

## INVESTIGATIONS ON THE DIMENSIONAL ACCURACY AND SURFACE STRUCTURE OF A TENON JOINT

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**Abstract.** The study investigated execution tolerances and profile load capacity curves occurring in industrial conditions. Using graphic images of fits expanded by profile load capacity curves, an attempt was made to explain the effect of the profile load capacity curve on the fitting character of the tenon joint.

**Key words:** mortise, tenon, fit tolerance, profile load capacity curve

### INTRODUCTION

Processing accuracy can be evaluated on the basis of differences that occur between the shape, dimension and geometrical structure of the nominal surface and that measured on the processed object.

Quite distinct differences can be observed in the course of the production process between nominal assumptions and the obtained shape, dimension and surface geometrical structure. Therefore, the accuracy of the processed material should be defined as the degree of its affinity with the perfection which is impossible to achieve in practice.

In the case of the tenon joints, due to small dimensions of elements to be united, the most important aspect of accuracy – from the point of view of functionality – is the dimensional precision as well as the accuracy of the surface geometrical structure.

The accuracy of the obtained dimension during the machining process should not exceed adopted boundaries of allowable deviations from the nominal dimension [Bajkowski 1990]. In the case considered in this study, we have to deal with a fit which represents a mortise and tenon joint. The character of this fit depends on boundary clearances which can occur between the elements that are to be connected. Therefore, while analysing the execution accuracy of a fit, it is necessary to examine the occurring clearance because it is this play that constitutes the measure of cooperation between individual parts (elements that are being united).

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Investigations dealing with the proportion of the surface geometrical structure in the tolerance area of the observed linked elements aim at a better understanding of the co-operation of elements forming the tenon joint. This makes it easier to explain such phenomena as wood swelling and shrinkage, selection of tolerance fits etc.

It is possible, from the measurements and calculations of the elements obtained in industrial conditions, to create a definite, specific model of dimensional contact of real surfaces taking into consideration their irregularities in the tenon joint.

It is clear, both from literature [Nowicki 1991] and experiments, that the current parameters of the surface geometrical structure –  $R_z$ ,  $R_m$ ,  $R_{max}$ ,  $R_a$ ,  $S_z$  – specified in the standard for surface roughness of wood and wood-based materials BN-84/D-01005, characterize the surface insufficiently because they say nothing about the shape of these irregularities and their course. This inconsistency of the above-mentioned parameters with the surface functionality of the united elements makes it necessary to seek other of its characteristics of which the proportion of the profile load-carrying capacity  $t_p$  appears to be the best. The profile load-carrying capacity curve proportion is also referred to as the outline of surface irregularities and it is the property which describes load carrying capacities in united elements. The load carrying capacity curve constitutes a graphic representation of the function dependence of the value of the carrying proportion  $t_p$  on the intersection level  $c$  [Wieczorowski et al. 1996].

The outline of irregularities is a development of a real surface of united elements, i.e. of the surface restricting the object from the surrounding medium constituting the curve of the load-carrying capacity proportion.

This study constitutes a continuation of investigations carried out at the Department of Woodworking Machinery and Basis of Machine Construction of August Cieszkowski Agricultural University of Poznań [Staniszewska et al. 1996, Staniszewska and Zakrzewski 1999/2000] and concerns elements that were manufactured from pine wood in industrial conditions.

The authors decided to conduct investigations of the outline irregularities on the real (non-filtered) profile because the surface waviness developed after milling of mortises and tenons appears to be more important for the functional characters of the fit than roughness.

The objective of this research project was to determine the dimensional accuracy of the execution of the tenon joint taking into consideration the surface geometrical structure of the connected elements.

## **METHODOLOGICAL ASSUMPTIONS AND DESCRIPTION OF THE PERFORMED EXPERIMENTS**

### **Experimental material and processing condition**

The experimental material comprised elements of the tenon joint, i.e. mortise and tenon. The choice of this joint was justified by its most difficult utilization conditions. It is well known that it is the most critical point of the entire construction of the chair because strong bending moments occur here during its utilization [Staniszewska et al. 1994]. The examined mortises and tenons derived from chairs made of pinewood intended for the domestic market and manufactured in a Cooperative Enterprise “Postęp” in Pniewy.

The average moisture content of the examined elements was about 10%, so it was at the level of the reference moisture content specified in the BN-81/7140-11 standard intended to be used in furniture industry. The moisture content was measured using a Tanel digital hygrometer. Tenons of the examined joint were made on a "Bacci Cascina" tenoning machine with a tool which consisted of a round cutterhead with 90 mm diameter and a circular saw of 190 mm diameter. The mortises were made using a "Renzo-Balestrini" single spindle drilling-milling machine using an end-cylindrical milling cutter.

### Method of measurement and calculation of the execution accuracy of joint elements

Measurements of mortises and tenons were conducted on sixty elements. Samples were obtained by setting the machine tool to the required dimension and correcting it to the value assumed using the test element method. Measurements of mortises were made along their length  $l_0$  and width  $s_0$  and of tenons – in the direction of their width  $s_w$  and thickness  $g_w$ . Values derived from three measurements, namely: mortise width  $s_0$  as well as tenon width  $s_w$  and thickness  $g_w$  were taken for the calculation of statistical parameters.



