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Effect of the wood particle size on screw withdrawal and lateral resistance of wood-polymer composites

CEZARY GOZDECKI

Institute of Technology, Kazimierz Wielki University in Bydgoszcz

Abstract: *Effect of the wood particle size on screw withdrawal and lateral resistance of wood-plastic composites.* Screw withdrawal and lateral resistance of wood-plastic composites were investigated. Five kinds of composites were made by means of injection moulding. Their matrix were polyethylene and a filler: wood flour and industrial wood particles of four various sizes, respectively. All the composites contained 40 % of wood particles. Screw fasteners commonly used in the wood industry were employed in the investigations. The effect of the size of a used wood particle and a mode of the position of a screw on the screw withdrawal resistance of composites. It was also noticed that using a larger size of a wood particle caused a higher lateral resistance of composites.

Keywords: WPC, wood-plastic composite, polypropylene, screw withdrawal resistance, lateral resistance, wood flour

INTRODUCTION

Wood-plastic composite (WPC) as a composition of thermoplastic material with a natural filler (usually in the form of lignocellulose particles) are one of the most dynamically developing materials. Special advantages of these materials result, among other things, from the possibility of free forming their physical and mechanical properties. WPC is relatively moisture resistant, what makes it a perfect material for external applications, where it is exposed to rainfalls. Therefore, it is suitable for manufacturing e.g. garden furniture, small architectural pieces, balustrades, platforms, details of roof slopes, and walls and others.

Despite the fact that WPC can processed by means of injection moulding, extruding, pressing and other ways, it is often not possible to make a ready product without using fasteners. Most frequently single elements are produced, that are afterwards connected, making a ready product. Since WPC, especially when highly filled with wooden material, can be machined with typical tools designed for wood machining, it is natural to use classic connection methods used in the wood industry. Investigations into new modes of connecting components made of WPC are still being carried out, however, the most commonly used are screw connections. Such a connection belongs to conventional construction systems, is easy to make and does not need using special tools.

Very few studies have been conducted on the performance of screwed joints in WPC panels. Investigations into an effect of the level of wood filler content in a polymer and pre-drilling on withdrawal resistance of a screw were carried out by Falk et al. 2001, Kociszewski et al. 2007 and Haftkhani et al. 2011 among others. It was generally proved that both an increase in a level of filling and a size of a pilot hole affect screw withdrawal capacity.

Components made of WPC are frequently exposed to long-lasting influences of variable climatic conditions. Investigations into their effect on withdrawal resistance of a screw were made by Gozdecki and Kociszewski 2008, Madhoushi 2009 among others. In their case wood material used a filler in polymers was in a very fine particle form, such as e.g. wood flour. The studies made by Gozdecki et al. 2011 show that WPC with coarse wood particles is characterized by higher mechanical properties than WPC with wood flour.

Therefore, the investigations were carried to determine an effect of a size of wood particles contained in a composite on screw withdrawal resistance and screw lateral resistance of WPC.

MATERIALS AND METHODS

The investigations were carried out on the composites made of polyethylene Moplen HP 548 produced by Basell Orlem Poliolefins Ltd., filled with industrial soft wood particles used for manufacturing three-layer particleboards, fine particles for face layers and coarse particles for a core layer. They were supplied by Kronospan Szczecinek (Poland). The particles were screened by an analytical sieve shaker LAB-11-200/UP using the sieves of 5, 10, 18, 35 and 60 mesh to obtain four particle sizes: very small, F1, 0.25−0.5 mm; small, F2, 0.5−1 mm; large F3, 1−2 mm; and very large F4, 2−4 mm. For comparison was also used wood flour C120 (mesh 100-200), produced by J. Rettenmaier & Söhne GmbH + Co.

The procedures approved for determination of screw fastener maintaining ability in wood-derived panels were used in the testing (PN – EN 13446). Screw lateral resistance was determined according to ASTM D 1037.

By means of injection moulding, using the Wh-80 Ap injection moulding machine, rectangular specimens were made with dimensions 50 x 50 x 20 mm in length, width and thickness, respectively, using a temperature programme just like for standard composites PE/wood flour. The composites thus produced contained 40 % of wood fraction. According to the standard PN – EN 13446, ø2 +/- 0.1 mm pilot holes were drilled in the samples, perpendicularly to the sample (a port hole in a parallel direction), 20 +/- 1 mm deep.

To determine the effect of a size of wood particle used as a filler EP on screw lateral resistance, ø 4 +/- 0.2 mm through pilot holes were drilled in the samples. Screws of 4 x 50 mm were screwed into the holes prepared in a way shown in Fig. 1.

