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Influence of pine wood (*Pinus sylvestris* L.) thermal modification on the withdrawal force of screws

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Abstract: *Influence of pine wood (Pinus sylvestris* L.*) thermal modification on the withdrawal force of screws*. In the study the force required to withdraw the screw from thermally treated pine wood was examined. Modification of pine wood was performed at a temperature range of 150 - 180°C. It was concluded that the process of wood modification does not significantly affect the force needed to pull a screw out, and therefore also the withdrawal capacity and the ability to maintain the screw. In the case of 3.5 x 35 mm and 4.0 x 35 mm screws, the withdrawal capacity constituted respectively 63% and 50% of the ability to maintain the screw.

Keywords: thermal modification, *Pinus sylvestris* L., screw, withdrawal force, withdrawal capacity

INTRODUCTION

Thermally modified wood has a number of characteristics which make it more suitable for external applications. Compared to untreated solid wood, thermally modified wood has higher resistance to humidity which translates to higher dimensional stability. Arnold (2010) reports that the equilibrium moisture content of spruce (*Picea abies* L.) modified at 180 - 220°C is about 40 - 60% lower than the equilibrium moisture content of wood before the modification. As a result of thermal modification of pine wood (*Pinus pinaster* Aiton), dimensional stability in the radial and tangential direction increased by 73% and 62% respectively (Esteves et al. 2008). Depending on the processing parameters, the wood can be used in use class 1 - 3 (classification according to EN 460:1994) e.g. for facades, terraces and garden furniture.

A negative effect of thermal modification of wood is the reduction of mechanical properties (Korkut et al. 2008). Modification of pine wood (*Pinus* spp.) at 200°C causes a decrease of bending strength and modulus of elasticity by 32% and 28% respectively (Shi et al. 2007). The shear strength of spruce (*Picea abies* Karst.) decreases with an increase of the temperature of modification, a significant decrease occurs at temperatures of 210°C and 230°C (Kariz et al. 2013). Changes in wood properties are mainly due to changes in chemical composition, in particular the degradation of hemicelluloses (Esteves et al. 2008). Such changes may also affect the ability of wood to maintain metal fasteners.

Due to the benefits of use, nails and screws are a popular means of connecting wood (Kotwica 2004). The ability of wood to maintain screws depends on many factors. Therefore, it is necessary to conduct independent trials. There are researches regarding the maintenance of nails and screws by untreated solid wood (e.g. Wilkinson and Laatsch 1970, Eckelman 1978, Korgól 1986). Unfortunately, the research and results presentation methodology utilised previously has changed due to the introduction of a new standard (EN 1382:1999).

With regard to the modified wood, Kariz et al. (2013) reported that an increase of the temperature of thermal treatment (150 - 230°C) causes a decrease of the screw withdrawal capacity (3.5 x 50 mm without drilling) in heat-treated spruce wood (*Picea abies* Karst.)

mainly in radial direction. The exception was wood modified at 190°C. Significant changes in the screw withdrawal capacity are in the tangential direction where the wood has been modified at 210 and 230°C. Similar results were reported for the screw withdrawal strength of pine (*Pinus banksiana*) (Kocaefe et al. 2010).

The aim of the study was to determine the effect of thermal modification of pine (*Pinus sylvestris* L.) on the force needed to withdraw the screw from the wood. Screw withdrawal capacity defined in EN 1382:1999 was compared with the ability to maintain screws specified in PN-D-04244:1974.

MATERIALS

In the study, pine wood (*Pinus sylvestris* L.) before (control variant W_control) and after modification in superheated steam was used. The temperature of the wood modification was 150, 160, 170 and 180°C (variants respectively T_150°C, T_160°C, T_170°C and T_180°C), and the appropriate modification phase (at a preset temperature) lasted 2.5 hours. The modification temperature was selected so as not to cause excessive lowering of the mechanical properties of the pine wood (Jankowska et al. 2014). After the conditioning of the specimens (12 of each variant) to the state of dry air in accordance with the recommendations of ISO 3130:1975, the wood density was determined by stereometric method in accordance with ISO 3131:1975. Wood moisture content was determined in accordance with ISO 3130:1975.

