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NATURAL FIBRE REINFORCED VENEER BASED PRODUCTS

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Abstract:

Veneer based products belong to the oldest engineered materials. Used in a broad range of applications, from structural elements, static products for furniture (boards/flat or moulded), sport equipment or in automotive industry. This paper gives an overview about the recent development of fibre reinforcement used for veneer based products, in order to overcome and improve the mechanical properties for these wood based composites. Current fibre reinforcement is primarily based on fibre fabrics originated from glass or carbon. Drawing the focus of this study on eco-friendly natural fibre reinforcement as the future prospect for replacing traditional fibre reinforcements. Several natural fibres such as flax, hemp or kenaf have shown competitiveness to glass fibre. The barriers for the implementation of natural fibre reinforcement at industrial level are mainly due to economic and technical issues as well as interacting low research focus.

Key words: *veneer based products; natural fibre; reinforcement.*

INTRODUCTION

Veneer based products are considered to be the oldest wood based material developed by mankind and had been further developed for various purposes throughout the last centuries (Niemz and Wagenführ 2008, Paulitsch and Barbu 2015, Kollmann and Kuenzi 1973). Applications are ranging from structural construction materials such as plywood, LVL etc. to deckings and floorings and for aesthetic purposes in the field of furniture and automotive as well as special applications for sport products, like ski-/snowboard-cores or surfboards and hockey sticks. Shapes of veneer based materials are not only limited to two-dimensional boards; moreover three-dimensional moulded products for furniture such as chairs or sports equipment were developed. Highlighting the great variety of possible applications, in general veneer based products belong to the family of ligno-cellulosic materials and are part of wood based composites beside timber-, chips/particle- and fibre-based products (Barbu et al. 2014). According to Niemz (1993, 2015) they can be categorized by the grade of compression/adhesive content, veneer-strands materials (PSL/OSL) and the grain orientation of the layers (LVL/plywood/etc.).

Veneers are defined as thin sheets of wood produced by cutting, slicing or peeling (Paulitsch and Barbu 2015). The process technology deeply influences the length, width as well as the texture of the veneer sheets (Wood 1963) and the mechanical properties due to the anisotropic orthotropic character of wood (Kretschmann 2010). In addition, the level of decomposition from solid wood to structural elements of wood-based materials - as defined by the scheme of Mara (Marra 1979) - has a direct influence on decreasing strength properties. Whereas in contrast e.g. homogeneity, isotropy and thermal insulation are increasing (Niemz and Wagenführ 2008). In contrast, the modulus of elasticity (MoE) increases with the level of decomposition behold the isolated element (Gassan and Bledzki 1999). Strength of veneer based products is influenced by the thickness of the single veneer layer, the board density and the solid resin content. Tensile strength depends on the direction of applied force and the grain direction of the face layer (Niemz and Wagenführ 2008, Niemz 2015).

To overcome the limitations of the mechanical properties, veneer based composites are used. Complexity arises about classifying composites, with no clear scientific consensus, by different classification model approaches (Stevenson 2010, Stokke et al. 2014, Callister and Rethwisch 2013, Dietz 1972, Weissbach et al. 2015). The general taxonomy given by Callister (Callister 2001) into particle-, fiber-reinforced and structural composites meets with the classification of wood based composites (Niemz and Wagenführ 2008, Paulitsch and Barbu 2015, Barbu et al. 2014). Veneer based products are defined as laminar composites (Paulitsch and Barbu 2015, Barbu et al. 2014, Stokke et al. 2014) using adhesives for bonding of the single layers. The combination between the laminar veneer based composites with fibre reinforcement results in a compound with improved mechanical properties.

