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THE INFLUENCE OF SINGLE DRAFT ON TRIP EFFECT AND MECHANICAL PROPERTIES OF 0.09C-1.57Mn-0.9Si STEEL WIRES

WPŁYW GNIOTU POJEDYNCZEGO NA EFEKT TRIP I WŁASNOŚCI MECHANICZNE DRUTÓW ZE STALI 0,09C-1,57Mn-0,9Si

In the work the influence of single draft on rate phase transformation retained austenite into martensite during wire drawing process has been shown. The experimental investigations allowed to estimate mechanical properties of drawn wires i.e. tensile strength R_m, yield strength $R_{0,2}$, contraction Z, uniform elongation A_r, total elongation A_{100}, number of twist N_t and number of band N_b. Whereas numerical simulation of the process on the base of Drawing 2D program allowed to describe parameters such as: drawing stress, residual stress, temperature and non-dilatation strain. The realised investigation shown that the volume of single draft in wire drawing process fundamentally influence on useful properties of wires from multiphase TRIP steel.

Keywords: drawing, single draft, wires, TRIP effect, mechanical properties

W niniejszej pracy określono wpływ wielkości gniotów pojedynczych na szybkość przemiany fazowej austenitu szczątkowego w martenzyt podczas procesu ciągnienia. Przeprowadzone badania doświadczalne pozwoliły na wyznaczenie własności mechanicznych ciągnionych drutów tj. granica plastyczności R_{02}, wytrzymałość na rozciąganie R_m, wydłużenie równomierne A_r, wydłużenie całkowite A_{100} przewężenie Z, liczbę skręceń N_t i zgięć N_b. Natomiast symulacja numeryczna procesu w oparciu o program Drawing 2D umożliwiła określenie takich parametrów jak: naprężenie ciągnienia, wzdłużne naprężenia własne I rodzaju, temperaturę oraz odkształcenia postaciowe. Przeprowadzone badania wykazały, że wielkość gniotu pojedynczego w procesie ciągnienia wpływa zasadniczo na własności użytkowe drutów ze stali wielofazowej typu TRIP.

1. Introduction

The important role in forming properties of drawn wires plays the drawing technology. One of the essential technological parameters influencing on properties of drawn wires is value of single draft. The assessment of optimal value of a single draft is a complex problem and depends on plasticity of material and his structure and method of deformation [1]. Up to now the investigation connected with a single draft was realised mainly for ferrite-pearlite steel. Little is known about the influence of a single draft on TRIP effect and properties of multiphase TRIP steel wires.

A multiphase structure TRIP steel is formed with specialized thermal treatments that allow for the formation of austenite, ferrite, bainite and perhaps martensite [2÷4]. The advantageous strength to ductility ratio in TRIP steels results from strain induced transformation of metastable retained austenite to martensite during plastic deformation (TRIP effect – ***TRansformation Induced Plasticity***).

2. Material and applied drawing technology

The material used to the investigation was wire rod about diameter 6.3 mm. The chemical composition of the used steel in the investigation is presented in table 1. Table 1.

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TABLE 1

The chemical composition of steel

C	Mn	Si	P	S	Cu	Ni	Cr	Mo	Sn	Al	N
0.09	1.57	0.90	0.01	0.008	0.02	0.01	0.003	0.007	0.006	0.001	0.003

Two-step heat treatment which allows obtaining in wire rod TRIP type structure, was realised in laboratory conditions in Czestochowa University of Technology in resistance furnaces. The scheme of two-step heat treatment is shown on fig.1, whereas TRIP steel structure is resented on figure 2. The volumetric phases contain in multiphase structure was estimated by MET-ILO program, table 2.

