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LOCAL MODIFICATION OF SCREW CONNECTIONS IN WOOD-BASED COMPOSITES

Keywords: MDF, chipboard, local modification, non-destructive, x-ray, polyurethane

1. Introduction

Wood-based boards with composite structure employed in furniture construction include, primarily, chipboards (CB) and medium-density fibreboards (MDF).

The chipboard is manufactured from specially machined resin-coated chips which are then pressed at elevated temperatures. External chips usually have other geometry and degree of gluing in comparison with internal chips which means that, in the course of manufacturing, three-layered boards are obtained where external strata are characterised by higher density, hence better strength properties than the internal layer [7].

The medium-density fibreboard, on the other hand, is manufactured from defibrated wood tissue formatted into boards and pressed at elevated temperature and, in the case of dry-formatted boards, with a small addition of glue. Boards of uniform strength properties on their surface are obtained; however, on the cross section, the near-surface layers have greater density and, therefore, are characterised by better strength properties [4].

Example density profiles of the chipboard (CB) and medium-density fibreboard (MDF) materials are presented in Figure 1.

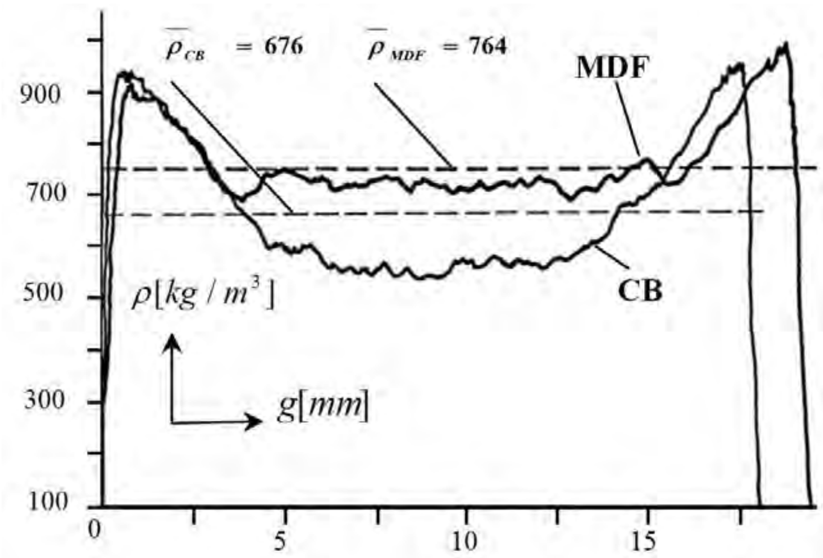
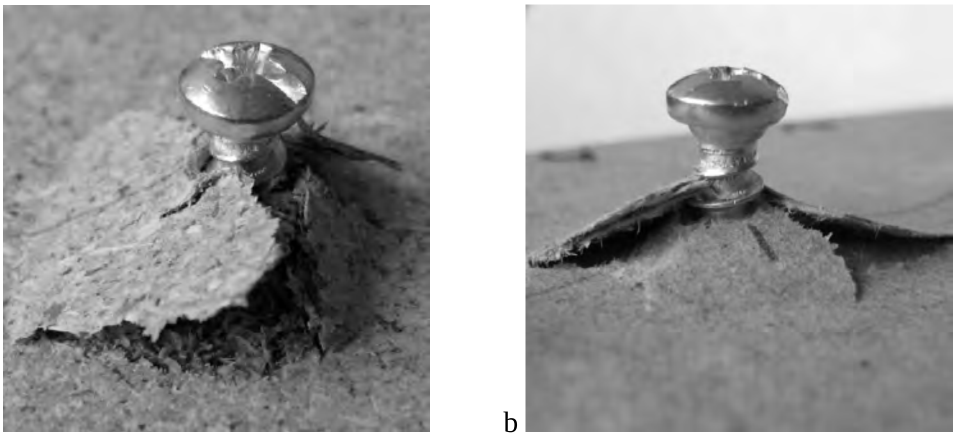


Fig. 1. Chipboard and MDF density profile [3]

Disassemblable joints of the above mentioned boards are made using screwed connections, primarily, various kinds of screws, fixtures, mandrels etc. whose thread coils cooperate directly with boards as well as jointing sleeves screwed in or hammered into holes made in boards to which mandrels are fixed with the assistance of metric threads. Figure 2 presents pictures of boards damaged as a result of tearing out of screws. The damage is caused, mainly, by decomposition and delamination of three-layered chip and fibre boards.



a b

Fig. 2. Pictures showing decomposition of layers of wood-based materials caused by screws being torn out: a – view of CB damage; b – view of MDF damage.