Fibre reinforcement

Based on the systematic of composites by Callister (2001), fibre reinforced composites can be continuous (aligned) or discontinuous (short), subdivided into aligned and randomly oriented. Fibre used for reinforcement can be classified as synthetic, artificial or natural origin. Synthetic fibre are based on synthetic polymers derived from fossil resources (Belgacem and Pizzi 2016). Natural fibre are extracted from organic (plant or animal based) and inorganic sources (mineral fibre) (Müssig and Slootmaker 2010, Sanjay et al. 2016, Aditya et al. 2017). Depending on the application of the fibre reinforcement, different semi-finished textile products are used, such as rovings, non woven and woven fibre fabrics (Kastner 2008, Lehmann and Herzberg 2011, Pietsch and Fuchs 2011, Neitzel 2014). The further focus is narrowly drawn on veneer based products reinforced with woven and non woven fibre fabrics. The entire field of fibre polymer matrix composites such as wood plastic composites will not be displayed.

The concept of fibre reinforcement for improving wood and wood based materials properties is not new. Barbu et al. (2014) mentioned that a patent for wooden shavings glued on flax fabric was introduced in 1889 and a similar lay-up for plywood followed later.

Bal et al. (2015) gives an overview about research on fibre reinforced wood based products, carried out since the 1960s. Wangaard (1964) and Biblis (1965) started the research on the mechanical properties of wood fibre-glass beams with epoxy resin. Theakston (1965) studied the feasibility for strengthening timber beams with fibre-glass. The research of Spaun (1981) and Bulleit (1980) was focused on fiberglass reinforcement for particleboards. These studies were a consequence of progresses in the field of synthetic resins and synthetic fibre between the 1930th and 1950th. A study carried out by Rowlands et al. (1986) stated that epoxy resins are adequate for reinforcing wood composites with glass, glass-fibre and other synthetic fibre such as Kevlar®. The introduction of LVL in the 1940s in the aviation and and in the 1970s 1970th in building sector for structural applications lead to research on reinforcing LVL beams with synthetic fibre, e.g. by Laufenberg et al. (1984) or Bal (2014, 2014) or for plywood and particle-board by Boehme & Schulz (1974). Xu et al. (1998) studied the effects of fibre length and orientation on elasticity of carbon fibre-reinforced plywood.

Economical pressure caused by rising raw material prices and resources availability shifted the focus on fast-growing tree species for wood based products. The disadvantage of lower mechanical properties are compensated with fibre reinforcement. Bal et al. (2015) used woven glass-fibre fabric for different orientated poplar plywood bonded with phenol-formaldehyde-resin. MoR and MoE increased, while SMoR and SMoE decreased. The reinforcement for poplar LVL with woven glass-fibre fabric bonded with PF-resin in the study conducted by Bal (2014) resulted in increased impact bending and shear strength. Additionally, tangential, volumetric swelling and water absorption decreased of reinforced LVL. Meekum & Mingmonokol (2011) studied the influence of hot press process parameters (pressure, temperature, press time) on the flexural properties of rubber wood fibre-glass reinforced LVL bonded with epoxy resin. This study led to the conclusion that the major impact effect on product properties is caused by pressure (decreasing pressure leads to increasing mechanical properties) and press time. Aiming to improve the dimensional stability and bio durability of veneer due to heat treatment Percin & Altunok (2019) investigated the effect of carbon fibre reinforcement for the production of LVL made from heat treated beech veneer on its mechanical and physical properties. Stating a positive influence of carbon fibre reinforced on the properties. Liu et al. (2017) evaluated the flexural properties of carbon-fibre fabric reinforced fast growing poplar/eucalyptus species as composite formwork plywood bonded by epoxy resin. To analyse the mechanical properties for several combinations of wood species and reinforcing fibre is important to measure the modulus of rupture (MOR) and modulus of elasticity (MOE). Surface layer reinforcement is mandatory for ultimate load carrying capacity.. Each research paper dealt with local wood species analysed by authors.

Research on fibre reinforced plywood focuses not only on mechanical properties. Furthermore, fibre reinforcement can influence surface durability. Král & Hrázský (2008) proposed a testing methodology for water-proof plywood material based on a phenol-formaldehyde foil surface finish combined with unwoven and woven glass-fibre. They stated that fibre reinforcement depends strongly on the application and economic aspects.

