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ISSN 0543-5846
METABK 52(1) 93-95 (2013)
UDC – UDK 669.784.15:621.778:620.16=111

THE EFFECT OF MULTIPLE BENDING OF WIRE ON THE RESIDUAL STRESSES OF HIGH CARBON STEEL WIRES

Received – Prispjelo: 2012-03-22
Accepted – Prihvaćeno: 2012-07-28
Preliminary Note – Prethodno priopćenje

Steel tire cord, springs and rope wires belong to the group of metal products from which the low residual stresses are required. In this paper the effect of multiple bending of wire on residual stresses of high carbon steel wires has been assessed. It was found that the application of the multi-roller straightening machine in the banding wire process enables to reduce the residual stresses in the drawn wires. It should be also noted that the value of the residual stresses depends on the type of straightener construction. The residual stresses on the basis of stress-strain curve has been determined. It has been stated that the application of seven-rolls straightener gives the best effect of straightening.

Keywords: high carbon steel, wires, residual stresses, straightener

INTRODUCTION

Wires and wires products create significant part in group of plastically treated articles. These products often work with high external loads and find wide application in situations where high reliability of working is required, like different kinds of machines and devices. Ropes in crane and lift devices, cord for car tires reinforcing, different kinds of flexible connectors, wire for reinforced concrete and also many different wire products belong to this group. Behaviour of different machine elements and constructions as well as operation reliability making work calm and safe are dependent on the surface layer condition. One of the most important parameters, which determine surface layer conditions are residual stresses [1-4].

Resultant state of stresses, present inside given article is equal to the sum of stresses caused by external load and residual stresses.

Taking residual stresses into consideration during determining of real stresses value is necessary, especially when residual stress have the same character as stresses produced as a result of external loading, since the sum of stresses in this case occurs. If these stresses pose negative character in relation to stresses caused by external load then they cause decreasing of total strain of material. Many a time residual stresses are higher than stresses created as a result of external load. Lack of residual stresses consideration give simplified image of material strain [5]. Researches conduced at Institute NIIMETIZ in Magnitogorsk showed, that with considerable residual stresses decreasing of fatigue strength about 20 % to 25 % occurs [6]. It results from researches performed by Golis that the highest fatigue strength was achieved in the cases of the lowest residual stresses value. Fatigue strength increasing with decreasing of residual stresses can be related with more favorable surface layer conditions in the presence of lower residual stresses value.

Straightening operation that is removing of residual stresses is still not precise treated in literature and is often passed over in industry also. It leads to situation when inserted in technological line straightener do not fulfill their functions. Higher and higher customer requirements regarding final product properties have led to wider interest in this stage of technological process. Appearing on the marked of newer and newer device for wire strengthening before entering the edge of coiler drum (so-called roll straightening units) goes to show it.

MATERIAL AND APPLIED DRAWING TECHNOLOGIES

The material applied for the investigation was of C76 high carbon steel wire rod. Before drawing, the wire rod was patented, itched and phosphating. The drawing process of ϕ 5,5 mm wires in the final wire of ϕ 2,7 mm was conducted in 6 passes with constant drawing speed v=1,6 m/s, in laboratory conditions, by means of a bull block machine.

Single drafts, Ds, total drafts, Dt, and drawing speeds, V, for wires summarized in Table 1. In drafts 1-6 calcareous lubricant Traxit GT60 was applied. In Table 2 the mechanical properties of ϕ 2,7 mm final wires was shown, where Rm ultimate tensile strength; Re yield stress; A elongation; Z reduction of area.

