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SPECIMENS FOR SHEAR TESTING OF SHEET METAL MATERIALS

The paper analyzes the influence of geometrical parameters of sheet specimens for shear tests in order to obtain stress-strain state indicators in the measuring zone. In order to provide close-to-shear deformation conditions, a new design of sheet specimens is proposed. The influence of geometrical characteristics of the proposed sheet specimens on the values of stress-strain state indicators has been determined as well as their difference in the measuring zone.

keywords: *stress, deformations, sheet material, shear tests, plane stress state.*

Problem statement

Crisis of resources leads to a more economical attitude of producers and consumers to their use, which results in wide application of the resource-saving methods, techniques and processing technologies. Plastic metal working is the most wide-spread method among them. Ensuring stable output of qualitative products is one of the main problems solved during manufacturing process design. This problem is solved mostly by an appropriate choice or design of processing modes taking into account plasticity of the material. A measure for evaluating the possibility to obtain this or that product by plastic deformation methods is criterion ψ proposed in the works of Gubkin, Smirnov, Aliayev, Ogorodnikov, Del and other authors [1] . The essence of this criterion consists in the fact that catastrophic failure necessarily occurs at the moment when ψ = 1 , i.e. at the moment when metal plasticity is exhausted. Calculation of the used plasticity resource could be performed by the formula [2]

$$\Psi = \int_0^{e_i} n \frac{e_i^{n-1}}{e_p(\eta, \mu_\sigma)^n} de_i \le 1, \tag{1}$$

where e_p – ultimate strain before failure occurs; e_i – deformation intensity; $e_P(\eta, \mu_\sigma)$ – ultimate strain surface; $n = 1 + 0{,}2 arctg\left(\frac{d\eta}{de_i}\right)$ – indicator that takes into account the character of plasticity variation depending on the stiffness of the stressed state; $\eta = \frac{\sigma_1 + \sigma_2 + \sigma_3}{\sigma_i}$ – stiffness of the stressed state; $\mu_\sigma = \frac{2\sigma_2 - \sigma_1 - \sigma_3}{\sigma_1 - \sigma_3}$ – type of the stressed state.

From expression (1) it is evident that the accuracy of the used plasticity resource estimation is considerably influenced by the ultimate strain surface $e_p(\eta, \mu_\sigma)$ constructed in dimensionless coordinates – stiffness of the stressed state η; indicator of the type of stressed state μ_σ (Nadai-Lode parameter). In accordance with procedure [2], ultimate strain surface is constructed on the basis of data obtained from tensile, compression and torsion (shear) tests:

$$e_P(\eta_2, \mu_\sigma) = \frac{e_P(0{,}0)\exp(-b\eta_2)}{1 + \lambda_1 \mu_\sigma + \lambda_2 \mu_\sigma^2}, \tag{2}$$

where $\lambda_1 = \ln\left(\frac{e_p(-1{,}0)}{e_p(0{,}0)}\right)$, $\lambda_2 = \ln\left(\frac{e_p(0{,}1)}{e_p(0{,}0)}\right)$, $b = \lambda_1 - \lambda_2$ – approximation coefficients; $e_p(0{,}0)$ -

ultimate strain during torsion (shear) tests; $e_p(-1,0)$ – ultimate strain during compression tests; $e_p(0,1)$ – ultimate strain during tensile tests. Actual value of ultimate strain, determined on the results of torsion tests, is refined by empirical expression [2] since on the surface of the material (in the value fixation zone) parameters η_2 and μ_σ vary in the range from -0,1 to 0,1.

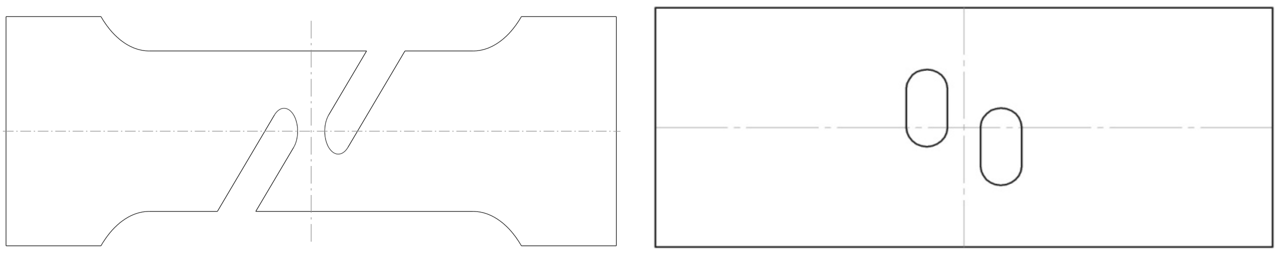
From (2) it follows that the accuracy of ultimate shear strain estimation has significant influence on the accuracy of plasticity diagram construction and, therefore, on the calculation of the used plasticity resource.

