Wood chip plastic composite – a novel bio-based material with high mechanical properties*)

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Abstract: Wood chip plastic composites (WCPC) with high mechanical properties were produced by combining long pine wood strands with formaldehyde-free binder systems. The obtained novel bio-based lightweight materials compensate major disadvantages of commonly used oriented strand board (OSB). WCPC are load- and application-optimized, non-toxic, with zero-waste and cost-efficient. Suitable binder systems and production process options for WCPC were selected. The behavior of strands when pressurized was investigated to specify the limit of the compression pressure, that did not cause damage of the wood cell walls. Specimens were produced with an experimental mold using thermoplastic as well as thermosetting binder systems and resin injection as well as hot compression molding techniques. Mechanical properties of WCPC were determined and compared with the properties of conventional wood-based materials.

Keywords: OSB, engineered wood, wood polymer composites, natural fiber reinforced plastic, formaldehyde-free binder.

Kompozyty polimerowe z udziałem zrębków drzewnych – nowe materiały o korzystnych właściwościach mechanicznych

Streszczenie: Otrzymano kompozyty polimerowe na bazie polipropylenu z udziałem długich zrębków drzewnych, spajanych octanem etylenowo-winylowym (WCPC). Materiały te kompensują wady tradycyjnych płyt OSB (orientowanych osiowo), są nietoksyczne, wytrzymałe na obciążenia, produkowane bezodpadowo i niewielkim kosztem. Dobrano odpowiedni system spajający oraz wariant procesu wytwarzania płyt WCPC. Określano wartość dopuszczalnego ciśnienia sprężania użytych zrębków drzewnych, nieuszkadzającego ich ścian komórkowych. Próbki wytwarzano w formie doświadczalnej z wykorzystaniem dwóch różnych układów spajających, metodą wtryskiwania żywicy oraz kompresyjnego formowania na gorąco. Oznaczano właściwości mechaniczne WCPC i porównano je z właściwościami konwencjonalnych materiałów drewnopochodnych.

Słowa kluczowe: OSB, drewno do zastosowań inżynieryjnych, kompozyty polimerowo-drzewne, tworzywa wzmocnione włóknem naturalnym, spoiwo bezformaldehydowe.

Processing of long wood chips (strands) is predominantly defined by the production of three-layered oriented strand boards (OSB) in double belt presses. During the conventional OSB manufacturing process, strands are wetted in a large-volume drum by a mixture of binder and additives, placed biaxial on a belt and compacted with specific temperature and pressure [1]. Edge areas of thus produced parts have to be costly reworked. The resulting mechanical properties of OSB are limited since only a small proportion of strands are aligned to the defined major load paths. The binder systems used for OSB are based on diphenylmethane diisocyanate in the core and melamine-urea-formaldehyde in the outer layers [2]. In June 2014, formaldehyde was classified as carcino- and mutagenic by the European Union [3]. Modification of the OSB manufacturing process and change of the used binder systems will lead to high load bearing, zero-waste and non-toxic wood chip plastic composites (WCPC). The aim of the work is to develop a production method that allows processing of formaldehyde-free matrices as well as wood strands without reducing their reinforcing effect. Figure 1 illustrates the production processes for conventional fiber-reinforced thermoplastics and thermosets [4].

Injection molding and extrusion are unsuitable to process wood strands due to high mechanical loads applied during conveying and melting of the plastics in a screw. As a result, they would provide a conventional WPC with

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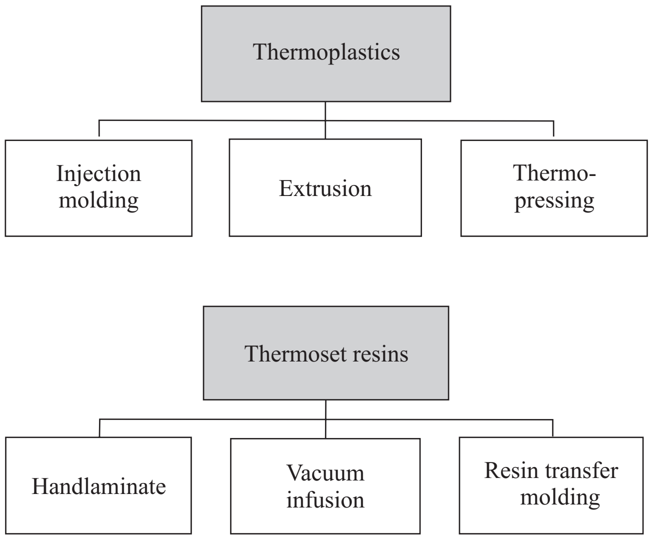