The value of the force tearing out the mandrel or sleeve from the material of the wood-based board without giving reasons of the damage (shear strength?) is commonly adopted as the basic criterion of a joint load-bearing ability. The so called "graded valuation system" of joints taking into account their load-bearing ability used in some catalogues (e.g. in point measure) meets only the decision-making requirements of assessment and selection of joints regarding boards of a specified manufacturer. According to radical investigations carried out by Hettich Company [2] of mean values of tearing out forces of 16 kinds of mandrels and 12 kinds of sleeves from CBs or MDFs, at 10 times replication of individual measurements, it is evident that, in a relative measure, ratios of standard deviations to the mean value (coefficients of variability) amounted to 15-20% for boards of a specific manufacturer and mean values may decrease by up to 50% in comparison with other world manufacturers [3].

2. Variability in the stress distribution in the connection of the mandrel joint with the board

Due to unequal elastic strains of the screw and the threaded element, non-uniform distribution of the axial load in the thread ($F/n \neq const$, where F – force, n – number of active threads) and, hence, unequal strains are found to take place in the thread. Figure 3 shows the dependence of the load distribution along the length of the threaded mandrel and in thread coils on the ratio of the mandrel elasticity moduli (E_t) and the body (E_m) of the coupling E_t/E_m.

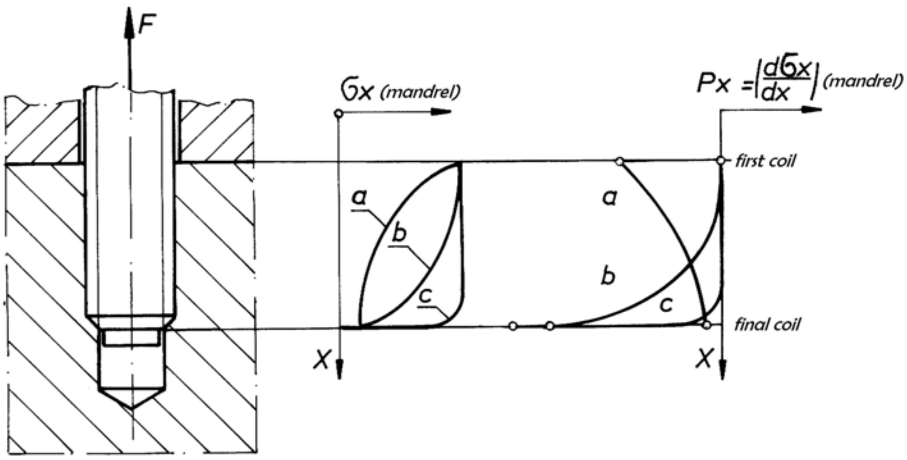


Fig. 3. Load distribution in the thread of a steel needle depending on the ratios of coupling elasticity moduli: a) Et/Em = 1 (steel body); b) Et/Em = 3 (body made of aluminium alloy); c) Et/Em = 15000 (rubber body) [3]

Methods of securing uniform load distribution typical for the machine structure on individual coils cannot be applied in the considered connection of the mandrel with the board since the ratio of mandrel and body elasticity moduli E_t/E_m = (1…10) in the metal material couplings considered earlier is significantly greater in comparison with the ratio of the elasticity moduli of the mandrel steel material and the board material for which it amounts to Et/Em = 56 (MDF) or E_t/E_m = 110 (chip board), respectively [3, 11]. The above data refer to properties of wood-based boards manufactured at the Kronopol Żary Ltd. [14].

