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BENDING PROPERTIES OF PLYWOOD I-CORE SANDWICH PANELS

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ABSTRACT

Lightweight structures as sandwich panels are one of the innovation products to drive the future of the wood/plywood industry for the near future. Material consumption, thus environmental impact, is the driving factor to replace commonly used plywood panels with the plywood sandwich structures.

The aim of this paper is to elaborate the design methodology for different core type plywood sandwich panels under the flexural loading. The methodology is based on sampling of the numerical experiments by the finite element code ANSYS and approximation of the response values of the four point bending tests. This methodology is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which structural responses are influenced by several variables and the objective is to optimize these responses. The methodology is often referred to as metamodelling as they provide a model of a model, replacing the expensive simulation analyses during the optimisation process.

Moreover, validations of metamodelling procedure for design of I-core sandwich panels with physical tests have been evaluated. The sandwich panels used in physical experiments were made of plywood outer plate and I-core filling strips and the bending properties have been tested according to EN 789.

The structural flexural stiffness capacity and weight efficiency have been elaborated for the I-core sandwich panels by the metamodelling procedure. The design guidelines have been elaborated and validated with the physical experiments.

Key words: veneer, birch, lightweight structures, wood based panels

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INTRODUCTION

Plywood production has a significant role in the economics of Latvia Forest production. Plywood production value was a 180 000 m^3 and its takes 6 % share of all European plywood production in 2008 (FEIC 2009).

Approximately 2.6 - 3 m^3 of raw materials (logs) are necessary for producing 1 m^3 of plywood. There are several technology process stages which cause reduction of production effectiveness. One of the last stages is edge trimming, which is due to the oversize of panels. The panels before the final cutting are oversized because of the aim to minimize the risk of edge delamination and range of veneer dimensions in production site. More than 10% of panel is cut off depending from customer specifications and plywood producing technology. When the dimension specifications of panel are very wide the cut-off part from panels could be more than 300 mm wide. It gives approximately 18000 m^3 of cut-offs yearly in Latvia. These cut-offs can be sold as a small dimension plywood panels or as fire wood (they could be chopped). The value (price) of cut-offs is relative low compared to the plywood in both cases. The fire wood chips cost approximately 6 EUR/m^3, the plywood average price in 2009 was 550 EUR/m^3 (Latvia Ministry of Agriculture 2009), and the lower grade birch veneer log price was 31 EUR/m^3. The price difference (fire wood, raw material, and wood panel) shows economical benefit to reuse cut-offs from edge trimming for new product production. In wood-based panel production in Latvia, More than 1000000 EUR could be saved up by using cut-offs instead a veneer logs.

A plywood production from edge trim plywood strips as a core of panel was described in USA patent 3970497. The trim strips in this patent are laid up side by side with the edges glued to produce a flat and solid core panel. The edge trim core panel is proposed to glue over with veneer sheets to produce a thick plywood panel.

The mechanical properties of sandwich panels manufactured from plywood with plywood cut-offs as core material are investigated in this paper. The sandwich panel core material is composed from plywood strips with several distances between strips with an aim to reduce panel weight. Such kind of solution gives two benefits – reduction of raw material usage and reduction of panel weight.

MATERIAL AND METHODS

The sandwich panels consist of plywood skins and plywood edge trim strips in a core (Fig. 1).

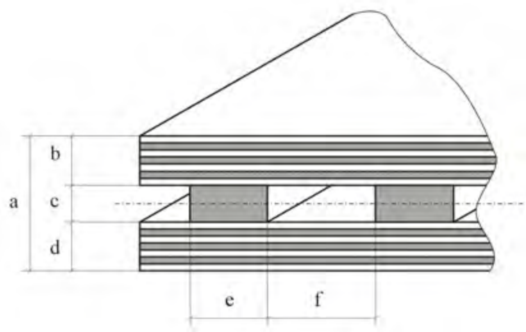

Fig. 1. Plywood sandwich panel

The plywood skins are made from birch (*Betula sp.*) veneers with thickness of 1.4 mm and glued with phenol formaldehyde resin glue. The core strips are made from the same birch plywood edge cut-offs. The grain direction in adjoining veneer layers is perpendicular. The 9 mm plywood was made from 7 and 6.5 mm from 5 birch veneer. The nominal dimensions of sandwich panels are shown in Table 1.