Fig. 1. Options of a production process for WCPC

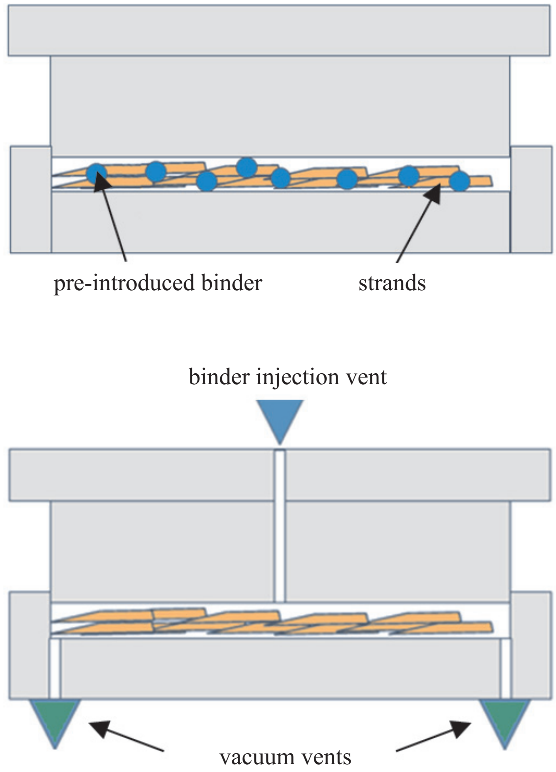

Fig. 2. Thermopressing (above) and resin transfer molding process (below) applied for production of WCPC

shortened fibers and limited reinforcement. Compression pressures by hand laminate or vacuum infusion are insufficient to generate a suitable strand compression ratio. Consequently, solely two of the analyzed processes are applicable for the production of WCPC – thermopressing and resin transfer molding (Fig. 2). Both routes were examined in this work.

EXPERIMENTAL PART

Materials

Binder system

General requirements for a binder system suitable for WCPC production are:
- minor/no health-damaging effects;
- high surface adherence (adhesion, polarity);
- high inner strength (cohesion);
- high dimensional stability (low shrinkage, low moisture expansion, high heat resistance);
- resistance to solvents;
- modest costs.

Thermoplastic binder systems should have low melt viscosity for good impregnation and a wide processing range below the flame point of the utilized wood (pine tree approx. 220 °C). Thermoset resin binder systems should have a low initial viscosity, a low contact angle regarding planar wetting and a long processing time to ensure optimum mold filling.

Taking into account the above-mentioned requirements a powdery polypropylene (PP) (Moplen HP500V by LyondellBasell) and a hard dispersible polymer powder based on vinylacetate and ethylene (EVA, Vinnapas 5010N from Wacker Chemie) were selected as thermoplastic binder systems. Epoxy resin system (EP, Epikote MGS RIMR135/Epikure MGS RIMH134 by Hexion) and unsaturated polyester resin system (UP, Enydyne I69277A/Butanox M50 produced by Polynt Composites) were selected as thermoset binder systems.

Wood strands

Figure 3 illustrates an untreated pinewood strand, as used in the study. The strands have lengths of 50 to 150 mm and the moisture content is around 7 %.

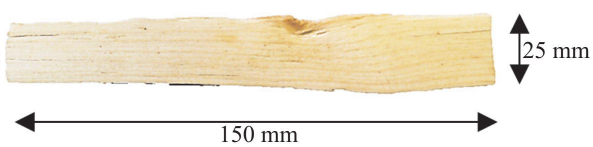

Fig. 3. Pinewood strand used in the study

The behavior of strands when pressurized was investigated in order to determine the compression pressure applied to the strands necessary to achieve maximum densification while avoiding damage of wood cell walls.

The bulk density of non-compressed strands can be seen at the beginning of the curve shown in Fig. 4. When reaching a compression pressure of 11 MPa, the stability of the cell walls results in an increased density of approximately 1.2 g/cm^3 and a cell fracture starts leading to a significant reduction of mechanical properties (Fig. 5).

