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THE THEORETICAL AND EXPERIMENTAL ANALYSES OF THE INFLUENCE OF SINGLE DRAFT ON PROPERTIES OF ROPE WIRES

ANALIZA TEORETYCZO-DOŚWIADCZALNA WPLYWU WIELKOŚCI GNIOTU POJEDYNCZEGO NA WŁASNOŚCI DRUTÓW LINIARSKICH

In the paper the influence of the value of a single draft on the properties of rope wires has been assessed. The drawing process of φ5.5 mm wire rod to the final wire of φ2.18 mm was conducted in 6, 11 and 17 drafts, by means of a block drawing machine with the drawing speed of 1.6 m/s. For the wires drawn with the medium single draft: 10.4%, 15.5% and 26.5% the investigation of mechanical-technological properties has been done, in which yield strength, tensile strength, elongation, contraction, number of twists and number of bands were determined. In order to explain the effect of value of a single draft on properties of rope wires, the fatigue strength, roughness and residual stresses of drawn wires have been also determined. In addition, the numerical analysis of the drawing process on the base of Drawing 2D in which distribution of redundant strain, effective strain, longitudinal residual stresses and temperature of drawn wires has been shown.

The theoretical-experimental analysis of drawing of rope wires have enabled the evaluation of optimal value of single drafts by which relatively the most advantageous and useful properties of wires can be used. The investigation has shown, that in manufacturing of rope wires small single draft in 10% range should be applied. It allowed to obtain products of good plasticity properties, low deformation inhomogeneity and residual stresses, high bending and fatigue strength.

The obtained data investigation can be applied while designing the production process of high carbon steel wires.

Keywords: rope wire, single draft, mechanical properties, fatigue strength, residual stresses, roughness, redundant strain, effective strain, temperature

W pracy określono wpływ wielkości gniotów pojedynczych na własności drutów liniarskich. Proces ciągnienia walcówki o średnicy 5.5 mm na średnicę 2.18 mm zrealizowano w 6, 11 i 17 ciągach na ciągarce jednobębnowej z prędkością ciągnienia 1.6 m/s Dla drutów ciągnionych ze średnim gniotem pojedynczym: 10.4%, 16.5% i 26.5% przeprowadzono badania własności mechaniczno-technologicznych, w których określono umowną granicę plastyczności, wytrzymałość na rozciąganie, wydłużenie równomierne i całkowite, przewężenie, liczba skręceń i liczbę zgięć. Dla pełniejszej oceny wpływu wielkości gniotu pojedynczego na własności drutów liniarskich przeprowadzono także badania wytrzymałości zmęczeniowej, chropowatości powierzchni i naprężeń własnych. Dodatkowo w pracy w oparciu o program Drawing 2d przeprowadzono analizę numeryczną procesu ciągnienia, w której określono odkształcenia postaciowe, intensywność odkształcenia, naprężenia własne i temperaturę ciągnionych drutów.

Przeprowadzona analiza teoretyczno-doświadczalna procesu ciągnienia drutów ze stali wysokowęglowej umożliwiła określenie optymalnych wartości gniotów pojedynczych przy których uzyskuje się względnie najlepsze własności użytkowe drutów. Stwierdzono, że przy wytwarzaniu drutów linairskich należy stosować małe wielkości gniotów pojedynczych, rzędu 10%. Pozwala to uzyskać wyroby o dobrych własnościach plastycznych, małej niejednorodności odkształcenia, małych naprężeniach własnych, wysokiej wytrzymałości na zginanie oraz dużej wytrzymałości zmęczeniowej.

Uzyskane wyniki badań mogą być wykorzystane przy projektowaniu procesu wytwarzania drutów ze stali wysokowęglowych.

1. Introduction

The drawing process of high carbon steel wires for ropes is complicated and consists of many technological operations. Accordingly, the process of wire drawing can weigh in a relevant way against the quality of produced wire and thereby against of the ropes [1÷4]. The technical development requires better and better qualities.

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The basic technological parameters that influence the properties of wires include the value of single drafts. The establishing the optimal value of the single draft makes a complex problem. The selection of the single draft depends on numerous factors, which include the following: the plasticity of material and its structure, and the conditions and mode of deformation [5÷9]. In consequence, the application of certain value of the single draft in wire drawing process can, in one hand, improve some properties of drawn wires i.e. mechanical properties, on the other hand deteriorate another ones as fatigue strength. The available literature on the subject being discussed does not fully explain the effect of the value of the single draft on the properties of rope wires. Therefore, the present work makes an attempt to assess the effect of this parameter on mechanical and technological properties, the fatigue strength, roughness of surface, residual stresses, temperature, redundant and effective strain of high-carbon wires.

2. Material and applied drawing technologies

The test material was 5.5 mm-diameter patented wire rod of C72 grade high-carbon steel (0.72%C), which was drawn on a bull block at a speed of 1.6 m/s using conventional dies with an angle of $2\alpha = 12°$ according to the following technological variants:

– **Variant A** – 6 draws; an average single draft of **D_{av} =26.5 %**

– **Variant B** – 11 draws; an average single draft of **D_{av} =16.5 %**

– **Variant C** – 17 draws; an average single draft of **D_{av} =10.4 %**

Single drafts, D_s, and total drafts, D_t, for drawing Variants A, B and C are summarized in Tables 1-3.