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Table 1 **Distribution of single drafts, total drafts and drawing speed**

Draft	ϕ / mm	Ds / %	Dt /%	V / m/s
0	5,50	-	-	-
1	4,90	20,63	20,63	1,60
2	4,35	21,19	37,45	1,60
3	3,85	21,67	51,00	1,60
4	3,40	22,01	61,79	1,60
5	3,05	19,53	69,25	1,60
6	2,70	21,63	75,90	1,60

Table 2 **Mechanical properties of φ 2,7 mm drawn wires**

ϕ / mm	Rm / MPa	Re / MPa	A / %	Z / %
2,70	1544	1399	1,8	45

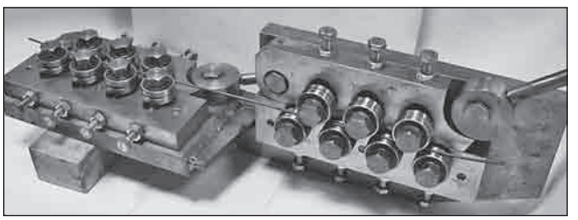

Figure 1 The scheme of two-planes seven rolls straightening machine

EXPERIMENTAL

Proper investigations consisted in estimation of deformation process and influence of straightener construction on residual stresses value in high carbon wires.

As introduction of researches observation of straightener work in one of wire drawing industrial plant was made. On the basis of this observation and collected data one can affirm, that in spite of this operation simplicity, straightening is not correctly realized. Adjusting of straightener rolls is realized by the means of attempts and errors method, by the force of events it gives discontent effects. It often happens, that straightener are placed outside their working plane or one of straightener is used for straightening of wires with different diameters.

It was decided to present in this work an influence of straightener construction on residual stresses value and to choose the most effective straightener from used for investigations ones.

Symbols of investigated specimens after passing through adequate straightener are:

A – specimen before straightener,
B – specimen after two-planes seven-rolls straightener,
C – specimen after two-planes five-rolls straightener,
D – specimen after two-planes three-rolls straightener,
E – specimen after four-planes five-rolls straightener (planes arrangement: horizontal, vertical, horizontal, vertical),
E1 – specimen after four-planes five-rolls straightener (planes arrangement: each 45 °),
F – specimen after three-planes five-rolls straightener (planes arrangement: horizontal, vertical, horizontal),
F1 – specimen after three-planes five-rolls straightener (planes arrangement: each 60 °),
G – specimen after two-planes seven-rolls straightener (planes arrangement: horizontal, vertical).

In Figure 1 the example of two-planes seven-rolls straightening machine was shown.

Determination of residual stresses on the basis of stress-strain curve

Stresses σ_{lw} which act inside specimen during stretching are equal to the sum of external stresses σ_{lz} and residual stresses $\sigma_{lwł}$ [7]:

$$\sigma_{lw} = \sigma_{lz} + \sigma_{lwł} \quad (1)$$

Assume that Young modulus is not dependent on stresses one can accept that beginning of plasticization suits point, in which tensile curve starts to be deviated form straight line. In this connection residual stresses on external surface of wire can be determined on the basis of plasticization condition:

$$\sigma_{lz} + \sigma_{lwł} = \sigma_p \quad (2)$$

hence

$$\sigma_{lwł} = \sigma_p - \sigma_{lz} \quad (3)$$

Therefore in order to residual stresses determination, knowledge about yield stress σ_p in necessary (σ_{lz} is known from received graph) [7]. Therefore in the work, for all variant the tensile tests were performed. In Figure 2 the example of tensile test for A variant was presented

$$\sigma_{lwł} = \sigma_p - \sigma_{lz}$$

Variant A - $\sigma_{lwł} = 1399 - 850 = 549$ MPa

The same procedure of the determination of residual stresses for rest of variants were conducted.

Considering influence of number of rolls on straightener on the basis of investigations one can suitably rank specimens, from specimen, for which the lowest residual stresses were obtained: B, C, D, A – not relaxed (Table 3 and Figure 3.

While taking into consideration number of straightener planes and their arrangement the following se-

