Electronic Journal of Polish Agricultural Universities is the very first Polish scientific journal published exclusively on the Internet, founded on January 1, 1998 by the following agricultural universities and higher schools of agriculture: University of Technology and Agriculture of Bydgoszcz, Agricultural University of Cracow, Agricultural University of Lublin, Agricultural University of Poznan, Higher School of Agriculture and Teacher Training Siedlce, Agricultural University of Szczecin, and Agricultural University of Wroclaw.

ELECTRONIC JOURNAL OF POLISH AGRICULTURAL UNIVERSITIES

2002
Volume 5
Issue 2
Series WOOD TECHNOLOGY


SMARDZEWSKI J., PREKRAD S. 2002. STRESS DISTRIBUTION IN DISCONNECTED FURNITURE JOINTS **Electronic Journal of Polish Agricultural Universities**, Wood Technology, Volume 5, Issue 2.
Available Online http://www.ejpau.media.pl

# STRESS DISTRIBUTION IN DISCONNECTED FURNITURE JOINTS

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## ABSTRACT

The objective of investigations was to determine rigidity and strength of temporary joints applied in cabinet furniture. In particular, the authors intended to determine the distribution of ordinary stresses in wood, metal and plastic connections of temporary joints and in parts of boards in direct contact with these fastenings. The performed laboratory investigations and numerical calculations showed that trapezoid temporary joints with metal construction were characterised by the most advantageous rigidity-strength properties, while wood dowels in these joints were found to play a significant role supporting their strength.

**Key words:** cabinet furniture, disconnected joints, stress distribution

## INTRODUCTION

Attempts to arrive at a product, which is not only aesthetic and functional but also sturdy and not over-invested materially, draw the attention of designers to rigidity-strength problems of designed furniture. On the basis of literature data [1,2,3] it can be stated that durability of furniture depends primarily on the quality of joints. Therefore, they should be characterised by strength and rigidity similar to the strength of individual component elements. One of the more important stages of construction design is to carry out the analysis of mechanical work of the entire system. The objective of such an analysis is to identify displacements and to determine the state of stresses in individual elements. This, in turn, allows the selection of optimal dimensions of component

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elements of the construction in such a way so as to meet, on the one hand, the requirements of their high strength and, on the other, to reduce expenditure of the adopted solution.

In practice, we use numerical calculations, which employ the method of finite elements (FEM) and they provide a useful tool during the initial stage of engineering design of the product and assist CAD/CAM/CIM systems.

In recent years, following a rapid development of computer techniques and their utilisation in the designing process, increasing attention has been paid to cost and functional aspects of the manufacture of furniture products. There are, however, no papers dealing with the analysis of the state of stresses and deformations in temporary joints of cabinet furniture.

## OBJECTIVE OF RESEARCH PROJECT

The undertaken investigations aim at determining rigidity and strength of temporary joints from the group of eccentric and trapezoid joints found in constructions of cabinet furniture. In particular, the authors intended to determine the distribution of ordinary stresses in wood, metal and plastic connections of temporary joints and in parts of boards in direct contact with these fastenings.

## RESEARCH METHODOLOGY

Laboratory and analytical investigations were conducted on the following three groups of temporary joints: eccentric fastenings with the symbol VB 36M/19 (Fig. 1a), plastic TZ 28 trapezoid fastenings (Fig.1b) and metal TZ 32 S trapezoid fastenings (Fig. 1c). The objective of laboratory investigations was to determine rigidity and strength of the examined construction nodes and to select values of mean loads necessary to carry out strength calculations.