TABLE 1

Distribution of single drafts and total drafts for wires from Variant A

Draft number	0	1	2	3	4	5	6
φ wire, mm	5.50	4.70	4.00	3.40	2.93	2.53	2.18
D_s, %	–	27.0	27.6	27.8	25.7	25.4	25.8
D_t, %	–	27.0	47.1	61.8	71.6	78.8	84.3

TABLE 2

Distribution of single drafts and total drafts for wires from Variant B

Draft number	0	1	2	3	4	5	6	7	8	9	10	11
φ wire, mm	5.50	5.08	4.70	4,33	4.00	3.65	3.35	3.05	2.78	2.53	2.35	2.18
D_s, %	–	14.7	14.1	15.	14.7	16.7	15.8	17.1	16.9	17.2	13.7	13.9
D_t, %	–	14.7	27.0	38.0	47.1	56.0	62.9	69.3	74.5	78.8	81.7	84.3

TABLE 3

Distribution of single drafts and total drafts for wires from Variant C

Draft number	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
φ wire, mm	5.50	5.20	4.95	4.70	4.45	4.22	4.00	3.80	3.60	3.40	3.2	3.05	2.88	2.70	2.53	2.42	2.30	2.18
D_s, %	–	10.6	9.4	9.9	10.4	10.1	10.2	10.8	10.2	10.8	10.3	10.3	10.8	12.1	12.2	8.5	9.7	10.2
D_t, %	–	10.6	19.0	27.0	34.5	41.1	47.1	52.3	57.2	61.8	65.7	69.3	72.6	75.9	78.8	80.6	82.5	84.3

3. The mechanical-technological properties of drawn wires

In order to establish the effect of the value of the single draft on mechanical properties of wires, mechanical investigation was carried out by means of Zwick Z100 testing machine, according to PN-EN ISO 6892-1:2009 standard. For the wires drawn according to variant A÷C the following were determined: yield stress, YS; ultimate tensile strength, UTS; uniform elongation, ELU; reduction of area, RA; Fig. 1÷4.

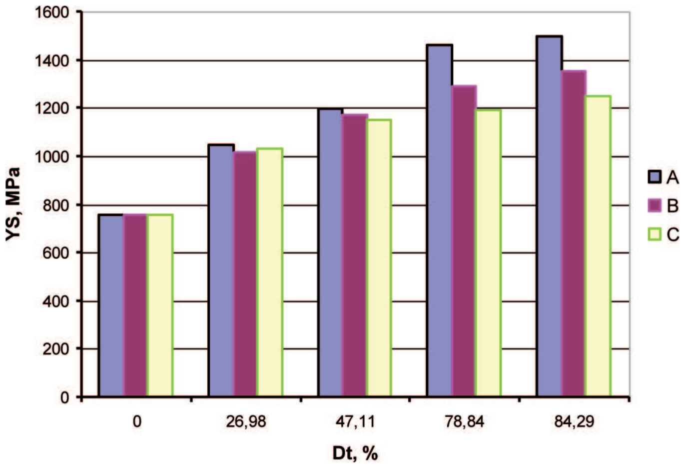

Fig. 1. The influence of the value of single draft on yield stress

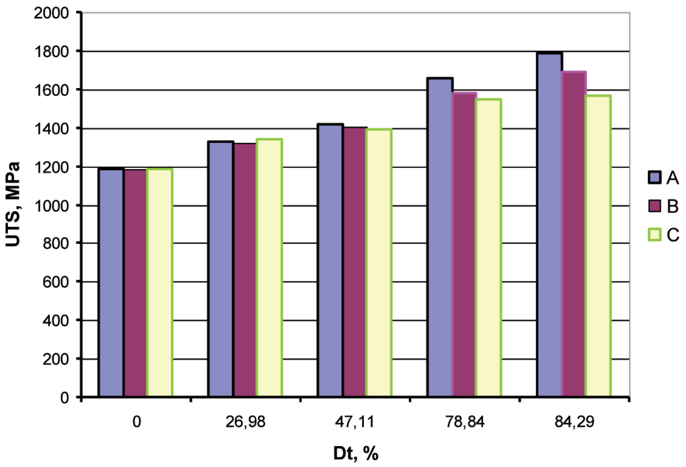

Fig. 2. The influence of the value of single draft on ultimate tensile strength

It can be found from Figs.1÷4 that the value of single drafts influences essentially the mechanical properties of rope wires. The application of higher single drafts causes an increase in their strength properties, i.e. the yield point and the ultimate tensile strength. The final wires from variant A (D_{av} =26.5%), as compared to the wires from variants B (D_{av} =15.5%) and C (D_{av} =10.4%), are distinguished by YS higher by 9.7% and 16.4%, and UTS higher by 5.6% and 12.4%, respectively. The increase in the strength properties of wires drawn with large single drafts (D_{av} =26.5%) has also contributed to a 10% decrease in their plasticity properties (i.e. the uniform elongation, A, and the contraction, Z).

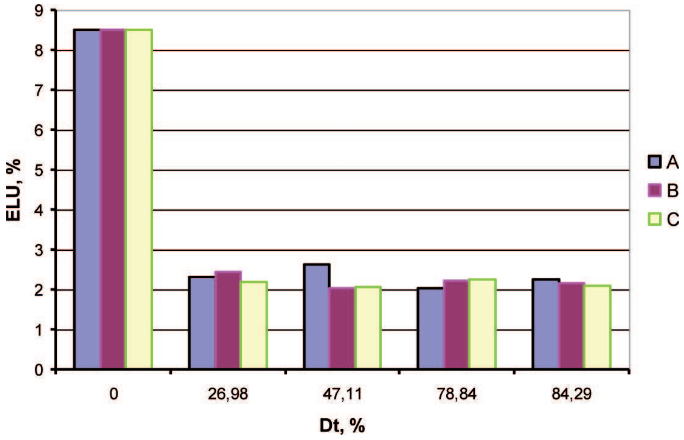

Fig. 3. The influence of the value of single draft on uniform elongation

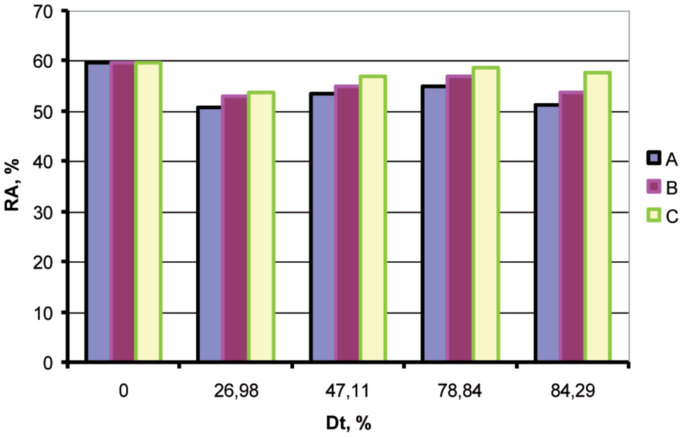

Fig. 4. The influence of the value of single draft on reduction of area

The parameters defining the tensile properties and plasticity of wires are also the number of twists, N_t, and the number of bends, N_b. In spite of the fact that these tests are characterized by a large scatter of results, as they are affected by internal defects (such as inclusions in the case of N_b) and surface faults (such as cracks and scratches on the wire surface in the case of N_t), they reflect the actual state of the material in a way, as the technological properties, i.e. N_b and N_t, are determined by both their strength and their plasticity. Therefore, the technological tests of wires were carried out within the present work for particular technological variants according to PN-EN 10218-1:2001 standard, as shown in Fig. 5÷6.