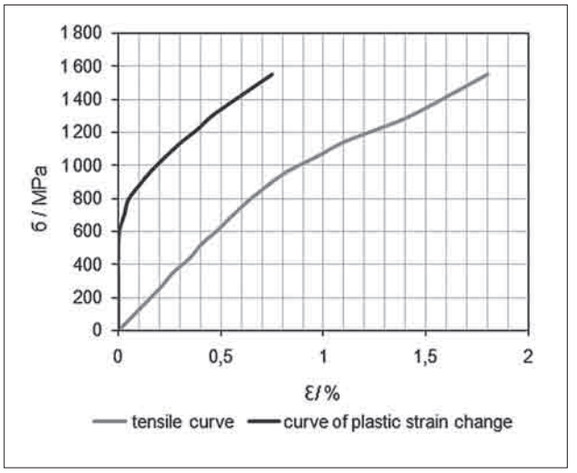

Figure 2 The tensile test for A variant

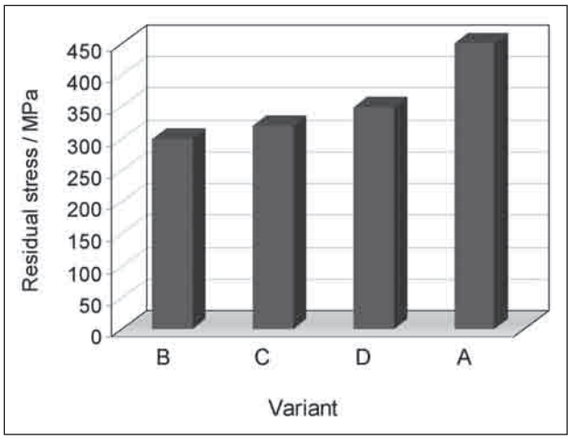

Figure 3 The residual stresses in wires after straightening process in depends on number of rolls

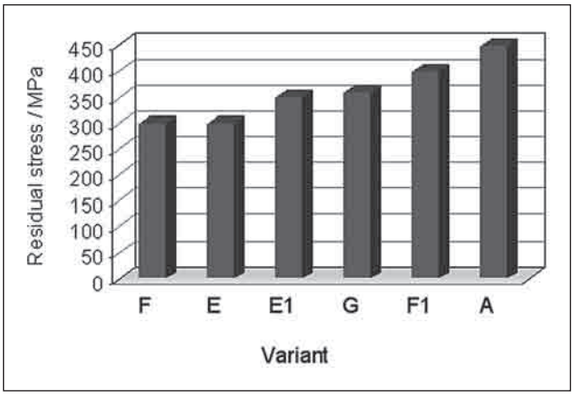

Figure 4 The residual stresses in wires after straightening process in depends on straightener planes and their arrangement

Table 3 **The residual stresses of drawn wires**

Variant	Residual stress / MPa	Number of rolls
B	299	7
C	319	5
D	349	3
A	449	---

Table 4 **The residual stresses of drawn wires**

Variant	Residual stress / MPa	Number of rolls
E	299	4- each 90 °
F	299	3- each 90 °
E1	349	4- each 45 °
G	359	2- each 90 °
F1	399	3- each 60 °
A	449	---

quence were: F, E1, G, F1, A – non relaxed, Table 4 and Figure 4.

The data investigations presented in Tables 3, 4 and Figures 3, 4 shown that the application of the straightening machine causes the decrease of the residual stresses. In consequence the wires after straightening should have better fatigue strength. It is especially important because the metal product i.e. springs, ropes from which the highest fatigue strength is required, are producing form high carbon steel wires.

CONCLUSIONS

From experimental tests carried out, the following findings and conclusions have been drawn:

The application of the straightening machine influences essentially on the residual stresses of high carbon steel wires.

The application of the straightening machine cause the decrease of residual stresses of drawn wires. It depends of type of straightener the decrease of residual stresses, approximately by 35 % was observed.

Comparing straightener and taking into consideration number of rolls one can state, that seven-rolls straightener gives the best effect of straightening, i.e. after passage through this straightener wire is characterized by the lowest residual stresses value.

Considering next group of straightener with respect to the number of planes and their arrangement apparently is, that from two- three- and four-planes straightener (with different planes arrangement) four-planes straightener (planes arrangement: horizontal, vertical, horizontal, vertical) is the most effective one.

The most effective straightener is when angle between planes is equal 90 °.

It should be emphasized that efficiency of straightener depends not only on their construction but on their correct arrangement too.

The decrease of residual stresses after straightening process should improve the properties of drawn wires i.e. fatigue strength, number of twists and number of bands.

The obtained data of investigations can be applied in wire industry while implementing the new technologies of manufactures of ropes and springs.

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Note: The professional translator for English language is Czesław Grochowina, studio – Tekst, Częstochowa, Poland