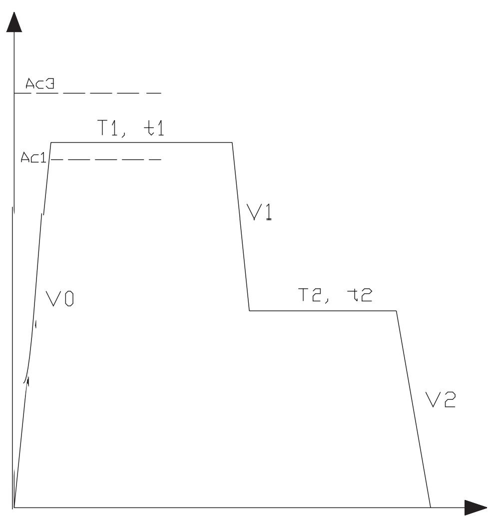


Fig. 1. Diagram of heat treatment wire rod in laboratory conditions, where: V_0=2 ^{0}C/s – heating rate, T_1= 760 ^{0}C – anealing temperature in intercritical range, t_1=240 s – anealing time in intercritical range, V_1=50 ^{0}C/s – speed of cooling from γ-α range to anealing temperature in bainitic range, T_2=410 ^{C} – anealing temperature in bainitic range, t_2=105 s – anealing time in bainitic range, V_2 – water quenching

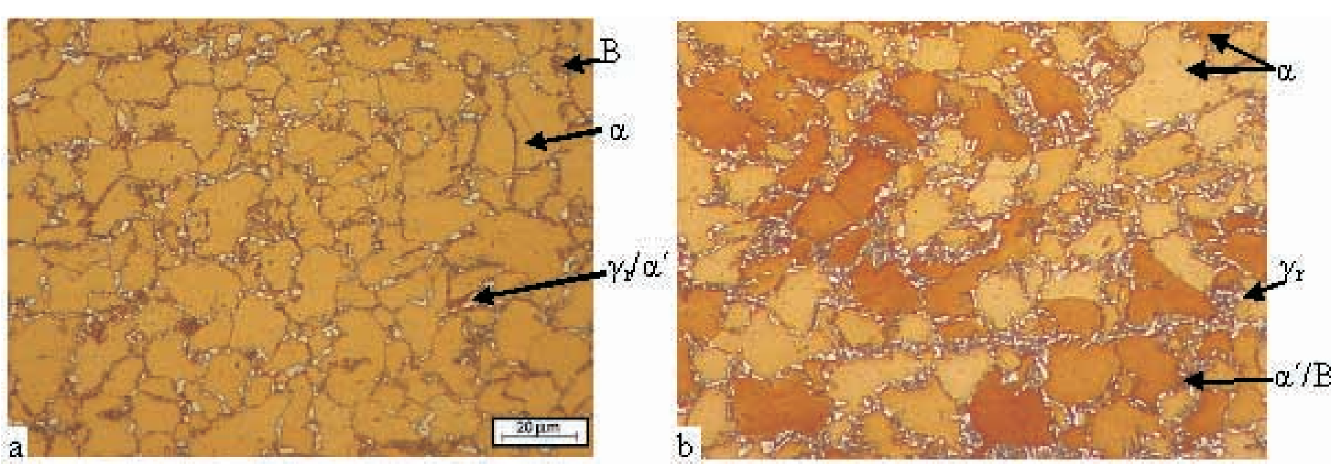


Fig. 2. TRIP type structure: a) LePer etched, b) nital+ metabisulfite sodium etched

TABLE 2

The volumetric phase contain Phase contain

Phase contain			
Ferrite, %	Bainite, %	Retained austenite + ~Martensite[1], %	Retained austenite[2] %
74.6	16.8	8.6	7.8

[1] etched LePera reagent;

[2] etched nital+ metabisulfite sodium reagent

After heat treatment and metallographic investigation which confirmed obtained TRIP type structure, TRIP steel wires drawn with different values of single draft from diameter 6.3 mm to 1.9 mm by using classical die with sintered carbides about angle 2α=12°. In table 3, the main parameters of drawing process are shown, where: V_c – drawing speed, $G_{pśr}$ – medium single draft, G_c – total draft.

