ENHANCED IMPACT ABSORPTION PROPERTIES OF PLYWOOD

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ABSTRACT

Impact response of plywood laminate composites with imbedded glass and flax fibre fabrics utilising different adhesives were both experimentally produced and studied. Moreover the impact energy absorption of wood products as veneer, three and seven plies plywood and particle board were estimated. Therefore, laminate composites were subjected to drop-weight tests with initial energy of 150J and striker with diameter 20 mm in order to determine the impact force, energy absorption and deflection rate.

The experimental results approved poor impact absorption properties for both single veneer ply and particle board, the impact resistance was significantly higher in plywood products. In combination with thermoplastic polymer and textile fabrics the absorbed energy of laminates was considerably enhanced. The highest specific absorbed energy values have been observed for plywood laminate produced by polyethylene adhesive and incorporating the glass fibre fabrics. During the drop-weight impact tests all samples were punctured, showing local damage in the upper ply and much more extensive at the bottom ply. The damage extent was smaller in composite laminates reinforced with the fibre fabrics.

Keywords: drop-weight impact, bio-composite, veneer, flax fabric, plywood, laminates

INTRODUCTION

Plywood panels may be considered as the highest performance wood products frequently utilised by building and transportation industry as in concrete formwork systems, floors, walls and roofs in vehicles, container floors etc. Plywood production may be considered of particular interest because of inherent orthotropic nature of wood properties describing independent mechanical properties in the directions of three mutually perpendicular axes showing the highest load carrying performance in fibre direction taken as longitudinal. Therefore, manufacturing of plywood made of veneer sheets with varying fibre direction allows homogenising the strength properties of wood. It also significantly enhances the bending stiffness of the laminate structure, but still the strength properties in transverse direction are limited like poor impact resistance (Forest Products Laboratory, 2010).

The performance of wood and wood products can be improved incorporating it with other materials as fibre reinforced polymer (FRP) layers. The FRP layers can be used as outer layers of wood panels acting as protective and decorative coat enduring the stress from internal load abuse, damage from road debris, cracking caused by varying weather conditions. Therefore, FRP/plywood composite combines the structural properties of plywood – durability, bending strength and stiffness, dimensional stability and workability – with the long-wearing and weather-proof surface of a fiberglass-reinforced-plastic overlay, which also provides added strength and stiffness (www.apawood.org). Incorporation of FRP layers has been found useful in combination with glulam and OSB panels (Gardner, 2011). In general, the largest increases in strength can be obtained with the lower grades of wood due to a larger difference in relative tension/compression strength values, which can be remedied by adding FRP tension reinforcement (Dagher et al., 1996). Implementation of glass fibre as reinforcement in FRP composites is more common whereas carbon fibre usage has not been found economical in terms of stiffness enhancement. Thus FRP materials allow increased utility of low-quality wood in construction; improved structural efficiency and reduced structural member size requirements and weight; to improve the serviceability; and to reduce the costs in some applications (Raftery, 2011; Pirvu et al., 2004).

Glass fibre fabrics are extensively used in polymer based laminate composites used in aerospace, transportation and marine industry especially for vehicle body production due to the highly specific mechanical properties. Polymer matrix based composites based on thermo set polymers with glass fibre reinforcement are brittle and subjected to extensive delamination while the impact response can be enhanced by implementation thermoplastic matrix and three dimensional textiles (Shyr and Pan, 2003; Zike et al., 2011; Reyes and Sharma, 2010).

Moreover, glass fibres are the class of synthetic fibres involving large energy sources in production and are hardly recyclable. Concern about environmental problems promoted by the steep increase of waste in disposals and high energy consumption is becoming more intensified. Consequently legislation has been set by the

European Directive 2005/64/EC devoted to decrease the environmental impact of vehicle waste; introducing recyclable materials in vehicle production thus implementation of natural products from renewable and biodegradable sources. Therefore, instead of synthetic fibre fabrics natural fibre textiles could be used providing biodegradability, low cost - natural fibres as flax and hemp fibres are up to 40% cheaper than standard glass fibres, nonabrasive nature, low energy consumption, high specific properties, low density, etc.