Another field of research for fibre reinforced veneer based products are applications as lightweight panels. One approach to weight reduction for wood based panels are sandwich cores (Paulitsch and Barbu 2015).

Zudrags et al. (2009) introduce a design methodology based on numerical experiments using finite elements method for different plywood sandwich panels configurations, in order to develop a simulation tool for optimizing the sandwich panel geometry without cost intensive testing during the optimization process. Validating the model by physical experiments. Šliseris & Rocēns (2011) present an optimization method for geometrical and mechanical parameters of plywood panel consisting of plywood faces and a cylindrical moulded plywood core. Labans & Kalnins (2013) introduced experimental sandwich prototypes, combining plywood faces with glass-fibre reinforced plastic stiffeners as core layer. The initial plywood core was replaced with corrugated glass fibre composite. Using finite element code and design of computer experiments for product optimization led to 65% weight reduction, while stiffness was kept unchanged. Further development in prototyping and experimental testing, Labans et al. (2017) introduces a single step manufacturing procedure for a three dimensional sandwich panel core formed by thermoplastic glass fibre / polypropylene composite bonded to plywood faces. The board density was reduced to 235 kg/m^3, with additional foam as space filler reaching a density of 325kg/m^3. In this way sandwich composite boards are competitive to solid wood based panels. Numerical analysis is suitable as a tool for evaluating mechanical performance for design optimization. Kavermann (2013) carried out similar research on lightweight sandwich panels with corrugated core and foam as space filler.

Natural fibre reinforcement

The performance behaviour of lignocellulosic flax fibre reinforcement compared to glass-fibre ~~in order~~ to improve the tension value perpendicular to grain strength for glulam timber was carried out by André (2007). The unidirectional fibres were glued with epoxy resin to the GLT specimen. Flax fibre proved to be comparable to glass-fibre reinforcement and enhance the strength of the timber structure. Speranzini & Tralascia (2010) used flax, hemp and basal fibre for reinforcing LVL and solid wood with epoxy resin to compare with glass and carbon fibers for bending behavior. They reported comparable results for natural fibre reinforcement. Wang et al. (2011) reinforced poplar LVL with ramie fibre bonded with phenol-formaldehyde resin in different layups. MoE improved up to 21%, MoR up to 15% and shear strength perpendicular to grain up to 40.5%. Upitis & Dolacis (2012) studied birch plywood composite material with hemp fibre reinforcement. A bio component binder was used, to compare the effect of the long fibre of dried hemp and hemp yarn woven technical fabrics embedded in a matrix, to determine the changes in the mechanical properties of plywood composite. ~~Increasing~~ the bending strength increased about 21.8%, and MoE static bending by 23%. Basterra et al. (2012) reinforced longitudinal poplar duo beams with flax (dry and wet application method), glass and carbon fibre. The tests for MoR and MoE were carried out according to European standard EN408 with determining a significant increasing for MoE and MoR only for carbon fibre reinforcement. The reinforcement with flax influenced MoE and MoR, whereas dry application resulted in significant higher values. Borri et al. (2013) used flax, hemp, bamboo and basalt fibre fabrics in different layups to examine reinforcement in flexure of timber beams. Significant increases regarding load-carrying capacity and deflection ductility were recorded.

Chen et al. (2017) conducted a feasibility study for a high-performance composite on the effects of veneer orientation and loading direction on the mechanical properties of bamboo-bundle/poplar LVL. The bamboo laminated surface layers increased the mechanical performance in terms of MoE, MoR and surface soundness. Moezzipour et al. (2017) reinforced horn beam plywood with date palm and kenaf fibre bonded with urea formaldehyde resin. Kenaf fibre improved the physical and mechanical properties of reinforced plywood. So it was demonstrated the potential of the effective utilization of natural fibre for reinforced plywood production. Liu et al. (2019) used fiber surface treatment to improve the bonding strength of basalt fibre reinforced bamboo and poplar veneer with positive side effect on dry and wet shear strength and MoR. An alternative raw material for the plywood production could be Jabon wood (*Anthocephalus cadamba*) and coconut (*Cocos nucifera sp.*) fibre. Dungani et al. (2019) examined the stability and mechanical properties of the hybrid composite plywood material using non-/woven coconut mats bonded by urea formaldehyde and phenol formaldehyde resin. Dimensional stability and mechanical properties of plywood improved due to hybridization of Jabon trunk and coconut.

