The limiting deformation degree of the welded cylindrical blanks during shaping operations of sheet-metal stamping

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Abstract
The dependencies that allow determining the limiting degree of deformation when expansion and breaking-down of welded cylindrical blanks were obtained based on the schematized assessment of the less deformed layers influence on the possibility of local thinning in more deformed ones and plastic deformation of the weld zone. The technics and processing methods of increasing the deformability of the weld seam of the blank of its formation stages: before, during and after the shaping operations were systematized and generalized.
Keywords: WELDED CYLINDRICAL BLANK, RIM, WELD-AFFECTED ZONE, STAMPING, EXPANSION, BREAKING-DOWN

1.Introduction

The main industries such as mechanical engineering, machine tool building, aircraft, rocket building, shipbuilding, atomic energetics, agriculture and communal facilities cannot be developed successfully without being supplied with axisymmetric light-sheet parts obtained from welded tubular blanks of required quality and size. Finding the causes of defects of welded cylindrical blanks and ways of dealing with them on the basis of ascertain the nature and degree of the individual factors influence on the process of deformation is relevant and actually is one of the main problems of the theory and practice of stamping. Preventing the destruction of the weld seam zone and elimination of deformations localization previous the destruction is extremely important in design, development and expansion of the limiting possibilities of stamping technologies. In addition, it helps to obtain minimum gage interference parts with high surface quality and enhance the competitiveness and operational reliability.

Parts forming from cylindrical blanks is carried out by various technological processes [1-3]:

- Breaking-down and expansion on the presses in rigid and flexible matrices hydraulic blasting, electro-hydraulic and magnetic-pulse stamping (Fig. 1.);

Figure 1. General view of the parts produced by explosive stamping of welded cylindrical blanks

- Tool roller (spinning) or friction tools, radial rotary shaping, bending at the three-roll bending machines.

A breaking-down of the hollow cylindrical blanks shell parts is a relatively new direction in the field of advanced methods of forming[3] in combination with shortening this method is used in the manufacture of spherical shells (“ball” part) (Fig. 2).

The radial-rotary profiling method and stamping techniques with combining shaping operations take a special place among the manufacturing process of products made of welded cylindrical blanks. Under the conditions of serial and mass production of wheel rims radial-rotary profiling method is the most efficient technological process.

Theory and technology of the radial-rotational profiling, combined processes of shaping, bending of welded cylindrical and conical shells on a three-roll bending machine started to develop rapidly. This allowed for the past decade to significantly improve the production of a large product range from welded cylindrical blanks, to develop new types of equipment, machining attachments and tools.

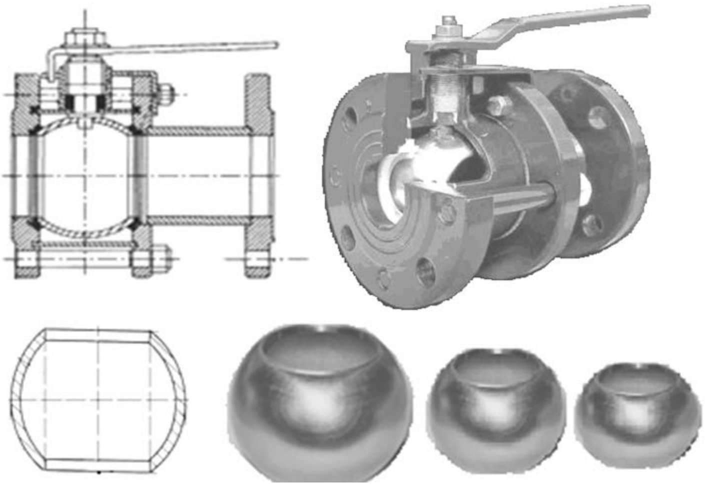

Figure 2. Crane of ball steel manufacture

However, in practice the formula of Popov E. A. is used for the calculation of welded cylindrical blanks [4]. This formula determines the limiting degree of deformation or the maximum diameter D_{max} of the blank edge portion, which can be obtained by distribution (or minimum at breaking-down) as the limit for seamless cylindrical blank. Formula of Popov E. A. [4] does not provide satisfactory accuracy of estimated diameter increase of the welded blank. This leads to an overestimation of the allowable diameter increase of the blank by 15-25%. As a consequence, it is impossible to predict the blank destruction when expansion. Therefore, it is necessary to define joint movement limiting values in the heat affected zone and beyond.