In the paper the influence of the form and geometrical parameters of the specimens for shear tests on the stress-strain indicators in the measuring zone is analyzed.

Stress-strain state of the specimen during shear tests

In order to determine ultimate torsion strain, cylindrical specimens with the form that corresponds to the requirements of the Standard are used. As to ultimate shear strain estimation for sheet materials, geometrical parameters of such specimens have not been determined. Therefore, the main purpose of this work is to refine geometry of the specimen for shear testing of the sheets and to reveal its influence on the stress-strain state indicators.

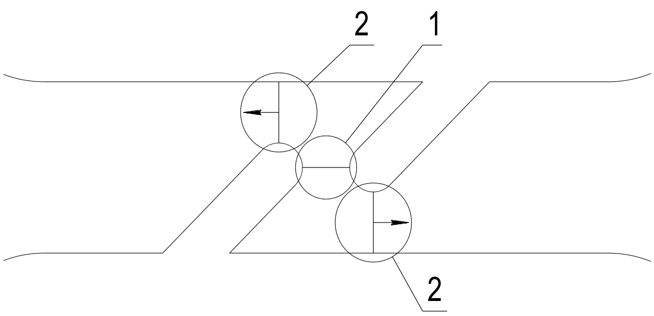
In a number of works [2 , 3] several types of specimens are proposed (Fig. 1).



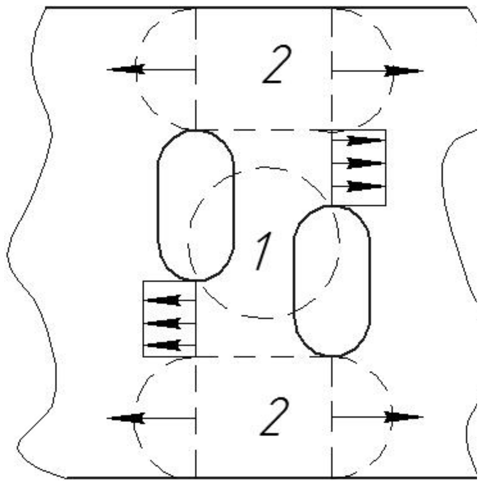
a) b)

Fig. 1. Design of the specimens for shear testing of sheet materials:
a) – specimen proposed in [2];
b) – specimen proposed by the authors

Let us consider mechanical models of the specimen deformation process (Fig. 2). During tests of the specimen, shown in Fig 2a), on the tensile testing machine working area 1 is subjected not only to the action of slide loads but also to the action of torque. Under the influence of tensile forces working part of the specimen is in the state of eccentric tension, i.e. not only a simple shear of the specimen area occurs (plane stress), but a more complex process is observed: shear in area 1 with its simultaneous elongation, while in section 2 tension and bending occurs. Due to the torque, right and left parts of the specimen are trying to turn so that the bridge would coincide with the direction of the gripper motion, which leads to considerable difference of stress-strain state in zone 1 from that of shear. This is confirmed by modeling and full-scale tests of the specimens (Fig. 3a, 4a).

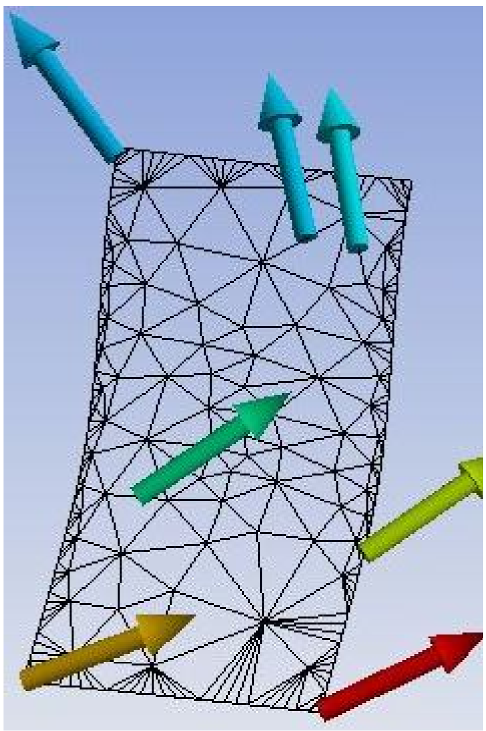


a)