Current industrial applications

The use of fibre reinforcement in the veneer based industry for wide ranging applications is low. The major upgrades for veneer based products are non-fibre reinforced plywood for applications ranging from construction, furniture, packing, transport and flooring material, as well as LVL as construction material. The fibre reinforced panels can be considered as niche market products for transport, lightweight furniture e.g. chairs or table decks. These reinforcement can be considered as preservation solution for ancient wooden beams.

Veneer based products used in the automotive sector are mainly used for design and esthetical purpose with no demand for fibre reinforcement. The use of fibre composite materials of synthetic and natural fibre is quite common. Similar utilizations are in the aviation and nautical sector. In case of sports equipment, the use of fibre reinforced veneer based products for ski/snowboard cores is since years in application. Other utilizations of fibre reinforced veneers are for surfboards or skateboard decks. This constructive solution is used for handmade sports equipment such as ski cores, surfboards or bicycles.

CONCLUSION

Research on fibre reinforcement of veneer based products had been taken place since the beginning of their industrial production. On main importance were the developments during the mid of the 20th century and the introduction and broad availability of synthetic resins as well as the development of synthetic fibers. The awareness of the limitation and endlessness of fossil based resources, consumer awareness and concerns about environmental issues and growing demand the development of high performance materials made from natural resources is increasing worldwide. New developments for the industrial application of natural fibre reinforced veneer based products are considered as an opportunity in the context of resources scarcity.

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REFERENCES

Aditya L, Mahlia TMI, Rismanchi B et al. (2017) *A review on insulation materials for energy conservation in buildings* Renewable and Sustainable Energy Reviews 73, pp. 1352-1365.

André A (2007) *Strengthening of Timber Structures with Flax Fibres* Licentiate Thesis, Department of Civil, Mining and Environmental Engineering, Luleå University of Technology.

Bal BC (2014) *Flexural properties, bonding performance and splitting strength of LVL reinforced with woven glass fiber* Constr. Build. Mater. 51, pp. 9-14.

Bal BC (2014) *Some physical and mechanical properties of laminated veneer lumber reinforced with woven glass fiber* Constr. Build. Mater. 68, pp. 120-126.

Bal BC, Bektaş, Mengeloğlu F, Karakuş K, Ökkeş Demir H (2015) *Some technological properties of poplar plywood panels reinforced with glass fiber fabric* Construction and Building Materials 101, pp. 952-957.

Barbu MC, Reh R, Irle M (2014) *Wood based composites* In: Aguilera, A.; Davim, J. P. (editors) (2014): *Research Developments in Wood Engineering and Technology* Engineering Science Reference, Hershey.

Basterra LA, Acuña L, Casado M, López G, Bueno (2012) *Strength testing of Poplar duo beams, Populus x euramerica (Dode) Guinier cv. I-124, with fibre reinforcement* Construction and Building Materials 36, pp. 90-96.

Belgacem MN, Pizzi A (editors) (2016) *Lignocellulosic Fibers and Wood Handbook - Renewable Materials for Today's Environment* Wiley & Sons, Hoboken.

Biblis EJ (1965) *Analysis of wood-fiberglass composite beams within and beyond the elastic region* For. Prod. J. 15 (2):81-89.

Boehme C, Schulz U (1974) *Tragverhalten eines GFK-Holzsandwichs* Holz als Roh- und Werkstoff, Vol. 32(7):250-256.

Borri A, Corradi M, Speranzini E (2013) *Reinforcement of wood with natural fibers* Composites: Part B, Vol. 53, pp. 1-8.

