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ANALYSIS OF RESISTANCE TO AXIAL WITHDRAWAL OF SCREWS EMBEDDED IN LOCALLY REINFORCED MDF

This paper presents results of the analysis on screw withdrawal strength in locally reinforced MDF. Various amounts of the agent locally reinforcing the boards were applied and universal screws and euro screws were tested. Experiments were conducted using a universal strength testing machine, with samples collected following the guidelines of the ISO 27528:2009 standard. The following parameters were measured: 1) work required for maximum force, 2) maximum force, 3) withdrawal capacity and 4) stiffness. The research showed a 100% increase in resistance to axial withdrawal of universal screws and a 50% increase in euro screws in comparison to the analogous results for the non-reinforced board. Optimal amounts of the reinforcing agents were also determined.

Keywords: screw, universal screw, euro screw, withdrawal, holding strength, MDF, fibreboard, local modification, local reinforced

Introduction

Medium-density fibreboard (MDF) is produced by binding wood fibres with a synthetic binding agent. In Europe this board is available in a thickness ranging from 1.8 to 60 mm and it is commonly used in the furniture industry and as architectural built-in elements. Structures made from MDF are frequently exposed to considerable loading and one of the methods typically used to connect MDF is to apply steel threaded fasteners. The strength of structural steel is at least 10 times greater than that of wood-based materials (in practice it is 10-15 times greater). The failure of an over-stressed joint comprising of steel threaded fasteners causes the failure of wood-based board. Thus, joint strength is determined by the strength of wood-based panel elements rather than that of screw connectors. Furniture design requires quality verification in terms of its rigidity and the strength of the applied construction solutions [Smardzewski and Kłos 2011]. In the past to improve the strength of wood-based boards, twenty or thirty percent solutions of gluten glue or urea-formaldehyde resin were applied

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inside the pilot holes. This solution provided an enhanced screw holding capacity and uniform values for different fastening directions [Ławniczak and Paprzycki 1961]. Wood based composites were also investigated after vacuum-impregnation of copper azole and chromated copper arsenate [Taşçioğlu et al. 2014]. Advances in polymer chemistry have led to the development of novel polyurethane products with potentially advantageous properties [Proszyk 2009].

The aim of the study was to investigate the effect of local reinforcement of MDF with a novel polyurethane product on resistance to axial withdrawal of screws.

The experiment described in this paper was conducted whilst taking into consideration the conclusions and observations made in the course of preliminary studies by Pohl and Wołpiuk [2011], e.g. the range of applications was increased, the experimental stand was modified to ensure the acquisition of increased measurement data, while changes were introduced in the design of the pull-out testing machine to increase its rigidity. Additionally, the strength properties were precisely determined for the MDF, from which samples were collected.

Material and methods

Analyses were conducted on MDF of 18 mm in thickness. The wood-based panel was composed of three layers (fig. 1) [Geimer et al. 1975; Wilczyński and Kociszewski 2007]. The averaged material properties of the two outer (face) layers (of arbitrarily assumed 2.2 mm thickness) were identical, while the core, of lower density, was characterised by markedly different material properties.

The research was used on a board produced by the same manufacturer as used in the Kociszewski's study [Kociszewski 2014]. Table 1 presents the numerical values of the material properties for layers of MDF, from which samples were collected.

Analyses were conducted for two types of fasteners, commonly used in the assembly of furniture joints, i.e. universal screws of 4×35 and euro screws of 6.3×23 in size (fig. 1).

MDF samples had dimensions of $75 \times 75 \times 18$ mm (specified in the standard ISO 27528:2009). Fasteners were mounted in the face of test pieces to a depth of 15 mm into previously drilled pilot holes with a diameter corresponding to the minor diameter of the screw (diameter D_3 in fig. 2). The manner of screw mounting in the panel samples and the direction of the pull-out force is presented in figure 3.