Fig. 1. Examined tenon joint of the backrest leg with the side underframe

Rys. 1. Badane połączenie czopowe nogi oparciowej z oskrzynią boczną krzesła

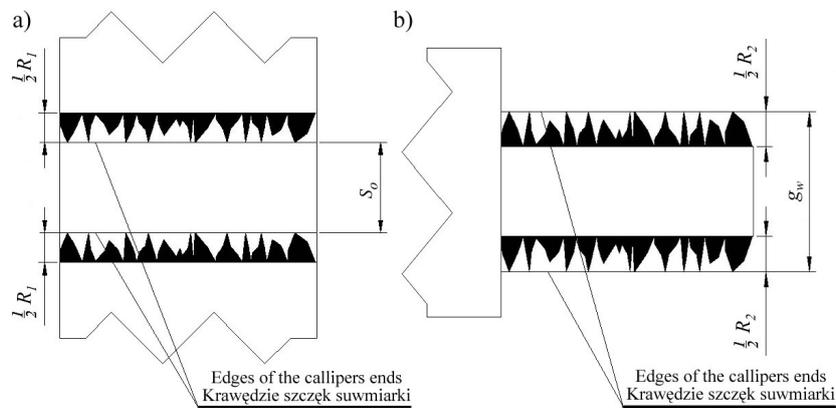


Fig. 2. Visual presentation of the measurement of the tenon thickness dimension taking into account surface irregularities: a – mortise, b – tenon

Rys. 2. Poglądowy sposób pomiaru wymiaru grubości czopa z uwzględnieniem nierówności powierzchni: a – gniazda, b – czopa

Due to the rounding of its ends, the length of the mortise  $l_0$  was measured only once. The fitting of the mortise width  $s_0$  with the tenon thickness  $g_w$  was conventionally designated as “a” and of the mortise length  $l_0$  with the tenon width  $s_w$  – as “b”. The above-measurements were taken using a TESA DIGIT CAL type 05.300 32 callipers assuming that its measuring ends rest on peaks of surface irregularities and, by doing so, yield the minimum measurements of the mortise and the maximum ones of the tenon.

Samples were made in one series after replacing the old tools with new ones. Measurements of element dimensions were taken across the marks of machining. Figure 3 shows diagrammatically the dimensions of the fitted mortise and tenon.

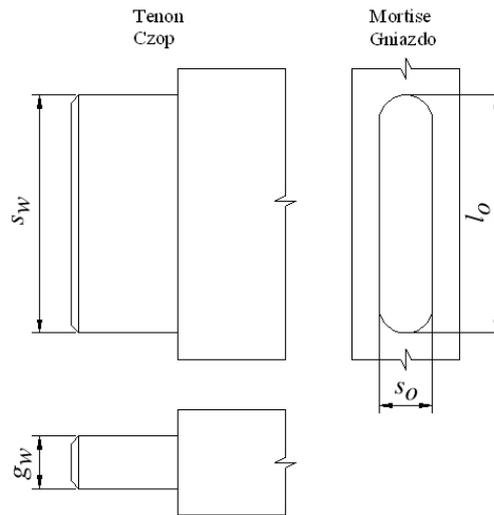


Fig. 3. Diagram showing the dimensions of the mortise and tenon

Rys. 3. Schemat ilustrujący wymiary gniazda i czopa

Treating the examined dimension as a random variable, the arithmetic mean of the measurement results  $\bar{x}$  and the mean deviation  $\sigma$  were calculated. The value of six mean deviations, constituting the dimension scatter, was referred to in this study as the ‘observed tolerance’ [Staniszewska and Zakrzewski 1988] and may be described as the difference between the upper  $B_r$  and lower  $A_r$  observed dimension  $T_r = B_r - A_r = 6\sigma$ . This tolerance must be smaller than  $T_z$  that contained in the BN-81/7140-11 standard, in other words the  $T_r \leq T_z$  inequality must occur. In practice, in the case of fitted elements, the comparison of the observed deviations with the standard ones is the easiest. In such case, bearing in mind the principle of a constant hole applied in the furniture design:

$$ES_r \leq ES_z, es_r \leq es_z \text{ and } ei_r \geq ei_z,$$

where: ES, es – upper deviations of the mortise and tenon,  
ei – lower deviation of the tenon.

The r and z indices mean, respectively: ‘observed’ and ‘standard’.

### The method of fit determination

Following the numerical recording of the observed fit which consisted in recording the basic dimension together with deviations for the mortise and tenon, the type and class of the fit was determined from standards. Because measurement tolerances, their deviations as well as allowances and negative allowances are disproportionately small in comparison with the dimensions of the united elements, the graphic images do not show the mortise and tenon and present only the zero line which corresponds to the basic dimension. Instead of dimensions, positive deviations are shown over the zero line and negative deviations below it. In other words, images of mortises and tenons are shown as rectangles with their heights equal to dimensional tolerances [Staniszewska and Zakrzewski 2006]. The position of rectangles representing mortises and tenons make it possible to infer information about clearances and negative allowances of the fit. Rectangles representing intervals of the allowance variability, conventionally referred to as observed tolerances  $T_{pr}$ , were placed behind rectangle representing individual mortises and tenons.

$$T_{pr} = L_{r \max} - L_{r \min} = T_{ro} + T_{rw},$$

where:  $L_{r \max}$ ,  $L_{r \min}$  – observed maximum and minimum clearance,

$T_{ro}$ ,  $T_{rw}$  – observed tolerances of mortises (holes) and tenons (rolls).