Bulletin WM (1980) *A theory for reinforced particleboard in flexure* WSU Report 12-136, For. Prod. Lab., Madison.

Callister WD, Rethwisch DG (2013) *Materialwissenschaften und Werkstofftechnik - Eine Einführung* Wiley-VCH Verlag & Co., Weinheim.

Callister WD (2001) *Fundamentals of Materials Science and Engineering - An Interactive eText* 5th Edition John Wiley & Sons, New York.

Chen F, Deng J, Li X, Wang G, Smith LM (2017) *Effect of laminated structure design on the mechanical properties of bamboo-wood hybrid laminated veneer lumber* Eur. J. Wood Prod. 75, pp. 439-448.

Dietz AG (1972) *Composite materials: a general overview* In: Jayne, B. A. (editor) (1972): *Theory and Design of Wood and Fiber Composite Materials* Syracuse University Press, New York.

Dungani R, Karliati T, Hadiyane A, Suheri A, Suhaya Y (2019) *Coconut fibres and laminates with Jabon trunk (Anthocephalus cadamba Miq.) veneer for hybrid plywood composites: dimensional stability and mechanical properties* European Journal of Wood and Wood Products 77, pp. 749-759.

Gassan J, Bledzki AK (1999) *Composites reinforced with cellulose based fibres* Progress in Polymer Science, Vol. 24(2):221-274, Elsevier.

Kastner A (editor) (2008) *Faser- und Gewebekunde* Verlag Handwerk und Technik, Hamburg.

Kavermann SW (2013) *Mechanical Properties of Lightweight Sandwich Panels with corrugated Plywood Core* CACM, Department of Mechanical Engineering, University of Auckland, PhD Thesis.

Kollmann FFP, Kuenzi EW (1975) *Principles of Wood Science and Technology II Wood Based Materials* Springer-Verlag, Berlin Heidelberg New York.

Kretschmann DE (2010) *Mechanical Properties of Wood* In: Ross, R. J. (editor) (2010): *Wood Handbook - Wood as a n Engineering Material* Forest Products Laboratory USDAFS, Madison.

Král P, Hrázský J (2008: *A contribution to the resistance of combined plywood materials to abrasion* Journal of Forest Science, 54(1):31-39.

Laufenberg TL, Rowlands RE, Krueger GP (1984) *Economic feasibility of synthetic fiber reinforced laminated veneer lumber (LVL)* For. Prod. J. 34(4):15-22.

Labans E, Kalnins K (2013) *Investigation of wood based panels with plywood and GFRP* composite components 4th International Conference Civil Engineering 13 Proceedings Part I Structural Engineering.

Labans E, Zudrags K, Kalnins K (2017) *Structural performance of wood based sandwich panels in four point bending* Modern Building Materials, Structures and Techniques, MBMST 2016 Procedia Engineering 172, pp. 628-633.

Lehmann B, Herzberg C (2011) *Garnkonstruktionen und Garnbildungstechniken* In: Cherif C., (editor) (2011): *Textile Werkstoffe für den Leichtbau* Springer Verlag, Berlin-Heidelberg.

Liu H, Luo B, Shen, Shijie Li L (2019) *Design and mechanical test of basalt fiber cloth with MAH grafted reinforced bamboo and poplar veneer composite* European Journal of Wood and Wood Products 77, pp. 271-278.

Liu Y, Guan M, Chen X, Zhang Y, Zhou M (2019) *Flexural properties of carbon-fiber fabric reinforced poplar/eucalyptus composite plywood formwork* Composite Structures 224, 111073.

Marra G (1979) *Overview of wood as material* J. Educ. Modules for Mater. Sci. Eng. 1(4):699-710.

Meekum U, Mingmongkol Y (2011) *Experimental Design onLaminated Veneer Lumber Fiber Reinforced Composite: Processing Parameters and its Durability* Journal of Civil Engineering and Architecture, Vol. 6(8):1029-1038.