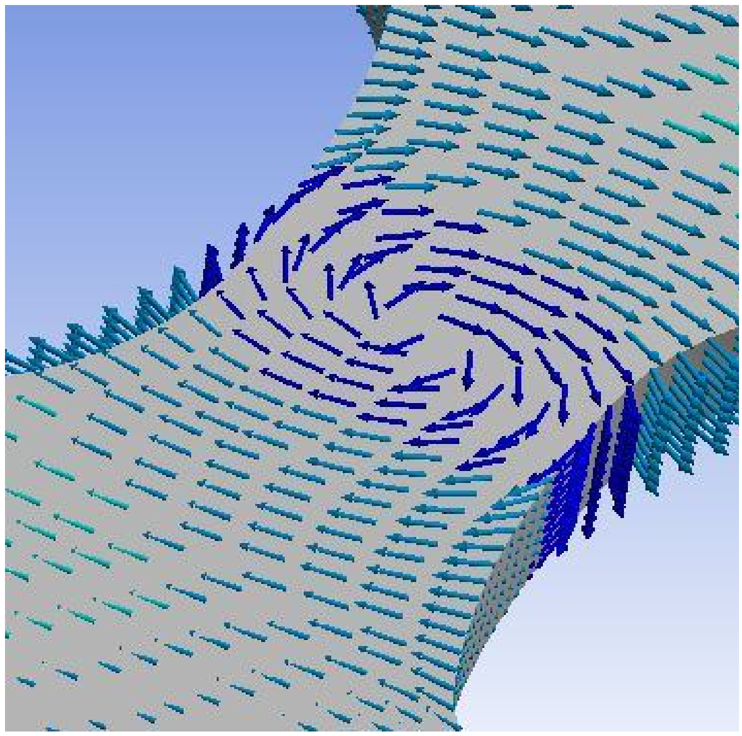


b)

Fig. 2. Mechanical models of specimen deformation:
a – specimen proposed in [2];
b – specimen proposed by the authors



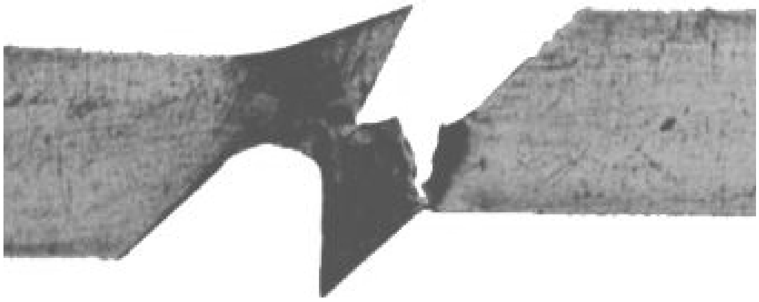
a)



b)

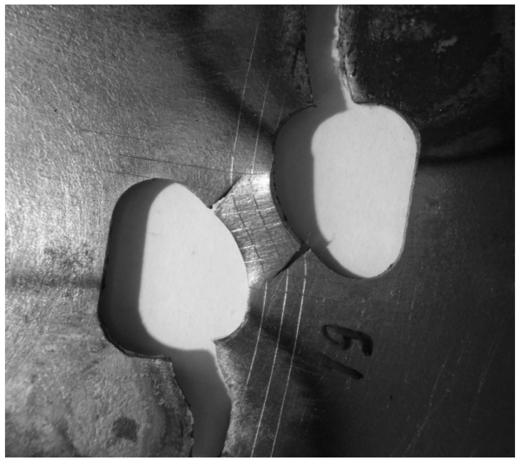
Fig. 3. Direction of displacements of the bridge points during deformation process:
a – specimen proposed in [2];
b – specimen proposed by the authors

As different from specimen *a,* during specimen *b* deformation process stress-strain state in region 1 (Fig 2b) is more close to that of shear. This is explained by the fact that efforts of the right and lefts parts of the specimen to shift in relation to each other are compensated by deformations of zones 2 (Fig. 3b, 4b). The same effect could be achieved by the application of special guides that will limit the mutual motion of the specimen halves.