The force required to withdraw a screw from the wood in the radial direction was determined according to EN 1382:1999. The screw withdrawal capacity defined in EN 1382:1999 was compared with the ability to maintain the screw defined in PN-D-04244:1974 (possibility of comparison with the results of previous publications). Screws 3.5 x 35 mm (diameter of the shank = 1.6 mm), 4.0 x 35 mm (diameter of the shank = 2.0 mm) with countersunk heads were used. The screws were placed in pre-drilled holes of 2.2 mm diameter. The screw insertion depth (including the blade) was 13 mm. The study was conducted with the use a universal testing machine, using a feed of 5 mm/min and a load range of 0 to 1000 daN. Statistical analysis of the research results was performed using the Dunnett's test at a significance level of 0.05.

RESULTS AND DISCUSSION

The 3.5 x 35 mm and 4.0 x 35 mm screws used in the tests are normally used to join different types of fittings in wooden products e.g. furniture, window and door woodwork and facade elements. Therefore, the obtained results have practical significance. According to the recommendations (Kotwica 2004), the diameter of the drilled holes did not exceed 0.7 of the diameter of the screw threaded section.

Before the thermal modification, the average density of pine wood in dry air conditions was 590 $kg \cdot m^{-3}$. The density must be regarded as typical for semi-finished pine for furniture, window and door woodwork. In the production of these elements, it is preferable to use wood without knots, mature wood from basal parts of trunks having a smaller width of annual growth rings, and thus with a higher proportion of late wood and higher density.

As a result of the modification, there was a slight decrease in the density of pine wood of about 1%, the weight loss of about 3 - 4%. An important consequence of the modification of pine was clear differentiation the equilibrium moisture content of wood in a given climate (temperature 20°C, relative humidity 65%), confirming the results obtained by Arnold (2010). The thermal modification resulted in the reduction of wood moisture content to 8% (a reduction of over 30%), compared to 12% moisture of untreated solid wood. Lower moisture content of heat-treated pine wood certainly had an effect on the results of the force to maintain the screws (Figure 1).

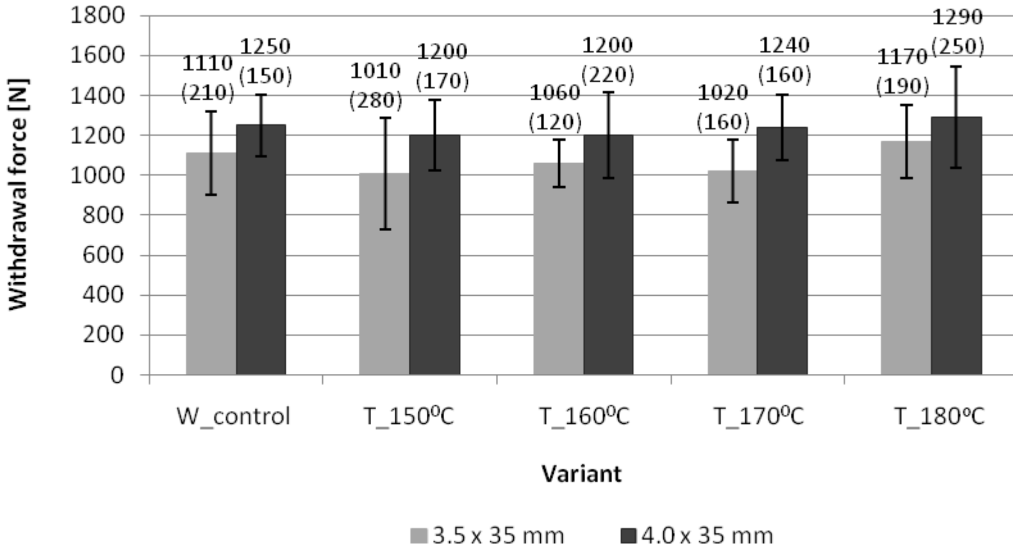

Figure 1. Withdrawal force depending on the diameter of screws (standard deviations in brackets)