TABLE 3

The parameters of drawing process

Variant	Drawing method	V_c, m/s	Drafts number	$G_{pśr}$, %	G_c, %
A	Bull block	0.75	11	19.5	90.9
B	Bull block	0.75	17	12.9	90.9

TABLE 4

The distribution of single and total draft for wires from variant A

Draft number	0	1	2	3	4	5	6	7	8	9	10	11
ϕ wire, mm	6.3	5.6	5.0	4.5	4.0	3.6	3.23	2.93	2.53	2.3	2.1	1.9
G_p, %	–	21.0	20.3	19.0	21.0	19.0	19.5	17.7	25.4	17.4	16.6	18.1
G_c, %	–	21.0	37.0	49.0	59.7	67.4	73.7	78.4	83.7	86.7	88.9	90.9

TABLE 5

The distribution of single and total draft for wires from variant B

Draft number	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
ϕ wire, mm	6.3	6.0	5.6	5.2	4.8	4.5	4.2	4.0	3.7	3.4	3.23	2.93	2.7	2.53	2.3	2.1	2.0	1.9
G_p, %	–	9.3	12.9	13.8	14.8	12.1	12.9	9.3	14.4	15.6	9.8	17.7	15.1	12.2	17.4	16.6	9.3	9.8
G_c, %	–	9.3	21.0	31.9	42.0	49.0	55.6	59.7	65.5	70.9	73.7	78.4	81.6	83.7	86.9	88.9	89.9	90.9

3. The influence of value of single draft on TRIP effect

In order to determine the influence of the value of a single draft on TRIP effect, in work the metallographic investigations of drawn wires were done. To estimate the rate of transformation retained austenite into martensite during drawing of TRIP steel wires after certain drafts, two-step steel etching was used e.g. natal + metabisulfite sodium which allows to making an identification of retained austenite. For each variants made 10 structure photographs were taken and then photographs were analysed in MET-ILO program. The data investigation (medium from 10 areas) defining the amount of retained austenite in structure of wires V_γ [%] in function total draft was shown in table 6 and on fig.3

TABLE 6

The contain of retained austenite in TRIP structure wires drawn according to variant A and B vs total draft

Variant	G_c, %	0	21.0	37.0	42.0	49.0	59.7	73.9
A	V_γ, %	7.84	2.33	1.31	–	0.76	0.23	–
B		7.84	2.81	–	1.32	1.12	0.62	0.31

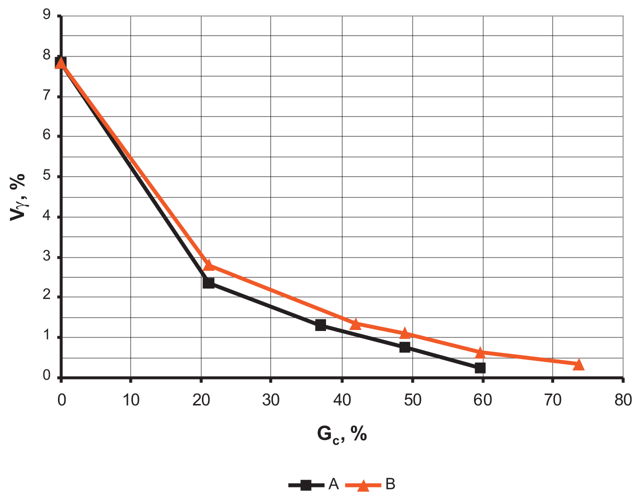


Fig. 3. The amount of retained austenite in structure TRIP steel wires drawn according to variant A and B vs total draft

On the basis of data investigation shown in fig. 3 it was found that the value of a single draft in drawing process influences on TRIP effect. For wires from variant B, in comparison to wires from variant A, lower rate of phase transformation was found. The differences between variants for total draft 21 % were approximately 6 %, and for Gc=49 % approximately 5 %.

The decrease of rate transformation in wires drawn according to variant B allowed to extend TRIP effect to total draft 70 %. It should have an effect on theirs plasticity properties. It was supposed that the factor which cause a faster phase transformation is a bigger non-dilatation strain. The increase of non-dilatation strain causes the increase of total strain, and this is the reason why wires from variant A TRIP effect finished with much lower total draft.