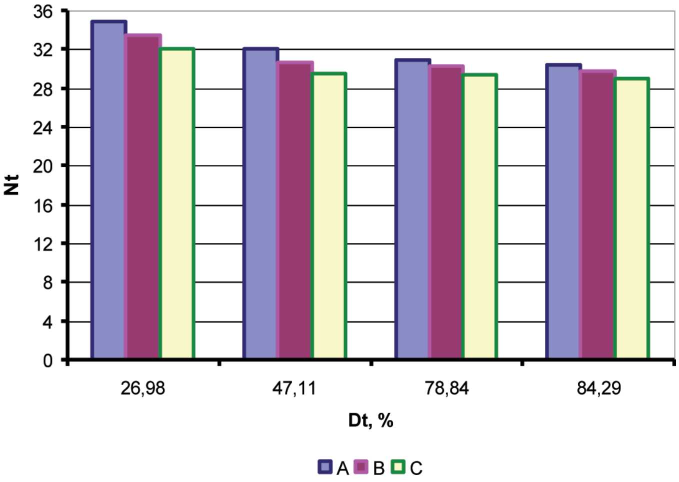

Fig. 5. The influence of the value of single draft on number of twists

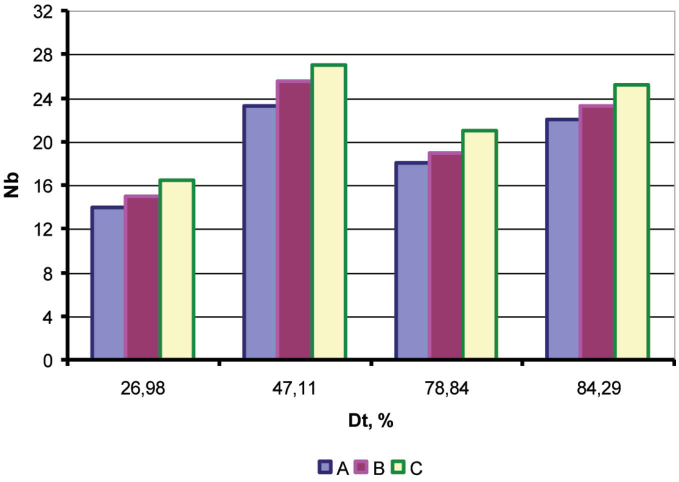

Fig. 6. The influence of the value of single draft on number of bends

The tests carried out have shown that the value of individual drafts in the drawing process influences significantly the obtained number of twists and the number of bends of rope wires. Fig. 5 indicates that increasing the number of draws has an unfavourable effect on the torsional strength level of wires. The wires drawn with the single draft of D_{av} =26.5%, as compared with the wires from Variants B (D_{av} =15.5%) i C (D_{av} =10.4%), exhibit a number of twists higher by 8%, on average, depending on the total draft. Thus, the increase of the single draft does not impair the torsional strength of wires, contrary to what is suggested by some authors [8]. It is supposed that the higher strength properties of those wires influenced favourably the obtained number of twists.

Apart from the number of twists, also the number of bends is determined in technological tests of wires. The tests carried out have shown an adverse effect of the value of single drafts on the bending strength of wires. For the wires from Variant A, as compared to those from Variants B and C, a number of bends lower by 11% and 20%, respectively, was obtained. In the author's view, the high bending strength of the wires from Variant C (D_{av} =10.4%) might be associated with their much better plastic properties, especially those of the sub-surface layer. Therefore, the effect of the value of single drafts on the inhomogeneity of strain in the high-carbon wire drawing process has been established within the present work. Theoretical analysis of the wire drawing process is presented in chapter 6.

4. Fatigue strength and roughness of drawn wires

The fatigue strength tests on wires were carried out on a testing machine built in the Institute of Modelling and Automation of Plastic Working Processes at the Czestochowa University of Technology, modelled after the design of the PUL DRABI SCHENCK fatigue testing machine. A diagram of the machine is shown in Fig. 7.

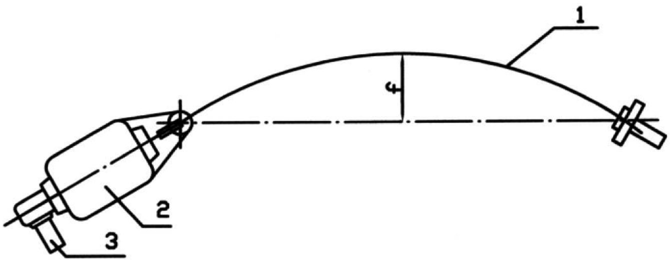

Fig. 7. Diagram of the testing machine used for testing the fatigue strength of wires in the wire under investigation; 1 – wire, 2 – motor, 3 – revolution counter, f – deflection

The fatigue tests of wires were conducted under the conditions of rotary bending for the final wires φ2.18mm; the maximum bending stress in the outer wire layers was calculated from Formula 1, while substituting in the formula the actual value of Young's modulus, as determined from the tensile tests performed on the testing machine. In these tests, the number of cycles (N) completed until the break of the wire was determined.

$$\sigma_{\max} = \pm \frac{6 \cdot f \cdot d \cdot E}{l^2} \tag{1}$$

where: f – deflection, d – wire diameter, E – Young's modulus, 1 – specimen length.