Given the variability of the characteristic, no significant differences in the withdrawal force of screws between untreated pine wood and modified wood in the temperature range from 150 to 180^{o}C were noted. For 3.5 x 35 mm screws, the force reached the level approx. 1.10 kN and for 4.0 x 35 mm screws - 1.25 kN. Using the empirical formula ($P = 108.25G^2DL$) to estimate the withdrawal force of screws from wood (Soltis 1999), the following results are obtained: 1.71 kN for the screws with a diameter of 3.5 mm and 2.20 kN for the screw with a diameter of 4.0 mm (a value approx. 60% higher than those obtained in the performed experiment). This shows that the use of general empirical formula is not always effective after narrowing the tested wood species down to only one, in this case to Scots pine (*Pinus sylvestris* L.).

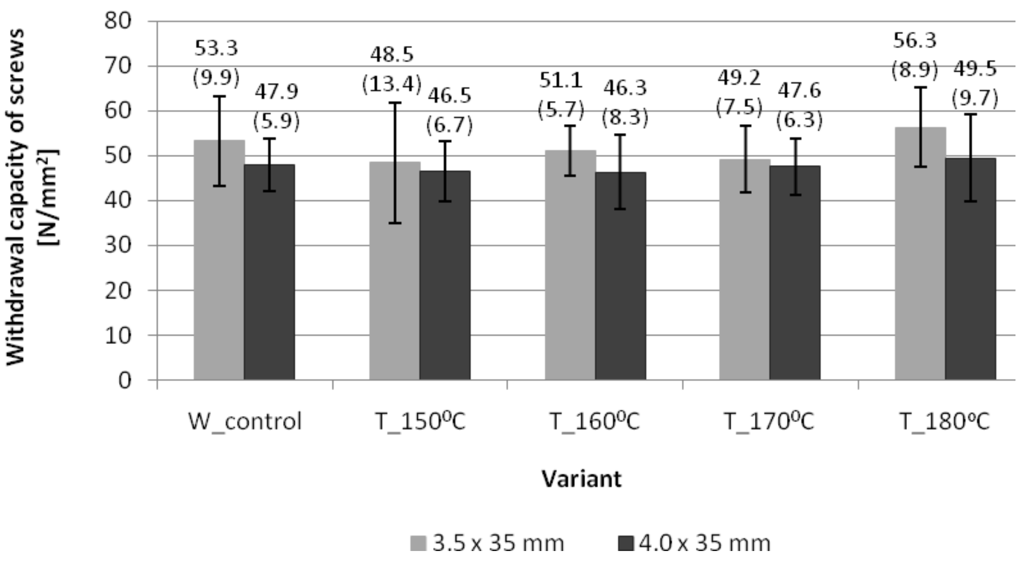

Figure 2. Withdrawal capacity of screws according to EN 1382:1999 (standard deviations in brackets)

The screw withdrawal capacity of pine from the test is shown in Figure 2. For the 3.5 x 35 mm screws the withdrawal capacity was at a level of approx. 50 N/mm^2 and for the 4.0 x 35 mm screws at the level of approx. 47 N/mm^2. These results are significantly higher than those obtained by Babecki (2011) for normal screws with a diameter of 4.5 mm embedded in pine wood in the tangential and radial directions (less than 30 N/mm^2).

The statistical analysis indicates that within a particular type (size) of screws, the effect of heat treatment on the screw withdrawal capacity was insignificant. Thus, the results do not confirm earlier observations (Kariz et al. 2013) which relate to the decrease of the screw withdrawal capacity of thermally modified spruce. This is probably due to two reasons: a smaller temperature range of pine wood modification and a significantly lower equilibrium moisture content of wood after the modification. Dry wood is more dense and less prone to deformation, which somewhat compensates its undesirable brittleness.

