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Conference Paper

Accumulation of Deformation in the Winding Circuit

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Abstract

The formulas and an approximate analysis of the results of the accumulation of deformations in the operations of winding the wire into a spiral and unwinding it to its original state are given. The results of the experiment on winding a thin silver wire on the mandrel and unwinding it to its initial state are presented. The experiments on stretching the wire took place before and after the loading. It was revealed that under the test conditions the notional yield limit increases abruptly, relative elongation is reduced and tensile strength changes slightly. Comparison of load-extension diagrams before and after testing is given as well.

Keywords: wire, hardening, silver, stretching, winding, deformation, stress, mechanical properties.

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1. Introduction

Recently, much attention has been paid to the processes of accumulation of large plastic deformations. This allows us to grind the metal structure, to get a more durable metal without the use of expensive alloying elements or hardening heat treatments, due to the effect of grain-boundary hardening. Industrial schemes for the accumulation of large plastic deformations are aimed at obtaining a cast billet of sufficiently large size, and then stretching it in length while reducing the cross section. The methods of rolling [1], extrusion [2], drawing [3] are based on this. However, these schemes lead to the fact that at the beginning of the process the workpiece must have large size, which does not allow to obtain a finely-ground structure due to the characteristics of crystallization. To avoid this, it is desirable to carry out the process of accumulating deformations without changing the shape. For example, such processes as equal channel angular pressing [4–6] and twisting of the workpiece [7] are aimed at this. At the same time, to expand the set of metal forming processes, in which it is possible to accumulate deformation without significant change in shape is desirable.

The aim of the work is to test the method of accumulation of plastic deformation while bending.

2. Analytical Part

It is proposed to accumulate plastic deformation with giving the spiral shape to the blank, followed by straightening the spiral.

It's assumed that, with profile bending 1 on rod 2 with radius R (Fig. 1), the angle of rotation is φ, and the profile length over a neutral section is L and it remains the same after bending:

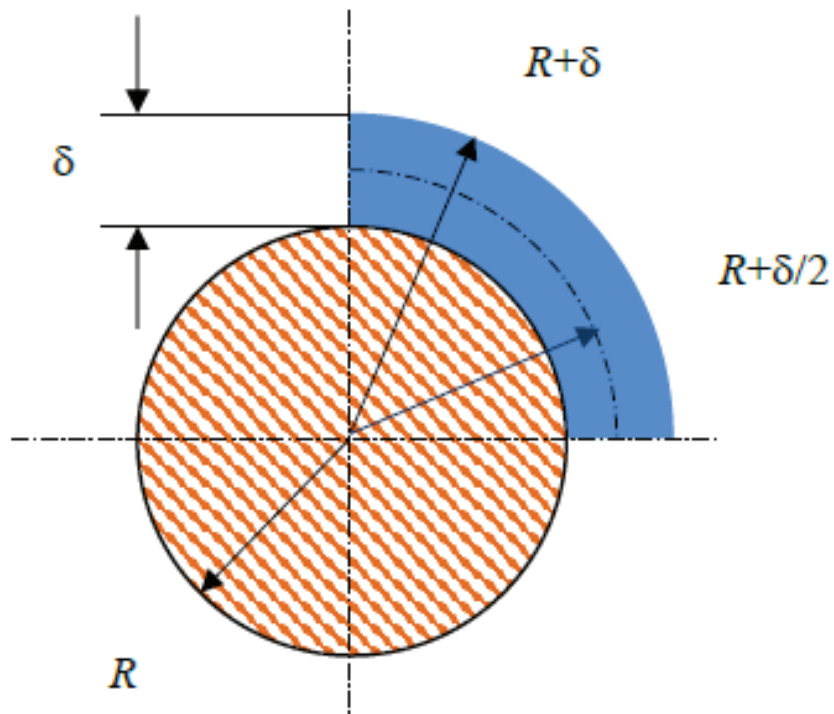$$L = \left(R + \frac{\delta}{2} \right) \varphi. \tag{1}$$

Figure 1: The scheme of winding the wire on the rod .

