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# ENSURING THE ACCURACY OF MANUFACTURING DETAILS FROM THERMO SETTING MATERIALS

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**ABSTRACT**

The article examines the influence of eight variable factors (input parameters, such as the percentage of resin-$P_r$, humidity-H, molding temperature-$T_m$ and the regional value of the type-size-R, holding time $\tau_{hold}$ of details in the form under pressure) on the absolute calculated shrinkage of the outer (D) and inner diameters (d) of the bushings. It has been established that by controlling the (P, T, $\tau$). It is possible to achieve the required accuracy and quality of details made of thermo active materials. It was determined that the shrinkage of the studied materials predetermines their quality indicators (accuracy, strength, hardness, etc.). It has been experimentally established that from the operating parameters, the pressing pressure and holding in the press form strongly affect the quality of details made of thermo active materials.

**Keywords:** Thermosetting plastics, Homogeneity, Regression.

## INTRODUCTION

The strategy for searching for the optimal accuracy of manufacturing details from thermosetting plastics is to determine, with a small number of experiments, the optimal pressing conditions, which, taking into account the quality indicators of the initial press material, provide the minimum relative calculated shrinkage ($Q_{cal}$) of specific details (bushing, glass, lid) (Braginsky, 1967; Kerimov and Gasanova, 2018).

The work investigated the influence of eight variable factors (input parameters) on the relative calculated shrinkage of the outer (D) and inner (d) diameters of bushings made of press materials based on industrial press compositions of grades K-214-2 and K-18-2. Considering the high complexity of the experiments, at the first stage it was decided to limit ourselves to sixteen experiments, forming a plan type $2^{8-4}$ (1/16 replica of the full factorial experiment of type $2^8$). Since there is no a priori information about interaction effects, it can be assumed, based on general theoretical considerations, that of all interactions, pair interactions can have the most significant effect on the shrinkage Q, and the rest can be neglected (Gasanova, 2020).

Factor levels were assigned according to manufacturing guidelines. The steps of variation of factors ($X_1$ $X_8$) were chosen in such a way as to cover the area of research of practical interest. Errors of uncontrollable factors were eliminated by randomizing the order of the experiments; each experiment was repeated three times. Measurement of the corresponding dimensions was carried out with an indicating hole gage and a indicating gage. The shrinkage of the bushings was determined as the difference between the dimensions of the shaping elements of the form, which for those indicated in Table 1 the diameters of the details are respectively equal: 79.96; 63.95; 28.07; 11.96 mm and the size of the resulting bushings in strictly fixed mutually perpendicular sections.

## MATERIALS AND METHODS

### Purpose of the study

When choosing experimental plans, we were guided by considerations of “separate” assessment of linear effects and joint assessment of paired interactions (Sokolv, 1969; Peak and Sindarovskaya, 1960; Gasanova, 2017; Gasanova, ,2021; Manliang et al., 2015).

After the implementation of the planning matrices in both cases, the homogeneity hypothesis was checked using the Cochran’s criterion, and the values of the regression coefficients $S^2\{y\}$, $S^2\{bi\}$ $\Delta b_i$ were calculated. The results of these calculations are shown in Table 1.

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**Table 1**. Intervals, levels of variation of factors and results of statistical processing for press materials of grades K-214-43 and K-18-53.

| **Levels of variation of factors for materials: K-214-43/K-18-53** | **$X_2$, (mm)** | **$X_3$, (%)** | **$X_4$, (°C)** | **$X_5$, (s)** | **$X_6$, (MPa)** | **$X_7$, (mm)** |
|---|---|---|---|---|---|---|
| | b | c | e | f | g | h |
| Upper level+1 | 200/180 | 2,6/1,8 | 185/170 | 456/264 | 35/35 | 80(64)/- |
| Main level 0 | 180/160 | 1,8/1,2 | 175/160 | 336/192 | 30/30 | 54(38)/80(64) |
| Lower level-1 | 160/135 | 1,0/0,6 | 165/150 | 216/120 | 25/25 | 28(12)/- |
| Variation interval ($\lambda_i$) | 20/20 | 0,8/0,6 | 10/10 | 120/72 | 5/5 | 26/- |

