Infill Planks for Horse Stable Constructions: Thoughts about Kick Resistance Determination and Alternative Material Development

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Abstract

In the context of animal welfare, namely reducing the risk of injury to horses kept in boxes, and to prevent compensation claims in the case of injury, infill planks in horse stables have to be resistant to powerful kicks. Because of the common practice of designing infill planks without considering the individual properties of the wood species used, this paper aims to describe the current situation of horse kick load determination, give an overview of possibilities to determine the kick resistance of infill planks and provide ideas for alternative wood species and engineered wood products to replace tropical timbers as plank material. The objective of this effort is to form a basis on which the strength of infill plank can be tested, respectively, impact resistant materials can be developed in future. As a result of the presented findings from impact bending tests on real-dimensioned infill planks, a suitable test set-up for impact bending test is proposed, and mechanical properties of laminated bamboo lumber, a popular plank material, are given. In this context, shock resistance according to DIN 52189 was found to be a useful guide when screening high impact resistant alternative wood species.

Keywords: *Stereotypical kicking, shock resistance, infill plank, horse stable interior, laminated bamboo lumber, tropical timber*

Zusammenfassung

Zur Bestimmung der Trittfestigkeit von Holzbohlen und der Entwicklung alternativer Materialien zur Ausfachung von Stahlrahmen-Konstruktionen für den Pferdestallbau

Mit Blick auf Bestrebungen des Tierschutzes, hier das Verletzungsrisiko beim Auskeilen von Pferden in Boxenhaltung, sowie die Vermeidung von Schadensersatzforderungen im Verletzungsfall, müssen Ausfachungen von Stahlrahmen-Konstruktionen beständig gegen Pferdetritte dimensioniert werden. In der gängigen Praxis werden die individuellen Eigenschaften der verwendeten Holzart jedoch nicht systematisch berücksichtigt. Ziel dieses Artikels ist es daher, den aktuellen Stand der Bestimmung auftretender Kräfte beim Auskeilen von Pferden darzustellen und einen Überblick zu Möglichkeiten der Schlagfestigkeitsbestimmung an Ausfachungsmaterialien zu geben. Darüber hinaus werden verschiedene Holzarten und Holzwerkstoffe als mögliche Alternative zu derzeit noch häufig verwendeten Tropenhölzern vorgeschlagen. Die vorliegende Arbeit soll helfen, zukünftig die Trittfestigkeit von Stallbauhölzern bestimmen sowie schlagfeste Alternativmaterialien entwickeln zu können. Anhand von Schlagbiegeversuchen an Holzbohlen zur Boxenausfachung wird ein hierfür praktikabler Versuchsaufbau entwickelt und die mechanischen Eigenschaften von Bambusschichtholz, einem weitverbreiteten Ausfachungsmaterial, dargestellt. Die Bruchschlagarbeit nach DIN 52189 ist für die Suche nach besonders schlagfesten Alternativhölzern und Holzwerkstoffen eine hilfreiche Prüfgröße.

Schlüsselwörter: Stereotypes Auskeilen, Bruchschlagarbeit, Boxenausfachung, Pferdestalleinrichtungen, Bambusschichtholz, Tropenholz

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Introduction

Horses kept indoors are typically housed in boxes made of a steel frame construction with a wood filling at the bottom and a metallic grid on the top. In addition to the design and representative appearance of the stalling, with the increased importance of a horse for its owner safety demands are of increasing interest. Regardless of the individual motivation, the reduction of risk of injury in housing is a current focus of animal welfare. In Sweden (Hammerström & Åkerström, 2007) and in Germany (BMELV, 2009) for example, horseboxes have to be designed to be resistant to horse kicks. Although no mandatory regulations exist, 40 mm plank thickness is generally recommended (BMELV, 2009). Such an unspecific benchmark does not take characteristic wood species' strength properties into account, although they are evident when comparing commonly used softwoods (e. g., larch) and hardwoods (e. g., azobé).

In commercial practice, infill planks are dimensioned on the basis of company-internal experience. A lack of systematic data on the impact resistance of infill materials and little verified knowledge on the impact load of horse kicks permit no more than a rough plank thickness recommendation. As a consequence, the kick resistance of horse stable interior partitioning cannot be assessed by a defined standard. This means that in case of material failure and resulting injuries, compensation claims are foreseeable and objective judgements are hard to reach.