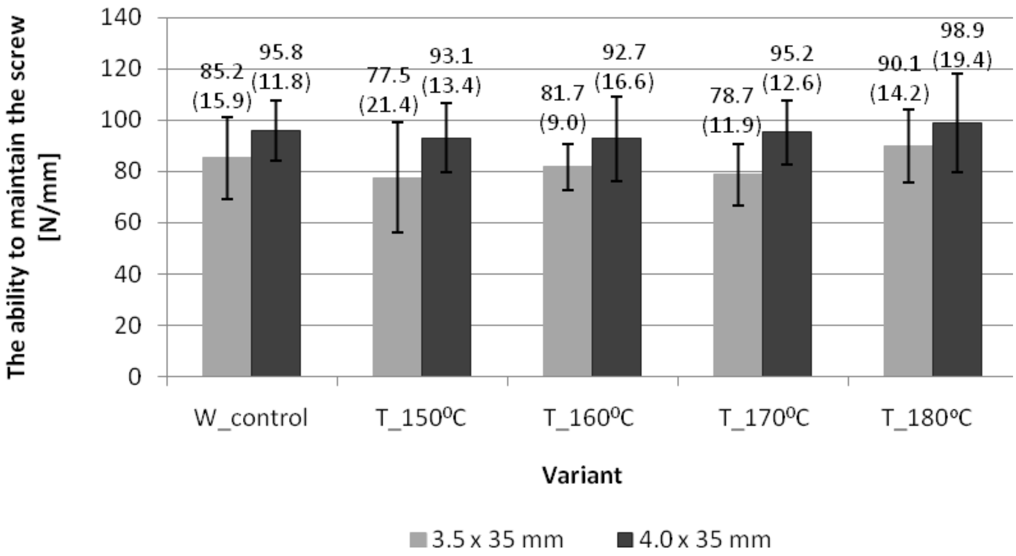

Figure 3. The ability to maintain the screw according to PN-D-04244:1974 (standard deviations in brackets)

The screw retention ability of pine calculated in accordance with PN-D-04244:1974 is shown in Figure 3. This method of presenting the data causes the inversion of the results, compared to the results shown in Figure 2. The screws of smaller diameter have a slightly lower ability to maintain the screw compared to screws with a diameter of 4.0 mm. In the case of the 3.5 x 35 mm screws the withdrawal capacity is about 63% of the ability to maintain the screws. For the 4.0 x 35 mm screws the withdrawal capacity is about 50% of the ability to maintain the screws.

CONCLUSIONS

Based on the research of the ability of pine to maintain screws, following conclusions were drawn:

1. Thermal modification of pine wood (*Pinus sylvestris* L.) at the temperature range of 150 - 180°C did not have a significant effect on the force required to withdraw the screws (embedded perpendicularly to the grain) axially in the radial direction.
2. The force necessary to withdraw the screws, withdrawal capacity and the ability to maintain the screw by modified pine wood are practically the same as in the untreated wood.
3. Regardless of the variant of tested sample, 3.5 x 35 mm screws embedded in wood to the same depth of 13 mm as 4.0 x 35 mm screws were characterized with lower force needed

to withdraw the screw from the wood, higher withdrawal capacity and lower ability to maintain the screw, and the differences were not significant.

4. The withdrawal capacity of 3.5 x 35 mm and 4.0 x 35 mm screws constituted respectively 63% and 50% of the ability to maintain the screw.

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Streszczenie: *Wpływ termicznej modyfikacji drewna sosny (Pinus sylvestris L.) na siłę utrzymania wkrętów.* W pracy badano wielkość siły potrzebnej do wyciągnięcia wkręta z drewna sosny poddanego modyfikacji w parze przegrzanej. Modyfikację drewna sosny prowadzono w zakresie temperatur 150 - 180^{o}C. Stwierdzono, że proces modyfikacji drewna nie wpływa w istotny sposób na siłę potrzebną do wyciągnięcia wkręta, a w związku z tym na wytrzymałość na wyciąganie wkręta i zdolność utrzymania wkręta. W przypadku wkrętów 3,5 x 35 mm oraz 4,0 x 35 mm wytrzymałość na wyciąganie stanowiła odpowiednio 63 i 50% zdolności utrzymania wkręta.

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