Table 1. Sandwich panel dimensions

Abbreviation	a	b	d	e	f
6.5×9@17	28	6.5	9	15	17
9×9@17	28	9	9	15	17
9×9@22	28	9	9	15	22
9×9@27	28	9	9	15	27

The core consists of 15 mm thick plywood strips which are set in three different distances from each other – 12; 17; 22 mm. The panels were pressed in cold press with pressure 1 MPa and time 6 h. The panel dimensions are 300 mm wide and 1200 mm long. The core strips are oriented lengthwise. Three panels from each type were tested. The bending properties were evaluated according to the EN 789 standard test method.

Metamodelling procedure

In industrial applications, to cut down the computational cost of complex, high fidelity scientific and engineering simulations, metamodels, also referred to as surrogate models, are constructed that mimic the behaviour of the simulation models as closely as possible while being computationally much cheaper to evaluate (Chen et al. 2006, Kalnins et al. 2006, Kalnins et al. 2008, Kalnins et al. 2009a). The process of design optimization involving metamodelling usually comprises three major steps which may be interleaved iteratively: 1) sample selection (known as design of experiments); 2) construction of the metamodel that best describes the behaviour of the problem and estimation of its predictive performance; 3) employment of the metamodel in the optimisation task, i.e., finding the best values for input variables with which the system achieves the optimum response.

In this study, for metamodelling a sparse polynomial model building approach called Adaptive Basis Function Construction, ABFC (Jekabsons 2009a) is used. The approach enables automatic adaptive generation of sparse polynomials of arbitrary complexity and degree specifically for the data at hand. A more complete discussion on the ABFC is given in (Jekabsons 2009a). ABFC together with a number of other metamodelling techniques is implemented in the freely-available VariReg software tool (Jekabsons 2009b).

Pure plywood solid panel versus I-core plywood sandwich have been modelled according to the EN 789 using ANSYS 4-node shell element SHELL 181. It was assumed that each ply has thickness of 1.4 mm both for solid panel and sandwich design. Moreover stacking sequence has been modelled assuming that each layer is perpendicular to the upper and lower one, thus the plywood always consists of an odd number of plies. The stiffness responses from the four point bending test under the constant load P = 1000 N have been elaborated by extracting the global deflection value. The stiffness ratio ΔK is calculated as division of solid plate stiffness value Kp by corresponding sandwich plate stiffness Ks value extracted from the numerical analyses. The ΔK value indicates the stiffness increase or decrease of the sandwich concept versus pure plywood plate design. Another measurement extracted is weight efficiency ratio ΔW, which indicate the weight savings from the sandwich design concept. Five design variables are chosen for the sandwich panel design: the panel height – *H*, the number of plies in the upper sandwich plate – *T1*, the number of plies in the lower sandwich plate – *T3*, the number of plies for the I-core stiffener plate – *T2*. The stiffener spacing ratio is independent variable – *K1*, which directly influences the simulation section width – *B* for both panel and sandwich designs. The numerical values of the design spaces are outlined in (Kalnins et al. 2009b).

RESULTS AND DISCUSSION

The panel surface weight is shown in Fig. 2.

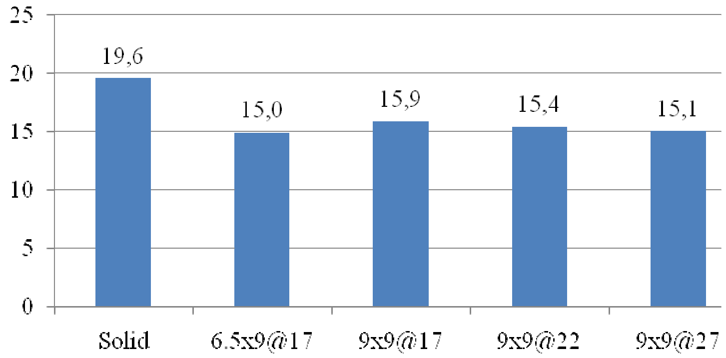

Fig. 2. Birch plywood (solid) and sandwich panel surface weight $m^2\ kg^{-1}$

The weights of 6.5×9@17 and 9×9@27 are very close, but due to functionality reasons, more sandwiches are investigated with skin lay-up 9 mm plywood on a top and bottom. In these cases sandwiches are lighter by 19 – 23 % comparing to the solid birch plywood. Bending properties of the sandwiches are shown in Fig. 3.