This paper aims, therefore, to form a basis to enable the construction of kick resistant and, consequently, low-injury risk horse stables in the future. With this intention, an overview of the current status of testing for the impact bending strength of wood, particularly large dimensioned samples, and horse kick impact load determination is given. Additionally, results of impact bending tests on infill planks are presented and discussed. In addition, promising alternative wood species and engineered wood products are proposed as substitutes for the use of tropical timber as plank material. Finally, the mechanical properties of laminated bamboo lumber, a popular plank material, are presented.

Why horses kick

Kicking, a stereotypical behaviour by horses, can be seen as a response to poor animal welfare conditions and environmental stress (Broom, 1983). Despite the fact that horses are social animals, housing in single-stalls or pens is still common. Box design with a minimum contact between neighbouring horses is one main factor for the increased abnormal behaviour of confined horses (McGreevy et al., 1995). Stereotypic behaviour has no function and can be either frustration-induced or malfunction-induced (Mason & Rushen, 2006). Among classic equine stereotypes like weaving (locomotion) or cribbing (oral), stall or wall kicking can be categorised as self-mutilation (McDonnell, 2011). As long as the kicking force is low, stall kicking can be considered a bad habit. However, powerful kicks may cause material failure, legs can get stuck and result in life-threatening injuries when releasing or – in the worst-case scenario – not releasing the horse after it gets stuck.

Current state of horse kick impact load determination

The focus of horse kick impact load determination has to be placed on infill planks, because most kicking damage occurs in the lower 5 feet (~ 1.5 m) of the partition, which is commonly built of rough cut, tongue and groove wood planks (Wheeler et al., 2002).

In 2011, von Wachenfeldt et al. published a study aiming at the reduction of injury and accident risk for kicking horses with correct structural design and an appropriate choice of building materials and stall shape. For this purpose, the kick impact load by horses on fittings and building construction was determined by placing a measuring wall equipped with load cells and a computerized measuring system in a number of horse stables. Based on impact load and kick duration, measured for the greatest impact caused by a horse kick, an impulse of 150 Ns was suggested to be relevant while taking a certain safety margin into account. Derived from this, the impact resistance demand for horse stable elements was proposed to be equivalent to 350 Joule.

Further research in this field is currently being conducted by the *German Agriculture Society* (DLG) at its *Test Center Technology and Farm Inputs*, Groß-Umstadt, Germany, as can be concluded from first publications (Gäckler, 2012; Glaser, 2012). In contrast to von Wachenfeldt et al. (2011), Gäckler (2012) added a high-speed camera to the test set-up, meaning more detailed information can be expected on the impact energy of a horse kick.

Current state of impact bending test

The experimental set-up of impact bending tests is in principal the same as for three-point bending tests (e. g. DIN 52186; DIN - EN 310) to determine modulus of elasticity (MOE) and rupture (MOR), whereby the load is applied to the test object in fractions of a second. The aimed result is the shock resistance, which is the ratio of energy causing complete failure related to the cross section area of the sample. While the fracture energy is the scalar product of the impact bending force multiplied by the deflection of the sample until complete failure occurs, the same amount of shock resistance can be reached by a sample with high strength but low flexibility, as well as by a sample with low strength but high flexibility. However, in general, brittle wood species (low flexibility) provide a low shock resistance (Widmann, 2009). More characteristics of the fracture behavior can be obtained by evaluating the fracture pattern: brittle wood species show a short-fiber fracture while a tough fracture has a long-fibered appearance (Kerch, 1960). Information on the character of the wood species can be obtained when the impact bending force and the deflection of the sample is recorded during the test (Broeker & Salamon, 1989). The drawn curve provides information on the characteristics of the test sample within the load-deflection diagram: a short and steep curve (high maximal force and a low deflection) belongs to brittle materials while a long stretched curve (low maximal force) belongs to tough materials (Widmann, 2009).

The shock resistance of timber is determined on small, clear specimens with a pendulum impact tester in accordance with DIN 52189. The impact energy applied to the specimen derives from the mass *m* (kg) and the initial position *h* (m) of the drop weight. After actuating the release mechanism and the potential energy E_{pot} (Nm), (Equation 1) of the drop weight is transferred into kinetic energy E_{kin} during free fall and reaches its maximum (E_{pot} = 0; E_{kin} = max) at the lowest point of the circular path where the sample is positioned. The shock resistance results from the difference between the initial potential energy and the maximal reached potential energy after causing complete failure of the sample. When the pendulum test device is equipped with load and displacement transducers, it is able to interpret force-deflection diagrams and deliver more detailed data on the fracture behavior.

$$E_{pot} = mgh \tag{1}$$

where
g is the gravitational acceleration (m s^{-2}) and was assumed to be 9.81 m s^{-2}.