Table 4 shows the results of the fatigue strength tests of rope wires. For a better analysis of the effect of the single draft on the fatigue strength of wires, the percentage differences in the number of fatigue cycles (N) between Variant A (taken as 100%) and Variant B and C were also calculated for different levels of bending stress.

TABLE 4

The average values of the number of fatigue cycles (N) completed until the break of wires drawn according to Variants A÷B for different levels of bending stress, and the percentage differences between Variant A (taken as 100%) and Variant C

σ_{max}, MPa	Variant	Number of fatigue cycles, N	Difference, %
1092.1	A	13600	-6.1
	B	11500	
	C	14434	
970.8	A	25230	-3.9
	B	24270	
	C	26220	
849.4	A	47640	-11.4
	B	44756	
	C	53060	
728.1	A	64420	-22.7
	B	61680	
	C	79040	

Based on the results given in Table 4, fatigue strength graphs (Wöhler curves for the fatigue strength, Z_g) were plotted for wires from Variants A, B and C, by approximating the obtained results with a logarithmic function (Fig. 8).

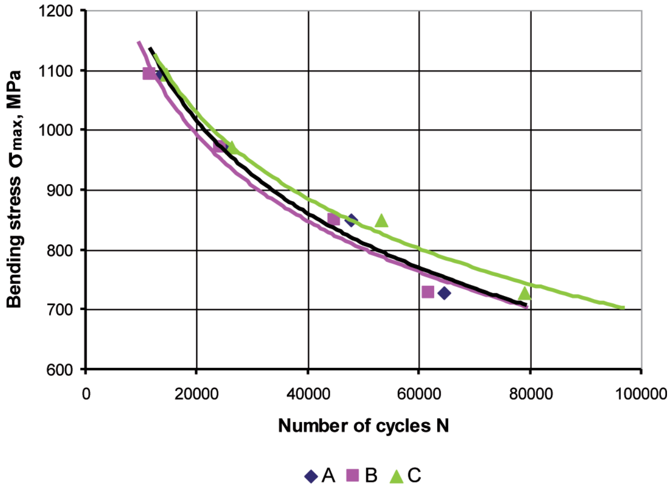

Fig. 8. Diagrams of the temporary fatigue strength of φ2.18mm wires drawn according to Variants A÷C

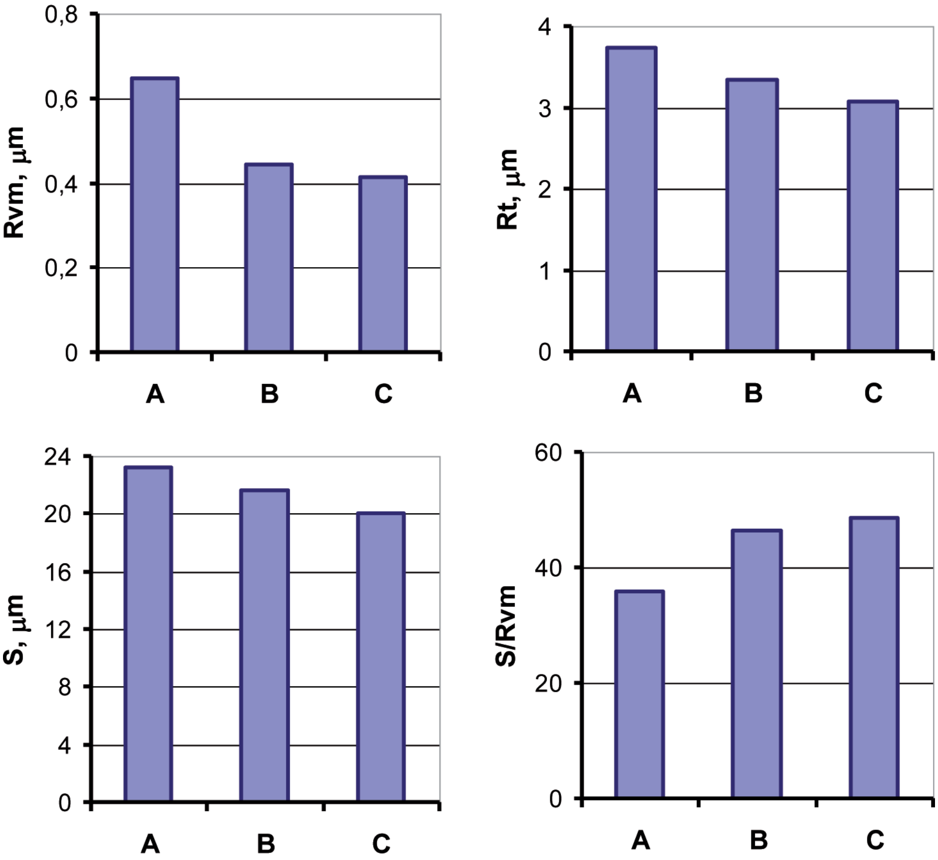

Fig. 9. The values of the profile parameters of the surface roughness of φ2.18 mm wires drawn according to Variants A, B and C

The investigation results presented above show that the value of the single draft has an essentially influence on the fatigue strength of rope wires. The significant differences in fatigue strength between Variants A, B and C are confirmed by the large percentage differences (Table 4). With decreasing bending stress, the differences in fatigue strength of wires between Variant A, B and C increases. For bending stress σ_{max} =700 MPa, wires drawn according to Variant A (D_{av} =26.5%) and Variant B (D_{av} =16.5%) in comparison to Variant C (D_{av} =10.4%) have lower fatigue strength by 20%.

The surface roughness of the drawn wire is ranked among the factors that substantially influence the achievable level of fatigue strength.

The examination of changes in the surface roughness of steel wires was carried out on a Form Talysurf Series profilometer. To illustrate the effect of the value of the single draft on the surface roughness of φ2.18mm wires, the following parameters were selected to be analysed:

- profile height parameters: R_{vm}, R_t,
- horizontal profile parameter: S,
- Newman's ratio: S/R_{vm}.

The values of the roughness of wires drawn according to Variant A÷C are represented in Fig. 9.