a)

Fig. 4. View of the specimens after full-scale tests:
a – specimen proposed in [2];
b – specimen proposed by the authors



b)

Another drawback of both specimens is the loss of the bridge stability (in the specimen plane) during deformation and, consequently, loss of the specimen flatness. However, this could be avoided by application of additional plates on the bridge zone or by reduction of the bridge width. In reducing the bridge width to the minimal values there is an essential limitation in the possibility of the shift identification by different types of marks. So, to our mind, the following combined solution will be a more effective one: reduction of the bridge thickness with simultaneous application of additional plates for fixing displacements in the direction perpendicular to the sheet surface.

Thus, taking the above-mentioned into account, specimens presented in Fig. 1b are more preferable.

In order to reveal the influence of the specimen geometrical parameters on the stress-strain state indicators, a series of simulation calculations was performed for studying the influence of geometrical characteristics of the specimen, proposed by the authors, on the stress-strain state indicators. For increasing the efficiency of calculations a parameterized model of the specimen was built (Fig. 5).

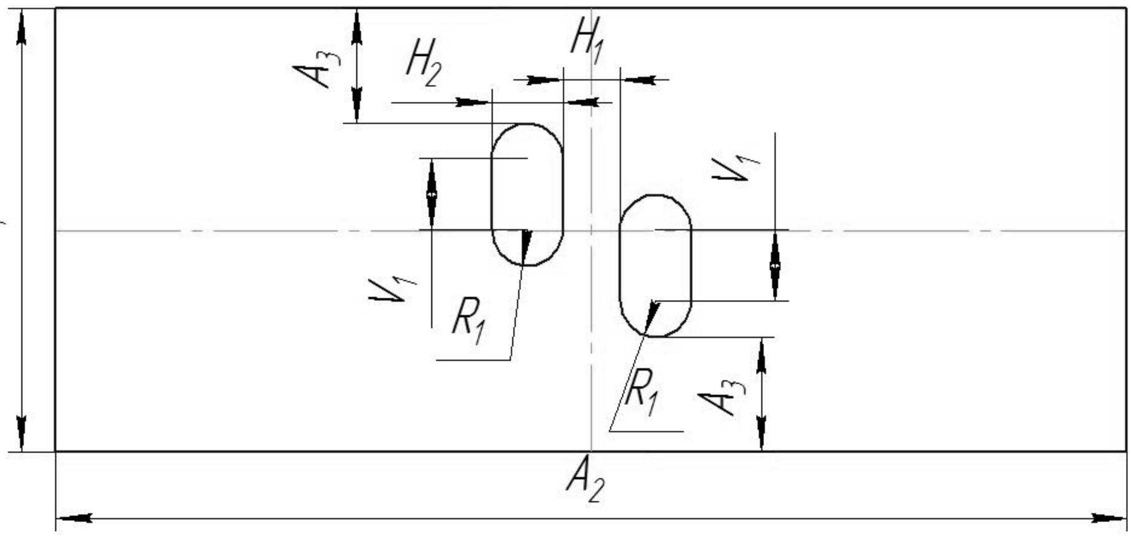
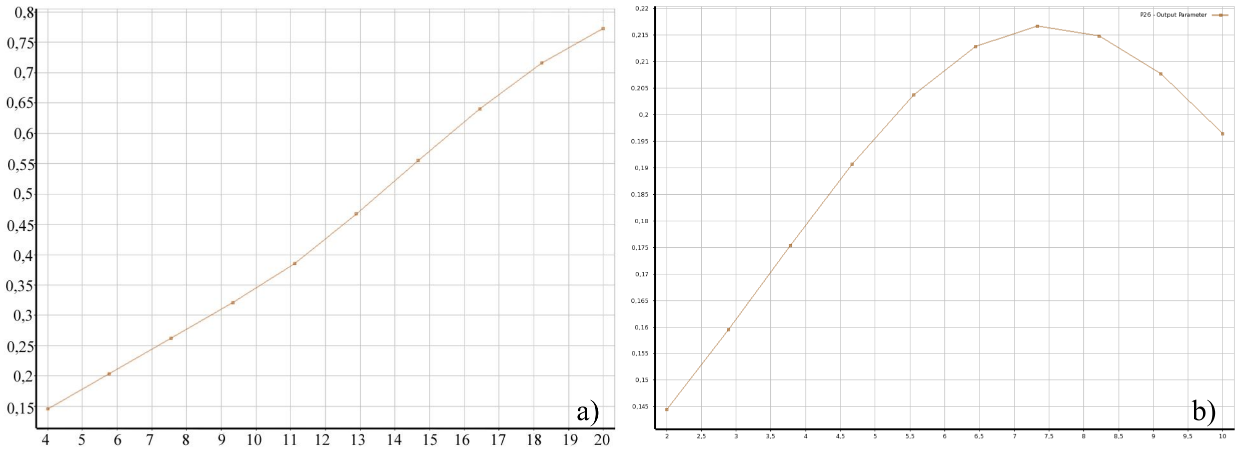