Main drawbacks are considered to be low thermal stability, low resistance to moisture and seasonal quality variations even between individual plants in the same cultivation (Ashori, 2008).

Commonly used adhesives are phenol- and urea-based formaldehyde resins which are toxic and sensitive to the external moisture. Therefore, replacing the existing adhesives with non-toxic, water resistant and good adhesion promoting materials may be considered beneficial (Forest Products Laboratory, 2010).

Formaldehyde is a toxic gas that can react with proteins of the body to cause irritation and, in some cases, inflammation of membranes of eyes, nose, and throat. However, formaldehyde is efficiently consumed in the curing reaction, and the highly durable phenol-formaldehyde, resorcinol-formaldehyde, and phenol-resorcinol-formaldehyde polymers do not chemically break down in service to release toxic gas. However, some emission of uncured components is observed in service life of products (Forest Products Laboratory, 2010). Additionally, manufacturing could be significantly enhanced and more efficient if instead of spreading glue between veneers, adhesive layer compatible with whole plywood lamination process could be used.

The walls and roofs in transport vehicles, also container floors can be subjected to the damage from road debris, tool drop and other small object impact under low velocity.

Thus, this research was focused on the development of plywood laminates with increased impact energy absorption capacity. In plywood laminates thermoplastic polymers as high density polyethylene (HDPE) and fibre fabrics made of glass and flax were incorporated. HDPE is preferred because the melting temperature is in range of 130-140^{o}C compatible with plywood processing technology.

Furthermore, the impact properties as energy absorption, specific energy, impact load and damage extent were compared between composite laminates introducing woven and non-woven fabrics made of flax and glass fibre (GF) textiles, additionally laminates without textiles where experimentally produced to evaluate the influence on adhesive type bonding between plywood plies.

MATERIALS AND METHODS

Materials

Experimentally made laminated composites consisted of single veneer or three plies plywood as outer layers and GF/flax fabrics as inner layers. The fabrics used in this study were made of woven plain-wave structure and non-woven or stitched fibre fabrics (Fig.1). Commercially available non-woven stitched glass fibre fabrics made of four layers with fibre stacking 45/90/45/0^{o}, flax fibre fabrics of two layers with stacking 0/90 ^{o} and GF mat fabrics were used. Flax fabrics were prepared in the Institute of Textile Material Technologies and Design of the Riga Technical University (RTU) by Maris Manins.

In the experimental production of laminated composites two types of adhesives as traditionally utilized phenol-formaldehyde and high density polyethylene (HDPE) films and sheets representing class of thermoplastic polymers were employed. Moreover, once used HDPE film was employed being utilized for outdoor environmental exposure during the period of one year with thickness 80 µm. Composites with incorporated fabrics were made introducing HDPE sheets with thickness 1 mm.

Furthermore, the birch veneer plies, phenol-formaldehyde adhesive and also three and seven layer plywood which has been investigated in the present study was generously granted from the company A/S “Latvijas finieris”.

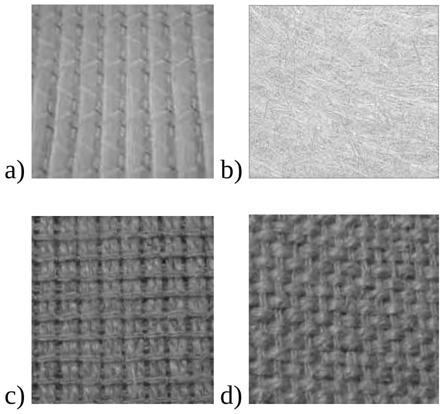

Figure 1. Fabrics implemented in this study: a) stitched GF; b) GF mat; c) non-woven flax fibres; d) woven plain-wave flax fibres.

Laminate manufacturing process

Experimental production of laminated composites involved stacking of separate sheets maintaining veneer plies as outer layers with overall dimensions 62 x 62 cm (Fig.1). Between veneer layers plies of thickness 1.4 mm each, HDPE and flax/glass fibre fabrics were incorporated. The processing of laminates was performed on laboratory equipment of the RTU, Institute of Materials and Structures –

handmade hot press (Fig.2). The laminates were hold for 10 minutes at the temperature of 150°C without pressure to ensure melting of thermoplastic adhesive and for 10 minutes under the pressure of 2bar. As the next step the composites were cooled down at the room temperature under pressure to avoid twisting or warping of the laminate specimens due to the thermal expansion and creep of separate layers. The obtained laminates were cut into specimens with dimensions of 10 x 10 cm according to the impact testing standard (ISO 6603-2).