It can be observed from Fig. 9 that the value of the single draft influences essentially the roughness parameters of high carbon steel wires. The application in drawing process small values of single draft (D_{av} =10.4%) results in a decrease of wire roughness. The final wires φ2.18 mm from variant C (D_{av} =10.4%), as compared to the wires from variants A (D_{av} =26.5%), are distinguished by profile height parameters R_{vm}, R_t lower by 28% and profile deviation parameter R_a lower by 24%, respectively.

Temporary fatigue strength, Z_g, of wires is directly proportional to the converse of the surface geometrical ratio, as defined by Newman:

$$Z_g \cong \frac{c}{a} \cong \frac{S}{R_{vm}} \tag{2}$$

From the data shown in Fig. 9 it can be found that with the decrease in the value of the single draft Newnan's ratio increases. The wires from Variant C drawn with the single draft of D_{av} =10.4%, as compared with the wires from Variants A (D_{av} =26.5%), exhibit a Newnan's ratio higher by 35%. This indicates a favourable effect of small value of the single draft on the parameters that have the influence on the fatigue strength of wires.

5. Experimental measuring of residual stresses

The experimental measuring of residual stresses on the basis of longitudinal grinding wires, so called Sachs-Linicus, method was assessed. According to this method, wires are ground up to half diameter what causes the violation of stress equilibriums (Fig. 10).

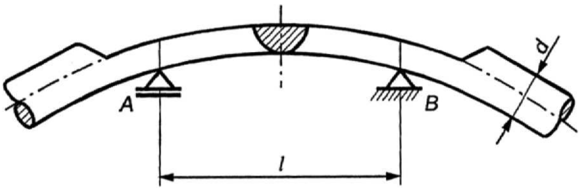

Fig. 10. The deformation of wires after longitudinal grinding to the half diameter [10]

The residual stresses $\sigma_{r\,surf}$ on the wire surface can be measured by formula (3), presented in [10]:

$$\sigma_{r\,surf} = \frac{48EIf}{l^2r^3},\ \text{MPa} \tag{3}$$

where:

$\sigma_{r\,surf}$ – longitudinal residual stress on wire surface,
E – Young modulus,
l – length of wire between supports,
r – wire radius (r=0.5d),
f – band arrow of wire between supports,
I – moment of inertia semi-circle in relation to neutral axis ($I=0.1098r^4$).

The investigations of residual stresses for wires φ2.18 mm drawn according to variant A and B were realized (10 specimens on each variant). The data investigation are presented in Table 5.

TABLE 5
The results of residual stresses tests carried out by the Sachs-Linicus method

Variant	Longitudinal residual stress $\sigma_{r\,surf}$, MPa
A	542,9
B	423,3
C	291,8

The test that was carried out have shown that applying small values of the single draft in the wire drawing process of high carbon wires causes the decrease of residual stresses. For the wires drawn according to variant C, in comparison to the wires drawn according to variants A and B, the decrease of longitudinal residual stresses, respectively by 46,3% and 22% has been noted.

As the method of Sachs-Linicus enables to estimate residual stresses only on the wire surface, numerical analysis of drawing process of high carbon steel wires has been conducted in the work. On the basis of simulations the residual stresses on the cross section of wires were determined.

6. The theoretical analysis of wiredrawing process

Theoretical analysis of the wire drawing process on the base of the software Drawing 2D has been conducted [11]. The simulations were performed for a wire with the plastic properties corresponding to those of the pearlitic-ferritic steel C75 (~0.75%C). It was assumed that the drawing process took place with the identical distribution of single and total drafts to that of the experimental tests (Table 1÷3), with the friction coefficient of μ =0.07. Fig. 11 shows typical examples of effective strain distributions on the cross-section of φ2.18 mm wires drawn according to Variant A.

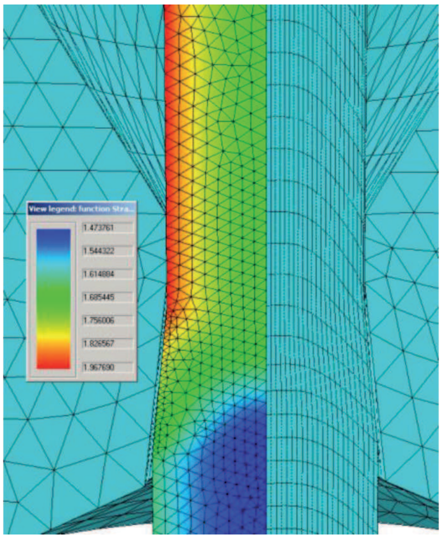

Fig. 11. The distribution of effective strain, ε_c, in φ2.18 mm wire drawn according to Variant A

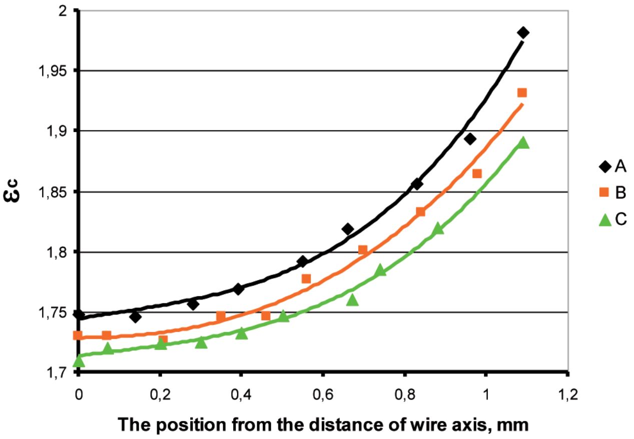

Fig. 12. The distributions of the effective strain ε_c on the cross-section of φ2.18 mm wires drawn according to Variants A÷C

The redundant strains on the wire surface in the following drafts for Variants A÷C are presented in Fig. 12. For the wires drawn according to Variants A, B and C, functions approximating the distributions of effective strain (Fig. 13) and redundant strain (Fig. 14) were determined as the function of the wire radius, R.