On the stretched fiber, the length will increase, because radius here is $R + \delta$:

$$L_p = (R + \delta)\, \varphi. \tag{2}$$

Since the bend angle for all sections is the same, it is possible to find the ratio between the lengths:

$$\frac{L_p}{L} = \frac{R + \delta}{R + \frac{\delta}{2}}, \tag{3}$$

the last ratio is equivalent of the stretching coefficient.

Here to find the logarithmic strain of elongation is possible, it is equal to:

$$\varepsilon = \ln\frac{L_p}{L} = ln\frac{R+\delta}{R+\frac{\delta}{2}} \; . \tag{4}$$

You can also determine the relative elongation in the outer fiber profile percent:

$$\varepsilon_\% = \frac{L_p - L}{L}100 = \left(\frac{L_p}{L} - 1\right)100 = \left(\frac{R+\delta}{R+\frac{\delta}{2}} - 1\right)100. \tag{5}$$

We are to estimate the situation when the rod diameters and the transverse size of the profile to be bent are equal, that is, $\delta = 2R$.

With the formula (5) we have:

$$\varepsilon_\% = \left(\frac{R+2R}{R+R} - 1\right)100 = \left(\frac{3}{2} - 1\right)100 = 50\%. \tag{6}$$

It can be seen here that, with applying the method of wire winding on the rod, a significant deformation, equivalent to a relative elongation of 50%, can be achieved. Having the wire unwound, we are getting the same result again. It is more convenient to track the accumulation of deformation with logarithmic indicators, since these indicators can be summarized to determine the accumulated deformation.

In the considered case, with the formula (4) we get:

$$\epsilon = \ln\frac{L_p}{L} = \ln\frac{R+2R}{R+R} = \ln\frac{3}{2} = 0,41. \tag{7}$$

Consequently, in one cycle of winding and unwinding we get $\epsilon = 0.82$, in two cycles 1.64; in three cycles 2.46, etc. It should be noted that the resulting level of deformation refers to the outer stretched fiber of the profile. The same level of deformation, but with the reverse sign, refers to the internal profile fiber adjacent to the surface of the rod. A neutral section is localized in the center of the wire, near which the level of deformation will be lower than that determined for the surface of the wire. However, the principle of accumulation of deformation will be followed: with a larger number of stages, the average hardening will increase. The accumulation of deformation by numbers of cycles N is shown in Fig. 2 on the example of calculations with parameters $\delta / (2R) = 1$ and $\delta / (2R) = 0.375$.

The diagram shows that after 5 loading cycles with $\delta / (2R) = 1$, we can get accumulated deformation with 4.1, with a decrease in the parameter and $\delta / (2R) = 0.375$, we get a reduction in the rate to 1.2. At the same time, these data cannot be extended to the entire cross section of the wire, they relate only to the localization zones of deformation at the surface.
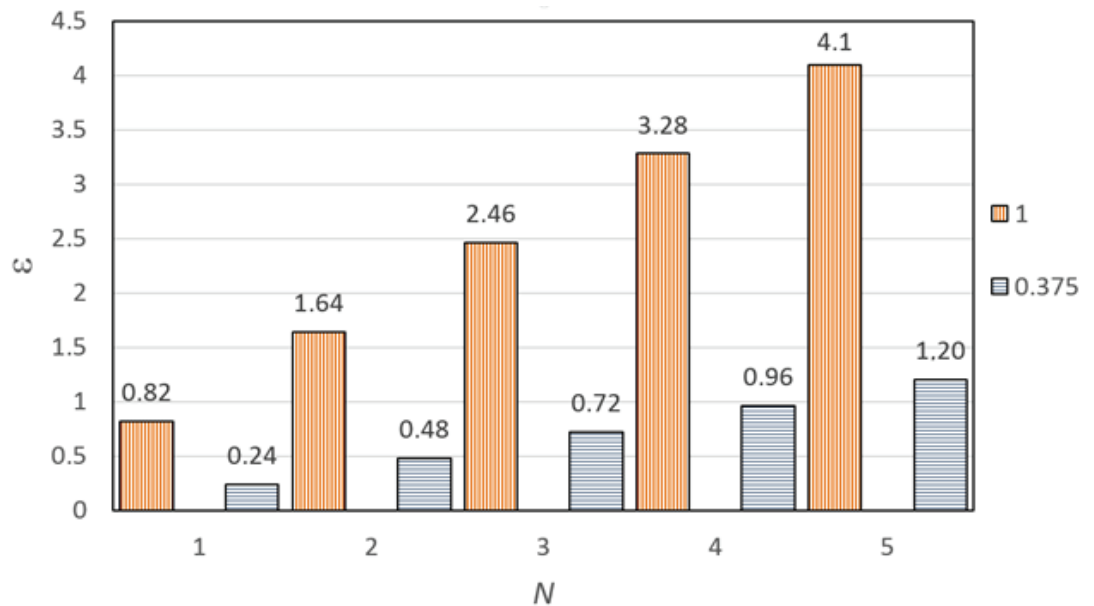
Figure 2: Diagram of accumulation of deformation by numbers of cycles N with the parameter δ / (2R) = 1 and δ / (2R) = 0.375.

