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Determination of Ultimate Technological Deformability of Metals when Rolling Wedge-Shaped Samples

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Recommended advanced method of metal ultimate reduction definition when rolling wedge-shaped samples helps to raise accuracy and simplify the experiment. This method was tested in laboratory conditions in order to determine the rational combination of integrated effect factors when microalloying with complex strontium-scandium and hydrogen treatment of melt which ensure the significant increase of deformability of aluminum cast alloy.

Keywords: ULTIMATE TECHNOLOGICAL DEFORMABILITY, ROLLING, WEDGE-SHAPED SAMPLES

Introduction

One of the methods to investigate technological properties of metals is estimation of their ultimate deformability until abnormality of forming process. Plastic working type (rolling, drawing, pressing, etc.) has a considerable effect on this value because of various patterns of stressed-deformed state of metal [1]. For example, during rolling such abnormality can be fracture of article due to exhaustion of its plastic properties, slip of hot-rolled breakdown in rolls, breakage of rolls because of their inadequate strength, etc. Usually, identification of process abnormality is defined by research problem and has no difficulties.

Results and Discussion

Usually it is necessary to define the ultimate deformability of metal at which the abnormality occurs in such experiences. Wedge-shaped samples (**Figure 1**) are used for this purpose, and the value of ultimate logarithmic "true" deformation $\varepsilon_{ultimate}$ is determined from formula [1]:

$$\varepsilon_{\text{ultimate}} = \ln \frac{F_{0\text{characteristic}}}{F_{1\text{characteristic}}} \qquad \text{(Eq. 1)}$$

where $F_{o\ characteristic}$ and $F_{1\ characteristic}$ - cross-sectional areas of samples in the characteristic cross-sections matching together, before (index "0") and after (index "1") rolling (for example, in the point of sample fracture or its slip in the rolls).

Value $F_{1\ characteristic}$ is determined according to measured values of height h_1 and width $b_{characteristic}$ of rolled samples in the characteristic cross-section (**Figure 1**).

It is more difficult to define unknown in advance place on the initial sample $h_{0\ characteristic}$ high on a distance $x_{0\ characteristic}$ from its fast-head end that corresponds to the place of future characteristic cross-section (fracture) on the rolled sample. To solve this problem, longitudinal matchmarks are applied on a lateral face of initial wedge-shaped sample before rolling [2].

However, these scratch marks can be additional stress concentrators that promote a premature failure of sample in the course of plastic deformation, and similar application of matchmarks by painting pigments results in diminution of accuracy of characteristic cross-section determination because of change of their sizes at deformation of metal. Also such sample preparation complicates the experiment.

The task of present investigation is to improve the procedure of definition of ultimate technological deformability of metals when rolling wedge-shaped samples.

We considered two possible optional versions.

1. The sample is rolled without fracture and slip. Then the maximum amount of reduction ε_{max} is defined by cross-section of its back end face by

formula (**Figure 1**):

$$\varepsilon_{max} = \ln \frac{h_{02} \cdot b_0}{h_1 \cdot b_{12}} \quad \text{(Eq. 2)}$$

In this case, technological deformability limit of metal is not depleted.

$$\varepsilon_{ultimate} > \ln \frac{h_{02} \cdot b_0}{h_1 \cdot b_{12}} \quad \text{(Eq. 3)}$$

2. The sample is rolled with any recorded process abnormality. For example, point of sample fracture after rolling is defined visually (**Figure 2**), and sample length $l_{fracture}$ to this point (**Figure 1**) can be measured.

Thus it is necessary to determine amount of sample reduction taking into account its original height $h_{0\ characteristic}$ in the cross-section that corresponds to value $l_{fracture}$.

For this case we have:

- after rolling in characteristic cross-section (where fracture /slipping is):

$$F_{1characteristic} = h_1 \cdot b_{characteristic} \quad \text{(Eq. 4)}$$

- before rolling in the corresponding cross-section (unknown yet):

$$F_{0characteristic} = h_{0characteristic} \cdot b_0 \quad \text{(Eq. 5)}$$

For wedge-shaped samples:

$$h_{0characteristic} = h_{01} + \frac{h_{02} - h_{01}}{l_0} \cdot x_{0characteristic} \quad \text{(Eq. 6)}$$

From constant volume condition:

$$V_1 = V_0 \quad \text{(Eq. 7)}$$

where v_0, v_1 - metal volume before and after rolling of sample to its characteristic cross-section.