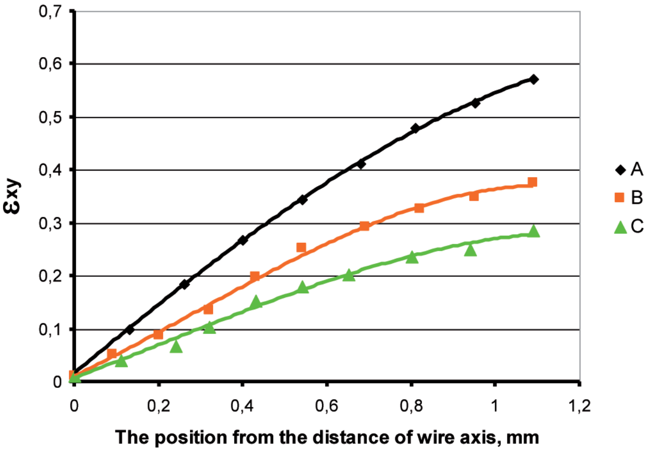

Fig. 13. The distributions of the redundant strain ε_{xy} on the cross-section of φ2.18 mm wires drawn according to Variants A÷C

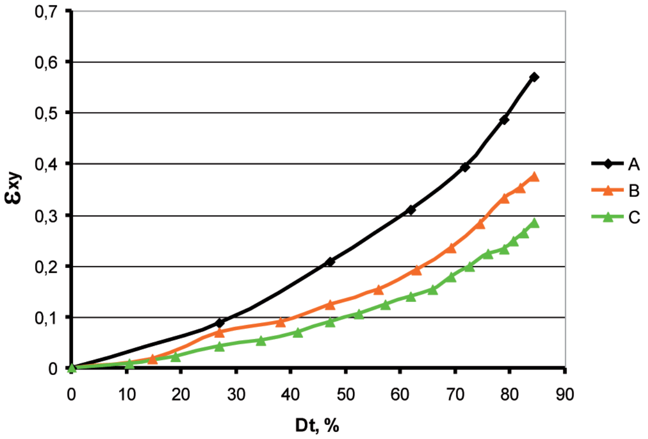

Fig. 14. The distribution of redundant strain ε_{xy} on the wire surface for wires drawn according to Variants A÷C in the total draft function

From the investigation carried out it has been found that the value of the single draft influences on effective and redundant strain (Fig.12÷14). The biggest differences were found in the sub-layers of drawn wires. The wires from variant A (G_{av} =26.5%), as compared with the wires from variant B (G_{av} =16.5%) and variant C (G_{av} =10.4%), exhibit a higher effective strain respectively by 32% and 53%. The increase of effective strain in wires drawn according to variant A refers to bigger for this variant non-dilatation of strain, which can cause additional work hardening. In consequence it causes the increase of inhomogeneity of mechanical properties and residual stresses of the drawn wires.

The analysis of the distribution of stress σ_y (longitudinal stresses compatible with the drawing direction) on the cross section of wire makes it possible to estimate the residual stresses. From the distributions of longitudinal stresses of φ2.18 mm wires (Fig. 15) the numerical values of the stress on cross section of the wire were read out.

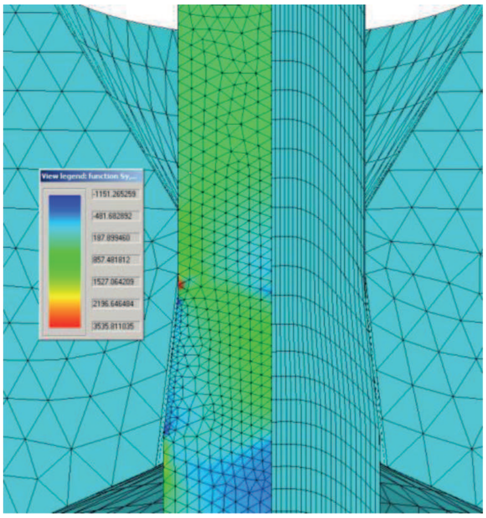

Fig. 15. The example of the distribution of longitudinal stresses σ_y in the final wire φ2.18 mm drawn according to variant A

In the drawn wire after the exit from a die the longitudinal stress σ_y is the sum of drawing stress σ_d and a distribution of residual stresses σ_r. In order to determine the drawing stress and the distribution of residual stresses, longitudinal stresses σ_y, described in the wire radius r function, were approximated with the function of second-degree, which reflects the distribution of residual stresses [12]. The functions approximating the distribution of longitudinal stresses σ_y in the wire radius r function, the value of drawing stresses σ_d and maximum values of residual stresses (on wire surface) in Table 6 were shown, while in Fig. 16÷17 the functions which illustrative the distribution of longitudinal and residual stresses in wires φ2.18 mm were presented.

TABLE 6

The approximation functions of the distributions of longitudinal stresses σ_y, the values of drawing stress σ_d and maximum values of residual stresses σ_r for the final wires φ2.18 mm drawn according to variants A÷C

Variant	σ_y =f(R)	σ_d MPa	$\sigma_{r\,\max}$ MPa
A	σ_y =741,03 r^2+262,09	555,6	586,9
B	σ_y =537,39 r^2+78,62	291,4	427,7
C	σ_y =438,81 r^2+53,00	226,8	347,5

On the basis of Table 6 and Fig. 17 it can be observed that in the drawing process the value of the single draft fundamentally influences on the value and the distributions of residual stresses of high carbon steel wires. It was found that in the surface layers of the drawn wires there are tensile residual stresses, while in internal layers there are compressive ones.