The observed limiting allowances were calculated from the known deviations, namely:

$$L_{r \max} = ES_r - ei_r, L_{r \min} = -es_r,$$

because in the applied principle of a constant hole  $EI_r = 0$ .

$$\text{The mean allowance } L_{r \acute{s}r} = \frac{L_{r \max} - L_{r \min}}{2},$$

where:  $ES_r$ ,  $EI_r$  – observed mortise upper and lower deviations,

$es_r$ ,  $ei_r$  – observed tenon upper and lower deviations.

The choice of the standard fit results from the knowledge of the observed fit. Its selection is based on the principle that the observed tolerances for the mortise and tenon should be contained within standard tolerances [Staniszewska and Zakrzewski 1990].

In practice, the setting of the required type of fit assumes the utilization of the allowance variability analysis in industrial conditions taking into consideration the mean allowance. This allowance can be employed as a parameter controlling the fit quality capability. In other words, while the dimension control is a technological operation aiming at bringing the dimension arithmetic mean to the tolerance centre, the allowance control aims at bringing the mean allowance to the fit tolerance centre.

The required fit in the quality capable process  $c_p = \frac{T_{pz}}{T_{pr}} > 1$  can be achieved by con-

trolling the observed mean allowance  $L_{r \acute{s}r}$  in such a way that it will take the position of the fit tolerance centre  $L_{z \acute{s}r}$ . A method was elaborated which makes it possible to control the observed mean allowance by regulating the arithmetic mean of the tenon dimension [Zakrzewski and Staniszewska 2002].

The value of the fit non-alignment:

$$\Delta L_{r \text{ } \acute{s}r} = L_{z \text{ } \acute{s}r} - L_{r \text{ } \acute{s}r}.$$

The increment of the arithmetical mean of the tenon dimension:

$$\Delta \bar{x}_w = -\Delta L_{r \text{ } \acute{s}r},$$

where:  $L_{r \text{ } \acute{s}r}$ ,  $L_{z \text{ } \acute{s}r}$  – mean allowance of the observed and standard fit.

### Investigations of the outline of irregularities

Measurements of surface irregularities were carried out by the method of contact profile representation employing a WZI-252 Kalibr type surface analyser. The rounding radius of the gauging point was  $10 \pm 2.5 \mu\text{m}$ , and its pressure – 0.016 N. The measurement was carried out on surfaces which constituted the length of mortise and the width of the tenon along a measuring section of 21 mm. The narrowing of the measuring section to 21 mm was caused by the shape and dimension of mortises and tenons. Due to technical restrictions resulting from the shape and dimension of the gauging point of the surface analyser, the mortises were cut.

In order to take into consideration not only the surface roughness but also its waviness resulting from the marks left by the cutting edge of the mill on the worked surface, a non-filtered (real) profile was applied to calculate the carrying proportion of the profile of irregularities along the length of the measurement section. Diagrams and numbers referring to the carrying proportion of the surface of all samples were archived in the computer and later on one correlation was elaborated for the mortise and the tenon which represented averaged Abbott's curves for mortises and tenons.

Figure 2 shows the mortise width  $s_o$  and the tenon thickness  $g_w$  together with the irregularities occurring on their respective surfaces constituting the outline of irregularities. In addition, it shows positions of measuring edges of the callipers' jaws determining the minimal dimension of the mortise width and the maximum dimension of the tenon thickness. It was assumed that, at the moment of taking the measurement, the jaw edges of the callipers rested on the peaks of irregularities.

In Figure 2 a, symbol  $\frac{1}{2} R_1$  designates the maximum height of the profile of irregularities  $R_{\text{max}}$  for one side of the mortise. Since the cooperation of the mortise with the tenon during the process of uniting takes place simultaneously on both of the fitted elements, the authors assumed the double value of the height of irregularities  $2R_{\text{max}} = R_1$  to determine the outline of irregularities in the tolerance field. Similarly, in Figure 2 b, symbol  $\frac{1}{2} R_2$  designates the maximum height of the profile of irregularities  $R_{\text{max}}$  for one side of the tenon and the double value of the height of irregularities of the tenon  $2R_{\text{max}} = R_2$  was assumed for further considerations. Measurements of irregularities on surfaces confining the length of the mortise  $l_o$  and the width of the tenon  $s_w$  were neglected due to the rounding of corners. Measurements in those places were impossible using the available measurement tools.

## RESEARCH RESULTS AND THEIR ANALYSIS

## Calculation results of dimensional accuracy of fitted elements

The results of measurements and calculations of the dimensional execution accuracy of the “a” and “b” fits are presented in Table 1.