**Fig. 1. Temporary fastenings selected for investigations: a/ VB 36M/19, b/ TZ 28, c/ TZ 32 S**

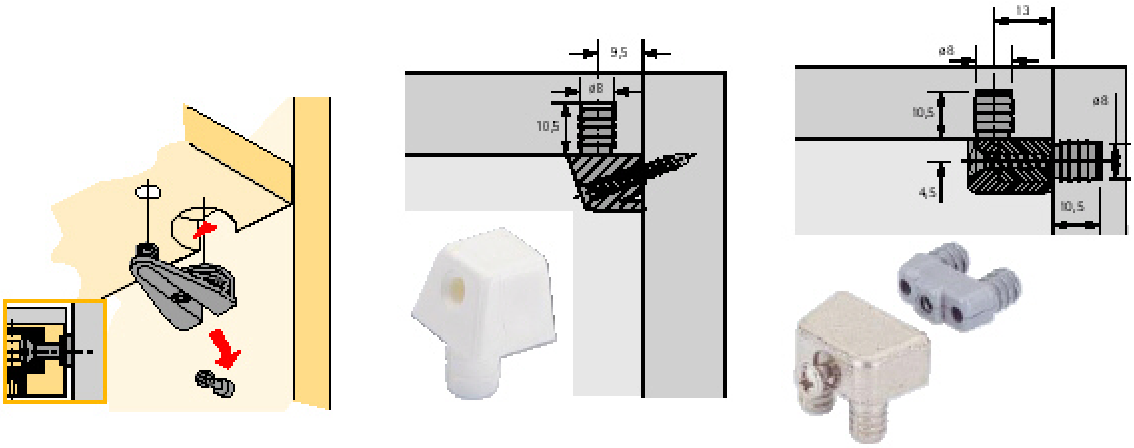
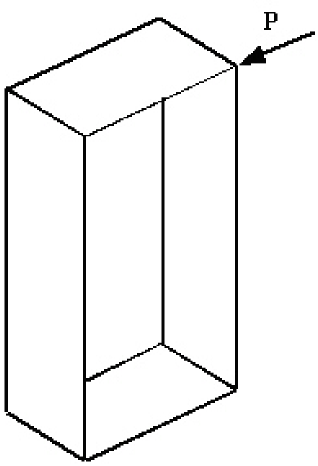
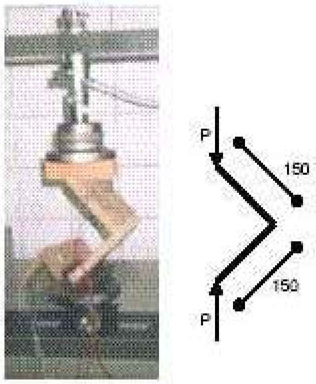



**Fig. 2. State of loads turning the furniture body**



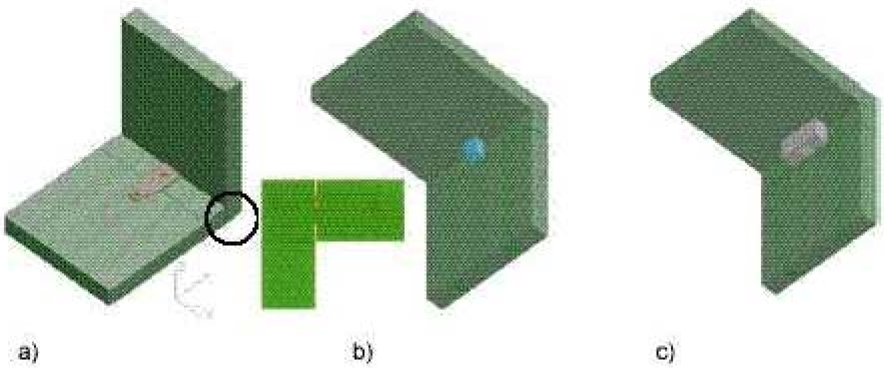
Initial numerical simulations of furniture bodies loaded with operational forces [1,2,3] allowed arriving at the conclusion that joints of adjacent elements of boards are exposed primarily to bending. This was used as the basis for the selection of the most appropriate procedure of loading of angle joints with concentrated forces as shown in figure 3, whereas the obtained maximum values of breaking forces were averaged and introduced into numerical calculations.

