences in the elastomechanical properties of the studied wood species are up to 30 % [14], which can affect the value of the maximum pressure. The influence of hardness of wood, where differences are up to 4 times, is not confirmed.

Higher differences between the studied wood species were found at the emitted average sound pressure (P_{eq}). The trend and differences between species were comparable with those in density. The lowest average pressure was measured in spruce (P_{eq} = 16.2 dB; $CV\%$ = 4.4) and the highest in beech wood (P_{eq} = 18.8 dB; $CV\%$ = 5.8) (Fig. 5). This result indicates the correlation between the average emitted sound pressure and plastic sub-surface deformations in the wooden floorings. These irreversible deformations are also caused by the Brinell hardness testing in the wood structure [12-14].

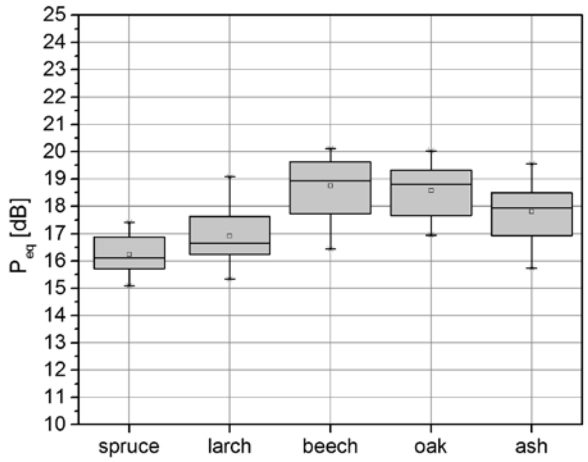

Figure 5 The emitted average sound pressure at testing of different wooden floorings

We confirmed the connection between static and dynamic sub-surface deformations in wooden floor coverings. If this is determined indirectly, by means of the emitted average sound pressure the characteristic connection of the latter with the hardness of the substrate is confirmed (Fig. 6).

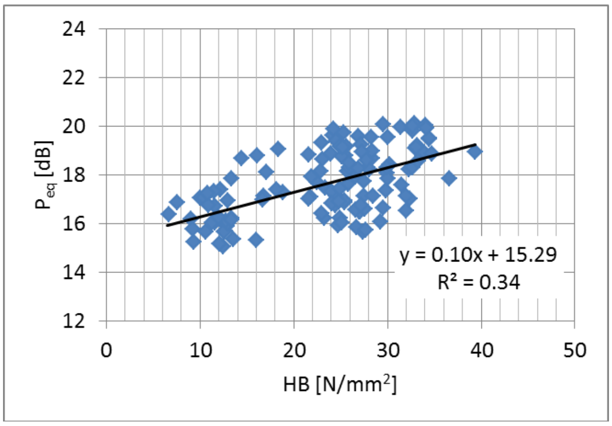

Figure 6 The relationship between average sound pressure and Brinell hardness of tested wooden floorings

An even more significant connection exists between the average pressure of the emitted sound and the density of the wooden floorings (Fig. 7). Confirmed connections allow a better understanding of the influence of the density and hardness of wooden floorings on the sound emission in residential and other facilities. It turns out that sound emission is stronger with denser and harder flooring.

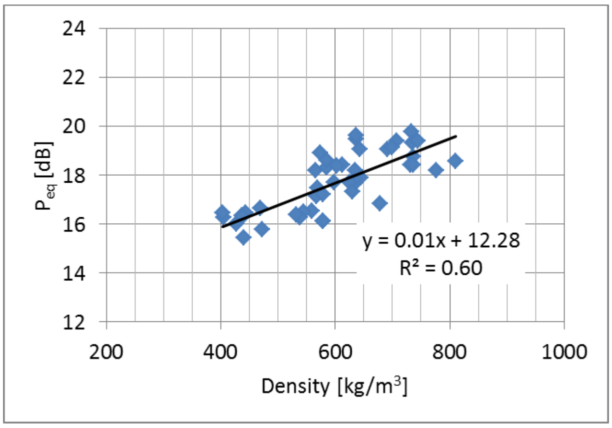

Figure 7 The relationship between average sound pressure and density of tested wooden floorings

In the case of low dense wooden floorings, a more even frequency spectrum of the emitted sound was detected. The sound power was highest at frequencies up to 1 kHz and comparable in the range of 4 to 6 kHz (Fig. 8).

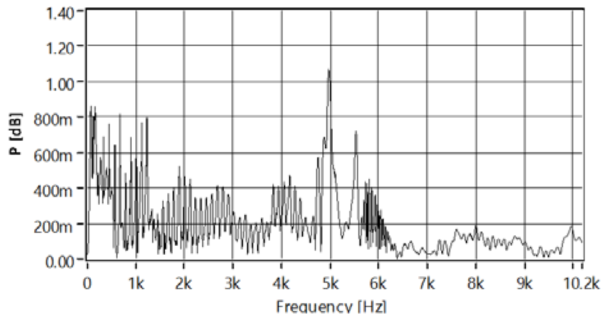

Figure 8 Frequency spectrum of emitted sound at spruce flooring

For denser wood with a higher hardness, the measured spectrum of the emitted sound was different. The sound power was highest at frequencies up to 2 kHz; at higher frequencies (> 2 kHz), the intensity was negligible (Fig. 9).

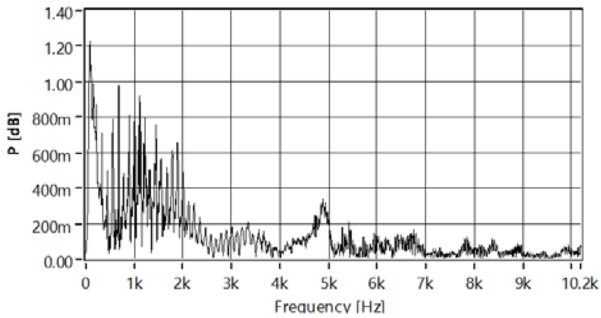

Figure 9 Frequency spectrum of emitted sound at beech flooring

4 Conclusions

The study confirmed the statistically significant positive correlation between the hardness of the wooden floorings and the density of the material. In parallel, the positive correlation of the average sound pressure with hardness and density of wooden floorings was confirmed by measuring the characteristics of the emitted impact sound. A more homogeneous frequency spectrum of emitted sound in the range of up to 5 kHz is achieved with less dense wooden floorings.

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