Impact bending tests on large-scale samples are performed using test devices applying the impact load by a drop weight (Widmann, 2009; Kalberer, 2006; Ammann, 2006; Leijten, 2004; Malo, 2004; Sukontasukkul et al., 2000; Jansson, 1992; Mindess & Madsen, 1986). While impact energy and impact velocity v_1 (m s^{-1}) (Equation 2) for such a test set-up can be calculated corresponding to pendulum impact tests, the determination of the remaining energy after causing sample failure is more difficult and requires additional electronic measurement equipment.

$$v_1 = \sqrt{2gh} \tag{2}$$

where
g is the gravitational acceleration (m s^{-2}) and was assumed to be 9.81 m s^{-2}, *h* is the initial height of the drop weight (m).

One way the absorbed energy can be calculated is to determine the velocity of the drop weight at the moment of complete sample failure v_2 (m s^{-1}), which occurs subsequent to the moment of maximal bending. Applying Equation (3) the kinetic energy at the moment of impact $E_{kin\ 1}$ (Nm) and the moment of sample failure $E_{kin\ 2}$ (Nm) can be calculated. The result of subtraction is the energy to cause complete failure of the sample. The deflection of the sample has to be measured in order to calculate the velocity of the drop weight and may be done with an optical system, built of a light emitting diode (LED), line grid and a photo cell, as was described by Widmann (2009), a high-speed video system (Ammann, 2006), or a rotating roller which detects the relative motion between guide axis and drop weight (Ammann, 2006).

$$E_{kin1/2} = 0.5mv_{1/2}^2 \tag{3}$$

where
m is the mass of the drop weight (kg), v_1 is the velocity (m s^{-1}) of the drop weight at the moment of impact, v_2 is the velocity (m s^{-1}) of the drop weight at the moment of failure.

Alternatively, the absorbed energy can be calculated by integrating the force along the path during sample deflects until failure occurs. This requires force detection with a load cell integrated in the head of the drop weight. The absorbed energy is represented by the integral of the force-deflection diagram (area under the curve).

With the application of an acceleration sensor (Kalberer, 2006; Amman, 2006), all required data can be calculated by the mass of the drop weight, the time elapsed after releasing the drop weight, and the detected acceleration.

A simple way to measure the absorbed energy was conducted in this study. With a certain similarity to the Hatt-Turner Test (ASTM D 143), a drop weight applies an impact load to the test object while the height of drop weight is increased step-wise until failure occurs. This approach avoids the determination of the remaining energy after sample failure so that no electronic measurement equipment is required. One of the weaknesses of this test set-up is the variation of the impact velocity when mass and the initial position of the drop weight has to be adapted to reach a certain impact load. Furthermore, the lack of data during failure prevents detailed information on the fracture.

About laminated bamboo lumber

Bamboo is a fast growing plant, which differs clearly from wood logs with its smaller diameter and hollow culms. This means that to utilize bamboo on a large commercial scale, for instance like timber planks as infill for horseboxes, composite materials will need to be manufactured (Jiang et al., 2002). Laminated bamboo lumber (LBL), traded under the generic name COBAM (concentrated bamboo), is made of bamboo culms, split lengthwise into strips of about 5 mm thickness and 20 mm width, glued with phenol formaldehyde (PF) resin, dried, arranged in parallel order, consolidated under high pressure to a high density panel and finally cut into timber-like planks (Jiang & Tang, 2003). The content of the PF resin can be estimated at between 10 and 30 %.

Bending properties of LBL were determined according to DIN 52186 to be 13,016 (± 1,831) N mm^{-2} (MOE) and 153 (± 22) N mm^{-2} (MOR) by Huebner (2005), who tested 126 samples cut out of terraces planks [ρ = 1.09 (± 0.07) g cm^{-3}]. Own experiments in accordance with EN 310 resulted in bending properties of 13,189 (± 157) N mm^{-2} (MOE) and 157 (± 15) N mm^{-2} (MOR), while testing 8 samples cut out of infill planks for horseboxes [ρ = 1.13 (± 0.03) g cm^{-3}]. In addition to bending properties the shock resistance of LBL was determined in accordance with DIN 52189 to be 136 (± 18) kJ m^{-2} [n = 10; ρ = 1.16 (± 0.07) g cm^{-3}]. There were no significant differences between the properties of LBL determined by Huebner (2005) and own experiments.