Table 1. Calculation results of fit parameters if the mortise width and tenon thickness as well as mortise length and tenon width, mm

Tabela 1. Wyniki obliczeń parametrów pasowania szerokości gniazda i grubości czopa oraz długości gniazda i szerokości czopa, mm

Name of the item Nazwa wielkości	Symbol Symbol	Mortise width Szerokość gniazda ↔		Mortise length Długość gniazda ↔	
		Tenon thickness Grubość czopa (type a – typ a)	Tenon thickness Grubość czopa (type a – typ a)	Tenon width Szerokość czopa (type b – typ b)	Tenon width Szerokość czopa (type b – typ b)
		mortise gniazdo	tenon czop	mortise gniazdo	tenon czop
Arithmetic mean Średnia arytmetyczna	$\bar{x}$	10.06	10.19	44.26	44.39
Sample size Wielkość próbki	N	30	30	30	30
Standard deviation Odchylenie standardowe	$\Sigma$	0.046	0.039	0.125	0.247
Observed tolerance Tolerancja zaobserwowana	$T_r$	0.276	0.234	0.75	1.482
Upper observed dimension Górny wymiar zaobserwowany	$B_r$	10.20	10.31	44.63	45.12
Lower observed dimension Dolny wymiar zaobserwowany	$A_r$	9.92	10.07	43.87	43.65
Nominal fit dimension Wymiar nominalny pasowania	$A_{no} = N_r$	9.92	9.92	43.87	43.87
Observed upper mortise deviation Odchyłka górna gniazda zaobserwowana	$ES_r$	0.28	–	0.76	–
Observed lower mortise deviation Odchyłka dolna gniazda zaobserwowana	$EI_r$	0	–	0	–
Observed upper tenon deviation Odchyłka górna czopa zaobserwowana	$es_r$	–	0.39	–	1.25
Observed lower tenon deviation Odchyłka dolna czopa zaobserwowana	$ei_r$	–	0.15	–	–0.22
Observed maximum clearance Luz maksymalny zaobserwowany	$L_{r \max}$		0.13		0.99
Observed minimum clearance Luz minimalny zaobserwowany	$L_{r \min}$		–0.39		–1.25
Observed mean clearance Luz średni zaobserwowany	$L_{r \text{sr}}$		–0.13		–0.13
Observed fit tolerance Tolerancja pasowania zaobserwowana	$T_{pr}$		0.52		2.24
Fit record Zapis pasowania		9.92 H4/m4 – tightly fitted 9.92 H4/m4 – mocno wciskane		43.87 H4/k9 – lightly fitted 43.87 H4/k9 – lekko wciskane	

The predicted nominal dimension of the “a” type fit was 10 mm and for the “b” type – 45 mm. It is evident from the values given in Table 1 that the observed execution tolerance of the mortise width was  $T_{r_0} = 0.28$  mm, while that of the tenon thickness –  $T_{r_w} = 0.23$  mm. This gave, respectively, to the mortise and the tenon, the 4th and the 3rd classes of dimensional execution accuracy [BN-81/7140-11]. On the other hand, the execution tolerance of the mortise length reached 0.76 mm, which corresponds to the 6th class of accuracy, while that of the tenon width – 1.48 mm which corresponds to the 9th class of accuracy.

The numerical record of the obtained “a” type connection (expressed in millimetres) assumed the form:

$$O. 9.92^{0.28}$$

$$W. 9.92_{0.15}^{0.39}$$

The “a” type of fitting is presented graphically on Figure 4.

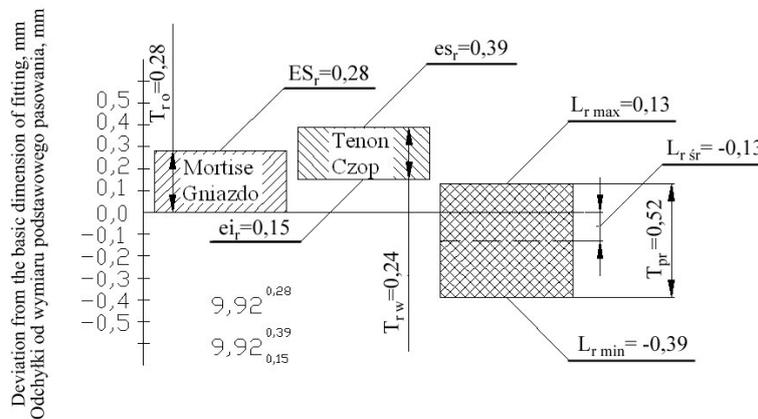


Fig. 4. The diagram of the observed “a” type fitting described in standards as H4/m4 – tightly fitted

Rys. 4. Obraz pasowania zaobserwowanego typu „a” opisanego normami jako H4/m4 – pasowanie mocno wciskane

Values of deviations from the basic dimension of the fitting amounting to  $N_r = A_{r_0} = 9.92$  mm were placed on the axis of ordinates. The rectangles represent the value and position of the observed tolerance of the mortise, tenon and fitting. The observed fit tolerance  $T_{pr}$  is an interval of clearance variability with marked clearances at the ends changing from  $L_{r \min} = -0.39$  mm up to  $L_{r \max} = 0.13$  mm. The broken line in the middle shows the value of the mean clearance  $L_{r \text{sr}} = -0.13$  mm. The tolerance fitting amounted to  $T_{pr} = L_{r \max} - L_{r \min} = T_{r_0} + T_{r_w} = 0.52$  mm. On the basis of the numerical record of the fitting, a symbol record was prepared in accordance with the BN-81/7140-11 standard. It is evident from the comparison of the observed deviations and those contained in the standard that:

$$ES_r = 0.28 < ES_z = 0.33 \text{ which gives the 4th class to the mortise,}$$

$es_r = 0.39 < es_z = 0.44$  and  $ei_r = 0.15 > ei_z = 0.11$  which gives the 4th class to the tenon in the m fitting (values in millimetres).