Table 1. Physical properties of wood-based panels used in research

Parameter		MDF[1]	MDF with PUR application[2]
Thickness t (mm)		18.0 ±0.2	
Moisture content φ (%)		7.7	
Density ρ (kg/m³)	mean	787.7	935.4
	outer layer	952.7	1031.2
	inner layer	732.5	904.4
Young's modulus (GPa) (EN 310)	E_{x1}	6.08	8.03
	E_{y1}	5.88	8.03
	E_{z1}	1.16	1.83
	E_{x2}	2.68	5.39
	E_{y2}	2.65	5.39
	E_{z2}	0.50	1.30

[1]According to Kociszewski [2014].
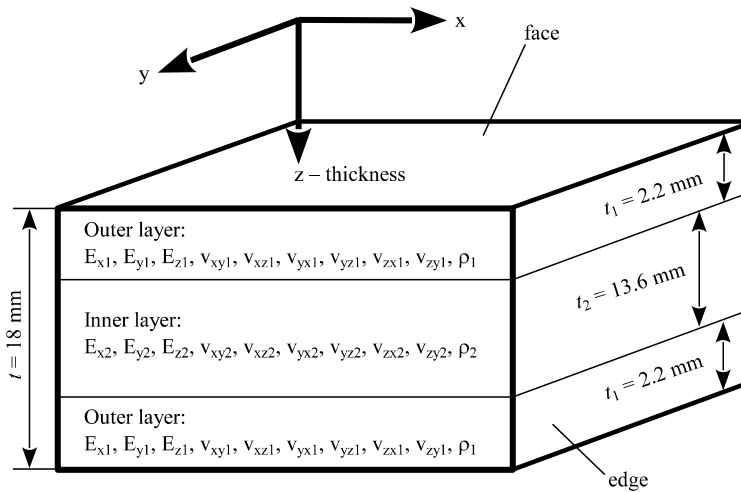[2]According to the authors' study.

Fig. 1. A model of a three-layer wood-based panel: x – in the board plane perpendicular to direction of mat formation, y – direction of panel production, z – perpendicular to board plane

The panel was locally reinforced using the PUR 555.6 nano polyurethane product by Kleiberit. The application rates of the product were determined based on the volume of fastener threads. The volume of the applied preparation is referred to as application unit (V), described by the formula:

$$V = \frac{\pi \left(D^2 - D_3^2 \right) \cdot L}{4}$$

where: L – depth of fastener mounting
$\quad\quad\quad D$ – major diameter of the thread
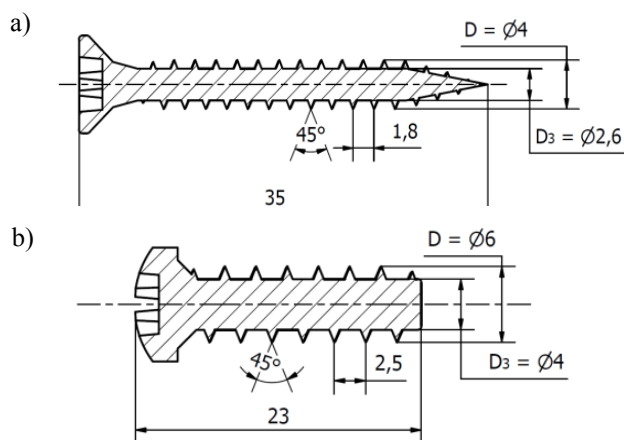$\quad\quad\quad D_3$ – minor diameter of thread.

a)

b)

Fig. 2. Fasteners used in tests: a) universal screw; b) euro screw
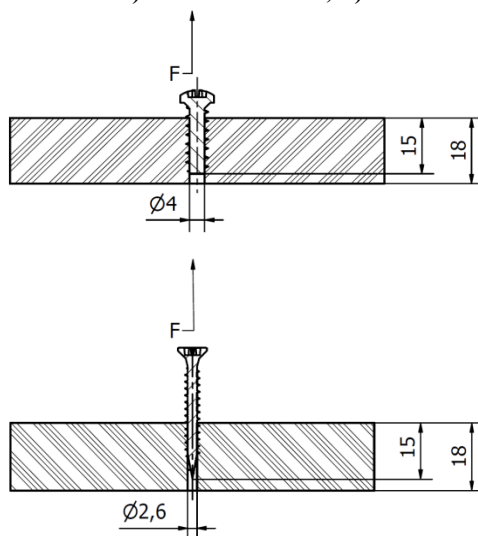

Fig. 3. Manner of fastener mounting

Thus the volume of the application unit depends on the dimensions of the tested screw. In the described experiment two values of the application unit were used: for universal screws $V_U = 0.12$ cm^3, while for euro screws $V_E = 0.28$ cm^3. Nine application rates were adopted, from zero to eight units (tab. 2).