The considered variability courses of screw tensile stresses and coil screw loads exhibit a growing non-uniformity together with the joint length increase (i.e. the number of active coils). Therefore, the increase of the joint load-carrying ability cannot be associated with the increase in the thread working length [3].

3. Investigations on the increase of the load-carrying ability by changes in the board property in the place of mandrel mounting

Screw mounting in wood-based materials (chip boards and medium-density fibreboards) occurs mainly in their central parts which are characterised by the worst strength properties (Fig. 1). In order to increase the load-bearing ability of the experimental joints, boards were locally modified by chemical agents in places where screws were to be mounted [5, 9] with the aim of improving their strength properties, especially in their central strata. The applied modifying agent was a polyurethane agent PUR 555.6 of the Kleiberit Company [13].

The described investigations were carried out on chip and medium-density fibre boards due to their wide-spread use in furniture industry, in particular, for the production of cabinet furniture. The following two kinds of fixtures most common as furniture hardware were employed in the performed experiments: 4 x 40 conical screws and EURO 6.3 x 20 screw type (Fig. 4).

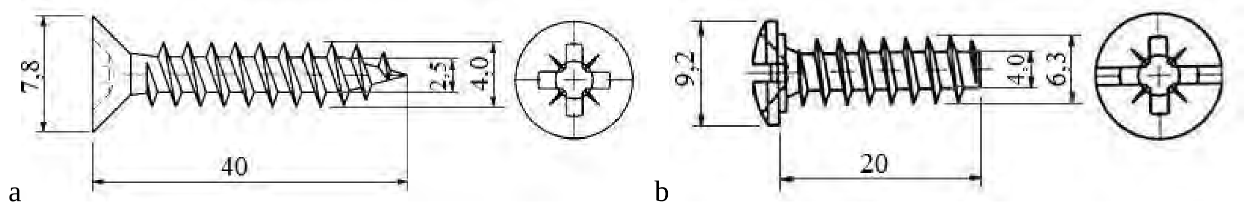


Fig. 4. Connecting elements used in experiments: a – conical screw; b – EURO type screw

The amount of the agent used to improve the load-bearing ability of the experimental joints referred to in the study as ‘an application unit’ was determined on the basis of the volume of the thread coils calculated as the difference between a cylinder volume of the thread external diameter and the cylinder volume of the screw core screwed into the joint. Hence, respectively 1, 2, 3, 4 and 5 application units were applied into the hole in the board and the sample without the application of the agent was treated as the “zero sample”.

Tearing out forces of screws mounted in the following two planes were investigated: wide and narrow. The connecting elements were mounted at the depth of 15 mm [12] on the board wide and narrow planes into predrillings of diameters corresponding to the core diameter of the fastener [6] directly following the application of the PUR 555.6 agent (Fig. 5).

The ability to hold screws in the fortified material was examined after complete polyurethane hardening [8], i.e. 72 hours after mounting of the connecting element. The screws were torn out along their longitudinal axis with the velocity of approximately 1 mm/s and the measurement results of the force and displacement read by Mitutoyo sensors were registered by computer.

Figure 6a shows the picture of a locally modified MD fibreboard after the application of the PUR 555.6 agent on the narrow board plane, while on Figure 6b – we can see the hole cross section on the wide plane of the MD fibreboard after the removal of the screw.