Impact testing

For the impact tests a drop tower INSTRON Dynatup 9250HV has been utilised. During the test impact the machine was equipped with a hemispherical punch with a diameter of 20 mm. Specimens with dimensions of 100 × 100 mm were fixed in pneumatic clamping system with inner ring diameter of 76.2 mm.

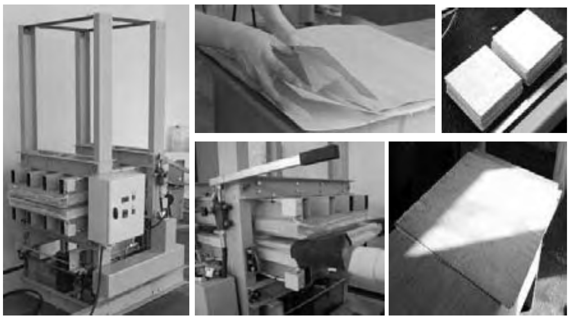

Figure 2. Experimental production of laminated composites.

The impact velocity was set to 3.4 m/s, height approximately 0.6 m and weight 26 kg in order to provide the resultant potential impact energy of 150 J.

RESULTS AND DISCUSSION

The impact response of any materials can be described by the amount of force and energy it can absorb. A typical impact response curve obtained in the tests may be subdivided in three following parts: ascending, peak force and descending part. The ascending part is related to the bending stiffness or material capability to resist the impact force in flexure. Maximum force shows the force needed to induce composite damage through the material fracture and delamination. The descending part depends on the material properties: brittle materials will show very sharp drop of load, laminated composites show gradual decrease because of delamination growth, in sandwich structured composites the load reached maximum peak can stay constant for a longer period if the resistance of the core material is sufficient, thus plateau can be observed. The larger the area under the load-deflection curve the higher the level of energy is absorbed by the material (Shyr and Pan, 2003; Zike et al., 2011; Reyes and Sharma, 2010).

Impact properties between different laminate configurations were examined, thus the experimental part can be sectioned in several parts: impact resistance of different all-wood products; composite laminates with incorporated GF/flax fabrics and damage evaluation of different specimens after drop-weight impact tests.

Impact properties of all-wood products

Therefore, first of all the impact response to free-falling object impact of different wood products as veneer, particle board, three and seven plies plywood based on phenol-formaldehyde and HDPE film adhesive was compared (Fig.3). The best impact resistance was shown by laboratory manufactured plywood consisting of seven plies with reused HDPE film. The absorbed energy of similar plywood made with phenol-formaldehyde adhesive was approximately twice lower and the impact force one and a half times lower. The worst impact resistance was observed by single veneer and particle board. Even the mass and thickness of the particle board was twice larger than that of the seven plies plywood, the absorbed energy was about twice lower (Table 1).

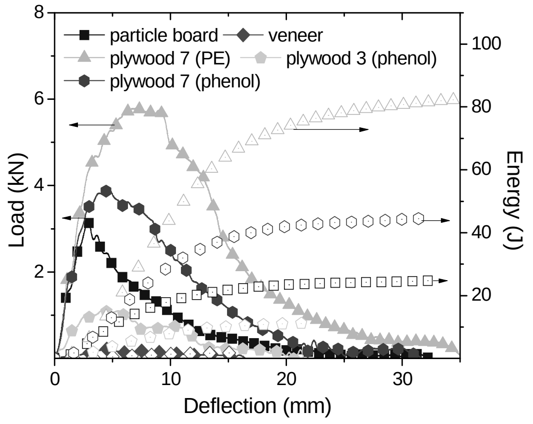

Figure 3. Impact force and absorbed energy of different wood products.