4. The mechanical properties of TRIP steel wires

In order to estimate the influence of the value of a single draft on the mechanical properties of wires with TRIP effect mechanical testing was done, in which defined: tensile strength R_m, yield strength $R_{0,2}$, contraction Z, uniform elongation A_r, total elongation A_{100}, number of twist N_t and number of band N_b. The findings of mechanical properties has shown in table 7÷8.

TABLE 7

The mechanical properties of wires drawn according to variant A ($G_{pśr}$=19,5 %)

Variant	ϕ wire, mm	G_c, %	$R_{0,2}$, MPa	R_m, MPa	Z, %	Ar, %	A100, %	N_t	N_b
A0	6.3	–	319.2	570.3	78.3	20.11	25.2	28.4	14.2
A4	4.0	59.7	803.3	972.5	56.7	2.61	3.23	5.6	8.6
A7	2.93	78.4	1020.5	1171.6	49.7	2.09	2.74	13.1	8.5
A8	2.53	83.9	1071.2	1225.6	49.0	1.74	2.20	21.2	12.0
A11	1.9	90.9	1184.4	1347.4	41.9	2.67	3.28	16.8	7.3

TABLE 8

The mechanical properties of wires drawn according to variant B ($G_{pśr}$=12,9 %)

Variant	ϕ wire, mm	G_c, %	$R_{0,2}$, MPa	R_m, MPa	Z, %	Ar, %	A100, %	N_t	N_b
B0	6.3	–	319.2	570.3	78.3	20.11	25.2	28.4	14.2
B7	4.0	59.7	771.6	951.4	57.4	3.01	3.32	7.5	10.3
B11	2.93	78.4	964.3	1145.3	51.2	2.37	2.74	15.5	9.8
B13	2.53	83.9	1019.5	1195.2	49.7	2.02	2.27	18.5	10.8
B17	1.9	90.9	1127.2	1309.2	42.5	2.99	3.51	14.2	6.3

On the basis of data investigation shown in table 7÷8 it was found that the application of higher single drafts in drawing process cause a small increase of strength properties of TRIP steel wires, approximately 2÷5 %.

Analysing the obtained values Z, A_r and A_{100} TRIP steel wires it can be affirmed that the application in drawing process lower single drafts causes an increase of plasticity properties of TRIP steel wires. The wires drawn according to variant B have approximately 7÷11 % higher uniform and total elongation.

The obtained data investigation from the tensile test allows to find that the value of single drafts has an influence on technological properties (N_t, N_b). Up to total draft 80 % wires from variant B ($G_{pśr}$=12,9%) have higher value of number of twist and number of band, approximately 20 %. However, for the total draft above 80 % a significant increase of N_t and N_b values for wires drawn with higher single drafts (variant A) approximately 13 % was found. Presumably to total draft 80 %, higher N_b and N_t values of wires from variant B are connected with their better plasticity properties, whereas crossing of the limit G_c=80 % work hardening, which is bigger for wires drawn with higher single drafts (variant A), is the factor that influences decisively on obtained number of twist and band.

5. The theoretical analysis of wiredrawing process

For better estimation of the influence of drawing speed on properties TRIP steel wires in the work, modelling of wire drawing process (in Drawing 2D program) has been carried out. It has been estimated: temperatures T, drawing stress σ_c, non-dilatation strain ε_{xy} and longitudinal residual stresses σ_w drawn wires. Used in program model multi passes drawing (with a few following after themselves single draft) allows to dissolve coastal task with the range of theory of plastic forming with complied contact, friction and transfer heat between material and tool conditions, and also heating material which is related to plastic strain.