Impact bending tests on infill planks

Experimental setup

The drop weight test was performed by applying different sized samples of azobé (*Lophira alata*), LBL and opepe (*Nauclea diderrichii*) – large-sized samples (20 mm x 85 mm x 1,200 mm) and real-sized samples – which were kindly provided by *Roewer & Rueb GmbH*, Thedinghausen, Germany. The real-sized samples were tested as delivered: 32 mm x 160 mm x 1,270 mm (LBL) and 40 mm x 129 mm x 1,270 mm (opepe). The cross section of the delivered infill planks were reduced at a certain length so that air slots are formed when the planks are slid side by side in the partition wall (cf. Figure 1). The minimized cross sections are 32 mm x 130 mm for LBL and 32 mm x 90 mm for opepe.

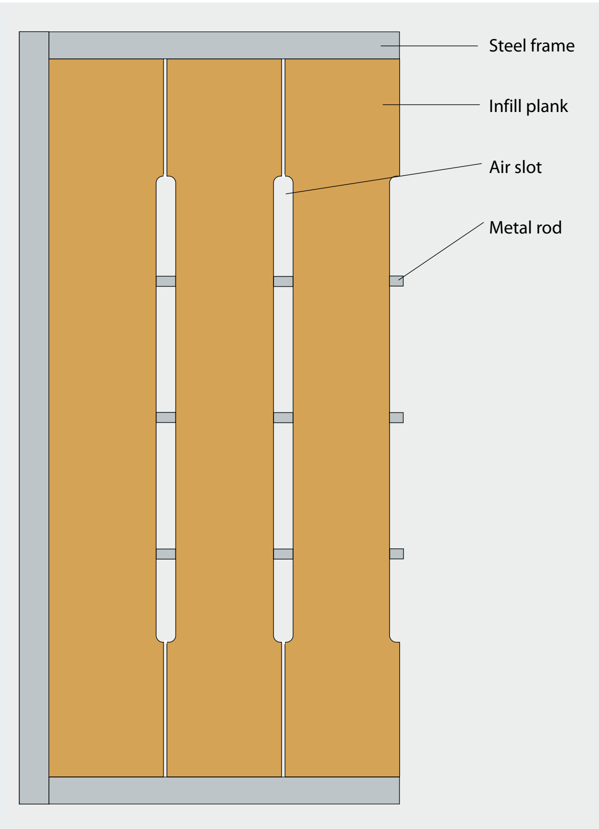

Figure 1
Front side planks slid on a reinforcing metal rod

The drop weight test device used is a construction of the *Swedish University of Agricultural Sciences* (SLU), *Department of Rural Buildings and Animal Husbandry* (LBT), Alnarp, Sweden, and was used inter alia from von Wachenfeldt et al. (2011) (cf. Chapter 3). The device comprises a steel frame to fixate a vertical axle, which guides the drop weight. The height of the drop weight is freely selectable to a maximum of 2.3 m. After actuating the release mechanism, the drop weight falls from a defined height onto the test object. The centrally positioned polyethylene plain bearing and a conscientious lubrication of the guide axle allow a free fall of the drop weight to be assumed. The head of the drop hammer is designed in the form of a horseshoe and is positioned at a 45° angle to the surface of the test object. In this way the kick of a horse should be realistically simulated. Contrary to the freely selectable height, the mass of the drop weight is adjustable only stepwise (6.68, 16.68, 26.68 and 36.68 kg). The support span of the impact bending tests was 1,100 mm.

Aiming to load a sample with defined impact energy, the required drop height was calculated in accordance to Equation (1) while considering the restricted adjustable drop weight mass and the maximal drop height of 2.3 m. The required (minimal) impact energy to cause a complete failure of the sample was calculated on the basis of the shock resistance and the cross section area of the sample in accordance to Equation (4).

$$E_{imp} = 10wA \tag{4}$$

where
E_{imp} is the impact energy (J), w is the shock resistance (kJ m^{-2}), A is the cross section area of the sample (mm^2)

If no visible break of the sample occurred within the first check, the height of the drop weight was gradually increased until the sample failed. This procedure parallels the Hatt-Turner Test where the height of drop weight is increased stepwise until failure occurs. In the case of failure within the first check, the height of the drop weight was decreased gradually until the sample material withstood the impact. In accordance to the drop weight test, the shock resistance was calculated based on the highest impact energy withstood by the sample without failure. The impact velocity v_1 was calculated in accordance to Equation (2).