Table 2. Volume of applied panel reinforcement agent depending on fastener type

No. of application units	Volume of reinforcement agent (cm^3)	
	V_U (universal screw)	V_E (euro screw)
0	0	0
1	0.12	0.28
2	0.24	0.56
3	0.36	0.84
4	0.48	1.12
5	0.60	1.40
6	0.72	1.68
7	0.84	1.96
8	0.96	2.24

The reinforcement agent was immediately applied into the previously drilled pilot holes using a syringe. Figure 4 presents the section of a hole left after the withdrawal of a euro screw, with the darker zone representing the area penetrated by the reinforcement agent.

Fig. 4. A cross section of the modified MDF sample by the PUR reinforcing agent (shows the area of modification of the prebored pilot hole for euro screw)

The screw holding capacity in the locally reinforced MDF samples was tested 72 hours after the reinforcement agent application and screw mounting, i.e. after the complete curing of the preparation. The pull-out test was performed in a Zwick Z050 universal strength testing machine at the following parameters:

1. initial force: 5 N,
2. after the initial force was reached screws were pulled out at 2 mm/min.

In the course of the experiment, the holding force of screws in the panel was measured depending on the translocation (withdrawal of the pulled-out screw from the hole). This made it possible to determine the following values:

1) The amount of work needed to reach maximum force (withdrawal work denoted as W_W, expressed in joules) – calculated on the basis of the pull-out strength (F) and displacement (s), which is represented by the area under the curve in figure 5,

2) The amount of withdrawal strength denoted as W_S, expressed in newtons) – read from the testing machine as a maximum force during each experiment,

3) The amount of withdrawal capacity denoted as W_C, expressed in newtons per millimetre) – the screw holding value of a test piece is the quotient of maximum force (F_{max}) and embedded depth of the screw (L) – according to the recommendations of ISO 27528: 2009,

4) stiffness (denoted as C_f, expressed in newtons per mm and being a quotient of force to limit of proportionality and translocation to limit of proportionality – fig. 5).
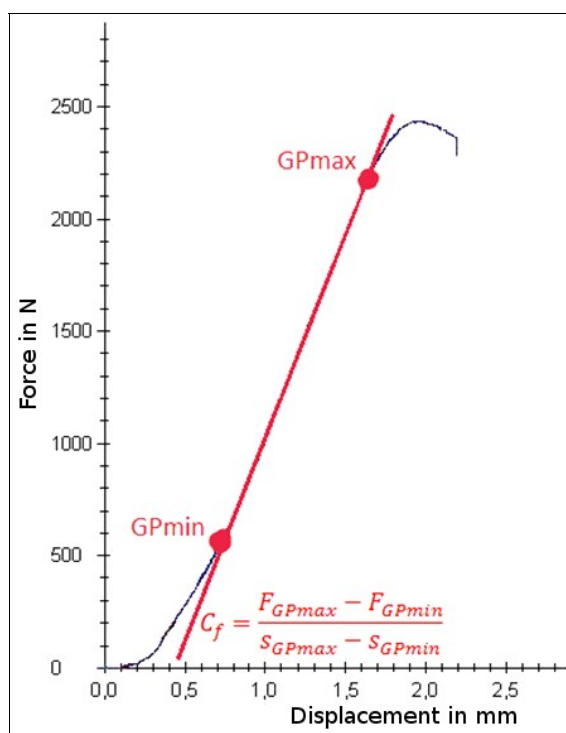

Fig. 5. Method of calculating stiffness

For each screw, a series of 9 samples were prepared for each application rate. For two types of the tested screws this yielded a total of 162 pull-out tests (9 samples in a series, 9 series – from 0 to 8 application units, 2 types of screws: $9 \cdot 9 \cdot 2 = 162$). Based on the nine replications performed for each series, the standard deviations were calculated for each series and shown on graphs as error bars.