| Output parameters | Regression coefficients and errors in their determination | | | | | | |
|---|---|---|---|---|---|---|---|
| K-214-43 | $b_0$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $b_6$ | $b_7$ |
| $Sh_{D3}$ | 0,36 | +0,007 | +0,006 | +0,002 | -0,017 | +0,003 | +0,15 |
| The height of the bushings h=const=8 mm $Sh_{d3}$ | $S^2_{\{y\}}$=0,0003; $S_{\{bi\}}$=0,0014; $\Delta b_i$=0,003; $G_{16,1}$=0,24 | | | | | | |
| $Sh_{d3}$ | 0,25 | +0,001 | +0,003 | +0,002 | -0,013 | +0,006 | +0,11 |
| | $S^2_{\{y\}}$=0,0002; $S_{\{bi\}}$=0,001; $\Delta b_i$=0,002; $G_{16,1(0,05)}$=0,26 | | | | | | |
| K-18-53 The height of the bushings h=const=8 mm $Sh_{D4}$ | 0,23 | -0,007 | +0,005 | +0,001 | -0,023 | -0,006 | - |
| | $S^2_{\{y\}}$=0,002; $S_{\{bi\}}$=0,001; $\Delta b_i$=0,002; $G_{16,1(0,5)}$=0,23 | | | | | | |
| $Sh_{D4}$ | 0,15 | -0,006 | +0,003 | -0,003 | -0,019 | +0,009 | - |
| | $S^2${y}=0,0003; S{bi}=0,0014; $\Delta b_i$=0,003; $G_{16,1(0,05)}$=0,24 | | | | | | |

Taking into account only significant coefficients with 95% probability, the regression equations were obtained, which are shown in Table 2.

**Table 2.** Experimental mathematical and statistical models.

| **Material** | **Regression equation** |
|---|---|
| | Outer diameter |
| K-214-43 | $Sh_{D1}$=0,42+0,068$X_1$+0,02$X_3$+0,034$X_4$-0,01$X_5$+0,18$X_7$ |
| K-18-2 | $Sh_{D2}$=0,30+0,012$X_1$+0,023$X_3$+0,02$X_4$+0,013$X_5$+0,12$X_7$ |
| K-214-43 | $Sh_{D3}$=0,36+0,00$X_2$+0,006$X_3$-0,017$X_6$+0,15$x_7$ |
| K-18-53 | $Sh_{D4}$=0,23-0,007$X_2$+0,005$X_3$-0,023$X_5$-0,006$X_7$ |
| K-214-2 | $Sh_{D1}$=0,36+0,05$X_1$+0,03$X_3$+0,02$X_4$-0,011$X_5$-0,013$X_6$+0,12$X_7$ |
| | Inner diameter |
| K-214-43 | $Shd_1$=0,24+0,04$X_1$-0,01$X_2$+0,01$X_4$-0,01$X_5$+0,17$X_7$ |
| K-18-2 | $Shd_2$=0,18+0,01$X_1$+0,01$X_3$+0,01$X_4$-0,006$X_5$+0,13$X_7$ |
| K-214-43 | $Shd_3$=0,25+0,01$X_2$+0,003$X_3$+0,002$X_4$-0,013$X_5$+0,11$X_7$ |

| | |
|---|---|
| K-18-53 | $Shd_4=0,15-0,006X_2+0,003X_3-0,003X_4-0,019X_5$ |
| K-214-2 | $Shd_1=0,18+0,03X_1+0,002X_3+0,02X_4-0,005X_6+0,10X_7$ |

When interpreting the regression equations (1-10), we had to assume the following: the levels of variation are chosen so that the effects can be neglected. The verification of the correctness of these assumptions was the subsequent experiments, after which, as a result of obtaining additional information, it became possible (was carried out) to interpret some significant effects of pair interaction.

**RESULTS**

**Solving the problem**

**Interpretation of the obtained results**: Regression equations for press materials K-214-2 and K-18-2 include significant factors $X_1$ and $X_7$, which vary during the experiment at different levels; of certain interest is the control check of these equations on industrial press compositions.

For this purpose, the following parties of press materials were selected: p.4419/4-K-214-2 and p.4425/4-K-18-2. The studied factors, except for X7, were set at a zero level (Table1).