In order to reflect the real work hardening in wire drawing process, curves work hardening determined from changing of yield point $R_{0,2}$ in function true strain ε were into program. The value of $R_{0,2}$ of wires after certain drafts was estimated in a tensile test and next cubic multinomial was approximated. The results have been shown on fig.4

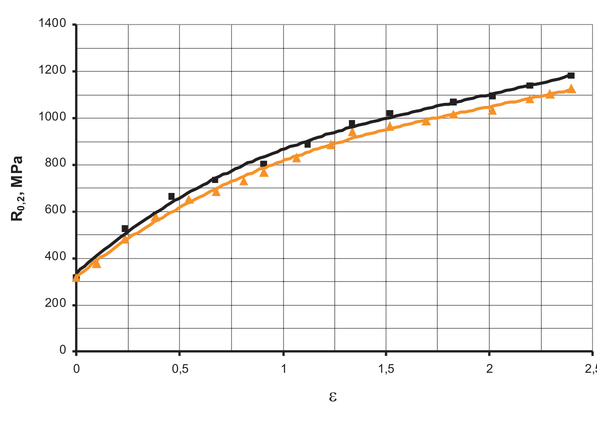
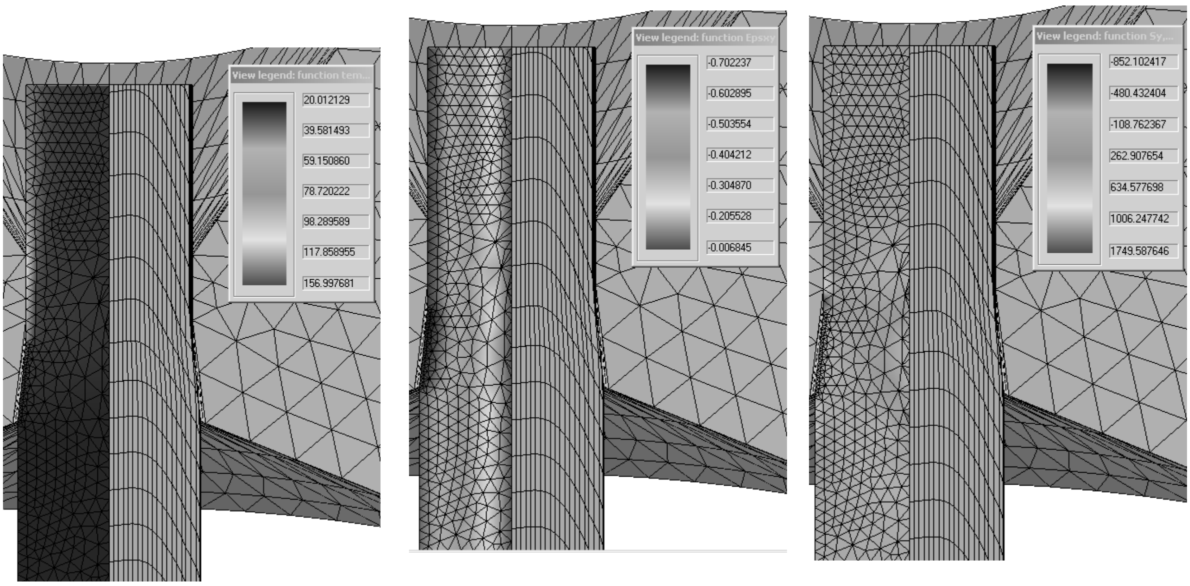


Fig. 4. The relationship yield point $R_{0,2}$ vs true strain ε for TRIP steel wires drawn according to variant A and B

The assumption that drawing process is realising in die about angle $2\alpha = 12°$ and coefficient of friction μ=0,08 was made. The initial temperature of wire before the entrance to the first and the following dies was 20°C. On fig. 5 shown the examples of distributions of temperature, non-dilatation strain ε_{xy} and longitudinal stresses for ϕ1,9 mm wires drawn according to variant A11 were shown.



Temperature non-dilatation strain longitudinal stresses

Fig. 5. The distributions of temperature, non-dilatation strain ε_{xy} and longitudinal stresses for ϕ1,9 mm wires drawn according to variant A11

On fig.6 the changing temperature of wire (T_{surf} and T_{axis}) in total draft function for variant A and B has shown.