Taking into consideration the above, the symbolic record of the fitting was established as 9.92 H4/m4. This is a mixed tight fitting in which both the mortise and the tenon are executed in the 4th class of accuracy.

Since both elements of the connection were made in the same class of accuracy, therefore the symbolic record can be arrived at using a different method, namely by the comparison of the observed limiting clearances with those contained in the standard. The clearance tables in the standard are elaborated in such a way that they contain only limiting clearances for the fits of the same execution accuracy of both elements. For the performed comparison, it follows that:  $L_{r \max} = 0.13 < L_{z \max} = 0.22$  and  $L_{r \min} = -0.39 > L_{z \min} = -0.44$ , and the observed fitting tolerance must be smaller than that contained in the standard  $T_{pr} = 0.52 < T_{pz} = 0.66$ . This comparison also corresponds to the 4th class of accuracy of the fit execution H/m.

Although the 4th class of accuracy is recommended by the standard for the stop house tenon joint, the m type fitting is less favourable than the l type. That is why, according to the standard, the optimal fit should be written down as: 9.92 H4/l4. The l type fitting is characterised by the fact that the lower deviation of the tenon  $ei_z$  is 0 which means that the limiting clearances are identical with regard to their absolute value, i.e.  $|L_{z \max}| = |L_{z \min}|$ . This type of fitting is shown in Figure 5.

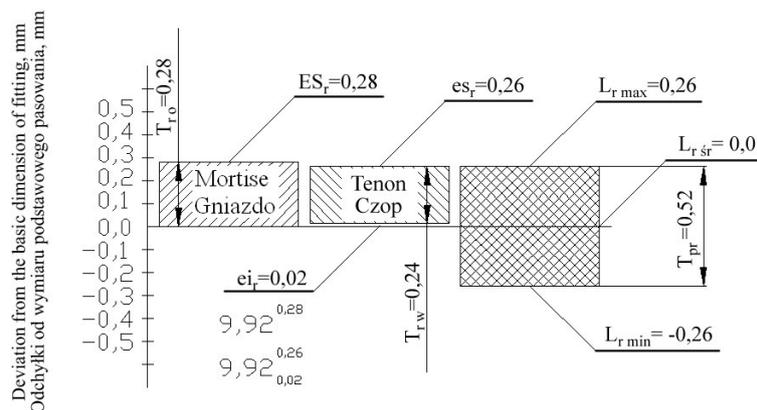


Fig. 5. Diagram of the observed fitting of type “a” described by standards as H4/l4 – negative allowance fitting

Rys. 5. Obraz pasowania zaobserwowanego typu „a” opisanego normami jako H4/l4 – pasowanie wciskane

The observed tolerances  $T_{ro}$  and  $T_{rw}$  did not change their value, but the rectangle representing the tenon was moved towards the axis of abscissas. Consequently, the rectangle containing the observed fitting tolerance  $T_{pr}$  moved upwards by the value of 0.13 mm. This kind of fitting can be achieved quite easily by controlling the mean clearance  $L_{r \text{ sr}}$ . In the case of Figure 4  $L_{r \text{ sr}} = -0.13$  mm, while in Figure 5 –  $L_{r \text{ sr}} = 0.00$  mm. In order to achieve zero mean clearance so as to obtain H/l fitting, it is necessary to decrease the set dimension of the tenon on the tenoning machine by 0.13 mm because:

$$\Delta L_{r \dot{s}r} = 0.00 - (-0.13) = 0.13 \text{ mm},$$

$$\Delta \bar{x}_w = -\Delta L_{r \dot{s}r} = -0.13 \text{ mm}.$$

In the observed fitting 9.92 H4/k4 obtained in this way, it is possible to compare the observed deviations with those occurring in the standard:

$$ES_r = 0.28 < ES_z = 0.33,$$

$$es_r = 0.26 < es_z = 0.33 \text{ and } ei_r = 0.02 > ei_z = 0.00.$$

It is evident from the comparison of clearances that:

$$L_{r \max} = 0.26 < L_{z \max} = 0.33 \text{ and } L_{r \min} = -0.26 > L_{z \min} = -0.33$$

In his experiments, Rybski [1976] found that the tenon joint of type “a” was characterised by a greater strength because the mean clearance  $L_{z \dot{s}r} = 0.1 \text{ mm}$ .

If this recommendation were to be followed, the position of the observed tolerance fit would have to be brought to the situation shown in Figure 6.