**Fig. 3. Scheme of sample loading**




When preparing numerical models of the examined joints, networks consisting of six- and eight node solid finite elements were constructed. Assuming geometry of connected elements as well as fastenings alone, their total consistency with dimensions and shapes of real objects was assured. In addition, it was assumed in numerical models that board elements were not in direct contact with one another but only through selected temporary joints. That is why a small distance of 0.1 mm was applied between board edges (Fig. 4).

**Fig. 4. Numerical models of joints: a/ VB 36M/19, b/ TZ 28, c/ TZ 32 S**




Elastic properties of chipboards necessary for rigidity and strength calculations were determined experimentally, whereas appropriate metal and plastic properties were assumed on the basis of data given by the manufacturer of fastenings. The obtained numerical values are shown in Table 1.

**Table 1. Elastic properties of materials used to make joints**

| Type of material | Young's modulus [MPa] | Kirhchoff's modulus [MPa] | Poisson coefficient |
|---|---|---|---|
| Chipboard | 2.948,46 | 1.147,70 | 0,3 |
| Beech wood | 12.000,00 | 4.615,38 | 0,3 |
| Metal | 202.000,00 | 77.692,31 | 0,3 |
| Plastic | 3.500,00 | 1.346,15 | 0,3 |

## ANALYSIS OF RESULTS

Courses of deformations of angle joints presented in Figure 6 allow concluding that the trapezoid TZ 28S joint turned out to be characterised by the highest strength and rigidity. It was found to carry the highest loads but, at the same time, suffered the smallest linear deformations. Therefore, beginning with Young's equation and Maxwell-Mohr's force method, it is possible to compare analytically the obtained characteristics and calculate substitute rigidity moduli for angle joints, Therefore, assuming that:

$$\mathrm{tg}\,\alpha = \frac{\sigma}{\varepsilon} = E \qquad \text{and that} \qquad E = \int_A \frac{1}{A\Delta l} \bar{M}\, M ds$$

for the scheme of loads from figure 3, we obtain the following equation:

$$E_z = \frac{Pl}{\Delta l} \frac{\sqrt{2}}{bh} \left[ 4\left(\frac{l}{h}\right)^2 + 4{,}12 \right]$$

and hence, numerical values of substitute rigidity moduli for:

- eccentric fastening VB 36M/19 $E_z$= 245,22 MPa
- trapezoid fastening TZ 28 $E_z$=320,6 MPa
- trapezoid fastening TZ 32 S $E_z$=801,6 MPa

Hence, it is evident that the trapezoid fastening TZ 32 S is characterised by a 2.5 times higher rigidity in comparison with other trapezoid fastening TZ 28 and by 3.3 times higher rigidity, in relation to the eccentric fastening VB 36M/19. Apparently, this regularity depended on elastic properties of materials making up the examined joints, since the TZ 32 S fastening was made completely from metal, hence its deformations did not affect the deformation of the entire constructional node. The remaining joints, because of converging characteristics of Young's moduli with the chipboard modulus, contributed to the increase of linear deformations and poorer rigidity of the joint. In this situation, it was interesting to determine the distribution of stresses in joint elements and their neighbourhood.

