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POLSKA AKADEMIA NAUK

A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S

Volume 56 2011 Issue 3

DOI: 10.2478/v10172-011-0091-z

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THE INFLUENCE OF THE HIGH DRAWING SPEED ON MECHANICAL-TECHNOLOGICAL PROPERTIES OF HIGH CARBON STEEL WIRES

WPŁYW DUŻEJ PRĘDKOŚCI CIĄGNIENIA NA WŁASNOŚCI MECHANICZNO-TECHNOLOGICZNE DRUTÓW ZE STALI WYSOKOWĘGLOWEJ

In this work the influence of the drawing speed on mechanical-technological properties of high carbon steel wires has been assessed. The drawing process of ϕ5.5 mm wires to the final wire of ϕ1.6 mm was conducted in 11 passes, in industrial conditions, by means of a modern Koch multi-die drawing machine. The drawing speeds in the last passes were: 5, 10, 15 and 20 m/s. For ϕ1.6 mm wires the investigation of mechanical-technological properties has been carried out, in which yield strength, tensile strength, uniform and total elongation, reduction of area, the number of twists and the number of bends were determined. On the basis of numerical analyses wire drawing process, the influence of the drawing speed on effective strain has been determined. The investigations have shown the essential influence of high drawing speed on mechanical-technological properties of high carbon steel wires. In the case of the wires drawn with speed 20 m/s the increase by 15% their strength properties and the decrease of plasticity properties about 25% have been noted. It has been shown that the increase of strength properties in wires drawn with high drawing speed is related to the occurrence in their bigger effective strain. The data of investigations prove the negative influence of high drawing speed on technological properties. The wires drawn with 20 m/s do not comply with the internal standard connected with torsional strength of wire, and despite having high strength properties, they cannot be used as the material for ropes, tyre cords or springs. The obtained data investigation can be applied in wire industry while implementing the new technologies of high speed drawing process of high carbon steel wires.

Keywords: drawing of high carbon wires, drawing speed, mechanical properties, number of twists

W pracy określono wpływ dużej prędkości ciągnienia na własności mechaniczno-technologiczne drutów ze stali wysokowęglowej. Proces ciągnienia drutów o średnicy 5,5 mm na średnicę końcową 1,60 mm zrealizowano w 11 ciągach, w warunkach przemysłowych, na nowoczesnej ciągarce wielostopniowej Kocha. Prędkości ciągnienia na ostatnim ciągu wynosiły odpowiednio: 5, 10, 15 i 20 m/s. Dla drutów ϕ1,60 mm przeprowadzono badania własności mechaniczno-technologicznych, w których określono umowną granicę plastyczności, wytrzymałość na rozciąganie, wydłużenie równomierne i całkowite, przewężenie, liczba skręceń i liczbę zgięć. Natomiast w oparciu o analizę teoretyczną procesu ciągnienia określono wpływ prędkości ciągnienia na intensywność odkształcenia. Przeprowadzone badania wykazały istotny wpływ dużej prędkości ciągnienia na własności mechaniczno-technologiczne drutów wysokowęglowych. Dla drutów ciągnionych z prędkością 20 m/s odnotowano wzrost o 15% ich własności wytrzymałościowych oraz spadek własności plastycznych o 25%. Stwierdzono, że wzrost własności wytrzymałościowych w drutach ciągnionych z dużymi prędkościami związany jest z ich większą intensywnością odkształcenia. Uzyskane wyniki badań świadczą o negatywnym wpływie dużej prędkości ciągnienia na własności technologiczne drutów. Druty ciągnione z prędkością 20 m/s nie spełniają norm branżowych dotyczących wytrzymałości drutu na skręcenie, co mimo ich wysokich własności wytrzymałościowych dyskwalifikuje je jako materiał na liny, kord, sprężyny. Uzyskane wyniki badań mogą być wykorzystane w przemyśle ciągarskim przy wdrażaniu nowych technologii szybkościowego ciągnienia drutów ze stali wysokowęglowych.

1. Introduction

The economy demanded on wire manufactures intensification of drawing process, which can be realized by the increase of value of single drafts and drawing speed [1÷2]. The modern multi-pass drawing mill makes possible to dry drawing of wire with drawing speed above 25 m/s. In practice in order to gain certain industry standards wire manufactures limit the drawing speed to 10-15 m/s in the last pass.

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The available literature on the subject indicate that high drawing speed can cause the change of the drawing conditions and deteriorate properties of high carbon steel wires [3÷6]. In this process the intensive heating of sub-layer surface of wire appears. It leads to deteriorating of lubrication conditions and cause also the increase of wire brittleness.