Moezzipour B, Ahmadi M, Moezzipour A (2017) *Physical and mechanical properties of reinforced plywood with natural fibers* J. Indian Awad. Wood Sci 14(1):70-73.

Müssig J, Slootmaker T (2010) *Types of Fibre* In: Müssig, J. (editor) (2010): *Industrial Application of Natural Fibres - Structure,Properties and Technical Applications* Wiley & Sons, Chichester.

Neitzel M, Mitschang P, Breuer U (2014) *Handbuch Verbundwerkstoffe – Werkstoffe Verarbeitung, Anwendungen* Carl Hanser Verlag, München.

Niemz P, Wagenführ A (2008) *Werkstoffe aus Holz* In: Wagenführ, A.; Scholz, F. (editors) (2008): *Taschenbuch der Holztechnik* Carl Hanser Verlag, München.

Niemz P (1993) *Physik des Holzes und der Holzwerkstoffe* DRW - Verlag, Dresden.

Paulitsch M, Barbu MC (2015) *Holzwerkstoffe der Moderne* DRW-Verlag Weinbrenner, Leinenfelden-Echterdingen.

Percin O, Altunok M (2017) *Some physical and mechanical properties of laminated veneer lumber reinforced with carbon fiber using heat-treated beech veneer* Eur. J. Wood Prod 75, pp. 193-201.

Pietsch K, Fuchs H (2011) *Vliesstoffhalbzeuge und Vließbildungstechniken* In: Cherif C. (editor) (2011): Textile Werkstoffe für den Leichtbau Springer Verlag, Berlin-Heidelberg.

Rowlands RE, Deweghe RPV, Laufenberg TL, Krueger GP (1986) *Fiber-reinforced wood composites* Wood Fiber Sci. 18(1):39-57.

Sanjay MR, Arpitha GR, Nalik LL et al. (2016) *Applications of Natural Fibers and its Composites: An Overview* Natural Resources, Vol. 7, pp. 108-114, Scientific Research Publishing.

Šliseris J, Rocēns K (2011) *Rational structure of panel with curved plywood ribs* World Academy of Science, Engineering and Technology, Vol. 76, pp. 317-323.

Spaun FD (1981) *Reinforcement of wood with fiberglass* For. Prod. J. 31(4):26-33.

Speranzini E, Tralascia S (2010) *Engineered Lumber: LVL and Solid Wood Reinforced with Natural Fibres* WCTE 2010, pp. 20-24.

Stevenson A (editor) (2010) *Oxford Dictionary of English* Oxford University Press, New York.

Stokke DD, Qinglin W, Guangping H (2014) *Introduction to Wood and Natural Fiber Composites* John Wiley & Sons, Chichester.

Theakston FH (1965) *A feasibility study for strengthening timber beams with fiberglass* Canadian Agric. Eng. pp. 17-19.

Upitis G, Dolacis J (2012) *Birch plywood composite material with hemp fibre reinforcement* Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology, No. 80, pp. 157-160

Xu H, Kakao T, Tanaka C, Yoshinobu M, Katayama H (1998) *Effects of fiber length and orientation on elasticity of fiber-reinforced plywood* J. Wood Sci. 44(5):343-347.

Wangaard FF (1964) *Elastic deflection of wood-fiberglass composite beams* Prod. J. 13(6):256-260.

Wang Z, Lu X, Huang X (2011) *Reinforcement of Laminated Veneer Lumber with Ramie Fibre* Advanced Materials Research Vols 332-334, pp. 41-44.

Weissbach W, Dahms M, Jaroscheck C (2015) *Werkstoffkunde - Strukturen, Eigenschaften, Prufung, 19th Edition,* Springer Vieweg, Wiesbaden.

Wood AD (1963) *Plywoods of the World* Johnston and Bacon, Edinburgh.

Zudrags K, Kalnins K, Jekabsons G, Ozolins O (2009) *Bending properties of plywood I-core sandwich panel* Proceedings of the 5th Nordic-Baltic Network in Wood Material Science and Engineering. Meeting, Copenhagen, p. 169-175.