Fig. 5. A parameterized model of the specimen proposed by the authors

While studying the influence of geometrical parameters on stress-strain state indicators, it was determined that parameters A1 , A2 , A3 and H2 do not have any significant influence. Thus, the most influential parameters are: R1 –radius of the slot curvature; H1 – width of the bridge (of the working zone); V1 – the slot length. To simplify identification of the measuring zone, it was assumed that measurements are performed in zone 1 of the proposed specimen that is at the distance of 2 mm from each of the slots and is limited by central curvatures of the slots. The studies were limited to the use of specimens with the thickness up to 6 mm since, as the calculations have shown, for specimens with greater thickness stress-strain state approaches volumetric deformation.

As a result of calculations, dependencies of parameters η (stress-strain state indicator) and μσ (parameter of Nadai – Lode) on the geometrical parameters R1, H1 and V1 have been obtained. Graphically, they are presented in Fig. 6 and 7.



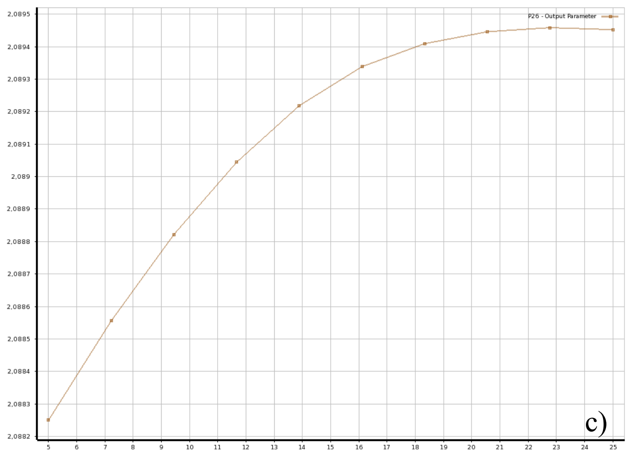
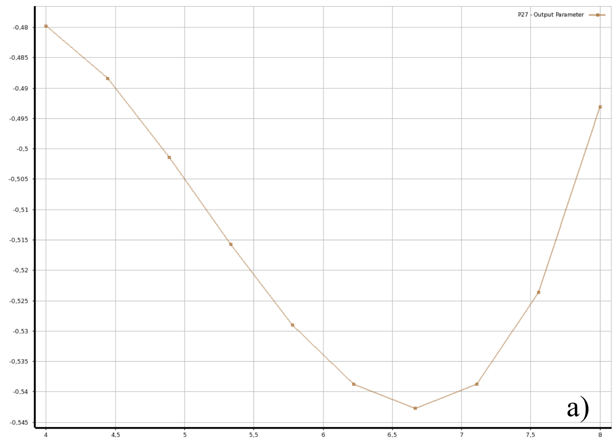


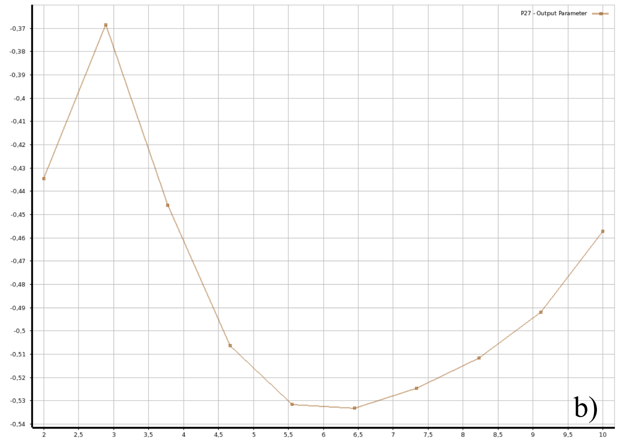
Fig. 6. Influence of the geometrical parameters on stress-strain state indicator η:
a – influence of the bridge width H1;
b – influence of the curvature radius R1 of the slot;
c – influence of the slot length V1

As it is evident from Fig. 6a and 7a, increase of the bridge width leads to the growth of stress-strain state indicators and further deviation from the flat stress state.