The performed calculation for bushings of various type-sizes showed that the relative calculated shrinkage of the outer (80 and 28 mm) and inner (64 and 12 mm) diameters, respectively, is equal to:

for equations (1) and (6)

$Sh^C_{D=80}$=0,58 mm, $Sh^C_{D=28}$=0,22 mm,

$Sh^c_{d=64}$=0,40 mm, $Sh^c_{d=12}$=0,07 mm,

for equations (5) and (10)

$Sh^C_{D=80}$=0,48 mm, $Sh^c_{D=28}$=0,27 mm,

$Sh^c_{d=64}$=0,24 mm, $Sh^c_{d=12}$=0,085 mm,

for equations (2) and (7)

$Sh^c_{D=80}$=0,41 mm; $Sh^c_{d=64}$=0,31 mm.

The actual values of the relative shrinkage under the given experimental conditions turned out to be correspondingly different:

$Sh^e_{D=80}$=0,55 mm, $Sh^e_{d=64}$=0,40 mm,

$Sh^e_{D=80}$=0,46 mm, $Sh^e_{d=64}$=0,25 mm,

$Sh^e_{D=80}$=0,45 mm, $Sh^e_{d=12}$=0,065 mm,

$Sh^e_{D=28}$=0,22 mm, $Sh^e_{d=12}$=0,080 mm,

$Sh^e_{D=28}$=0,24 mm, $Sh^e_{d=64}$=0,30 mm.

The maximum deviation from the calculated data is~11%. Control experiments have shown that the obtained quantitative dependences in the first approximation predict the value of the output parameter with sufficient accuracy for production at given intervals of variation of factors (in a given area of the factor space).

From the analysis of the regression equations (1)-(10), it follows that the results obtained for the main significant effects do not contradict the general theoretical considerations about the influence of the investigated factors on the optimization parameter and confirm the existing qualitative hypotheses about their signs.

**Shrinkage of the outer diameter:** The absolute shrinkage of the outer diameter of the bushing made of press material K-214-2 and K-18-2 increases with an increase in the percentage of resin–$P_r$, humidity-H, as well as with an increase in the molding temperature–$T_m$ and the regional value of the type-size - R, reverse effect on the optimization parameter is exerted by an increase in the holding time $\tau_{hold}$ of details in the form under pressure.

In accordance with the a posteriori ranking of factors, the strongest influence on the optimization parameter ($Sh_D$) in the case of the press material K-214-2 is exerted by $P_r$ (b%), an increase in which by 20% (1) when the other factors are set at zero level increases the $Sh_D$ by 0.14mm (33%). For the novolac press material K-18-2, the force of influence of Pr on the absolute shrinkage $Sh_D$ is less. Thus, an increase in the content of novolac resin by 10% while fixing the remaining significant factors at the main level causes an increase in shrinkage by 8% (0.02 mm). This is due to the fact that the shrinkage of both rezole and novolac press powders depends on the chemical processes occurring during the polycondensation of the resole resin or during the crosslinking of linear novolac chains during its curing under the action of hexamethylenetetramine.

The absolute value of shrinkage of details also determines the amount and nature of filler, and this is due not only to a change of resin and filler ratios, but also in that the filled plastic is a heterogeneous system with a formed spatial lattice which resists forces which occur during shrinkage phenomena. The properties of such systems are the result of the combined action of the binder and filler, which retain their specificity in the filled material. Since there is a bond between the binder and the filler particles, due to a decrease in the volume of the material during curing, the binder (with shrinkage ability) and the filler will tend to deform each other; the amount of deformation will depend on the modulus of elasticity of the components of the system, usually $E_f \gg E_b$. Therefore, the use of more rigid (mineral) fillers reduces the amount of shrinkage to a minimum, and this is also associated with a decrease in this case, the temperature coefficient of the filled system, which is a monolithic material, where elementary particles are interconnected and do not have complete freedom of movement.

These theoretical positions are confirmed by the obtained quantitative dependencies (1) and (3), (2) and (4), for example, by comparing the values of the free terms in these equations. Since the press powders K-214-2 and K-214-43; K-18-2 and K-18-53 were prepared, respectively, on resins of the same batch, then according to the regression equations, knowing the composition of the material, it is possible to estimate in a first approximation the strength of the effect of the nature of the filler (organic and mineral), the value of the regression coefficients in equations (1) ÷ (4).