As the thicknesses of the tested specimens was different, specific absorbed impact energy was introduced showing the absorbed energy per unit weight. The highest specific energy was calculated for experimentally fabricated plywood with HDPE adhesive and the lowest for single veneer and particle board. Therefore, production of plywood and implementation of HDPE adhesive significantly increases the efficiency of impact resistance of wood products. The effect of adhesive could be explained by quite different properties between thermoplastic and thermo set polymers or HDPE and phenol-formaldehyde, respectively. HDPE is a well-known thermoplastic material, because of the inherent molecular structure the thermoplastic polymers are more plastic and show higher toughness than thermo sets. The influence of adhesive toughness on overall performance on the composite impact properties in transverse direction is clearly evident by their higher performance. (Forest Products Laboratory, 2010).

Moreover, it can be observed that the impact response was highly dependent on the number of plies, for example, single veneer absorbs around 0.25J, three plies plywood four times more – 1J and seven plies plywood 4J, what is 16 times more comparing to single veneer ply (Fig. 3).

Impact properties of wood/GF & flax products

Implementation of fabric materials between veneer layers was expected to improve the plywood impact absorption properties more radically. In Fig.4 the impact response of composites made of different fabrics with phenol-formaldehyde adhesive was represented. The acquired results were compared with 3-ply plywood assuming the fabrics as the third ply (Fig.3). Therefore, incorporation of GF mat increased the impact force around 1.5 times, whereas non-woven flax and glass fibre fabrics increased the ultimate force values about 2 and 3.5 times.

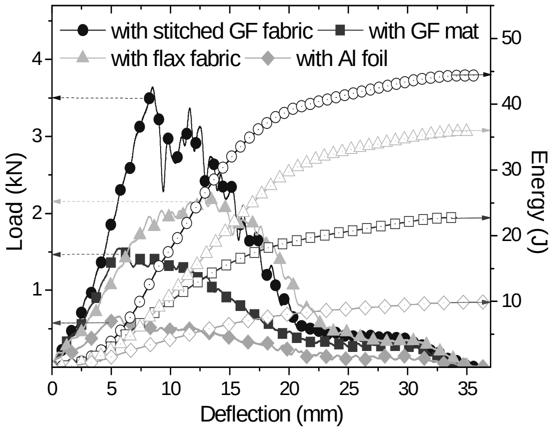

Figure 4. Impact force and absorbed energy of laminates with incorporated fabrics.

The energy absorption in composites increased more rapidly than the impact force, therefore, introduction of non-woven flax and GF fabrics can dissipate the impact energy 3.5 and 4.5 times more comparing with 3-ply plywood specimens. Laminated composite with stitched GF fabric showed similar impact strength properties as 7 -ply plywood and had 1.3 times lower weight, consequently, the specific absorbed energy was 1.4 times higher than laminates with stitched GF fabric. Furthermore, correlation study has been done to compare woven and non-woven GF fabrics laminate specimens made with single veneer and 3-ply plywood at the top plates. (Fig.5) An adhesive HDPE sheet was used to bond GF fabrics to the outer layers of veneer and plywood. However, the cover plate of 3 plies plywood was made of phenol-formaldehyde glue. The relation between the fabric type and impact response was more pronounced by laminates with outer layers made of single veneer ply. Laminate with woven GF fabric showed 2.5 times lower impact force and twice lower absorbed energy. Meanwhile the laminate made of 3-ply plywood in outer layers and woven GF fabrics showed 1.5 times lower impact force and 1.7 times lower impact energy absorption capacity. Therefore, larger enhancement was achieved employing less impact resisting sheets in outer layers.

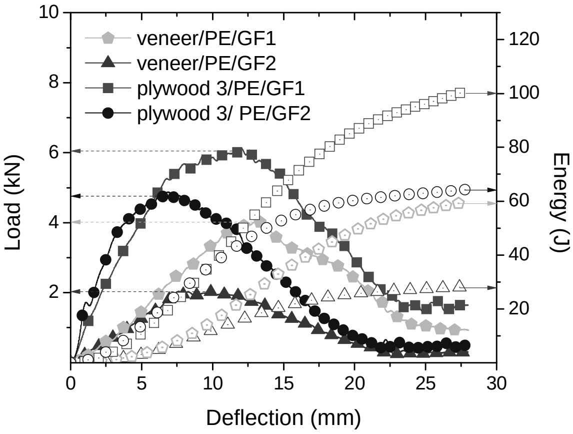

Figure 5. Impact force and absorbed energy of laminates with different GF fabrics and outer layers