With neglect of widening curvilinearity b_1, which is permitted at $b_0 \geq h_{02}$

$$V_1 \approx \frac{1}{2}\left(b_{11} + b_{characteristic}\right) \cdot h_1 \cdot l_{1characteristic} \quad \text{(Eq. 8)}$$

Initial volume corresponds to expression 9.

$$V_0 = h_{01} \cdot b_0 \cdot x_{0characteristic} + \frac{1}{2} \cdot b_0 \cdot (h_{0characteristic} - h_{01}) \cdot x_{0characteristic} \quad \text{(Eq. 9)}$$

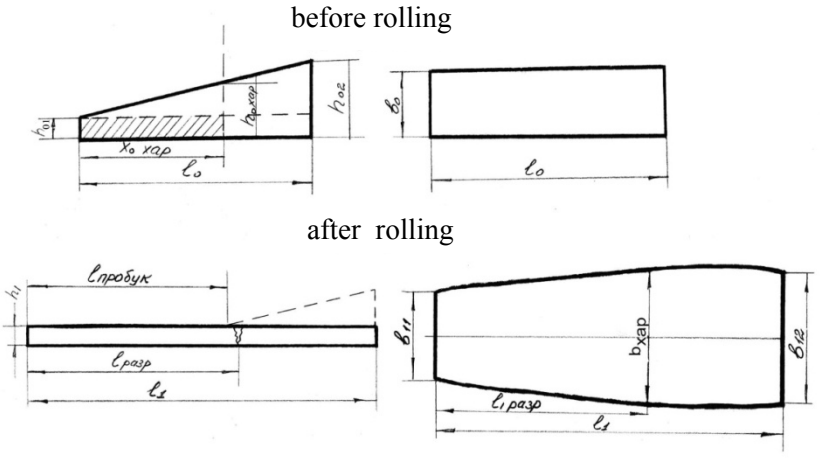
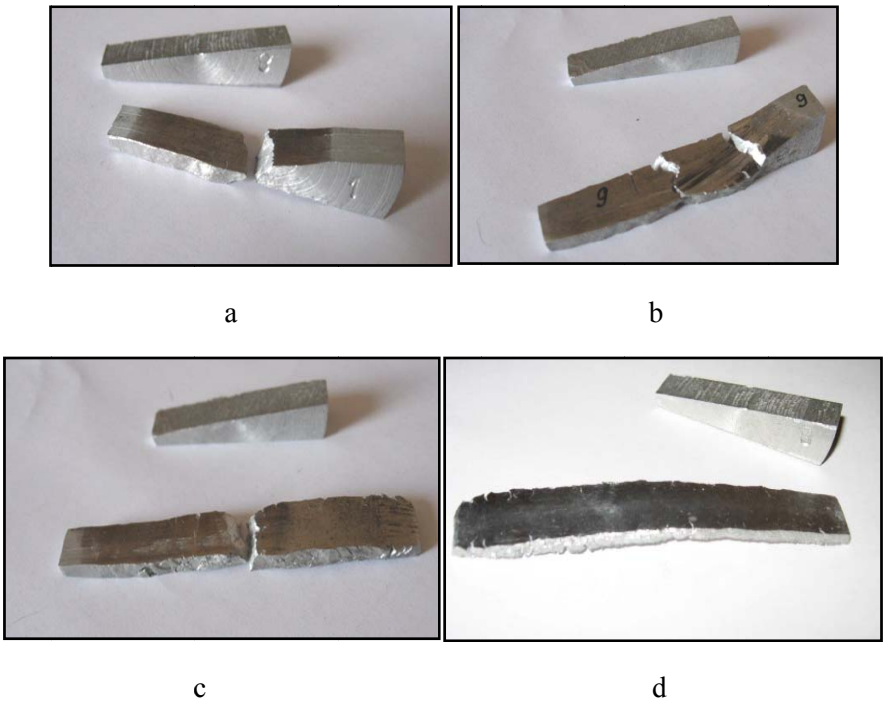


Figure 1. Wedge-shaped sample**:** *a* - end view drawing; *b* - horizontal projection; $l_{fracture}$, l_{slip} - distance from the head end of rolled sample to point of rolling process abnormality: fracture or slip respectively



a b c d

Figure 2. АК7ч alloy samples in the initial state and after technological deformability testing: *a, b*- original composition; *c, d* - with complex strontium-scandium added; *a, c* – as-cast; *d* - after hydrogen treatment of melt