Results and discussion

The results of the experiment are presented in four graphs (figs. 6-9). The bar graphs present the test results of the holding capacity of universal screws and euro screws mounted in the face of MDF. Figure 6 presents work to maximum force – withdrawal work (W_W), figure 7 – recorded values of maximum force – withdrawal strength (W_S), while figure 8 presents the holding force of screws per unit of screw penetration length (i.e. values from fig. 7 divided by the depth of screw mounting of 1.5 cm – withdrawal capacity) (W_C). Figure 9 presents changes in stiffness (C_f) depending on the number of application units of the reinforcement agent.
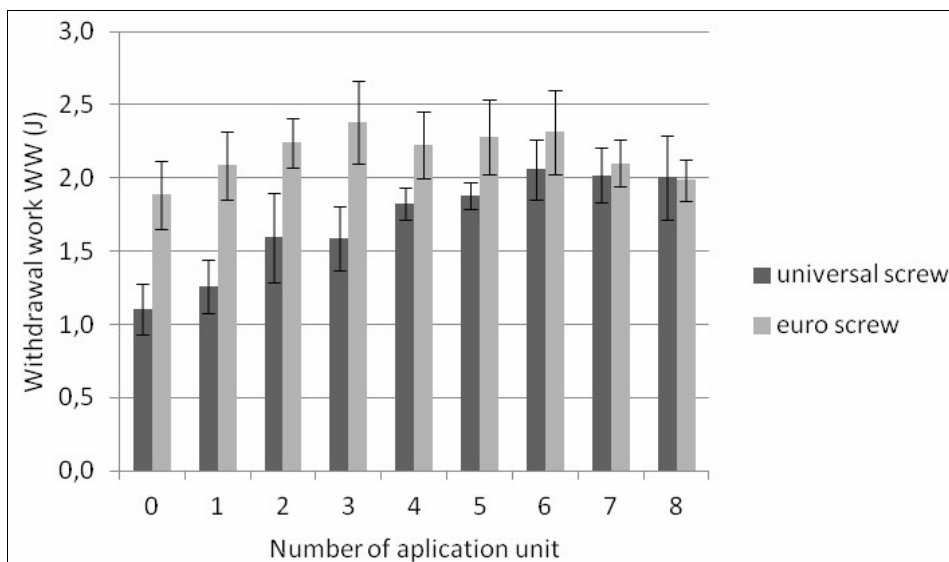

Fig. 6. Work to failure depending on the number of application units of reinforcement agent
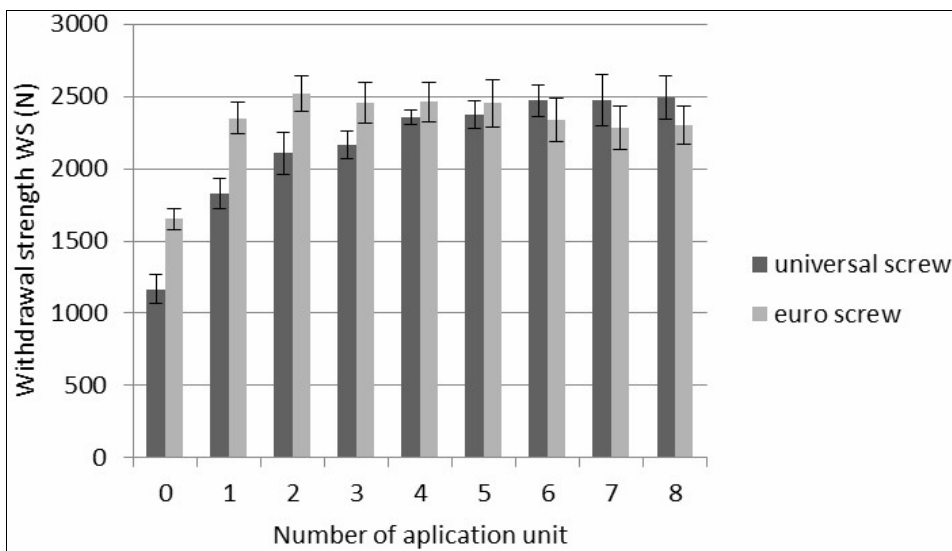
Fig. 7. Maximum holding force depending on the number of application units of reinforcement agent
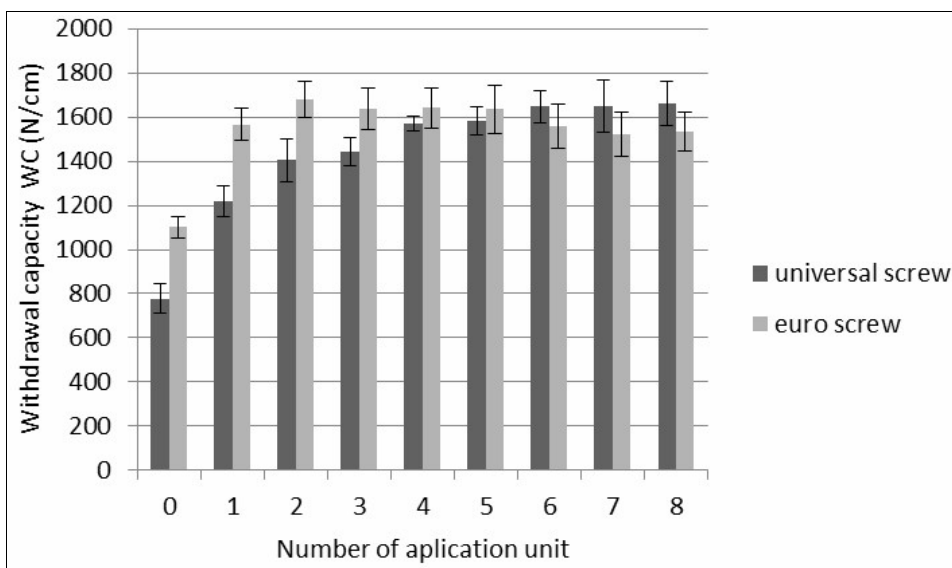