3. Description of the Experiment

Testing of silver wire Ag 99.99 with a diameter of 1.20 mm in the annealed condition was performed in four stages.

1. Testing the wire stretching with the use of the testing machine "Instron–3365" with the construction of the diagram of stretching in the coordinates "displacement - force". The speed of movement of the grippers on the testing machine was assigned 50 mm/min, which corresponds to a strain rate of 0.008 s^{-1} at the beginning of the test. The mechanical properties of five samples from the same batch were determined. Test data were averaged.

2. Winding the wire on the mandrel with a diameter of 3.20 mm. Winding was carried out with tension. Examples of finished samples are shown in Fig. 3a.

3. After winding, the wire was unwound to determine the effects of the use of plastic deformation; the appearance of the samples is shown in fig. 3b.

4. Samples of wire were tested in tension again under the conditions specified in paragraph 1.

In fig. 3a the appearance of the samples subjected to winding is shown, and fig. 3b the appearance of the samples subjected to unwinding is provided.
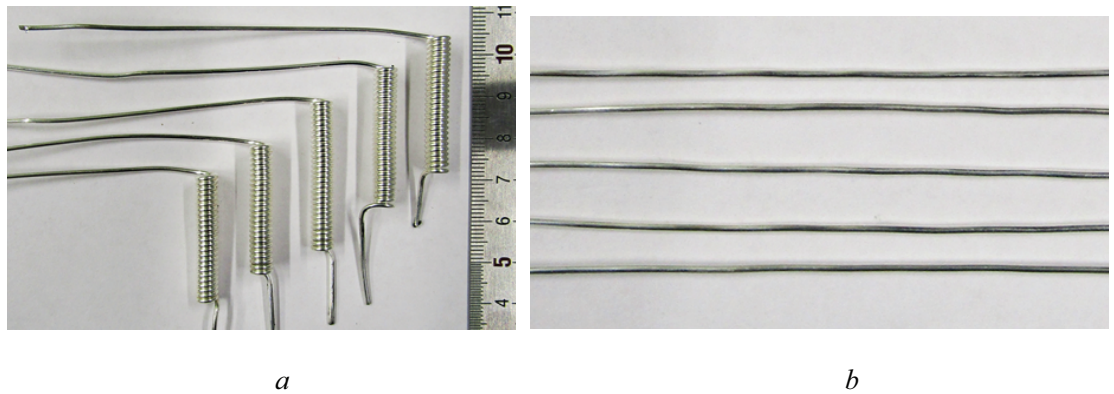
a   b

Figure 3: Photo samples of silver Ag 99.99 in the winding (a) and unwinding (b) states.

It is visible that the samples were able to unwind from the spiral state to the form of almost a straight line.