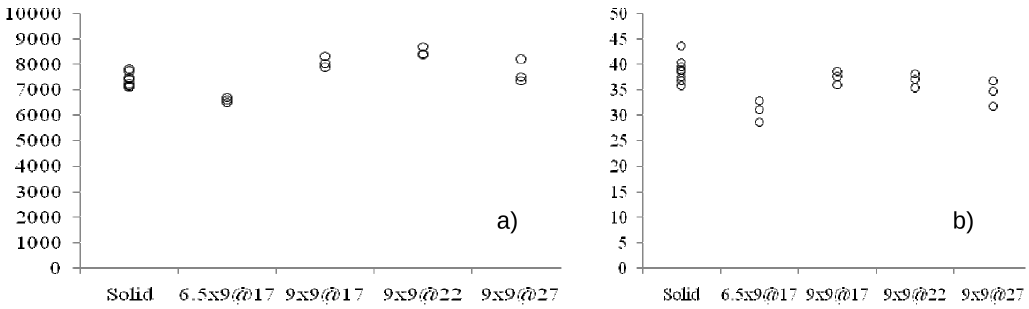

Fig. 3. Birch plywood (solid) and sandwich panel bending properties $N\ mm^{-1}$:
a) modulus of elasticity; b) strength

The sandwich panel shows higher specific strength of material. The panel weight could be reduced by 23 % (9×9@27) while reducing the bending strength by 11 %,

Optimization results

A Pareto optimisation problem is formulated where maximisation of the relative stiffness ratio ΔK is coupled with minimisation of the weight efficiency ratio ΔW. It could be assumed that the best performance could be reached when relative stiffness ratio tends towards the value of 1. Nevertheless the cost efficiency is directly linked with weight reduction. Thus dual strategies may exist for optimisation of sandwich performance: first to have sandwich panel stiffness close to the pure panel stiffness, which practically is weight inefficient, or second to have the sandwich height mach the stiffness while drastically reducing the total volume of the plywood.

A Pareto optimal front has been elaborated to evaluate the stiffness and weight effectiveness ratios for each panel height level. Comparison of the Pareto optimal front and physical experiments (Fig. 4) for different profile plywood sandwich designs indicates the overall tendency that there is no only one best solution between the stiffness ratio ΔK and the weight efficiency ratio ΔW thus decision for the trade off design should be left for the designer to decide. Thus the design guidelines elaborated by metamodeling procedure provide efficient tool for tailored plywood sandwich panel design and manufacturing procedure. Furthermore Pareto optimum fronts can be elaborated in any combination of design variables used for metamodeling thus the design could be tailored to meet the specific load carrying capacity and weight efficiency requirements.