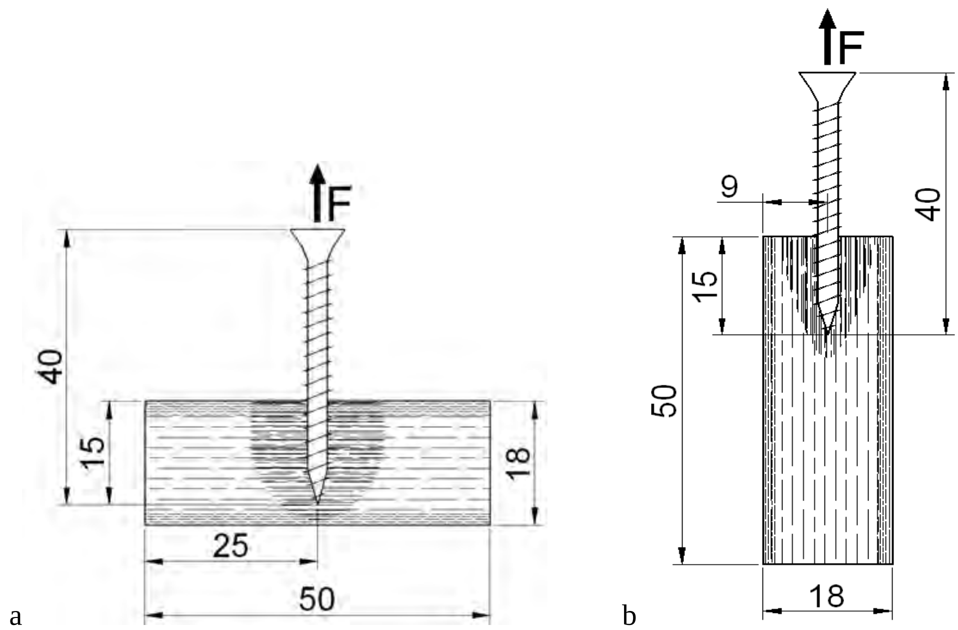


Fig. 5. Screws mounted in the holes of the modified composite in the:
a – wide and b – narrow board planes.

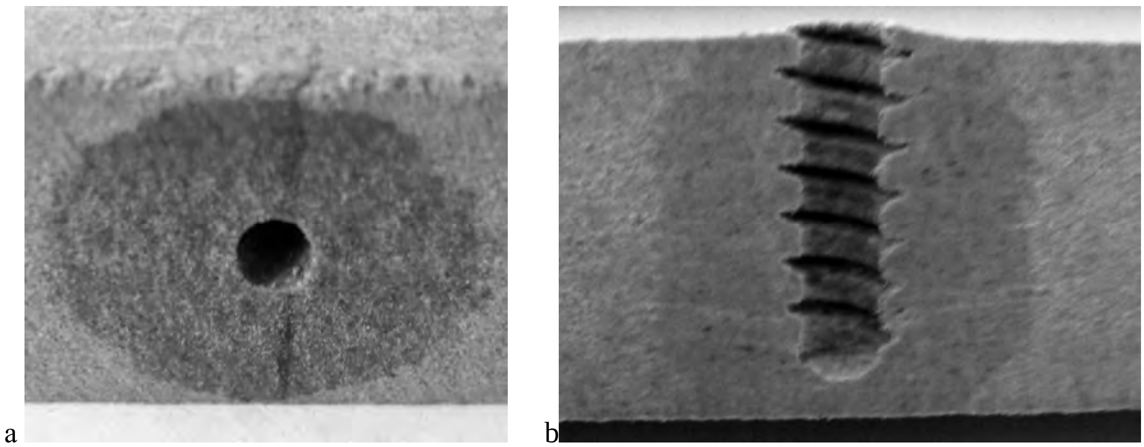


Fig. 6. View of the local MDF modification with the PUR 555.6 agent;
a – view of the modification of the narrow board plane;
b – cross section of the hole following the removal of the screw on the wide plane of the MDF

Figure 7 presents the percentage increase of screw holding capability for chipboards, while Figure 8 – for medium density fibreboards depending on the number of used application units. The holding force of screws without reinforcement was assumed as 100%. Hence, values of the force for successive application units of the reinforcement agent are presented in relation to the 'zero sample'.

The employed polyurethane PUR 555.6 agent increased the holding capability of the torn out screws from the wide chipboard plane by more than two times. The narrow plane of this board was fortified almost three-fold which was associated with the internal structure of the chipboard layer.

In the case of the experimental MDFs, the polyurethane PUR 555.6 agent increased the holding capability of the torn out screws by about two times. In the case of these boards, better results were recorded for the wide planes of boards.

The increase of the material reinforcement was found to stabilise up to the 4 application units of the agent. Further increase of the application units of the examined agent resulted in only a slight increase of the holding capability of screws.