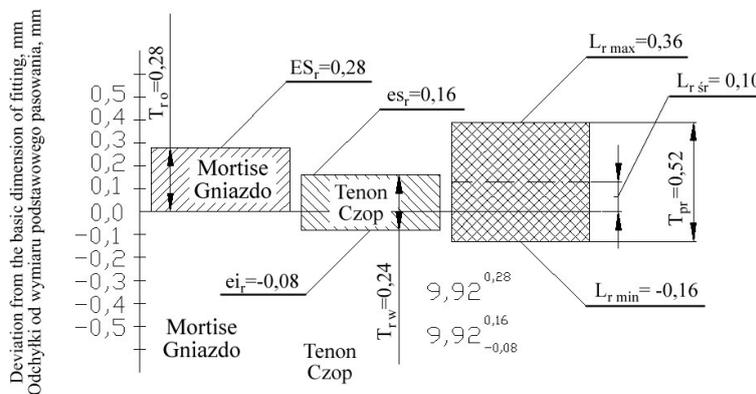


Fig. 6. Image of the type “a” fitting following regulation of the mean clearance according to Rybski’s recommendation described in standards as H4/k4 – slight negative allowance fitting

Rys. 6. Obraz pasowania typu „a” po regulacji luzem średnim według zaleceń Rybskiego, opisanego normami jako H4/k4 – pasowanie lekko wciskane

Therefore, it is necessary to change the tenon thickness on the tenoning machine by  $\Delta \bar{x}_w = 0.23 \text{ mm}$  because:

$$\Delta L_{r \dot{s}r} = L_{z \dot{s}r} - L_{r \dot{s}r} = 0.1 - (-0.13) = 0.23 \text{ mm},$$

$$\text{and } \Delta \bar{x}_w = -\Delta L_{r \dot{s}r} = -0.23 \text{ mm}.$$

The fitting obtained in this way is designated as 9.92 H4/k4 and is referred to as a fit with a slight negative allowance. It is clear from the comparison of appropriate deviations and allowances that:

$$ES_r = 0.28 < ES_z = 0.33,$$

$$es_r = 0.16 < es_z = 0.25 \text{ and } ei_r = -0.08 = ei_z = -0.08,$$

$$L_{r \max} = 0.36 < L_{z \max} = 0.41 \text{ and } L_{r \min} = -0.16 > L_{z \min} = -0.25.$$

Figure 7 presents the industrial execution of the “b” type connection. The numerical record of the fit was:

$$O. 43.87^{0.76},$$

$$W. 43.87_{-0.22}^{1.25}.$$

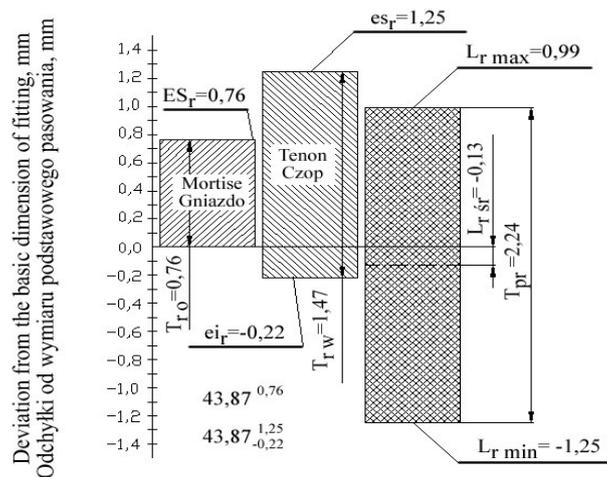


Fig. 7. Image of the type “b” fitting described in standards as H6/k9 – slight negative allowance fitting

Rys. 7. Obraz pasowania zaobserwowanego typu „b” opisanego normami jako H6/k9 – pasowanie lekko wciskane

It is evident from the comparison of the observed and standard deviations:

$$ES_r = 0.76 < ES_z = 0.88,$$

$$es_r = 1.25 < es_z = 1.45 \text{ and } ei_r = -0.22 > ei_z = -0.48.$$

that the mortise length falls within the 6th accuracy class, whereas the tenon width is contained in the 9th class of type k. Hence, the notation of the manufactured connection of type “b” has the form 43.87 H6/k9. It can be noticed from the comparison of boundary allowances that:  $L_{r \max} = 0.99 < L_{z \max} = 1.36$  and  $L_{r \min} = -1.25 > L_{z \min} = -1.45$ . From the point of view of the standard, this is not qualitatively capable because the index of the fitting quality capability according to Zakrzewski and Staniszewska [2002]

$$c_p = \frac{T_{pz}}{T_{pr}} = \frac{1.04}{2.24} = 0.46 < 1. \text{ The value of } T_{pz} (T_{zo} + T_{zw}) = 0.52 + 0.52 = 1.04 \text{ mm for}$$

the 4th fit accuracy class recommended by the standard, while the value  $T_{pr} (L_{r \max} - L_{r \min}) = 0.99 - (-1.25) = 2.24$  mm.