Analysis of Fig. 6b and 7b shows that the best radius value ranges from 1 to 2,5 mm. It should be also noted that growth of the slot length (Fig. 6c and 7c) to 20mm increases the stress-strain state indicators while further increase of the slot length has practically no influence on parameters η and μσ.

As a result of calculation data optimization by target function η, for specimens with thickness 1, 2, … 6 mm geometrical parameters and stress-strain state indicators have been obtained. (Table 1).





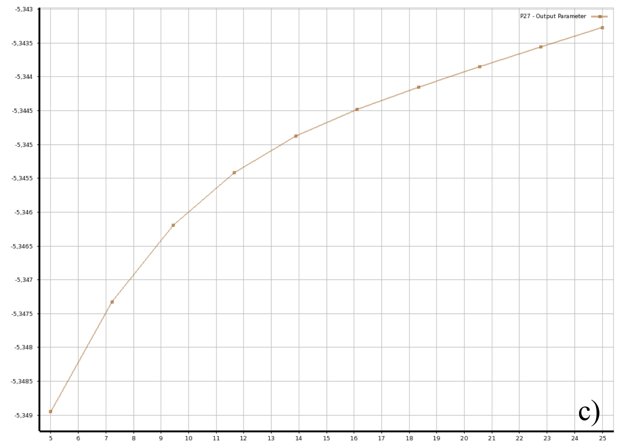


Fig. 7. Influence of the geometrical parameters on stress-strain parameter η:
a – influence of the bridge width H1;
d – influence of the slot curvature radius R1;
c – influence of the slot length V1

Table 1

Geometrical characteristics and respective stress-strain state indicators

Number of the specimen	Slot length V_1, mm	Double radius of the slot curvature R1, mm	Half-length of the bridge H1, mm	Indicator η	Nadai-Lode parameter μ_σ
1	2	3	4	5	6
Specimen thickness 1 mm					
1	17,250	4,600	2,750	0,094	-0,428
2	15,090	4,494	2,619	0,095	-0,417
3	6,690	4,658	2,926	0,091	-0,435
1	2	3	4	5	6
Specimen thickness 2 mm					
1	5,01	4,002	2,004	0,118	-0,358
2	16,53	4,037	2,355	0,127	-0,365
3	22,29	4,107	2,238	0,127	-0,371
Specimen thickness 3 mm					
1	5,01	4,002	2,004	0,118	-0,357
2	16,53	4,037	2,355	0,126	-0,365
3	22,29	4,107	2,238	0,127	-0,370
Specimen thickness 4 mm					
1	5,01	4,002	2,004	0,122	-0,371
2	22,29	4,107	2,238	0,127	-0,385
3	17,97	4,271	2,091	0,127	-0,385
Specimen thickness 5 mm					
1	5,01	4,002	2,004	0,109	-0,350
2	22,29	4,107	2,238	0,117	-0,375
3	17,97	4,271	2,091	0,118	-0,371
Specimen thickness 6 mm					
1	5,01	4,002	2,004	0,104	-0,323
2	16,53	4,037	2,355	0,109	-0,259
3	22,29	4,107	2,238	0,109	-0,277

Using the specimens given in Table 1 and taking into account the correction for the difference in the conditions of deformation from plane stress state, one of the key points of the plasticity diagram can be obtained. This, in its turn, makes it possible to assess the capabilities of plastic deformation processes. Analysis of the optimization results, presented in Table 1, shows that it is expedient to design specimens with the bridge width of 4 – 5 mm, slot curvature radius of 2 – 2,5 mm and the slot length of 5 mm.

Conclusions

1. The developed design of specimens for testing sheet materials enables ultimate strain estimation in close-to-shear conditions.
2. In order to reduce the value of measuring zone warp, the width of the specimen working zone should be reduced.
3. The following geometrical parameters of the specimen of the proposed design will be the best for providing close-to-shear deformation conditions: width of the bridge 4 – 5 mm, the slot curvature radius 2 - 2,5 мм, the slot length of about 5 mm.

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