Thus, the deterrent for further development and use of advanced technologies of welded cylindrical blanks forming is the lack of calculation dependencies predicting the destruction of the weld zone and deformation localization previous to the destruction [5] (Fig. 3).

Figure 3. Types of destruction of welded cylindrical blank in the weld zone during forming

2. Research objective

To carry out the theoretical analysis of the forming processes of the welded cylindrical blank at expansion (braking-down), to determine the factors affecting the formability of the weld zone and to get dependencies describing the limiting capabilities during expansion and breaking-down of welded blank. To substantiate the choice of processing methods for increasing formability of welded blank.

3. The research results

It is known [6-9] that the main factors limiting the forming possibility of welded blanks are: the presence of stress concentrators, residual stresses, deformations in the weld seam and in the weld zone and the change of physical and mechanical characteristics of the material in the weld zone.

The presence of stress concentrators in weld seam is due to the poor quality of welding and the unsatisfactory state of the welding surfaces, which is easy to remove by increasing the quality of the separation and welding operations.

Mathematical condition record of occurrence of the local increase in the tangential deformations ε_θ in the edge layer with taking into account the residual stresses in the end of blank can be represented as

$$dP = d(\sigma_\theta F_\theta) + d(\tau_{\rho\theta} F_\tau) + d(\sigma_r F_r) = 0, \quad (1)$$

where dP– the increment of tensile force in the edge layer;

$\varepsilon_\theta, \sigma_\theta$ – deformation and tangential stresses acting in the edge layer;

σ_r – residual stresses in edge layer;

$\tau_{\rho\theta}$ – shear stress acting on the boundary between edge layer and the adjacent layer, which is more distant from the edge;

F_τ, F_θ, F_r – areas which are respectively shear, tangential and residual stresses.

After completing all the necessary changes in accordance with a scheme of solving the problem in finding the limit degree of deformation was established [4], that the residual voltage did not affect the localization of deformation prior to destruction.

Let us consider how the weld seam affects the localization of deformation in the ring layer bordering on the edge of the blank using the assumptions and preconditions in accordance with [4].

The process of blank expansion with a weld seam (Fig. 4) is a preliminary operation before profiling of the wheel rims and lies in the expansion of end sections with conical punches (Fig. 5). It should be noted that when stretching the annular tensile element the more flexible elements will be plastically deformed in the beginning. Most of all it is the weld zone. Deformation will continue as long as the seam zone yield strength will reach the yield strength of the base material. If more malleable material does not hardened, that is uncharacteristically for the materials used in sheet forming, the localization of the deformation occurs therein. Therefore, there is no need to consider the joint plastic deformation of the blank weld zone. The development of local deformations in the edge layer is shown in Fig. 6.

Figure 4. Type of the blank with weld seam prior to profiling of the wheel rim

Figure 5. Expansion process (breaking-down) of the wheel rim blank before profiling

As a consequence of the deformation process involves two stages - undercritical that takes place with increase in the volume of an active deformed linear size of the more plastic component (when stretching), and aftercritical taken place from the joint plastic deformation of the blank base material and weld seam.