The lack of the type “b” fitting quality capability can be attributed to a particularly high tenon observed tolerance visible in Figure 7. It amounts to  $T_{rw} = 1.47$  mm and exceeds by nearly three times the value of  $T_{zw} = 0.52$  mm allowable by the standard. The observed tolerance of the mortise length  $T_{ro} = 0.76$  mm also exceeds the value allowed by the standard which, for the 4th class accuracy, amounts to  $T_{ro} = 0.52$  mm. In order to reach the fitting recommended by the standard (H4/14), the values of the observed tolerances of the tenon  $T_{rw} = 1.47$  mm and mortise  $T_{ro} = 0.76$  mm should be decreased to the value acceptable in the 4th accuracy class, i.e.  $T_{zo} = T_{zw} = 0.52$  mm. The execution accuracy of the tenon width and mortise length could be improved by reducing vibrations and clearances which occur in the OPNU systems of the applied machine tools. Later on, by controlling the observed mean clearances, as in the case of the “a” type of the fit, the observed mean clearance could be moved in such a way that it would assume the value  $L_{r\ \acute{s}r} = L_{z\ \acute{s}r} = 0.00$  mm.

On the other hand, if the value of the mean clearance were to adopt the value recommended by Rybski of  $L_{z\ \acute{s}r} = -0.70$  mm (for the strongest fit), the observed mean clearance would have to be brought to the same value, i.e.  $L_{r\ \acute{s}r} = L_{z\ \acute{s}r} = -0.70$  mm.

### Graphic fit image taking into consideration the outline of irregularities

Measurements of surface irregularities were conducted only for the “a” type of fitting. The determined value of the carrying capacity proportion of irregularities on the individual levels of the intersection  $c$  for the measurement section  $L$  was somewhat simplified and treated as the load carrying capacity for the entire surface of the mortise and tenon.

Figure 8 presents diagrams of curves of the proportion of profile irregularities in the tolerance region of the united elements. The parameters described in Figure 8 include: the observed tolerance of the mortise  $T_{ro}$  and tenon  $T_{rw}$  as well as their maximum

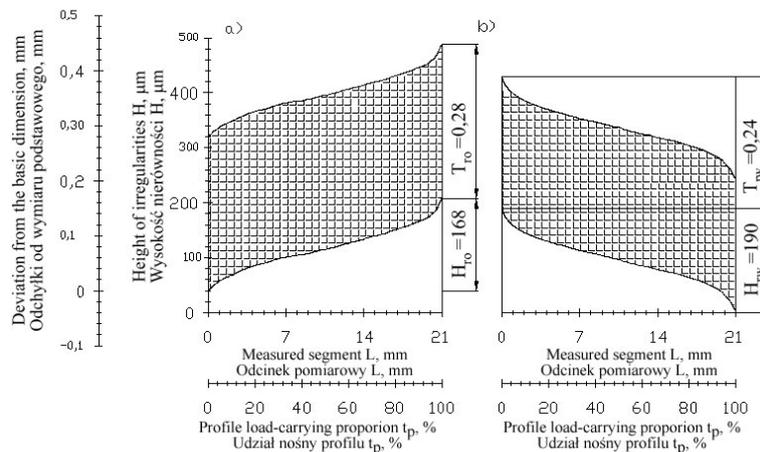


Fig. 8. The load-carrying proportion of irregularities in the mortise  $T_{ro}$  and tenon  $T_{rw}$  tolerance area for the 9.92 H4/m4 fitting: a – mortise, b – tenon

Rys. 8. Udział nośny profilu nierówności w polu tolerancji otworu  $T_{ro}$  i wałka  $T_{rw}$  dla pasowania 9,92 H4/m4: a – gniazdo, b – czop

heights of irregularities  $H_{ro}$  and  $H_{rw}$ . The maximum height of the irregularity outline clearance was  $H_{ro} = 168 \mu\text{m}$  and this constitutes its 60% proportion in the tenon tolerance area, which can be written down as:  $H_{ro} = 0.60 T_{ro}$ . On the other hand, this proportion for the tenon was slightly higher and reached 79%, i.e.  $H_{rw} = 0.79 T_{rw}$ .

It is evident from the diagrams presented in Figure 8 that outline of irregularities for the mortise decrease and for the tenon increase the observed dimension when constant tolerance value is maintained.

Figure 9 shows tolerance images of areas of connection elements together with the position of their load carrying capacity profiles for the executed 9.92 H4/m4 fitting. On the left, limiting clearances  $L_{r \min}$  and  $L_{r \max}$ , also shown in Figure 4, are visible, whereas on the right – the observed clearances: minimal  $L_{r1 \min}$  and maximal  $L_{r1 \max}$  corrected by the maximum proportion of the outline of irregularities can be seen.

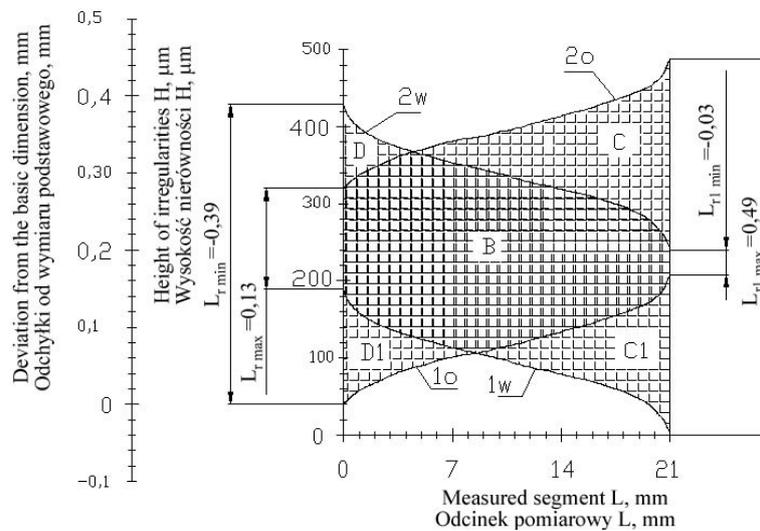


Fig. 9. Superimposition of load-carrying capacities in the connection in the a direction symbolically designated as 9.92 H4/m4