Moreover, both GF composites made with 3-ply plywood in outer layers showed higher impact resistance (Fig.5) than 7-ply plywood made of phenol-formaldehyde (Fig.2). The impact force was increased 1.1-1.5 times and energy absorption 1.5-2.5 times. Although laminates with GF fabrics introduced between 3-ply plywood were heavier, the specific absorbed energy was still higher of GF composites. Comparing the specimens with single veneer layers as cover sides no significant changes in specific energy absorption have been observed (Table 1).

In addition, by comparing the results with 7-ply plywood made with HDPE film adhesive (Fig.3) it has been observed that only composites with 3-ply plywood at the outer layer with stitched GF fabric in the middle layer shows higher impact properties (Fig.5). Therefore, 7-ply plywood absorbs 53% (80J) from the initial energy 150J, whereas 3-ply plywood with incorporated stitched GF fabric 67% (100J). It may be assumed that incorporation of HDPE film also in outer layers between plywood plies could additionally increase the impact resistance in transverse direction.

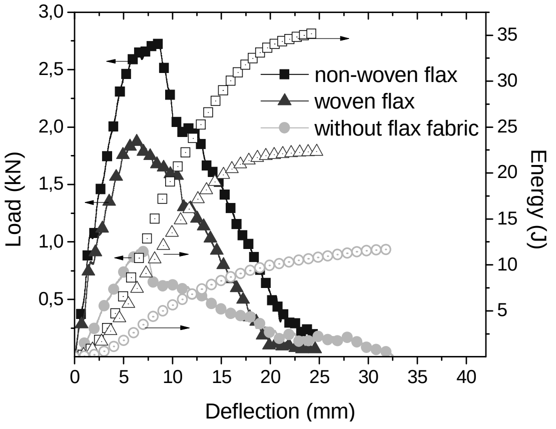

Figure 6. Comparison between composites made of different flax fabrics bonded between veneer sheets with HDPE adhesive.

Lower performance was observed by composites made of 3-ply plywood and woven plain-wave fabrics (Fig.5) showing 1.5 and 1.3 times lower impact force and absorbed energy rate comparing to composites with stitched GF fabric.

Additionally two types of flax fabrics incorporated between veneer layers bonded with HDPE adhesive were examined under the impact tests (Fig. 6). The drop-weight impact results showed the best performance of the laminate with non-woven fabric composed of two flax fabric layers. Therefore, non-woven flax fabric being twice heavier than the woven one showed about 1.5 times higher impact force and absorbed energy values. While two veneer sheets bonded with HDPE film show approximately 2-3 times lower impact force and absorbed energy values. In spite of enhancement composites made with flax fabrics showed lower energy dissipatig capacity comparing to GF fabrics.