**Fig. 5. Rigidity characteristics of temporary joints**

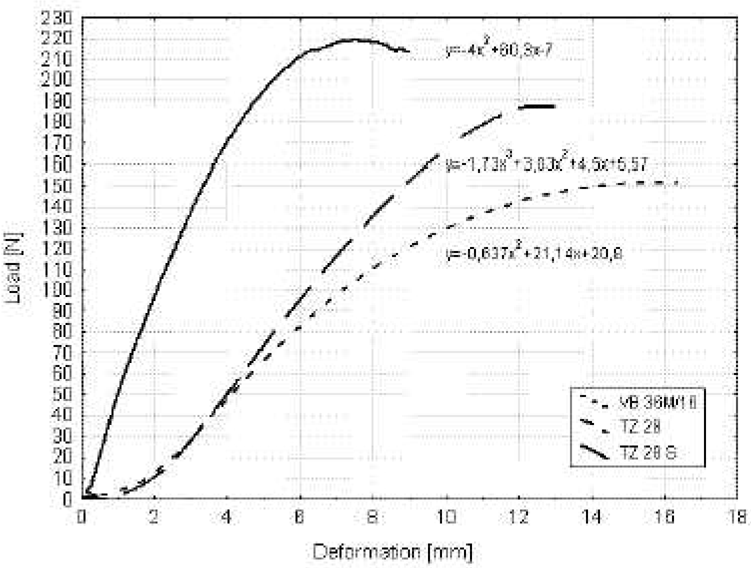



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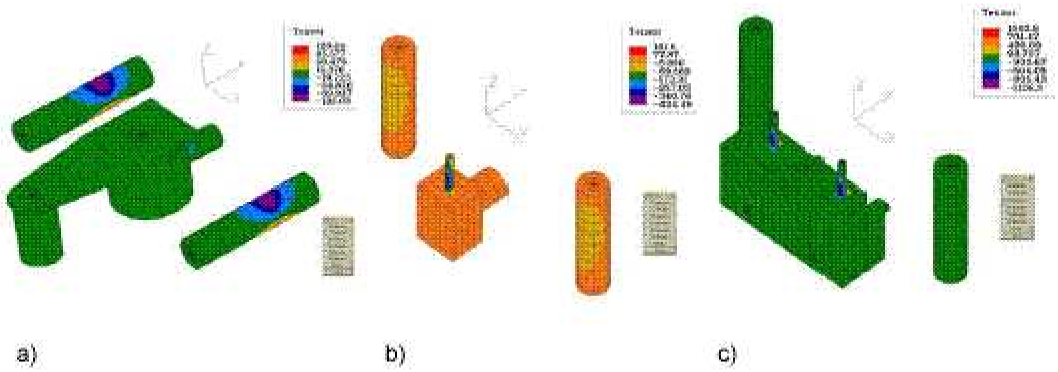
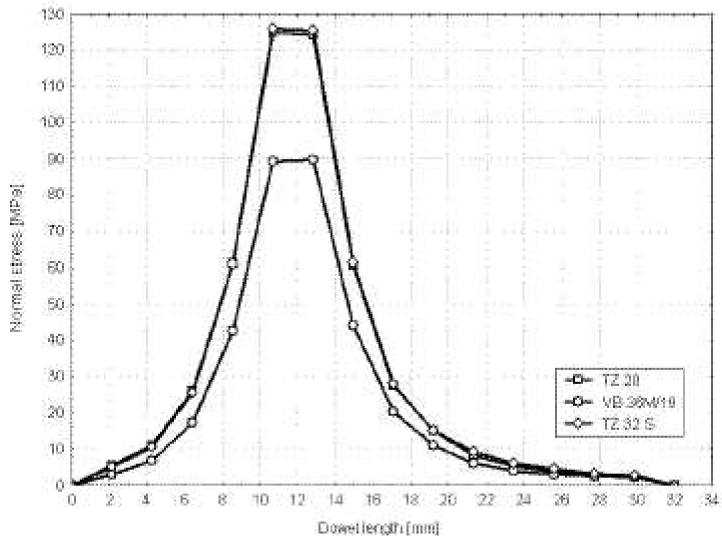
**Fig. 6. Stress distribution in elements of angle joints: a) VB 36M/19 b) TZ 28, c) TZ 32 S**




The distribution of ordinary stresses $S_w$ presented in Fig. 6 clearly indicate that, in the case of the eccentric fastening VB 36M/19 (Fig. 6a), loads are transferred primarily by wooden dowel pins. Stresses in these elements reached limiting values for beech wood for bending and amounted to approximately 135 MPa. It can, therefore, be assumed that the function of this joint was, mainly, to connect board elements and to transfer small bending moments. In the case of trapezoid fastenings, the most important constructional elements were metal elements screwed into the board. It was these elements that helped nodes achieve rigidity exceeding the rigidity of eccentric fastenings. It is quite evident from Fig. 6b that the metal screw fastened through a trapezoid cube to the chipboard transfers the main operational load in the trapezoid joint. Stresses found in this connection amounted to about 460 MPa, while those in dowels did not reach 90 MPa. This regularity is visible even better in the case of the metal fastening TZ 32 S (Fig. 6c). Here, maximum stresses in metal parts reach the value of 1 000 MPa, and thanks to the symmetrical allocation of screws, the node is characterised by the highest rigidity of all the examined joints. A precise distribution of bending stresses in wooden dowels occurring symmetrically on both sides of the temporary joint is shown in Figure 7.