Rys. 9. Połączenie krzywych nośności w połączeniu w kierunku a oznaczone symbolowo 9,92 H4/m4

It is evident, then, that two types of clearances occur, namely: those measured at the peaks of irregularities and those measured on their bottoms.

Clearance increments result from the proportion of the profile load carrying capacities along the length of the measured segment. The value of the observed fit tolerance is the same regardless of whether it is measured along peaks of irregularities  $T_{pr}$  or their bottoms  $T_{pr1}$ , in other words  $T_{pr} = T_{pr1}$ , because:

$$T_{pr} = L_{r \max} - L_{r \min} = 0.13 - (-0.39) = 0.52 \text{ mm},$$

$$T_{pr1} = L_{r1 \max} - L_{r1 \min} = 0.49 - (-0.03) = 0.52 \text{ mm},$$

where:

$$L_{r \max} = 0.13 \text{ mm} - \text{maximum clearance measured along peaks of irregularities,}$$

- $L_{r1 \max} = 0.49 \text{ mm}$  – maximum clearance measured along bottoms of irregularities,  
 $L_{r \min} = -0.39 \text{ mm}$  – minimum clearance (maximum negative allowance) measured along peaks of irregularities,  
 $L_{r1 \min} = -0.03 \text{ mm}$  – minimum clearance (maximum negative allowance) measured along bottoms of irregularities.

The outline of irregularities for the fitting created surfaces which are contained between the maximum mortise  $2o$  and maximum tenon  $2w$ . The D surface designates wood compression during the assembly process, while C – clearance for glue.

Between the minimum mortise  $1o$  and minimal tenon  $1w$ , there is even a greater area of compression D1 than in place D, and the clearance for glue C1 is significantly smaller than in place C. On the other hand, the B + C + C1 area, which is contained between the maximum mortise  $2o$  and minimal tenon  $1w$ , refers to the largest possible clearance for glue, whereas the B + D + D1 area, which is contained between the minimal mortise  $1o$  and maximum tenon  $2w$ , designates the strongest possible wood compression during assembly.

## CONCLUSIONS

The following conclusions can be drawn for the tenon joint of the backrest leg with the side underframe of a chair manufactured from pinewood in industrial conditions:

1. The case of fitting in the direction of the mortise width and tenon thickness, it is possible to achieve the 4th class of the fit accuracy which is in keeping with the standard recommendations. No such accuracy can be achieved in the case of fitting in the direction of the mortise length and tenon width.
2. In order to accomplish a complete compliance with the fitting standards (fitting with a slight negative allowance H4/l4) in the direction of the mortise width and tenon thickness (the executed fit was that of a strong negative allowance H4/m4), a small correction of the tenoning machine by  $-0.13 \text{ mm}$  is sufficient.
3. In order to accomplish a complete compliance with the fitting standards (fitting with a slight negative allowance H4/l4) in the direction of the mortise length and tenon width (the executed fit was that of a slight negative allowance H6/k9), first it is necessary to reduce the clearance spread (observed tolerance fit) and then change the type of fitting by controlling its mean clearance.
4. The value of the highest profile irregularity height reached  $168 \mu\text{m}$  for the mortise which constitutes 60% proportion of its outline clearance of irregularities in the area of the observed tolerance.
5. The value of the highest profile irregularity height reached  $190 \mu\text{m}$  for the tenon which constitutes 79% proportion of its outline clearance of irregularities in the area of the observed tolerance.
6. For the mortise width and for the tenon thickness, the proportion of the outline of irregularities in the area of the tolerance fitting results in the increase of maximum and minimum clearances by the same value equalling  $0.36 \text{ mm}$  which constitutes the sum of the greatest profile heights of the united elements.

7. The graphic fit image extended by the proportion of the outline of irregularities reveals areas representing wood compressions occurring during the process of assembly and utilisation. It is also possible to notice other areas representing depressions on the fitted parts free of material intended for glue.

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## **BADANIA DOKŁADNOŚCI WYMIAROWEJ I STRUKTURY POWIERZCHNI POŁĄCZENIA CZOPOWEGO**

**Streszczenie.** W pracy badano tolerancje wykonania i krzywe nośności powierzchni połączenia czopowego występujące w warunkach przemysłowych. Posługując się obrazami graficznymi pasowań poszerzonymi o udział skrajni zarysu nierówności, podjęto próbę wyjaśnienia wpływu skrajni zarysu nierówności na charakter pasowania.

**Słowa kluczowe:** gniazdo, czop, tolerancja pasowania, krzywa nośności

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