The extreme deformation ratio in sinking

V.F. Balakin, K.S. Bilan, V.V. Perchanyk

National Metallurgical Academy of Ukraine,
Dnipropetrovsk, Ukraine

Abstract

Plastic metal working is carried out with a number of limitations determining extreme conditions of process realization. These limitations depend on numerous factors of which tool and billet interaction and their mechanical properties are basic factors.

Extreme conditions of sinking realization include plasticity of the worked material. The paper considers relation between lengthwise and transverse deformations in sinking with round strikers. This relation permits to assess extreme conditions of realization of a complex periodic rolling process consisting of two processes: rolling and sinking.

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As opposed to the rolling processes where ultimate strain is determined by force-related conditions of contact interaction, extreme conditions of sinking are characterized by material plasticity. Zaykov and Peretiatko [1, 2] proposed to assess plasticity by the value of a real octahedral shear because the octahedral area equally oriented relative to three main stresses is a kind of ‘averaging’ area reflecting differently oriented cleavage planes in a polycrystal. Octahedral shear is given by equations [3]:

$$q_{oct} = 1{,}42e = 1{,}42\frac{1}{1-\psi}, \qquad (1)$$

where $e = \ln\frac{l_1}{l_0}$ is the main maximum real deformation during tensioning of a cylindrical specimen from length l_0 to length l_1;

$\psi = \frac{F_0 - F_1}{F_0}$ is reduction of cross section area of the cylindrical specimen from F_0 to F_1 at the moment of its breakage.

Relation between reduction of area and maximum real tensile deformation of the cylindrical specimen is easily obtainable from equation (1):

$$\frac{l_1}{l_0} = \frac{F_0}{F_1} = \frac{d_0^2}{d_1^2}, \qquad (2)$$

where d_0 and d_1 are the specimen diameters before and after deformation.

For a plane pattern of a unit width at $b_0 = b_1 = 1$, real deformation in cross section area reduction is given by:

$$\frac{F_0}{F_1} = \frac{h_0}{h_1}; \qquad (3)$$

where h_0 and h_1 are heights of a plane specimen before and after deformation.

Correlation between real and relative deformations with regard to the sinking processes is given by [4]:

$$\delta_h = \ln\frac{h_1}{h_0} = \ln(1-\varepsilon_h); \qquad (4)$$

$$\delta_l = \ln\frac{l_1}{l_0} = \ln(1+\varepsilon_l); \qquad (5)$$

where ε_h and ε_l are relative deformations of sinking and elongation.

So, the sum of relative deformations is approximately (to 10%) equal to zero:

$$\varepsilon_h + \varepsilon_l = 0; \qquad (6)$$

Fracture deformation in the capacity of which (for all kinds of deformed state) octahedral shear corresponding to a spatial pattern of stressed state is taken, is reduced to a linear loading pattern by means of index of stressed state to a ‘corresponding state’ representing relation of maximum main stress to material resistance at a uniaxial pattern at the same degree of deformation [5].

Authors of work [3] determine octahedral shear and criterion of stressed state through deformations and stresses averaged for a deformed specimen. For example, Zaykov and Peretiatko present a formula for an average index of stressed state at the moment of specimen breakage: $n = \frac{2}{1+\sqrt{1-\psi}}$. In our opinion, to determine extreme state of form change using standard tensile tests there is no sense in averaging sinking deformation, instead of this one can use maximum transverse deformation at the moment of specimen breakage. As it is said in work [5, p. 156], ‘…one shall determine plasticity indices in those zones of deformed volume where the stressed state pattern is hardest, i.e. tensile stresses are most prevalent in the pattern.’

Sinking deformation with a round striker from a fixed center combined with rolling is characteristic for the processes of periodical form change. It takes place due to the increase in the roll radius at a fixed center of rotation and occupies the contact region behind the center line in the instantaneous deformation zone of the plane pattern, i.e. the work roll is moving back and forth on the deformed strip seemingly ‘swelling’ in so doing.

It is important to determine the degree of deformation behind the center line, i.e. in the zone of pure sinking. Up to the center line, the rolling process combined with sinking takes place and as some authors [6] point out, ‘…essentially, rolling represents a process of continuous sinking between rotating strikers: rolls are continuously feeding for themselves new and new portions of material into the deformation zone while being plastically compressed’.

When considering the instantaneous deformation zone in the periodical form change, it is quite logical to reason on a stopped process in which both the rolling zone before the center line and the sinking zone after the center line are characterized by continuous sinking with rotating rolls with their radius position and size determining the degree of deformation at a conventionally stopped moment. In this process, compression deformations in the contact zone are not uniform as opposed to tensile deformations. Maximum compression takes place at the center line of instantaneous deformation zone.

To determine relation between lengthwise and transverse deformation of the strip, make use of the method of shifted volumes (or shifted areas in a flat pattern) which do not average nonuniformity of the compression deformation. Refer Fig. 1 showing a moment of sinking strip of height h_0 by $\Delta h = h_0 - h_1$ and lengthwise elongation Δl at a half-length of the initial strip profile corresponding to this moment (sinking is done with a round striker with radius growing from r_0 to r_1 in the process of sinking at a rate V).