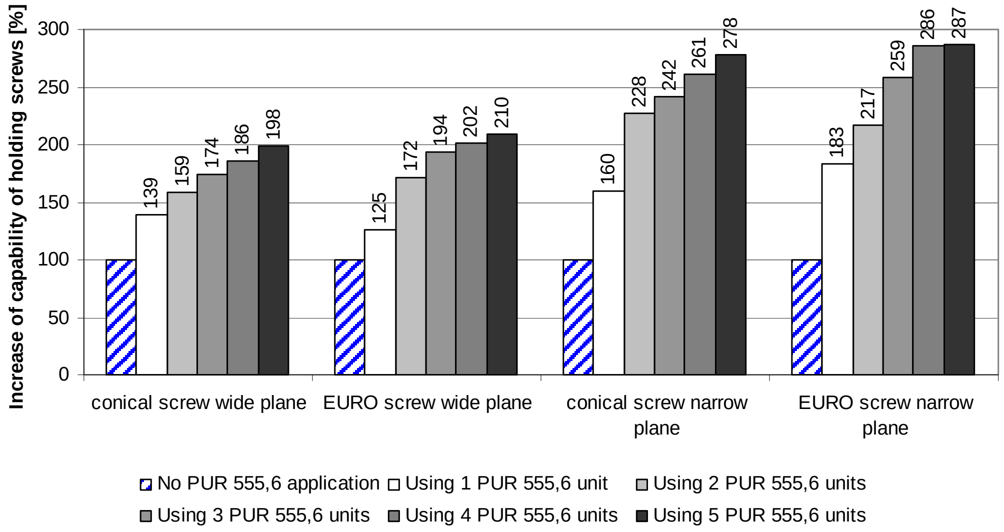


Fig. 7. Percentage increments of screw holding capability mounted in the chipboard before polymerization of the PUR 555.6 preparation

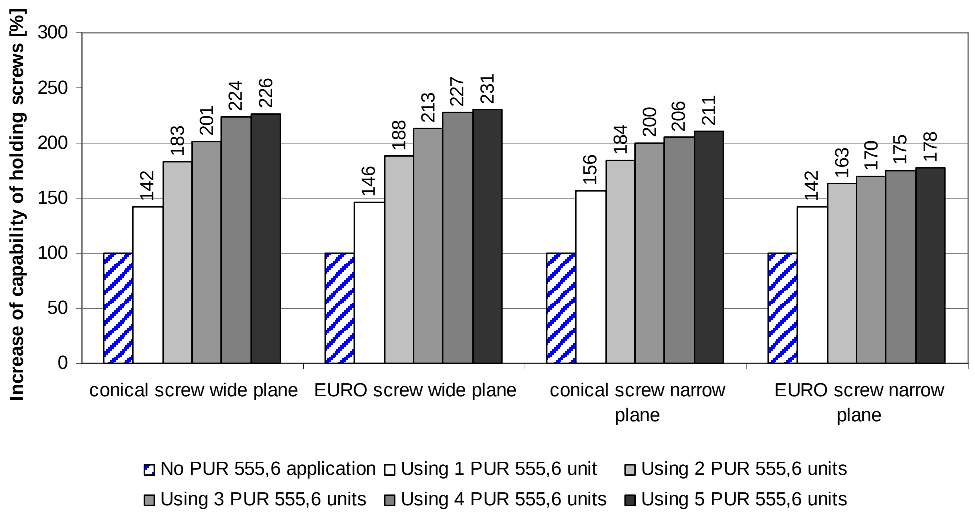


Fig. 8. Percentage increments of screw holding capability mounted in the MDF before polymerization of the PUR 555.6 preparation

4. Investigations of the area of modified zones using x-ray apparatus

In the course of further investigations, penetration zones of the PUR 555.6 reinforcing agent in the medium density fibreboards were investigated with the assistance of the X-ray apparatus [1, 10] and the obtained X-ray pictures were used to prepare 3D images of modified zones using a special program for graphic modelling.