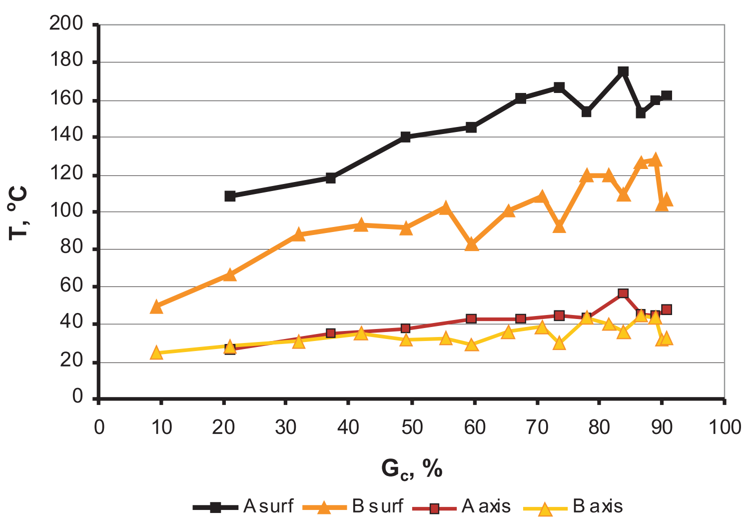


Fig. 6. The changing temperature on the surface and the axis TRIP steel wires on exit form gauging cylinder of die for wires drawn according to variant A and B in total draft function

On fig. 6 it was shown that the wires drawn according to variant A ($G_{pśr}$=19,5 %) in the comparison to the wires of variant B ($G_{pśr}$=12,9 %) have higher temperature, on the surface and in the axis the increase was about 25 %. The higher values of temperature in the axis and on the surface of wires from variant A, in the comparison to variant B, can weigh in a relevant way against the internal stresses. On fig.7÷8 drawing stresses σ_c and longitudinal residual stresses σ_w in function total draft for wires from variant A and B has been shown.

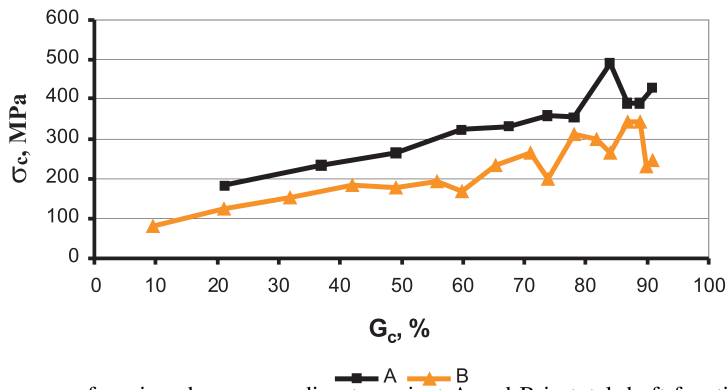


Fig. 7. The changing drawing stresses σ_c for wires drawn according to variant A and B in total draft function

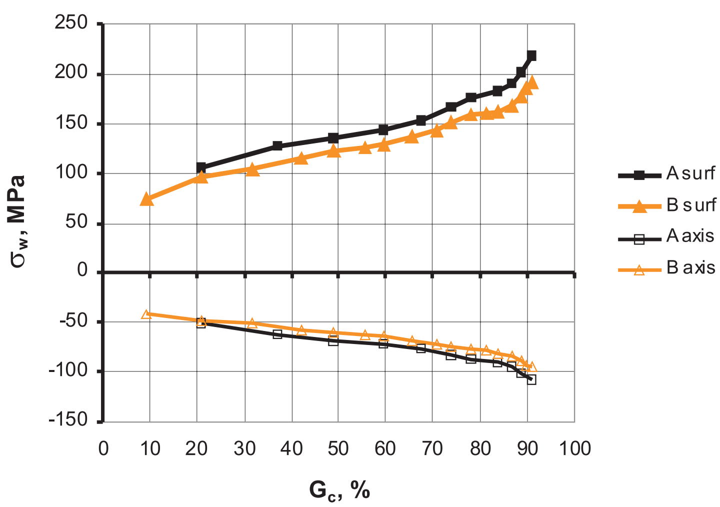


Fig. 8. The changing residual stresses σ_w for wires drawn according to variant A and B in total draft function

On the basis of data investigation shown on fig. 7÷8 it was found that the reduction of the value drawing stresses in wires drawn with smaller single drafts (variant B) significantly have an effect on the value of longitudinal internal stresses. For the wires form variant B, in the comparison to the wires from variant A, about 10 % decrease of longitudinal residual stresses on surface and in axis of wire has been observed.