Results

The shock resistance of large-sized LBL samples was determined to be 154 kJ m^{-2} and 138 kJ m^{-2} for real-sized samples. These values fit well to measurements of small samples in accordance to DIN 52189 (136 (± 18) kJ m^{-2}) (cf. Chapter 5). The shock resistance of large-sized azobé samples was determined to be 115 kJ m^{-2} and fit into the range of shock resistance given by Sell for small-sized samples of 90 to 150 kJ m^{-2} (1997). For large-sized opepe samples, the shock resistance was determined to be 66 kJ m^{-2} and 38 kJ m^{-2} for real-sized samples. These values fit into the range of shock resistance given in literature (30 to 40 kJ m^{-2}) by Sell (1997) as well.

These results show that the shock resistance determined on small clear specimens of timber may provide guidance when the kick resistance of horse stable infill planks is to be estimated and particularly when looking for alternative wood species. Further on, the data obtained may be used to calculate the required (minimal) dimensions of infill planks to withstand a horse kick of 350 Joule, which was cited as responsible impact load by von Wachenfeldt et al. (2011) (see Chapter 3). The minimal thickness (width) to withstand a horse kick can be obtained when solving Eq. (4) for *A*, inserting the responsible impact load and the wood species´ specific shock resistance into the formula, and, subsequently, dividing *A* (minimal cross section areas) by the typically provided width (thickness) of infill plank made of, e. g., LBL, azobé or opepe. The results obtained here (Table 1) show that infill planks made of LBL and azobé are kick resistant at their typically provided width (resp. thickness). Width (resp. thickness) could be decreased while kick resistance is maintained. Focusing on infill planks of stable front sides, the cross section of the planks is reduced due to the milling of air slots. Taking this reduction of cross section into consideration, planks made of LBL (130 mm) and azobé (97 mm) are further able to withstand a horse kick of 350 Joule. For planks made of opepe, a kick resistant width was calculated at 250 mm. This indicates that a single plank made of opepe cannot withstand a horse kick of 350 Joule. However, a firm bond of tongue and groove connected planks may be able to do this and has to be tested within further investigations. Tongue and groove connections cannot be applied in the case of planks with air slots (door fillings). A possible solution could be to equip the steel frame construction with horizontal metal rods upon which the planks are slid on (Figure 1).

Table 1

Theoretically required thickness (width) at given width (thickness) of different infill planks in order to withstand an impact load of 350 J. LBL = laminated bamboo lumber

Plank material	Required thickness at given width		Required width at given thickness	
	Width (mm)	Thickness (mm)	Thickness (mm)	Width (mm)
LBL	160	≥ 16	32	≥ 80
Azobé	125	≥ 23	40	≥ 73
Opepe	129	≥ 78	40	≥ 250

Discussion

The charm of the impact bending test device used for impact bending tests was its simple construction and easy usability. However, the limitations of this device are evident: impact velocity and impact energy depend on the mass and initial height of the drop weight and their calculation is limited to the moment of impact. While the adjustment of the drop weight mass is arranged step wise, the amount of different applicable impact energies is limited when holding the impact velocity constant. The number of applicable impact energies conforms to the number of steps in which the drop weight mass can be adjusted. The results of this test are less expressive due to the lack of data obtained while and after causing sample failure.

One experimental set-up of this test device is to check if sample material meets a certain required performance level – for example if the material withstands an impact energy of 350 J without failure. A second possibility is to determine the impact energy at which the failure of a sample occurs as was done within the preliminary test: increase the impact energy until the sample fails. However, the increase of impact energy has to be reached by increasing the drop weight mass while holding the drop weight height constant to test with a constant impact velocity. It would be desirable to know about the ordinary velocity of a horse kick to choose a comparable impact velocity of the drop weight. A disadvantage of the test performed in this study is the multiple testing of a sample. Although the sample may resist a certain load level, substantial material damage occurs, leading to a reduced impact strength and, presumably, allowing the plank to fail within one of the next attempts, as Leijten (2000) suspected for research results of Kloot (1954). The more scientific way to determine the kick resistance of infill planks is to perform impact bending as it was performed on large-scaled beams mentioned in Chapter 4. Here the impact energy exceeds the energy, which is required to cause failure of the sample so that data can be recorded by electronic equipment to calculate the residual energy of the drop weight after causing the sample failure. Proceeding like this, detailed data on the impact behaviours are provided for each specimen and significant results would be obtained.