The modified MD boards were x-rayed employing a digital X-ray apparatus of Shimadzu Company, model ZUD-L40DS. As a result of x-raying of the examined MDFs, their digital images in the DICOM format were obtained which were recorded in computer memory. These files were then re-formatted into JPEG format so that they could be used in the AutoCad program. The images were next re-scaled precisely and zones with the applied agent which were characterised by a significantly lighter colour than the remaining layers of the MD fibreboard were isolated. In the next step, sketches of the delineated fields were exported to the Autodesk Inventor program in which a 3D solid was modelled showing the volume of the reinforced zone. The employed program allowed identification in the developed solid its height (depth of the agent propagation), contact surface area of the non-fortified layer with the reinforced layer and its volume.

Images from the performed experiment are shown in Figures 9-11. Pictures 9a to 9d show the placement of samples on the detecting plate of which 9a and 9b regard the modification of the examined MDF across its width, while 9c and 9d – on the narrow plane of the material. The views of x-ray images (Figs. 10a to 10d) clearly show areas affected by the applied reinforcing agent. Pictures on Figs. 11a to 11d present images of 3D solids obtained in the Autodesk Inventor graphic program. The solid in Fig. 11a shows the representation of the modified zone from the wide plane of the MDF sample treated with one application unit of the PUR 555.6 agent, while the solid in Fig. 11b represents the sample modified with 7 application units of the agent. Appropriately, Figs. 11c and 11d present solids of the modified layers of the material treated with one and seven application units of the agent on the narrow plane.

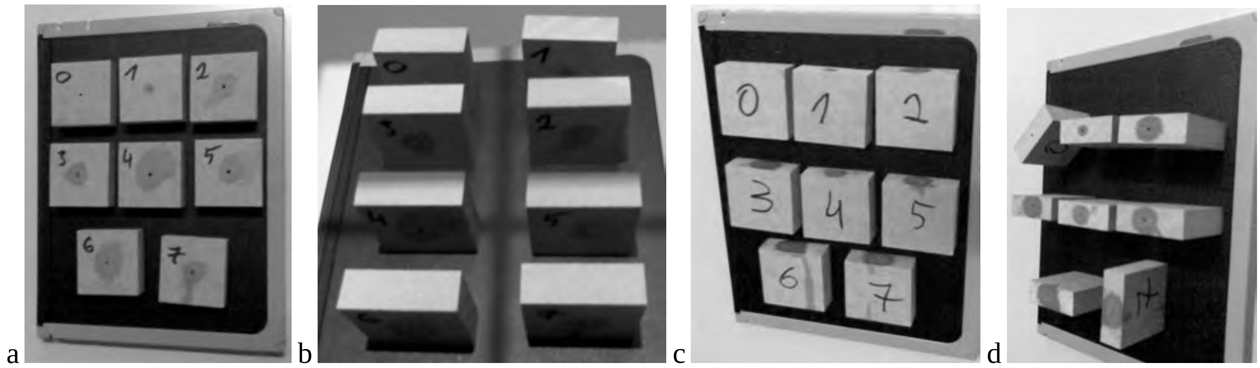


Fig. 9. View of samples arranged on the TFT detector plate; a, b – modification on the wide plane; c, d – modification on the narrow plane