As a result, it could be determined that a compression pressure of 10 MPa has to be selected as an upper limit for

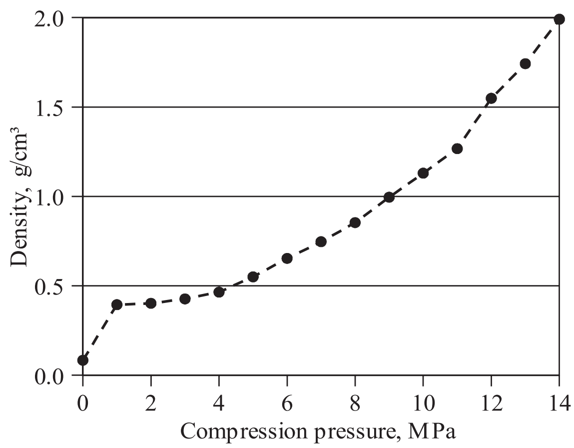

Fig. 4. Strand density as a function of compression pressure

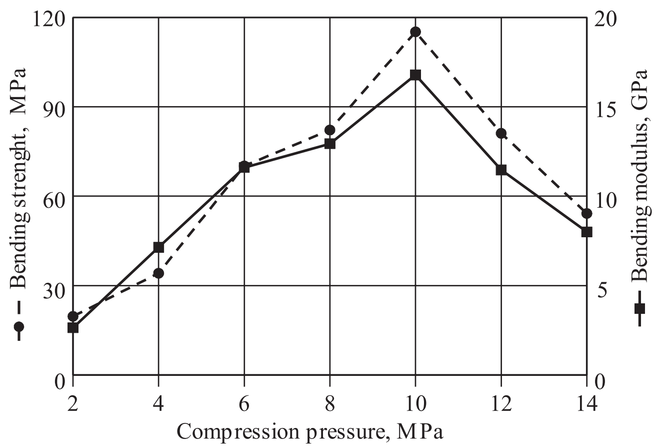

Fig. 5. Mechanical properties of unidirectional reinforced WCPC as a function of compression pressure

subsequent experiments with a maximum in mechanical stability.

Manufacturing process variants

The thermopressing process variant was to layer powered PP or EVA alternating with strands into the mold. Subsequent to thermal plastification, the compaction of the preform took place. Following solidification the part was demolded. This resulted in a rather lengthy process of plastification.

The resin transfer molding process variant was to inject low-viscous EP or UP into a closed mold cavity which was previously filled with strands. Subsequent to the compaction of the mold content and curing of the resin system the part was demolded.

Demonstrator

An experimental mold was developed in order to generate demonstrator parts displaying a broad variety of characteristics. The mold is compatible with both mentioned process variants and allows the processing of three dimensional WCPC parts with specific geometric areas, *i.e.*, different radii and deflection angles (Fig. 6).

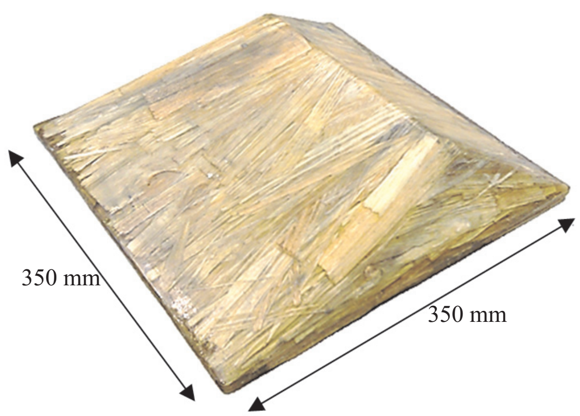

Fig. 6. Thermoset-based three dimensional WCPC part consisting of pine wood strands and epoxy resin

Methods of testing

WCPC specimens with dimensions of 150 x 50 x 5 mm (length x width x height) were tested for mechanical load according to German standard DIN EN 310 (Wood-based panels – Determination of modulus of elasticity in bending and of bending strength) using an universal testing machine by the company Hegewald & Peschke (inspekt 20) (Fig. 7).