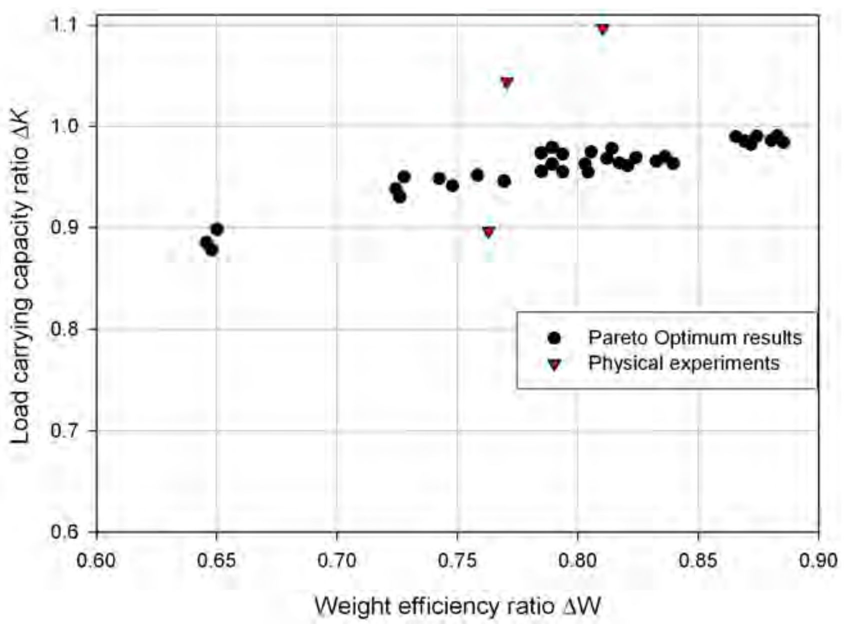

Fig. 4. Pareto optimal front between the load carrying capacity ratio and weight efficiency ratio for different 6.5 x 9 and 9 x 9 plywood sandwich panel designs compared with the solid plate designs.

It should be noted that physical experiments indicate stiffer structural response compared with the solid plate, this could be associated with the assumptions used in the numerical model as ply thickness as numerically no imperfection have been introduced.

However in fact there is a significant scatter in manufactured solid and sandwich panel overall thickness description scenarios. Nevertheless the decisions made upon the numerical solutions have been approved by physical experiments indicating around 20% scatter which is reasonably well predicted as far as numerical models for the wood structures have been considered.

CONCLUSIONS

The tests results shows that the best result was achieved for sandwich panel with be symmetrical lay-up. The difference of panel 6.5×9@17 and 9×9@27 weight is less than 1 %, but symmetrical lay-up (both skins from 9 mm plywood) shows 11 % higher results in bending strength and more than 16 % modulus of elasticity.

The Pareto optimisation problem has been formulated and methodology based on metamodelling has been developed for the plywood sandwich panel stiffness and the weight efficient designs. Five design variables were considered and elaborated in numerical sampling strength analysis procedure by finite element code ANSYS.

The elaborated metamodels applied in the optimum design guidelines provide efficient tool for tailored plywood sandwich panel design procedure.

A further study is needed to elaborate the geometrical imperfections influence on numerical modelling procedure.

REFERENCES

Chen, V.C.P., Tsui, K-L., Barton, R.R. & Meckesheimer M. 2006. A review on design, modeling and applications of computer experiments. IIE Transactions 38(4): 273-291.

FEIC 2009. 2009. Annual Report, General Assembly, Spain.

Jekabsons, G. 2009a. Adaptive Basis Function Construction: an approach for adaptive building of sparse polynomial regression models. In: Machine Learning. In-Tech (in press).

Jekabsons, G. 2009b. VariReg software tool, version 0.9.23. Available at: http://www.cs.rtu.lv/jekabsons/ [Cited 27 Aug 2009].

Kalnins K., Jekabsons G. & Rikards R. 2009a. Metamodels for optimisation of post-buckling responses in full-scale composite structures, 8th World Congress on Structural and Multidisciplinary Optimization, WCSMO 2009, Lisbon, Portugal.

Kalnins K., Jekabsons G., Zudrags K. & Beitlers R. 2009b. Metamodels in optimisation of plywood sandwich panelis. Shell Structures, Theory and Applications: Proceedings of the 9th International Conference on Shell Structures (SSTA 2009), 14-16 October, Jurata, Gdansk, Poland.

Kalnins, K., Ozolins, O. & Jekabsons, G. 2008. Metamodels in design of GFRP composite stiffened deck structure. Proc. of 7th ASMO-UK/ISSMO intern. conf. on engineer-ing design optimization, Association for Structural and Multidisciplinary Optimization in the UK, London, UK.

Kalnins, K., Skukis, E., & Auzins, J. 2006. Metamodels for I-core and V-core sandwich panel optimisation. In W. Piet-raszkiewicz & C. Szymczak (eds), Shell Structures: Theory and Applications; Proc. 8th intern. conf., Jurata, Poland, 12-14 October 2005, Taylor & Francis: London: 569-572.

Zemkopības ministrija. 2009. Meža nozares produkcijas ārējā tirzniecība Maijs 2009. Available at: http://www.zm.gov.lv/index.php?sadala=289&id=8261 [Cited 18 Aug 2009].

USA patent 3970497. 1976. End Trim Plywood Process.