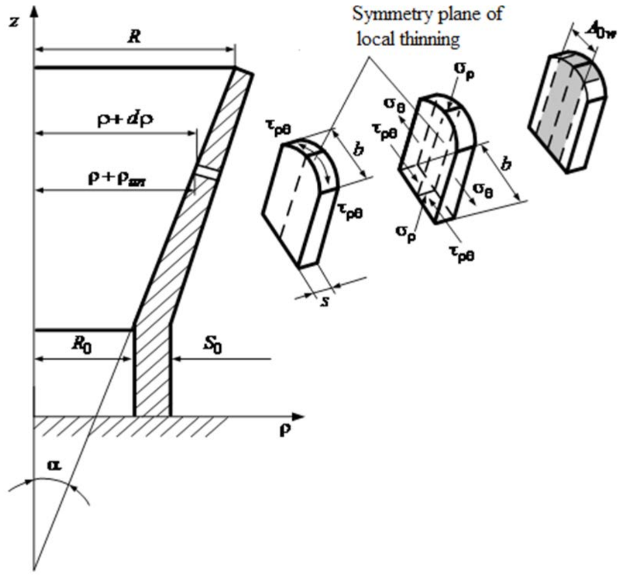

Figure 6. Development of local deformations in the edge layer:
b – the size of the heat affected zone; S – current thickness of the the blank ; A_{0w} – the initial length of the weld seam zone; R_0, s_0 – the radius and the thickness of the initial blank ; ρ, ρ_{UN} – current radius of the blank and the radius of the neck at the beginning of its formation; $\sigma_\rho, \sigma_\theta$ – meridional and tangential stresses; R – the radius of the blank edge layer; α – taper angle

Interconnection of the system true stresses: blank material and the weld seam, when $\delta \geq \delta_u$ is as follows:

$$\sigma_s = \sigma_u e^{\delta_{un}} \left(\frac{\delta}{\delta_{un}} \right)^{\delta_{un}}, \tag{2}$$

where $\delta_{un} = \ln \frac{l_{un}}{l_0}$ – main logarithmic deformation of system elongation before the necking in a tensile test;

l_{UN} – the length of the edge layer of the blank at the beginning of necking;

l_0 – the initial length of the blank edge layer;

σ_u – limit system strength;

σ_s – yield stress;

$\delta = \ln \frac{\rho}{R_0}$ – main logarithmic deformation of annular layer.

According to the data [4] without much loss of accuracy can be taken $\left(\frac{\delta}{\delta_{un}} \right)^{\delta_{un}} \approx 1$.

The dependence of true stresses of the blank material is expressed as follows

$$\sigma_s = \sigma_{um} e^{\delta_m}, \tag{3}$$

where σ_{um} – tensile strength of the blank material;

δ_m – logarithmic deformation of the blank material.

Law of the weld seam zone hardening is described by equation:

$$\sigma_s = \sigma_{uw} e^{\delta_{unw}}, \quad (4)$$

where σ_{uw} – tensile strength of the weld seam zone material;

δ_{unw} – logarithmic elongation deformation at the beginning of necking when the tensile test of weld seam zone material.

Equations (1-4) describe the deformation ratio of elongation (compression) elements of welded blank.

Let us expresses the ratio between the total deformation δ of the system through reduction per stands δ_{unw} of the blank weld seam material by equation:

$$\delta = -\ln\left(\frac{A_{0m}}{e^{\delta_m}} + \frac{A_{0w}}{e^{\delta_w}}\right). \quad (5)$$

where A_{0m} and A_{0w}–the ratio of initial lengths of elements to the initial length of the blank $2\pi R_0$ of the welded blank circumference.

In the undercritical area from equation (4) we can find the value of δ_w or e^{δ_w} when $\delta_m = 0$, $e^{\delta_m} = 1$. By substituting this condition into equation (5), we obtain the equation of the system:

$$\sigma_s = \frac{\sigma_{uw} e^{\delta} A_{0w}}{1 - e^{\delta} A_{0m}}. \quad (6)$$

In the aftercritical area of system the equation after similar transformation has the following form:

$$e^{\delta_w} = e^{\delta}\left(A_{0m} e^{\delta_{cr}} + A_{0w}\right), \quad (7)$$

where $\delta_{cr} = \ln \frac{l_{0w}}{l_{w\,cr}}$ – critical degree of deformation when less malleable material begin to deform;

l_{0w} – initial length of the weld seam zone;

$l_{w\,cr}$ –critical length of the weld seam zone.