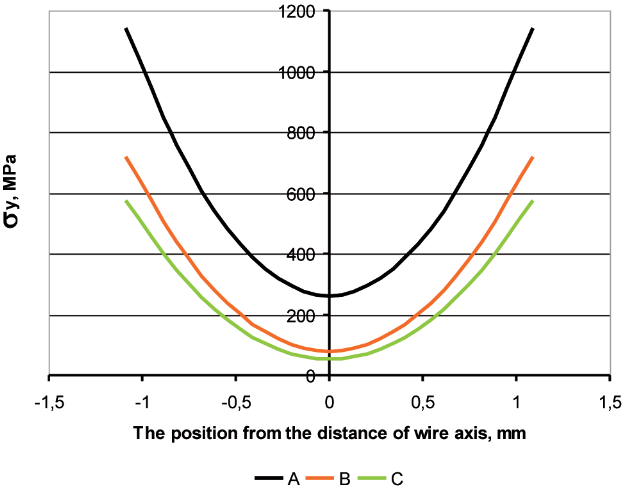

Fig. 16. The distribution of the longitudinal stresses σ_y for φ2.18 mm wires drawn according to variant A÷C

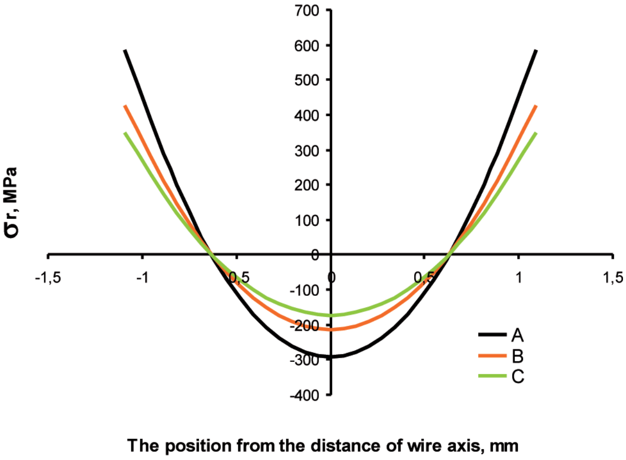

Fig. 17. The distribution of the first type longitudinal residual stresses σ_r for φ2.18 mm wires drawn according to variant A÷C

The wires from variant A (D_{av} =26.5%), as compared to the wires from variants B (D_{av} =16.5%) and C (D_{av} =10.4%), exhibit higher residual stresses on the surface, respectively by 27% and by 40.8%. The data investigation from numerical analysis are conformable with those obtained by Sachs-Linicus method, Table 5.

One of the factors which has a significant influence on residual stresses is temperature and inhomogeneity of strain. Therefore, the effect of the value of the single draft on the temperature and redundant strain have been established within the present work.

In Fig. 17 the changing of the average temperature T_{av} in the total draft function for variant A÷C has been shown. In Fig. 18 temperature distributions on the cross-section of φ2.18 mm wires drawn according to Variants A÷C after the exit from the bearing zone of a die has been shown.

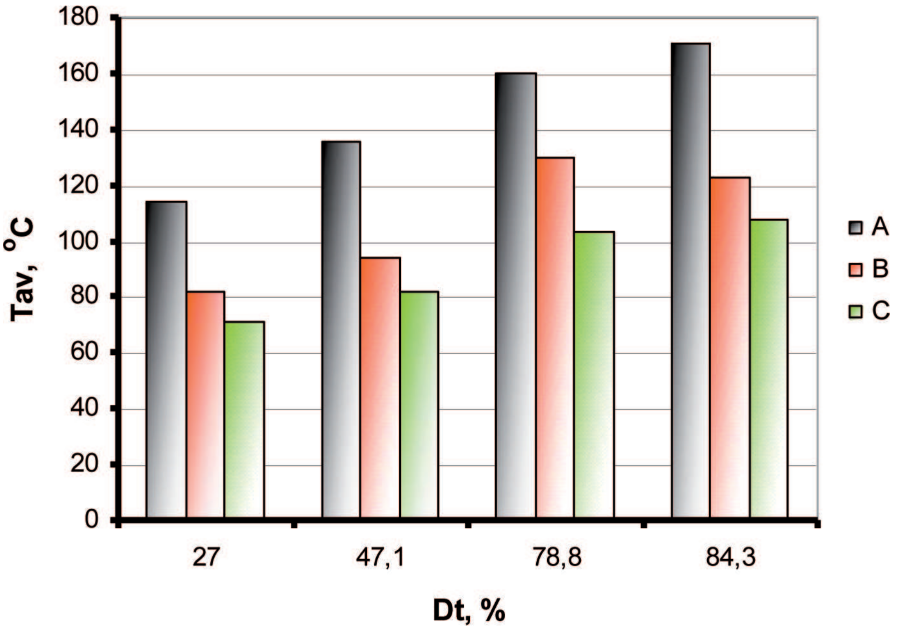

Fig. 18. The change of the average temperature for the wires drawn according to variant A÷C in the total draft function

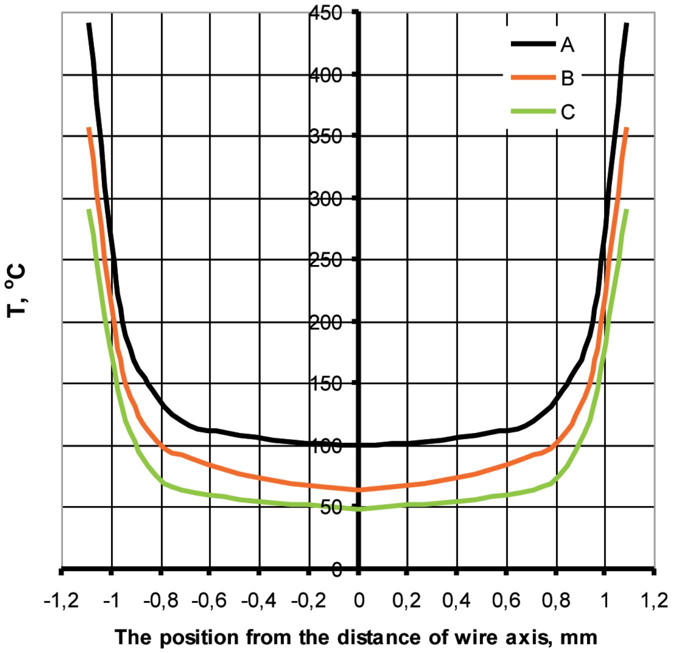

Fig. 19. The distribution of the temperature on the cross-section of φ2.18 mm wires drawn according to Variants A÷C after the exit from the bearing zone of a die

On the basis of Fig. 17÷18 it can be observed that the application of small single drafts in the drawing process essential influences on the decrease of the wire temperature.