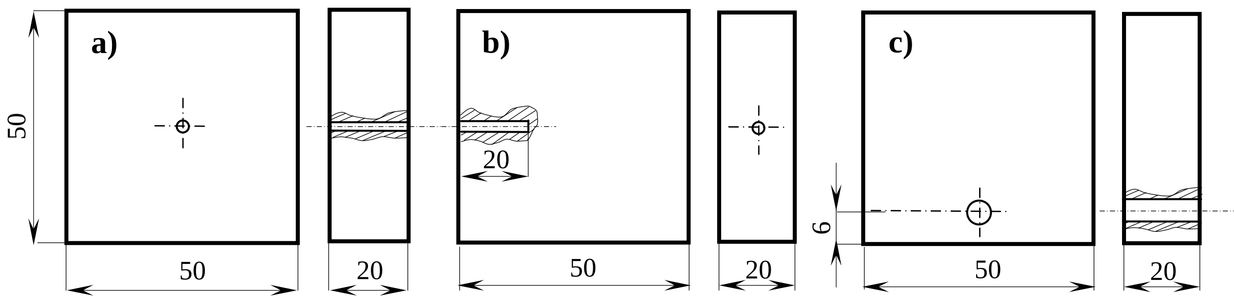

Fig. 1. Shape and dimensions of samples with drilled pilot holes: a) withdrawal resistance of a screw perpendicularly, b) withdrawal resistance of a screw parallel and c) screw lateral resistance

The samples were stored in the laboratory room in a temperature of approx. 21^{o}C and humidity of approx. 65%. The sample with a screw was then fixed in a testing machine in such a way as to provide axial action of the screw withdrawing force. During tests the force of screw lateral resistance was applied perpendicularly to a screw on both sides of the sample. The rate of travel of the testing machine cross-beam was set to 2 mm/min. Maximal force P_{max} required to withdraw the screw from the sample was noted each time. On this basis, the screw withdrawal resistance of the composites, was calculated, according to the following formula.

$$WR = \frac{P_{max}}{dl_P} \qquad (1)$$

where:
WR - withdrawal resistance (N/mm^2)
P_{max} – max. force applied to withdraw the screw (N),
d – nominal diameter of the fastener (mm), and
l_p – depth of the fastener embedding (mm).

Screw lateral resistance was represented as a maximal force causing destruction WPC.

RESULTS AND DISCUSSION

Examples of failure modes of WPC caused by withdrawal and lateral resistances were shown in Fig. 2 and Fig. 3.

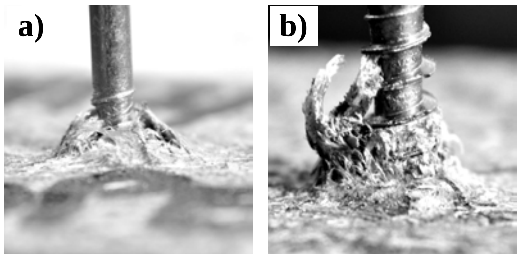

Fig. 2. Examples of failure modes of WPC caused by withdrawal resistance: a) composite with particle size F1 and b) composite with particle size F4

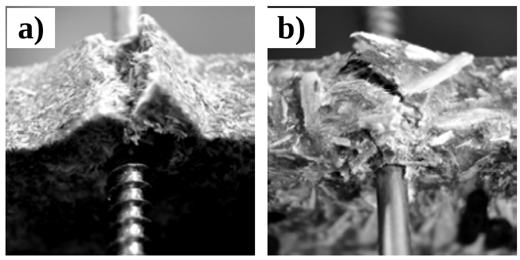

Fig. 3. Examples of failure modes of WPC caused by lateral resistances: a) composite with particle size F1 and b) composite with particle size F4

The effect of the wood particle size on the ability to maintain the screw for parallel and perpendicular loading directions is shown in Fig. 4. The effect of a wood particle size on the screw lateral resistance is shown in Fig. 5. Mean values with the same letter for each property are not significantly different at the 5% significance level.

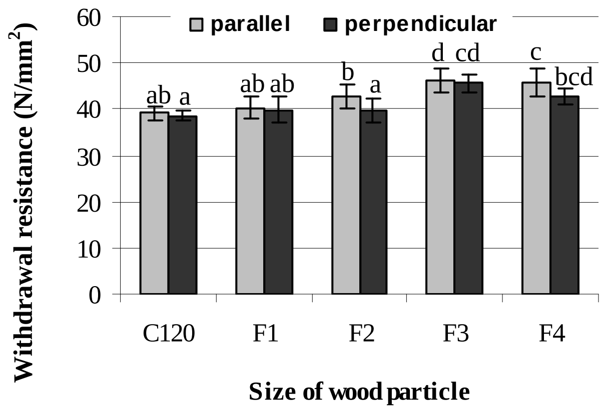

Fig. 4. Withdrawal resistance of a screw embedded in the composite parallel and perpendicular to the sample surface