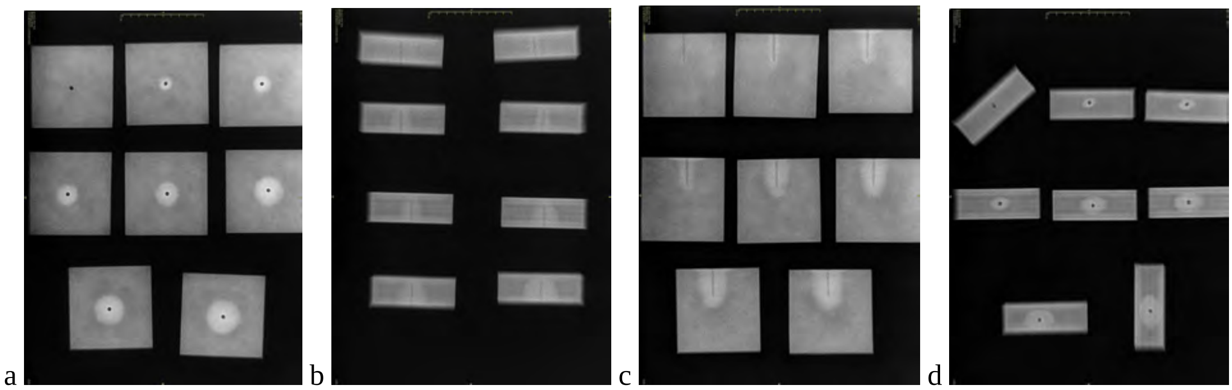


Fig. 10. View of x-ray images of MDF samples with local structure modification; a, b – modification on the wide plane; c, d – modification on the narrow plane

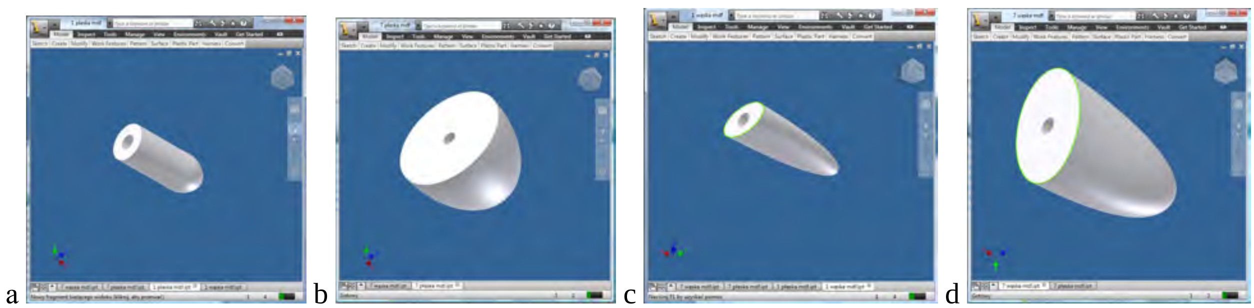


Fig. 11. Images of solids obtained from the Autodesk Inventor program; a, b – modification zones in the wide plane; c, d – modification zones in the narrow plane; a, c – one application unit; b, d – seven application units

The diagrams below present results obtained from measurements performed in the Autodesk Inventor graphic program. Figure 12 shows the penetration depth of the PUR 555.6 agent in the MD fibreboard depending on the number of the application units used. The penetration depth was determined from the board edge to the most distant layer of the modified material along the lead hole.

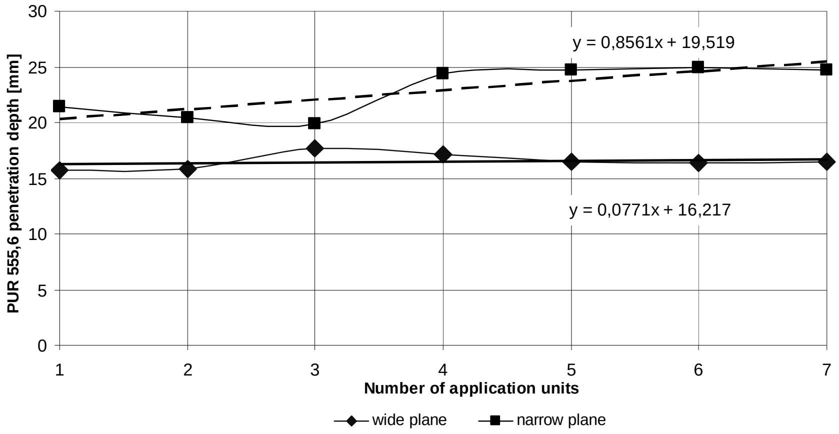


Fig. 12. Depth of the penetration area of the reinforcing agent in MDF

The volume of the modified zone in the function of numbers of the application units is shown in Fig. 13, while the contact surface area of modified and non-modified layers of the examined MDFs – in Fig. 14.