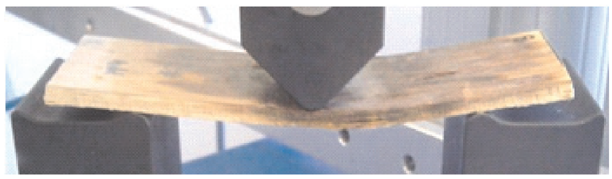

Fig. 7. 3-Point bending test of WCPC specimen in accordance with DIN EN 310 (1993)

The deformation behavior was investigated and characteristic mechanical properties were determined. The specific bending strength B_S was calculated by relating the measured bending strength in fiber direction $\sigma_{||}$ to the measured density of the specimen ϱ multiplied by the earth acceleration g:

$$B_S = \frac{\sigma_{||}}{\varrho \cdot g} \quad (1)$$

RESULTS AND DISCUSSION

The determined relation between density and specific bending strength parallel to the wood fiber direction of a WCPC specimen compressed at 10 MPa and consisting of 10 wt % polypropylene outperformed the OSB3 reference sample by 350 % as well as the comparative AlMg3F24 aluminum alloy sample by 70 % (Fig. 8).

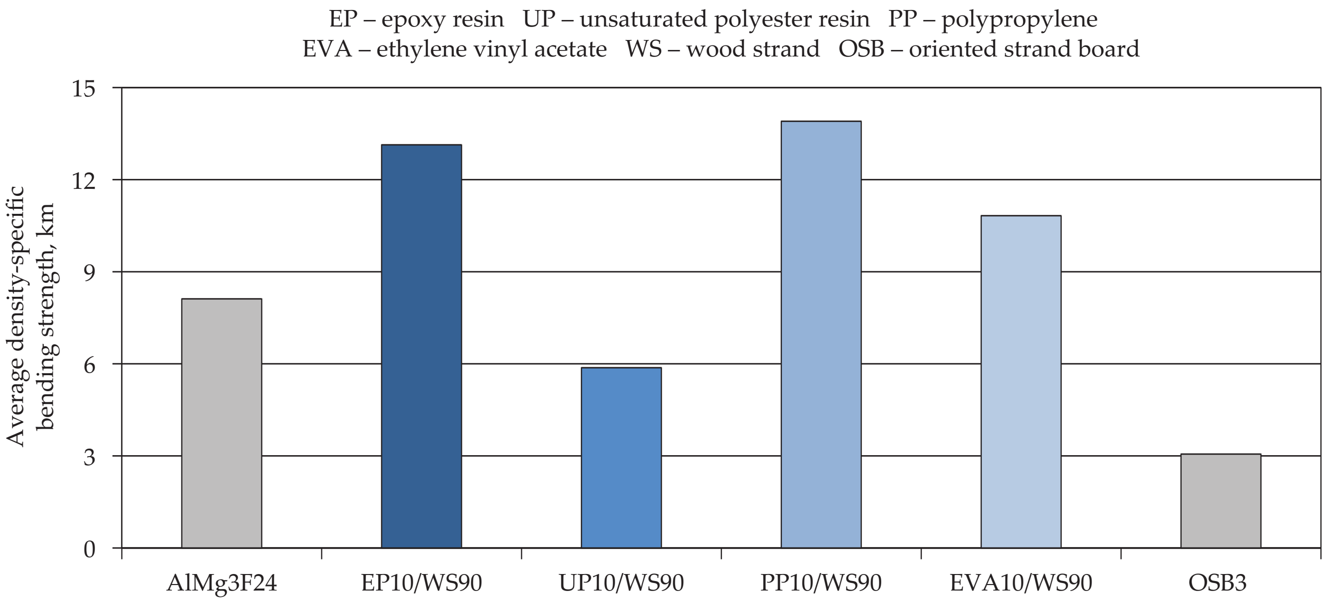

Fig. 8. Relation of specific bending strength parallel to fiber orientation to density of WCPC specimens compressed at 10 MPa and consisting of 10 wt % binder and 90 wt % wood strand in comparison with quasi-isotropic OSB3 and aluminum alloy AlMg3F24

Components made of WCPC are particularly attractive for high performance applications in construction, vehicles and furniture due to the low weight-specific cost of strands and the recognizable high material efficiency.

CONCLUSIONS

The investigations show that the processing of three dimensional WCPC parts in a closed mold is feasible and that thermoplastics as well as thermoset resins are suitable as binder systems. WCPC is environmentally friendly, cost-efficient and excellently suitable as lightweight material. Further investigations are targeted at specific properties such as swelling behavior and mechanical properties orthogonal to fiber direction. The suitability of known bioplastics as binder system will also be examined. Mold filling and design rules will be derived and a fully automatic handling system will be developed, that allows the placement of strands into the mold according to the predefined major load paths within the WCPC component to be produced.

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