The final wires from variant A, as compared to the wires from variants B and variant C, exhibit higher: surface temperature, respectively by 22% and 52%; the average temperature, respectively by 22% and 58%

Undoubtedly, the large increase of temperature in the sub-layer of the wires drawn according to variant A caused the rise of internal stresses related to the thermal expansion of steel. In consequence, it caused the increase of residual stresses.

The second factor which causes appearing of residual stresses is the redundant of strain. The external layers, in comparison to central layers, have bigger redundant of strain (Fig. 9) what causes the non-uniform distribution of stresses in the drawn wire. In consequence, after the drawing process the residual stresses are formed. Surely, the higher redundant strain for wires from variant A (Fig. 13) had an impact on increasing of residual stresses.

7. Conclusions

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

1. The value of the single draft in the drawing process of rope wires in essential way influences on their mechanical and technological properties. For wires drawn with D_{av} =26.5%, strength properties higher by approx. 15% compared to the wires drawn with D_{av} =10.4% were noted. The increase in the strength properties of the wires from this variant contributed to lowering of their plasticity properties, on average, by 10%.
2. The technological properties, i.e. the number of twists and the number of bends, are significantly influenced by the single draft. Applying large single drafts in the drawing process results in an increase in the number of twists of wires averagely by 8%,

and may contribute to a considerable reduction in their bending strength (by about 20%).

3. The greater number of twists in wires drawn with D_{av} =26.5% is associated with their higher redundant strain, which is confirmed by the higher values of the yield point and the ultimate tensile strength.
4. Greater hardening of sub-surface layers causes higher redundant strain in the wires drawn with D_{av} =26.5% reduce their bending strength. A more hardened surface layer is characterized by poorer plastic properties, which favour the increase of the risk of crack initiation at the surface of the wire being bent.
5. The value of the single draft in the drawing process fundamentally influences on the value and the distributions of residual stresses of high carbon steel wires. The wires from variant A (D_{av} =26.5%), as compared to the wires from variants C (D_{av} =10.4%), exhibit higher residual stresses on the surface by 40.8%.
6. The FEM simulation shown that applying in drawing process a large single draft causes the increase of temperature of the drawn wires. The final wires from variant A, as compared to the wires from variant C, exhibit a higher surface temperature by 52% and the average temperature, by 58%, respectively. The large increase of the temperature in the sub-layer of wires drawn according to variant A caused the rise of internal stresses related to the thermal expansion of steel. In consequence, it caused the increase of residual stresses. The second factor which causes appearing of residual stresses is the redundant of strain. Surely the higher redundant strain for wires from variant A had also an impact on increase of residual stresses.
7. The application of the drawing process of high carbon steel wires with small values of single drafts causes the increase of fatigue strength of drawn wires. The wires drawn with D_{av} =10.4%, in comparison to the wires drawn with D_{av} =26.5%, are distinguished by 20% higher fatigue strength. The high fatigue strength of the wires drawn with a small draft is related, among the others, to their better geometrical structure and lower residual stresses.
8. For a single draft D_{av} =16.5-26.5% did not find distinct in fatigue strength of the drawn wires. On the one hand higher strength properties of the wires drawn with the single draft 26.5% could improve fatigue strength of wires, but in other hand the wires from variant A have worse surface and higher residual stresses.
9. From the investigation carried out it has been stated that in manufacturing of rope wires small single draft should be applied. It allows to obtain products of good plasticity properties, low deformation inhomogeneity and residual stresses, high bending and fatigue strength.
10. In the author's view, it is not advisable to apply medium (approx. 15%) single drafts while drawing high-carbon wires, as they have the worst combination of service properties.
11. The obtained data investigations can be applied in the wire industry while designing the production process of rope wires.

REFERENCES

[1] M. Suliga, The influence of the high drawing speed on mechanical-technological properties of high carbon steel wires, Archieves of Metallurgy and Materials, Quarterly **56**, 3, Warszawa-Kraków, 823-828 (2011).

[2] M. Suliga, The influence of the multipass drawing process in classical and hydrodynamic dies on residual stresses of high carbon steel wires, Archieves of Metallurgy and Materials Quarterly **56**, 4, Warszawa-Kraków, 939-944 (2011).

[3] J. Łuksza, A. Skołyszewski, F. Witek, W. Zachariasz, Druty ze stali i stopów specjalnych, Wydawnictwo Naukowo-Techniczne, Warszawa (2006).

[4] M. Suliga, The influence of drawing speed on multi-pass drawing process of high carbon steel wires, Metallurgist-Metallurgical News (Hutnik-Wiadomości Hutnicze) **1**, 132-135 (2011).

[5] M. Schneider, Ciągarstwo, WGH, Katowice (1961).

[6] M. Suliga, Wpływ struktury i technologii ciągnienia na własności drutów ze stali TRIP, Metalurgia 2009 Nowe technologie i osiągnięcia, Seria: Monografie nr 1, Częstochowa, 189-217 (2009).

[7] M. Suliga, Z. Muskalski, The influence of single draft on TRIP effect and mechanical properties of 0,09C-1,57Mn-0,9Si steel wires, Archieves of Metallurgy and Materials, Quarterly **54**, 3, Warszawa-Kraków, 677-684 (2009).

[8] L. Godecki, The delamination of spring wires during torsion testing, Wire Industry **5**, 419-426 (1969).

[9] B. Golis, J.W. Pilarczyk, Druty stalowe. Metalurgia Nr 35, Politechnika Częstochowska, Częstochowa (2003).

[10] T. Lambert, J. Wojnarowski, Mechaniczne metody pomiaru osiowych naprężeń własnych w drutach stalowych. Zeszyty Naukowe Politechniki Śląskiej, Seria: Hutnictwo **1**, 3-16 (1971).

[11] A. Milenin, Software Drawing2D – general tool for analysis of technological processes of multi-pass drawing, Metallurgist-Metallurgical News (Hutnik-Wiadomości Hutnicze) **2**, 100-103 (2005).

[12] Z. Muskalski, Analiza wpływu kierunku ciągnienia drutów na ich wytrzymałość zmęczeniową i trwałość zmęczeniową lin stalowych, Seria Metalurgia nr 43, Politechnika Częstochowska, Częstochowa (2004).

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