Taking into account the conditions

$$e^{\delta_{cr}} = \frac{\sigma_{um}}{\sigma_{uw}}, \quad \sigma_{uw} e^{\delta_{cr}} = \sigma_{um}$$

occurrence of a critical state, and supplying (6) into equation (7), we obtain:

$$\sigma_s = \sigma_{uw}\left(A_{0m} e^{\delta_{cr}} + A_{0w}\right). \quad (8)$$

Solving the integral equation [4] of the integral sum of negative elementary forces for the whole area quasi-stable deformation

$$dP_\theta = \sigma_{uw} R_0 s_0 \left(A_{0m} e^{\delta_{cr}} + A_{0w}\right)\left(e^{\delta_l/2} - e^{(3/2\,\delta_l) - \delta_{un}}\right), \quad (9)$$

where dP_θ – elementary tangential force integrating in the range from δ_{un} to δ_l (δ_l – deformation of the edge elongation), we obtain:

$$P_\theta = \sigma_{uw} R_0 s_0 \left(A_{0m} e^{\delta_{cr}} + A_{0w}\right)\left(2e^{\delta_l/2} - 2/3\, e^{(3/2\,\delta_l) - \delta_{un}} - 4/3\, e^{\delta_{un}} \quad (10)$$

Without much loss of accuracy an exponential function can be replaced by the first expansion terms according to the ratio $e^{\delta} = 1 + \delta$. By equating P_θ to tangential force P_τ, acting on the border area of quasi-stable deformation [4], we obtain the value δ_l, characterizing limiting degree of deformation in the expansion:

$$\delta_l = \left[0{,}5 S_0 \sin\alpha - \frac{2}{3}(1 + \delta_{un})B\right] / \delta_{un} B, \quad (11)$$

where $B = R_0\left(A_{0m} e^{\delta_{cr}} + A_{0w}\right)$.

Dimensions of heat affected zone on either side of the weld seam can be determined from [7]:

$$b = 10\,(S_0 + 3). \quad (12)$$

Along the length b heat affected zone we determine values A_{0m} and A_{0w}. The calculation results of the wheel rims limiting diameters on ratio (11) after expansion and subsequent breaking-down is shown in the Table.

Experimental verification of the dependence obtained (11) was carried out under production conditions on the clamping machine (Fig. 5). The welded blanks of wheel rims W8-16 with diameter of 424 mm made of one roll of low carbon steel in an amount of 20 pieces were subjected to expansion. Quantitative evaluation of the experimental data was carried out by methods of mathematical statistics. Processing of the experiments results allowed us to conclude that the experimental values of the limiting deformations (diameters) of the blanks are subject to a normal distribution, the experiment reproducibility is confirmed by Cochran's criterion. The adequacy of the ratio (11) is confirmed by Fisher criterion when probability belief is 0.95. Error limits calculated by the adequacy dispersion are 8.8%, with a significance level of 0.05.

Table. The calculation results of limiting diameters of welded blanks depending on wheel rims according to (11) when expansion

Wheel type	Blank diameter D_b, (mm)	Limiting diameter during expansion D_{max}, (mm)
45Ex16	424	456.8
W8-16	424	456.8
DDW18Lx42	982	1103.2
W8-32	816	866.0
11.75x22.5	539	602.5
DW15Lx38	968	1024.0
DW15Lx34	867	920.0

Thus, the ratio (11) allows determining the value of limit deformation degree when expansion of edge section of the welded cylindrical blank. From the ratio (11) it follows that the allowable increase in diameter of welded blank (limiting deformation) when expansion growths with increasing the metal hardening degree of the weld seam zone, its plasticity and the relative thickness of the blank.

Therefore, one way to increase limit deformation degree of welded blank is increasing of hardening intensity of the weld seam zone (WS) and its plasticity.

In order to identify the methods and ways to improve the formability of welded blanks let us consider various processing methods. They can be divided into groups covering all stages of the parts manufacture from welded blanks: 1) processing methods on the stage of forming the weld seam; 2) the impact on preliminary weld seam before forming; 3)processing methods used in the weld seam deformation. Fig. 7 shows a block diagram of these techniques.