In fig. 4 typical loading diagrams in coordinates σ - true stress and ε - true deformation before winding and after unwinding - are shown.
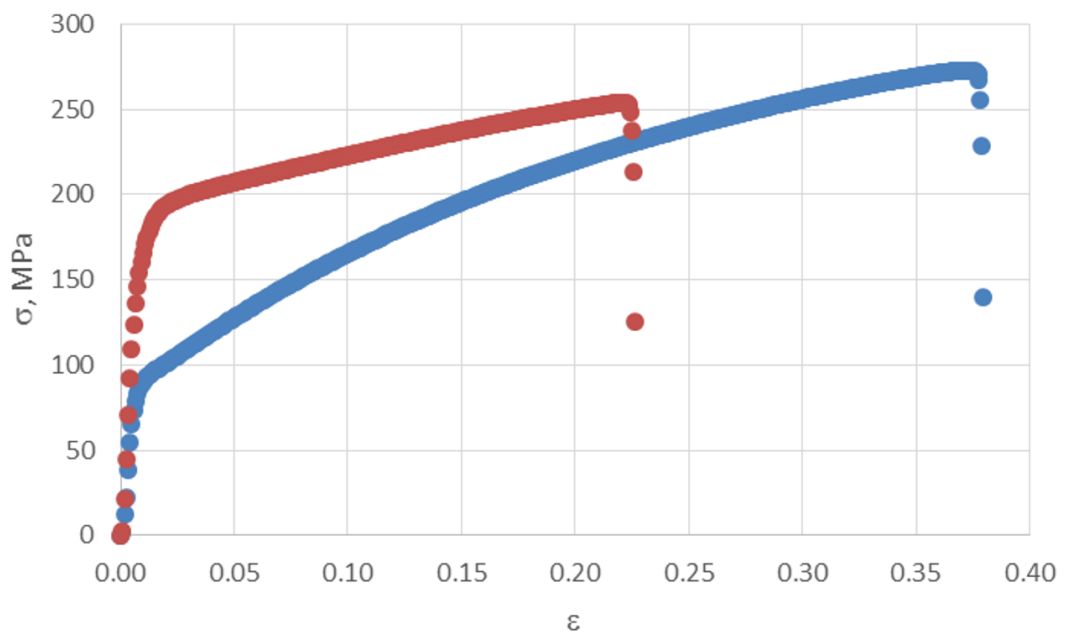

Figure 4: Sample loading diagrams before winding (blue) and after unwinding (red).

The graph in fig. 4 for the sample in the initial state has a sloping part with a low intensity of increase in function, which indicates a low yield strength of the material. In contrast, the diagram for the hardened state abruptly goes up. It can be seen from the diagrams that in the initial state the wire had a high deformation value before breaking, and after unwinding, this indicator decreased almost twice. Elongation reduced from 46 to 27%. After strengthening treatment, the maximum of the true stresses, equal to 270 MPa, was not reached, the obtained value is close to 260 MPa. However, in the area

of plastic deformation, the graph of the hardened wire is substantially higher than the graph for the wire in the initial state. At the same time, for small strains at the level ε = 0.02...0.05, the voltage of transition to the plastic state for the wind wire is about twice higher than for the wire in the initial state. The characteristic of the transition of the metal into the plastic state is the conditional yield strength of $\sigma_{0.2}$. Measurements showed that the conditional yield strength in the initial state is 84 MPa, and for the state straightened after winding, it is equal to 153 MPa, which is 82% higher.

Earlier, by calculation with formula (4) we obtained that with $\delta / (2R)$ = 0.375 after one loading cycle ε = 0.24. Judging by the fig. 4, the diagram point of the initial state at this abscissa corresponds to a voltage of 230 MPa, which could correspond to the conventional yield strength for the unwound wire state. However, the value of $\sigma_{0.2}$ for this case is equal to 153 MPa, i.e. 1.5 times less than expected. The length of the workpiece after the deformation cycle increased from 150 mm to 159 mm, i.e. by 6%. This demonstrates that only a small part of the cross-sectional area was subjected to significant deformation.

4. Summary

The application of the method of wire winding into a spiral with subsequent unwinding leads to the accumulation of plastic deformation with its localization in the surface zones. The experiments performed showed that with this effect, the tensile strength of the metal changes insignificantly, the relative elongation to rupture significantly decreases, the notional yield limit of the metal increases abruptly.

Acknowledgments

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