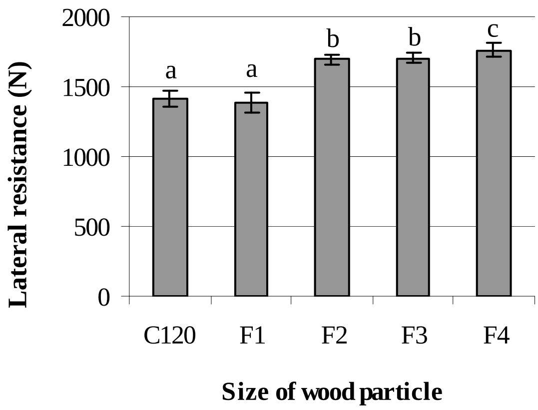

Fig. 5. Screw lateral resistance

Wood-plastic composites show good withdrawal and lateral resistances regardless of kind of a filler used in the testing. Generally the highest value of withdrawal and lateral resistances were noted when the composite contained large wood particles, F3 and F4. The phenomenon is common for both constructions, i.e. with the screw mounted perpendicular and parallel to the sample surface, with slightly higher withdrawal resistance being shown by the composites in which screws were parallel embedded in the composite. The difference amounted to less than 5 %. The highest withdrawal resistance is shown by the composites filled with wood particles F3, and when the screw was embedded parallel to the sample surface. The lowest one, about 17 %, was shown by the composites filled with wood flour, and when the screw was embedded perpendicular to the surface. Generally the differences in withdrawal resistances between the composites containing wood flour, wood particles F1 and F2 for both modes of screw embedment are statistically insignificant. A similar phenomenon can be observed for the composites containing wood particles F3 and F4.

When analyzing the results one can notice that the composites containing wood flour or wood particles F1 show values of lateral resistance close to each other. Similar relations occur when polyethylene is filled with wood particles F2 and F3. The differences between mean values of lateral resistances of such composites are statistically insignificant. The highest lateral resistance is shown by the composites filled with wood particles F4. Its value is greater by about 27 % than lateral resistance of the composites filled with wood particles F1 and wood flour. Using wood particles F2 and F3 as a filler causes slight (about 4 %) but statistically significant reduction of lateral resistance in comparison with the composite with wood particles F4.

When observing the samples during the withdrawal resistance and lateral resistance tests one can notice characteristic failure modes of WPC (Fig. 2 and Fig. 3). In the case of composites with wood particles F1 (Fig. 2a and Fig. 3a) it was "brittle fracture", and for composites with wood particles F4 (Fig. 2b and Fig. 3b) it was "fracture" and "delamination" at the edge of wood particles. One can admit that the reason for such a mode of composite destruction is a size of used wood particles. Most probably in the case of using "larger" wood particles for filling a polymer, composite destruction during withdrawal resistance and lateral resistance tests shows similarity to wood destruction during the same tests.

CONCLUSIONS

On the basis of the performed study, we can draw the following conclusions:

1. The tested composites show good screw withdrawal and lateral resistances, with the highest values of these properties being noted when a composite contained large wood particles (F3 and F4).
2. The withdrawal capacity of the screw embedded in the parallel direction in the composite material is slightly higher than in the case of the screw embedded in the perpendicular one, regardless of kind of a filler used in the tests.
3. Depending on the wood particles used for filling one can observe various failure modes of composites during withdrawal resistance and lateral resistance tests.

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Streszczenie: *Wpływ wielkości cząstki drzewnej na opór jaki stawia kompozyt drzewno-polimerowy przy wyciąganiu osiowym i przeciąganiu bocznym wkręta.* W pracy przedstawiono wyniki badań nad wpływem wielkości cząstki drzewnej na opór jaki stawia kompozyt drzewno-polimerowy podczas wyrywania i przeciągania bocznego typowego wkręta stosowanego w drzewnictwie. Metodą wtryskiwania do formy wytworzono pięć rodzajów kompozytów, w których osnowę stanowił polietylen a napełniacz odpowiednio: mączka drzewna oraz wióry przemysłowe o czterech różnych wielkościach. Dla wszystkich wytworzonych kompozytów zastosowano 40% udział cząstek drzewnych. Zauważono wpływ wielkości użytej cząstki drzewnej oraz sposób umiejscowienia wkręta, na opór jaki stawia kompozyt w trakcie wyciągania łącznika. Zauważono również iż użycie większej cząstki drzewnej skutkuje wyższym oporem kompozytu podczas przeciągania bocznego łącznika.

Corresponding author:

Cezary Gozdecki
Institute of Technology
Kazimierz Wielki University
Chodkiewicza 30 str.
85-064 Bydgoszcz, Poland
gozdecki@ukw.edu.pl