The values of internal stresses have the influence on technological properties. The increase (to total draft G_c=80 %) of number of twists and number of bands in wires drawn according to variant B ($G_{pśr}$=12,9 %), in the comparison to wires from variant A ($G_{pśr}$=19,5 %)with their lower longitudinal internal stresses. After crossing the total draft G_c=80 %, better technological properties show wires from variant A because the factor which mainly influences on obtained number of twist and band is tensile strength.

On fig. 9 the changing of non-dilatation strain ε_{xy} in function total draft for wires drawn according to variant A and B has been shown.

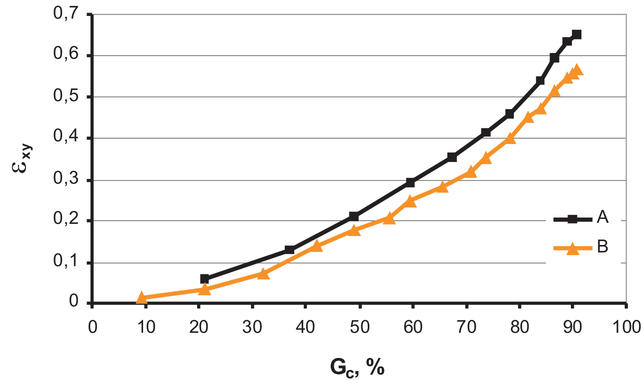


Fig. 9. The changing non-dilatation strain ε_{xy} on surface wires drawn according to variant A and B in total draft function

The data investigation received obtained from the numerical simulation allows to find that the value of single drafts fundamentally influences on non-dilatation strain. For wires from variant B ($G_{pśr}$=12,9 %) in comparison to wires from variant A ($G_{pśr}$=19,5 %) the increase of non-dilatation strain of approximately 12 % has been noted. The increase have a direct effect on strength properties of drawn wires. The increase of non-dilatation strain of wires causes their bigger work hardening. So the increase of tensile strength wires from variant A, in comparison to wires from variant B should be connected with their bigger values of non-dilatation strain.

6. Conclusion

1. The value of a single draft influences on mechanical properties TRIP steel wires. Wire drawn with higher single drafts (variant A) in comparison to wires drawn with smaller single drafts (variant B) show better strength properties ($R_{0,2}$ and R_m), approximately 2÷5 %.
2. The increase of strength properties of wires from variant A caused their deterioration of plasticity properties. The usage in drawing process of TRIP steel wires smaller single drafts (variant B) improves their plasticity properties. And it was confirmed with: contraction, uniform elongation (the increase of A_r i A_{100} values 7÷11 %).
3. The value of a single draft influences on the number of twists and bands TRIP steel wires. The higher values of Nt and Nb wires from variant B ($G_{pśr}$=12,9 %), in range G_c=0÷80 %, are related to their better plasticity properties and lower values of longitudinal residual stresses. However, after G_c=80 % the decisive factor is work hardening which is bigger for wires drawn with higher single drafts (variant A).
4. The higher temperature of wires drawn according to variant A caused the increase of longitudinal residual stresses.
5. The increase of strength properties e.g. R_m and $R_{0,2}$ of wires form variant A is connected with the occurrence bigger non-dilatation strain in them.
6. The lower values of non-dilatation strain in wires drawn according to variant B could cause the improvement of their technological properties, especially in range G_c=0÷80.
7. The higher speed of phase transformation retained austenite into marteniste in wires drawn with higher single drafts is the result of bigger non-dilatation strain in them.

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