**Fig. 7. Distribution of ordinary stresses $S_w$ along the length of dowel**

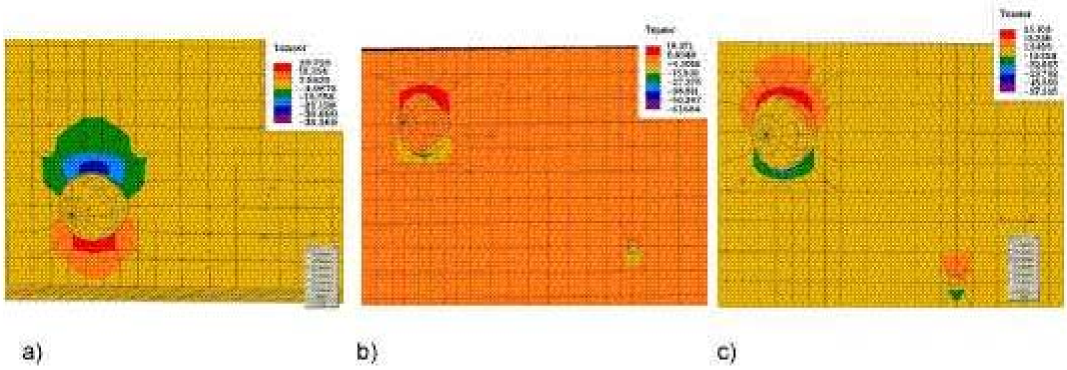



A high concentration of stresses along the length of 12 mm proves that where the two board elements come into contact, we observe bending of beech wood dowels in which efforts reach the limit of wood bending strength. In this case, only firm, metal elements of trapezoid fastenings can guarantee sufficient rigidity of nodes.

Rigidity of metal connectors is particularly important, since it should counterbalance poor bending and compression strength of boards. Especially, the latter parameter contributes to the weakening of constructional nodes. Distributions of stresses in the neighbourhood of the wooden dowel hole indicate that compression stresses in the board exceed considerably acceptable values. In the case of the eccentric fastening VB 36M/19 (Fig. 8a), these stresses reach the value of 39 MPa, in TZ 28 trapezoid joints (Fig. 8b) – about 18 MPa, while in TZ 28 S trapezoid joints (Fig. 8c) – up to 57 MPa. Significant differences in levels of these stresses are, undoubtedly, associated with differences in breaking loads; nevertheless, proportionally to their value, it is joint

TZ 32 S that is most advantageous. In the case of this joint, each 1 Newton of breaking load corresponds to 0.20 MPa of effort, as compared to 0.26 MPa - in the case of the eccentric joint and up to 0.32 MPa - in the case of the TZ 28 joint.

**Fig. 8. Distribution of ordinary stresses $S_w$ in the neighbourhood of dowel hole:a) VB 36M/19, b)TZ 28, c) TZ 32 S**



The above-presented results of investigations allowed the authors to draw a conclusion that the nodal rigidity in cabinet furniture with temporary joints depends on joint construction and kind of materials applied to make it.

## CONCLUSIONS

The performed investigations as well as the analysis of research results allow drawing the following conclusions:

1. Temporary joints from the group of trapezoid fastenings with a metal construction are characterised by the most advantageous rigidity-strength properties.
2. The applied numerical model of temporary joints reveals well the character of their work and way of stress distribution.
3. Wood dowels used in temporary joints play an important function supplementing the strength of constructional nodes.

When drying green timber of fast growing species, the low temperature schedules should not be applied, especially in summer, when temperature and relative humidity of ambient air are high.

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