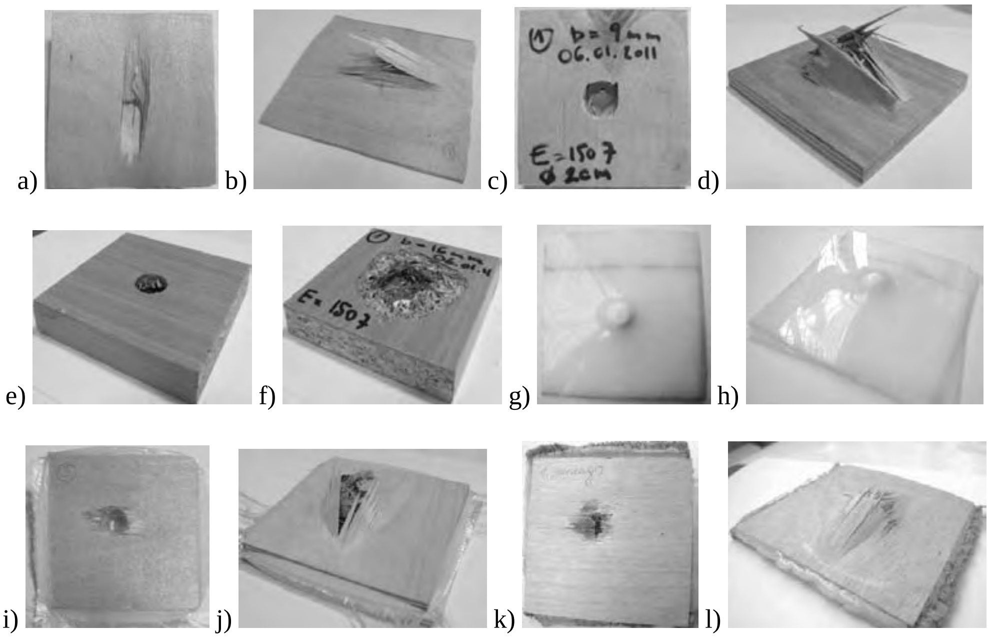

Figure 7. Speciments after the drop-weight impact tests: top (a) and bottom (b) of veneer; top (c) and bottom (d) of 7 plies plywood; top (e) and bottom (f) of particle board; top (g) and bottom (h) of HDPE; top (i) and bottom (j) of composite with GF fabric; top (k) and bottom (l) of composite with flax fabric.

Table 1

Specific energy of specimens subjected to drop-weight impact

Specimen	Thickness, mm	Impact force, kN	Absorbed energy, J	Mass, g	Specific energy, J/g
HDPE	1	1.3	18	9.7	1.86
Veneer	1.5	0.22	1.5	8	0.19
3-ply (phenol) plywood	4	1	12	27	0.45
7-ply (phenol) plywood	9	4	45	64	0.86
7-ply (PE) plywood	10	4	45	62	1.26
Particle board	16	3	23	111	0.21
Veneer/PE/GF/PE/veneer	4	2/3.8	30/ 60	43/50	0.7/1.22
3-ply plywood /PE/GF/PE/ 3-ply plywood	9	5 & 6	60 & 100	76.5/85	0.78/1.17
Veneer/PE/flax/PE/veneer	5	1.75/2.4	22/37.5	42/ 50	0.52/0.75

The specific absorbed energy by flax fabrics composites was within 0.5-0.75, whereas GF fabrics composites within 0.7-1.22 J/g (Table 1).

By graphical inspection of the tested specimens the damage in all specimens was more pronounced in wood fibre direction. (Fig.7) In the case of plywood and particle board the upper layer was damaged locally taking a circular form of striker head (Fig. 7c,e) more extensive damage was observed at the bottom layer also showing some pulled out middle plies (fig.7b,d,f). The amount of damage at the bottom of plywood samples could exceed the damage area at the specimen upper surface up to four times. Less extensive damage was observed in laminates with integrated HDPE film with both GF and flax fabrics (Fig.7j,l). The particle board due to drop-weight impact has disintegrated thus showing the most extensive damage among the tested samples (Fig. 7f). In plywood specimens fibre breakage, delamination between plies and crack growth has been observed both perpendicular and paralel to wood fibres. A plastic deformation of HDPE sheets may be noted explaining the better performance of plywood laminayed with HDPE (Fig. 7g,h).

CONCLUSIONS

Different wood products have been subjected to drop-weight impact tests from which the lower impact resistance has been observed by particle board and single veneer whereas the highest energy absorption capacity of 7-ply plywood with HDPE film adhesive. Such laminate can dissipate twice higher impact energy than 7-ply plywood based on phenol-formaldehyde adhesive. Laboratory manufactured samples incorporating glass and flax fabric have been tested to asses the benefit of textile reinforcement. It has been proved that the largest amount of initial impact energy can be absorbed by plywood laminate with stitched GF fabric. The highest specific absorbed energy values among the test specimens have been obtained for plywood made of HDPE adhesive film and by incorporating GF fabrics. It was outlined that the GF shows more significant enhancement of transverse impact properties compared to flax fabric textiles integrated in plywood laminate. Moreover, once incorporating the textile fabrics a considerable reduction of damage propagation and laminates ply failure has been observed under the impact load.

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