Alternative material development

Since the negative side effects of logging activities in tropical forests (e. g., deforestation due to agricultural spread along the logging roads (Kummer & Turner 1994) and over-exploitations came into public awareness, the use of tropical timber was discussed critically since the 1970s and has fallen into disrepute in various western countries. For instance, the *German Equestrian Federation* (FN) suggests renouncing the use of tropical timber for stable construction based on the argument of environmental protection (Düe, 1997; Hoffmann, 2009).

Over-exploitation of the traditional market species leads to increasing prices of such tropical timbers, while wood quality and quantity decrease (Poku et al. 2001). Furthermore, a continuous decline in the production level of large-sized logs, and an increasing use of smaller dimensioned trees from fast-growing plantations, has to be expected in tropical regions (International Tropical Timber Organization, 2002). Changes in wood quality can result from the harvesting of smaller, younger and lower-quality trees (Zobel 1984). Consequently, the availability of customary timber qualities will run short. Annual variations in listed timber species in price trend analyses due to export bans or restrictions (International Tropical Timber Organization, 2010) indicate the on-going search for alternative species and transformations in the market. In sum this results in the need to find adequate alternative timbers from regional and sustainably managed forests. However, the lack of a verified method to determine the impact resistance, respectively the kick resistance, of infill planks hinders an effective search for suitable wood species and the development of more kick-resistant infill materials.

Alternative wood species to tropical timbers

In the search for alternatives to tropical timbers, heavy hardwoods should be considered for use for horse stable constructions because they impart quality and durability. With regard to their high shock resistance (see Table 2), wood species like hickory (*Carya tomentosa*), black locust (*Robinia pseudoacacia*) and ash (*Fraxinus excelsior*) may provide a high resistance against horse kicks. Likewise oak (*Quercus robur*), hornbeam (*Carpinus betulus*), birch (*Betula pendula*) and beech (*Fagus sylvatica*) may also be suitable due to their comparative high shock resistance. However, the suitability has to be verified in impact tests on real-sized infill planks.

Table 2

Shock resistance according to DIN 52189 of selected wood species. Source: Sell (1997)

Wood specie	Shock resistance ($kJ\ m^{-2}$)
Black locust (*Robinia pseudoacacia*)	112 - 170
Hickory (*Carya tomentosa*)	120 - 150
Beech (*Fagus sylvatica*)	80 - 120
Hornbeam (*Carpinus betulus*)	80 - 120
Birch (*Betula pendula*)	70 - 100
Ash (*Fraxinus excelsior*)	67 - 88
Oak (*Quercus robur*)	50 - 74

Engineered wood products as an alternative to solid wood

One weakness of solid wood is its property variability due to knots, deviation of the fiber direction from the plank longitudinal axis, and other inconsistencies. Engineered wood products are advantageous because the natural variety of solid wood is equalized and loads can be supported with smaller safety margins. However, if film-faced plywood sheets are used as an alternative infill material, the natural aesthetics of solid wood planks get lost due to the coating and its plate-shaped dimensions. In consequence, the development of innovative infill materials has to consider aesthetic demands as were reached for LBL in the past.

Laminated veneer lumber

Laminate veneer lumber (LVL) is normally manufactured for engineered timber constructions by gluing soft wood veneers to beams parallel to the grain orientation. Here, the character of solid wood can be preserved while realizing homogenous properties. This also applies when using hardwoods for manufacturing LVL while a similar appearance and a good correspondence with common stable systems seems to be given. A high-quality grade infill material would be obtained in particular when using cost-effective rotary-cut hardwood veneers for the core layer and sliced or sawn veneers for the face layers.

Within a review of the utilisation of hardwoods for LVL manufacturing, Ozarska (1999) highlighted the superior strength properties of hardwood and LVL made of it. It was mentioned that mechanical properties could be further improved by increasing density, either by compression during processing or by impregnating some or all of the veneers with polymerized material. Such impregnation results in better weathering properties. In the case of localizing the denser material in regions of high stress (face layers), properties could be improved further.