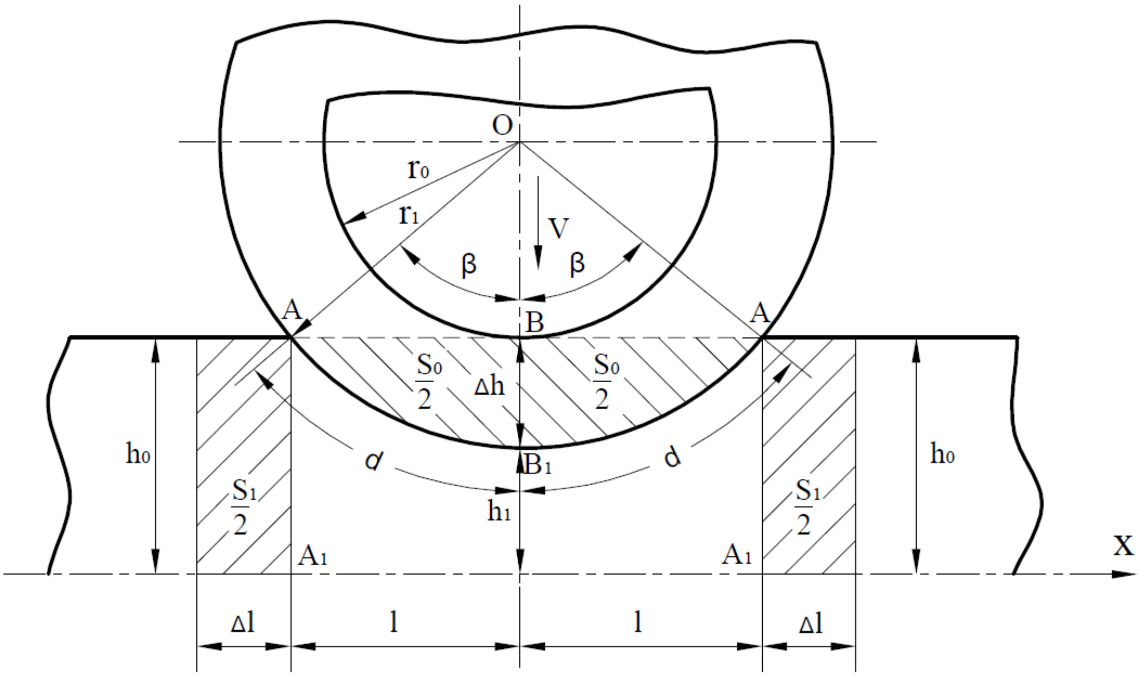

Fig.1 Pattern of plane sinking with a round striker from a fixed center

Areas S_0 in the contact zone AB_1A and S_1 outside the border AA_1 of the contact zone which were shifted by deformation are equal by the principle of integrity of incompressible material. Proceeding from equality $S_0=S_1$, it is easy to obtain relation between longitudinal deformation $\varepsilon = \frac{\Delta l}{l}$ and maximum lateral deformation $\psi = \frac{\Delta h}{h_1}$ with no use of averaging by means of pattern of stressedly-deformed state:

$$\psi = \varepsilon \frac{4\sin\beta(1-\cos\beta)}{\frac{\pi\beta}{90} - 2\sin\beta\cos\beta} \approx (1{,}44 \div 1{,}48)\varepsilon \quad ; \qquad (7)$$

where β is a half of the central angle in a degree measure limiting the contact zone.

Use of radian measure for small central angles (β≤0.7 rad) and shifted area

$$S_0 = dr_1 - l(r_1 - \Delta h), \qquad (8)$$

where d is a half of segment contact arc;
Δh is segment height
gives correlation between lengthwise and transverse deformations

$$\Psi = 2\varepsilon\,; \qquad (9)$$

It should be pointed out that the plain pattern of sinking with a round striker resembles by its form a neck in tensile tests. In this case, reduction of area $\psi = \frac{F_0 - F_1}{F_0}$ characterizes maximum plasticity more correctly than specific elongation $\varepsilon = \frac{l_0 - l_1}{l_0}$ [7]. For example, mechanical properties of steel at test temperature 20 °C are as follows [8]:

- for ferritic 20 grade steel:

ε_5 = 25%, ψ = 55%,

- for two-phase 45 grade steel:

ε_5 = 16%, ψ = 40%.

At the same time, relation $\frac{\psi}{\varepsilon}$ makes 2.2 for 20 grade steel and 2.5 for 45 grade steel.

Equations (7) and (9) are applicable in determination of limit lateral deformation at high temperatures because reference literature in most cases gives just the values of specific elongation ε at the moment of specimen breakage. Use of experimental values of limit deformation in combination with equation of marginal state of periodic form change [9] makes it possible to determine maximum feed and assess features of work tool design.

Conclusions

A new approach to analysis of periodic form change in the pilger rolling processes has been proposed. It consists in a similarity between the shapes of the deformed neck section during specimen breakage and the deformation zone during penetration of a round striker with increasing radius.

In determination of ultimate plasticity values in pilger rolling, effect of compressing stresses has been taken in consideration with an account for specimen necking during tensile tests.

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