**DISCUSSION**

As a result of the planning of the experiment, the influence of the holding time of the material under pressure on the shrinkage of the details was quantitatively determined. For press materials with wood fillers, the increase in shrinkage values with a decrease in the holding time is relatively small and less than the effect of an increase in the pressing temperature. However, in the case of processing press powders with mineral filler, the force of the influence of $\tau_{hold}$ increases sharply: for example, with an increase by a time equal to $2\lambda_5$ (Table 1), shrinkage decreases (with fixed values of other factors at a zero level) for K-214-43 by 10%; K-18-53-by 22%. The following sequence is observed: the influence of $\tau_{hold}$ on the optimization parameter is greater for novolac (fast-hardening) press powders than for rezole and this effect increases with an increase in the percentage of mineral filler.

This can be explained by the fact that, upon hardening of less polydisperse novolac resins, the required degree of condensation is more quickly achieved, which leads to a rapid decrease in $\alpha_{Tp}$ and a decrease in shrinkage. When the degree of hardening reaches about 30%, the subsequent increase in τhold will not affect the change in $\alpha_{Tp}$.

This hypothesis is confirmed by the results of the experiment. So, with an equal value of the coefficients $b_5$, the curing of K-214-2 lasts 240 s, and K-18-2-just 140 s, until the shear stress at the intermediate stage $\sigma$ =6MPa. With an increase in the cure time for all press materials, the difference in the degree of cure on the surface and inside the detail is negligible, due to which the shrinkage phenomena will be more varied. It can be assumed that in the case of materials with unequal filler (or with lower binder content) for press powders K-18-53 and K-214-43, shrinkage phenomena will be reduced to a minimum. To a greater extent, with an increase in $\tau_{hold}$, the effect of the resulting spatial rigid structure (less movable filled system), which compensates for the shrinkage process, is manifested. From here it follows that the noted influence of $\tau_{hold}$ on the optimization parameter is approved only for the investigated range of variation of the input characteristics.

As is known, the degree of influence of the pressing pressure on shrinkage depends on the design of the locking part of the mold and, judging by the published data, this influence is not unambiguously manifested. In our case, at the given variation intervals and the reproducibility error, the pressure does not significantly affect the optimization parameter for all studied press materials.

In order to test the results obtained for the press materials K-214-2, a planning matrix was implemented, in which, when varying the design factor $X_7$, the height of the product was not assumed to be constant (h=8mm==const), but the hinge of the details-bushing (g=10g); in this case $F=S/V_{lb}= S/V_{sb}$, where

S is the contact surface of the large and small bushings with the shaping elements of the form; $V_{l,s}$ — volume of pressed bushings; wherein

$F_{2\,1}>_{F1\,1}$ and $F_{2\,s}<F_{1\,s}$

Regression equations (5) and (10) were obtained, tab. 2, in which both the signs and the numerical values of the regression coefficients, taking into account the errors in their determination-$S_{\{bi\}}$, correspond to those previously considered. In equation (5), the coefficient characterizing the strength of the influence of the pressing pressure, which is commensurate with the linear effect b5, also turned out to be significant.

An estimate of the change in the height of the molded bushings at constant outer and inner diameters is the value of the free term $b_0$=0,36 of equation (5), which is less than in equation (6). It has been experimentally proven that with an increase in the ratio S/V, the accuracy of the outer diametral dimensions increases. Consequently, the free term in the equations reflects the design features of the detail, takes into account the nature of the filler of a given grade of material and the nature of the location of the detail element in the press form. The dependence of the shrinkage of details on the change in the nominal size of the investigated bushings under the given experimental conditions is determined by the value of the coefficient $b_7$, the value of which is different and changes with change of fluctuation of material shrinkage and, in addition, it also takes into account a number of factors characterizing the shrinkage of the detail itself.

**CONCLUSIONS**

1. In the article it has been established that by controlling the operating parameters (P,T,τ), it is possible to achieve the required accuracy and quality of details made of thermoactive materials.
2. It has been experimentally established that from the operating parameters, the pressing pressure and holding in the press form strongly affect the quality of details made of thermoactive materials.
3. It was determined that the shrinkage of the studied materials predetermines their quality indicators (accuracy, strength, hardness, etc.).

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