Colak et al. (2007) found the static bending strength of solid wood to be lower than that of LVL, however, the impact strength of beech solid wood is significantly higher than that of beech LVL. Brittle glue lines between the veneer layers may cause a decrease in impact strength. The lack of further studies on the shock resistance of LVL indicates the need for research on this topic, which may show contrary results. Strength properties of beech wood (*Fagus sylvatica*) (Volmary, 2005), (*Fagus orientalis*) (Aydin, 2004), red maple (*Acer rubrum*) (Wang et al., 2003) and rubber wood (*Hevea brasiliensis*) (Kamala, et al. 1999) LVL have been published, while no information on the shock resistance is given. Vlosky et al. (1994) mentioned studies of different authors on the use of northern red oak (*Quercus rubra*), sweet gum (*Liquidambar*), yellow poplar (*Liriodendron tulipifera*) and red maple (*Acer rubrum*) for the production of hardwood LVL, mainly for furniture application.

Parallel strand lumber

Parallel strand lumber (PSL) is a wood-based material used for engineered timber constructions like LVL. Similarities between LBL and PSL were already noticed by Huebner (2005). In the same way as discussed for LVL earlier, PSL could be produced from hardwoods to obtain an engineered material for stable constructions. Impact load tests on PSL were performed by Sukontasukkul et al. (2000). The shock resistance can be calculated based on the amount of absorbed energy determined in that study: in accordance to drop weight height and impact velocity the shock resistance is 228 $kJ\ m^{-2}$ (h = 500 mm; v_1 = 3.13 $m\ s^{-1}$) respectively 178 $kJ\ m^{-2}$ (h = 1,000 mm; v_1 = 4.43 $m\ s^{-1}$). These results are promising because the values exceed the shock resistance of LBL (136 $kJ\ m^{-2}$) and azobé (90 to 150 $kJ\ m^{-2}$). However, sample dimension (650 mm x 100 mm x 100 mm) and support span (550 mm) were not performed as in the experiments of this paper, or in accordance to DIN 52189, so that a direct comparison of the shock resistance values is inadmissible. Further research is necessary to check the usability of PSL, especially of hardwood PSL, as infill material for horseboxes.

Scrimber

With a greater degree of similarity to LBL than PSL, the engineered wood product Scrimber may be suitable as infill plank material. Debarked low-diameter logs are squashed in the manufacturing process for Scrimber, which largely maintains the original wood structure. The obtained bundles of inter-connected and aligned log fragments are glued and subsequently hot pressed into the desired forms. A high impact resistant material may be obtained from this process because Scrimber maintains significant parts of the wood structure and a decrease of the natural variability of properties.

Conclusion

It was the intention of this paper to enable the construction of kick-resistant and, consequently, low-injury risk horse stables in the future. For this purpose, information about the impact strength determination of infill planks was given. With background experience from impact bending tests on infill planks, an experiment design was found to be useful in which drop weight test devices were equipped with electronic measurement components. It is likewise advisable to use a test device, which enables the remaining energy after a sample failure to be measured and impact velocity and impact energy to be set. For brittle wood species it was found that a firm bond of tongue and groove connected infill planks has to be impact tested, respectively, that such planks have to be reinforced with a metal rod to withstand heavy kick loads. By summarizing the current situation of horse kick impact load determination, available data were found to be insufficient to formulate a realistic impact resistance demand.

With respect to renouncing the use of tropical timber as plank material, promising high impact strength alternative wood species from moderate climatic zone of the Northern Hemisphere and engineered wood products like LVL, PSL and Scrimber were proposed as plank material. The shock resistance of wood, determined on small clear samples in accordance to DIN 52189, was found to be a useful guide when looking for alternative wood species to tropical timbers or suitable engineered wood materials. Engineered wood products were found to be advantageous for infill plank manufacturing because the natural variety of solid wood is equalized and loads can be supported with smaller safety margins.

Acknowledgements

The authors would like to thank all those persons who supported Mr. Sebastian Maikowski in preparing his master thesis, which formed the basis of the research presented in this article: Prof. Dr.-Ing. Dr. Marius C. Barbu, *Hamburg University*, Germany, for his engagement and help as reviewer, Dr. Hans von Wachenfeldt and Dr. Michael Ventorp, *Swedish University of Agricultural Sciences* (SLU), *Department of Rural Buildings and Animal Husbandry* (LBT), Alnarp, Schweden, for the laboratory equipment used, and Mr. Rüdiger Deckert, *Roewer & Rueb GmbH*, Thedinghausen, Germany, for providing test materials.

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