Fig. 8. Screw withdrawal capacity depending on the number of application units of reinforcement agent
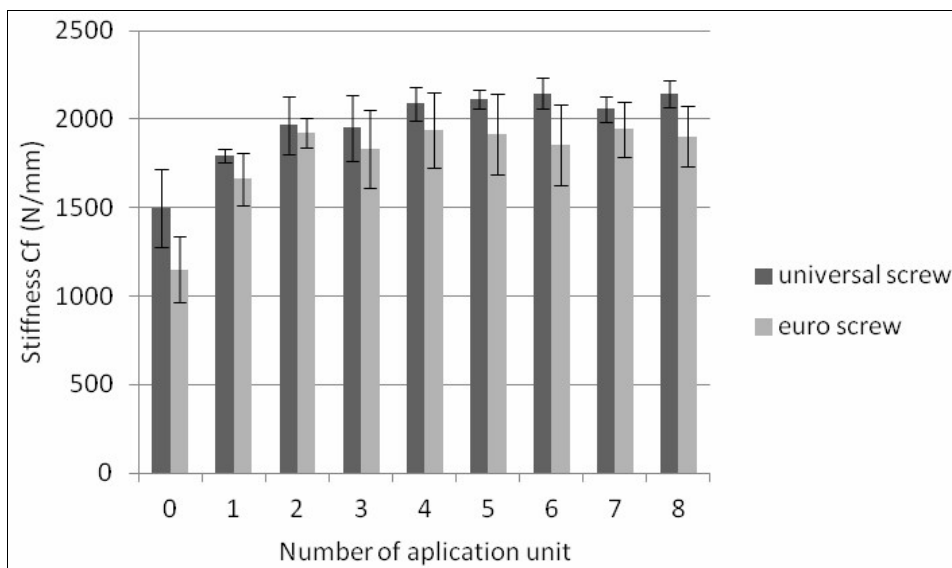
Fig. 9. Stiffness depending on the number of application units of reinforcement agent

Conclusions

- The polyurethane agent at the rate of 6 application units (0.72 cm^3) improved withdrawal capacity of universal screws by over 100% (from the initial approx. 780 N/cm to approx. 1650 N/cm – fig. 8). A further increase in the amount of the reinforcement agent did not result in an enhancement of withdrawal capacity of universal screws.
- In the case of euro screws the capacity increased by approx. 50% already at two application units (0.56 cm^3). A further increase in the number of application units of the curing agent resulted in a slight reduction of withdrawal capacity of euro screws, thus it is not justified (fig. 8).
- Stiffness, i.e. the ratio of force to the limit of proportionality, and translocation to the limit of proportionality in the case of universal and euro screws reached its maximum value at four application units (for 0.48 and 1.12 cm^3, respectively). In the case of universal screws stiffness increased by a maximum of approximately forty percent, while in the case of euro screws – by approximately sixty percent (fig. 9).

Based on the recorded results it may be stated that the use of local modification of MDF is justified in the case of strongly over-stressed joints. Screws mounted within locally reinforced panels exhibit an increased withdrawal capacity of fifty to one hundred percent in comparison to screws mounted within boards, which are not locally reinforced. Screws have to be mounted within a short time after the application of the reinforcement agent

(upon its complete curing it is practically impossible to mount the fasteners due to the significant increase in resistance of screws being screwed in).

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