And taking into account formulas (6):

$$V_0 = h_{01} \cdot b_0 \cdot x_{0characteristic} + \frac{1}{2} \cdot b_0 \cdot (h_{01} + \frac{h_{02} - h_{01}}{l_0} \cdot x_{0characteristic} - h_{01}) \cdot x_{0characteristic} \quad \text{(Eq. 10)}$$

At substitution of equations (8) and (10) in equality (7) we obtain:

$$x_{0characteristic} = -\frac{h_{01} \cdot l_0}{h_{02} - h_{01}} + \sqrt{\frac{h_{01}^2 \cdot l_0^2}{(h_{02} - h_{01})^2} + \frac{h_1 \cdot (b_{11} + b_{characteristic}) \cdot l_0 \cdot l_{1characteristic}}{(h_{02} - h_{01}) \cdot b_0}} \quad \text{(Eq. 11)}$$

Then algorithm of determination of ultimate amount of metal reduction is as follows:

- Samples are measured (**Figure 1**) and deformed with provoked possibility of rolling process abnormality. Characteristic cross-section l_{fracture} is visually defined after rolling;
- Required dimensions of sample after rolling are measured, and value $h_{0\ characteristic}$ is determined by formula (10);
- $h_{0\ characteristic}$ is defined by equation (6);
- $F_{0\ characteristic}$ - by equation (5);
- $F_{1\ characteristic}$ - by formula (4);
- Ultimate amount of reduction $\varepsilon_{ultimate}$ - by formula (1). Advanced technique was used in rolling at the rate 0.3 km/s on the laboratory mill 180. Steel quenched rolls with roughness $R_a \approx 1$ mkm and not lubricated surface were installed. Dimensions of initial samples according to **Figure 1** were $h_{01} = 3$ mm, $h_{02} = 11$ mm, $b_0 = 10$ mm, $l_0 = 46$ mm.

In the first set of experiments, cast alloy АК7ч samples not inoculated and inoculated with strontium and scandium [3, 4] as-cast and after hydrogen treatment accomplished according to conditions [5] were rolled at roll opening smaller than h_{01} (**Figure 1**). Each experiment was repeated 3 times. After rolling, we measured samples with

accuracy to 0.01 mm by means of micrometer (thickness, width) and 0.1 mm - caliper rule (length). Characteristic samples before and after rolling are presented in **Figure 2**. It follows from presented data that determination of sample dimensions after rolling is not complicated. Results of calculations of ultimate deformability of tested samples are presented in **Figure 3**.

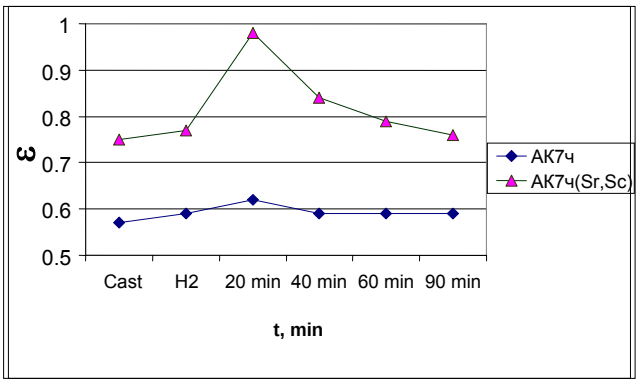


Figure 3. Interrelation between technological deformability of alloys АК7ч with original composition and containing complex strontium-scandium and mode of melt hydrogen treatment

According to these data it is possible, in particular, to select the type of material treatment which ensures the maximum deformability. In this case, it is shown that combined physic-chemical treatment of melt - strontium and scandium microalloying in optimum concentration [2, 3] - hydrogen treatment (20 minutes) has the greatest effect on deformability of alloy АК7ч. Thus deformability of alloy raises by 60 % in comparison with alloy of original composition.

Conclusions

This data can be used for estimation of technological deformability of other materials at rolling. Development of this procedure can be related to account of curvilinear lateral face of samples after rolling and also account of elastic recovery of roll that leads to insignificant variation of rolled sample thickness along the length.

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Определение предельной степени технологической деформируемости металлов при прокатке клиновидных образцов

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Предложена усовершенствованная методика определения предельной степени деформации металлов при прокатке клиновидных образцов, позволяющая повысить точность и упростить проведение эксперимента. Методика опробована в лабораторных условиях для выявления рационального сочетания факторов комплексного воздействия при микролегировании комплексом стронций-скандий и водородной обработке расплава, обеспечивающих значительное повышение деформируемости литейного алюминиевого сплава.