Investigations of the penetration depth of the PUR 555.6 reinforcing agent revealed lack of correlations between this parameter and the number of application units. The employed preparation penetrated only a small distance beneath the lead hole but infiltrated side layers of the MD fibreboard developing all kinds of elliptic forms. This is particularly apparent in the case of holes made in the wide plane of boards which is connected with their anatomical structure (arrangement of fibres in the board).

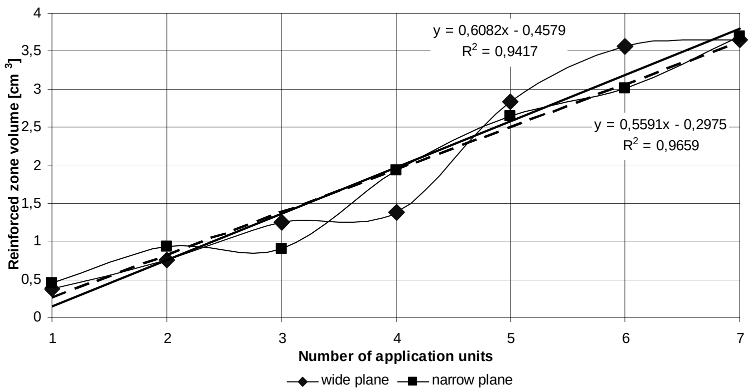


Fig. 13. Volume of the modified area in relation to the number of application units

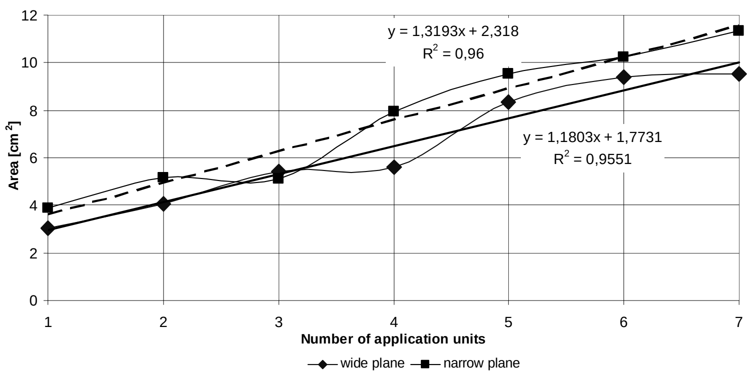


Fig. 14. Contact surface area of modified and non-modified layers of MDF

A close dependence of the volume of the modified zone and the area of the modified layer on the amount of the applied fortifying agent is distinctly noticeable in Figs. 13 and 14. This indicates a uniform distribution of the PUR 555.6 agent in the internal board layer. The performed investigations make it possible to predict how much of the reinforcing agent is required to modify a definite volume of the MD fibreboard.

5. Conclusions

- The examined polyurethane agent PUR 555.6 improves by more than two times the holding capability of screws torn out from the wide plane of chipboards. Moreover, it also reinforces by almost three times the narrow plane of fibreboards.
- The examined polyurethane agent PUR 555.6 improves by about two times the holding capability of screws torn out from MDFs. In the case of these boards, better results are obtained for wide planes of MD fibreboards.
- The reinforcement stability of the material was achieved by the use of up to 4 application units of the agent and further increase of the application units of the examined agent resulted in only a slight increase of the holding capability of screws.
- The employed X-raying of MDFs reinforced by the PUR 555.6 agent revealed distinct invisible modified structure.
- The volume of the modified MDFs depends strongly on the amount of the applied preparation.
- The amount of the applied fortifying preparation affects only slightly the penetration depth in MDFs.
- The internal surface area of the modified MDF layer was proportional to the number of application units and followed a linear course.

6. Directions of further research

Further investigations are planned to focus on the following directions:

- Carrying out experiments on the mechanical properties of chipboards and medium-density fibreboards (including: tensile and shear strength and elasticity modulus). The aim of these studies will be to elucidate phenomena described in Chapter 2 of this article and to develop an analytical model.
- Carrying out verification studies of the carrying capacity and rigidity of semi-rigid joints of locally modified chipboards and medium-density boards using screw fasteners.

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