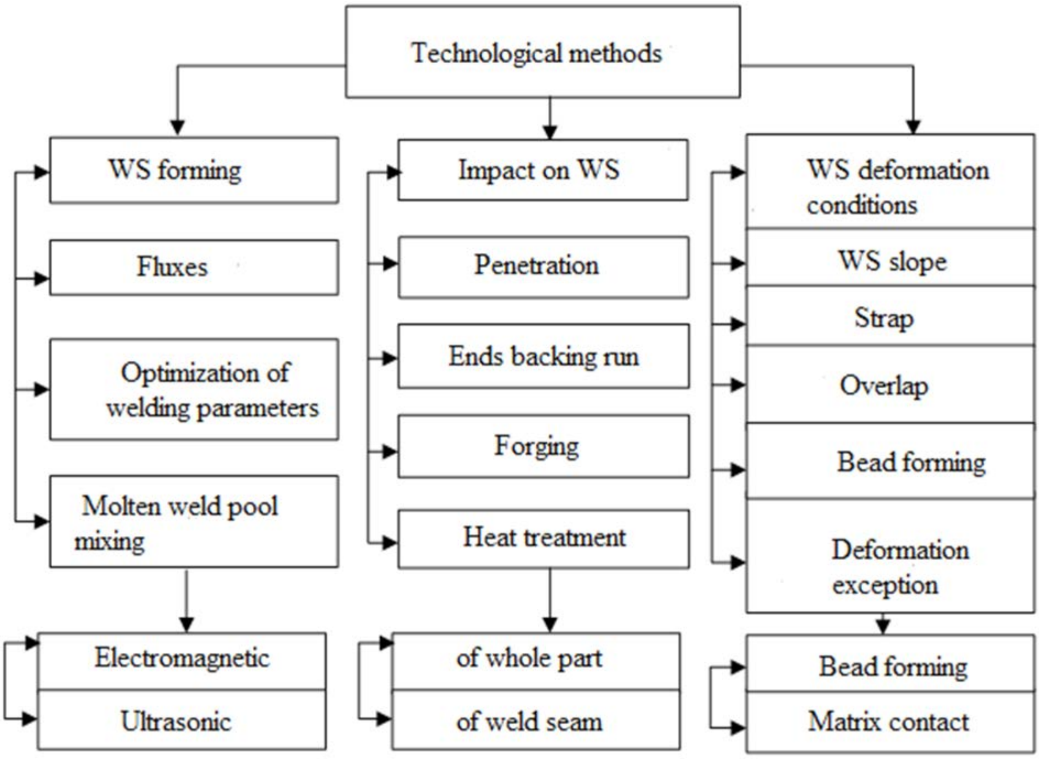

Figure 7. The block diagram of the processing methods that increase formability of welded blanksa

Application of most of these methods, such as mixing the molten weld pool during the welding process, the optimization of welding parameters, the use of fluxes etc. leads to an improvement of the plastic properties of the weld seam. The weld seam forging also increases the weld seam plasticity by refinement of its structure. The heat affected zone forging increases the intensity of metal hardening located in this zone.

Therefore, in this case, forging of the seam and heat affected zone is the most effective method of increasing the diameter of the welded blank when distribution and elimination of cracking. According to the results of experiments and testing the forging of the weld seam zone allowed us to exclude the destruction of welded blanks when expansion and profiling. At first transition of wheel rims manufacture we have an opportunity to increase the blank edge diameter by 12-15%.

4. Conclusion

On the basis of a systematic assessment of the weld seam zone impact on the process of plastic deformation of the welded cylindrical blank we obtained the dependence allowing defining permissible increase in diameter (limiting deformation) of welded blank edge zone. It has been established that the permissible limiting deformation of the welded blank depends on the weld seam plasticity and intensity of the heat affected zone hardening. Improving of these characteristics is achieved by forging (hardening by plastic deformation) of the weld seam and heat affected zone.

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