Therefore, the present work makes an attempt to assess the effect of high drawing speed on the mechanical and technological properties and effective strain of wires. The drawing process was realized in industry conditions according to typical technology.

2. Material and applied drawing technologies

The material applied for the investigation was of C72 high carbon steel wire rod. Before drawing, the wire rod was patented, itched and boraxed. The drawing process of ϕ5.5mm wires in the final wire of ϕ1.6mm was conducted in 11 passes, in industrial conditions, by means of a modern Koch multi-die drawing machine. The drawing speeds in the last passes were: variant **A** → **5** m/s, variant **B** → **10** m/s, variant **C** → **15** m/s, variant **D** → **20** m/s.

Individual drafts, D_i, and total drafts, D_t, are summarized in Table 1 while drawing speeds on individual drafts for wires from variants A÷D are presented in Table 2 and in Fig. 1. In drafts 1÷4 calcareous lubricant CONDAT Vicafil SUMAC 2T was applied while in drafts 5÷11 soda lubricant TRAXIT SL 202 BS was used.

TABLE 1

Distribution of individual drafts and total drafts for wires from variant A÷D

Draft number	0	1	2	3	4	5	6	7	8	9	10	11
ϕ, mm	5.50	4.92	4.38	3.90	3.50	3.12	2.80	2.50	2.22	2.00	1.78	1.60
D_i, %	–	19.98	20.75	20.72	19.46	20.54	19.46	20.28	21.15	18.84	20.79	19.20
D_t, %	–	19.98	36.58	49.72	59.50	67.82	74.08	79.34	83.71	86.78	89.53	91.54

TABLE 2

Drawing speeds (V, m/s) for variant A÷D

Variant	Draft number										
	1	2	3	4	5	6	7	8	9	10	11
A	0.53	0.67	0.84	1.05	1.32	1.63	2.05	2.60	3.20	4.04	**5**
B	1.06	1.34	1.69	2.09	2.63	3.27	4.10	5.20	6.40	8.08	**10**
C	1.59	2.00	2.53	3.14	3.95	4.90	6.14	7.80	9.60	12.12	**15**
D	2.12	2.67	3.37	4.18	5.26	6.53	8.19	10.39	12.80	16.16	**20**

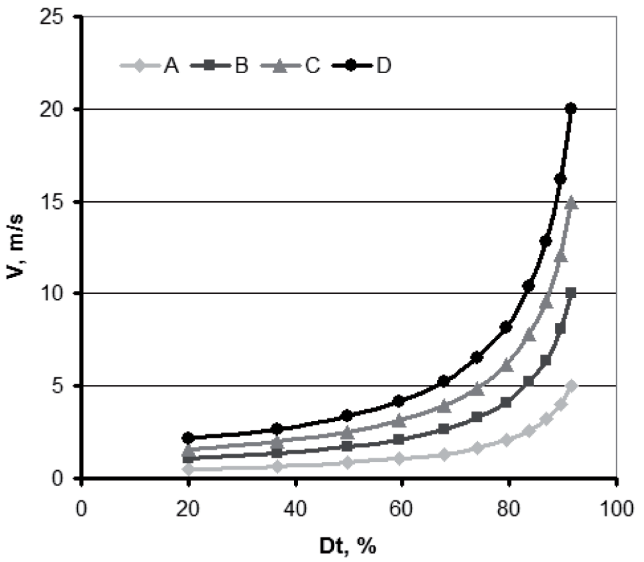

Fig. 1. Drawing speeds in total drafts function for wires from variant A÷D

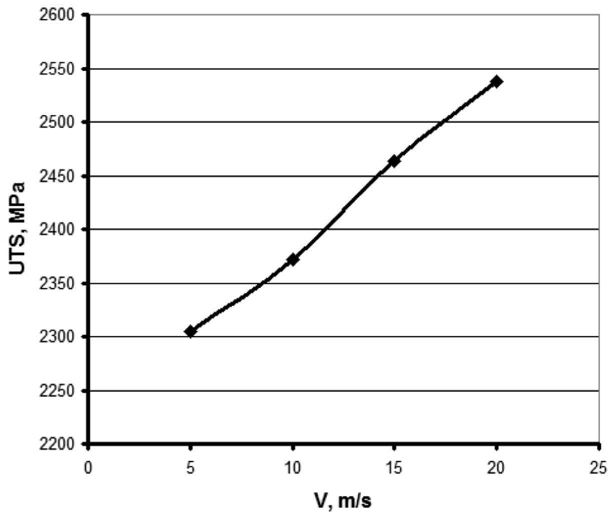

Fig. 3. Influence of drawing speed on ultimate tensile strength

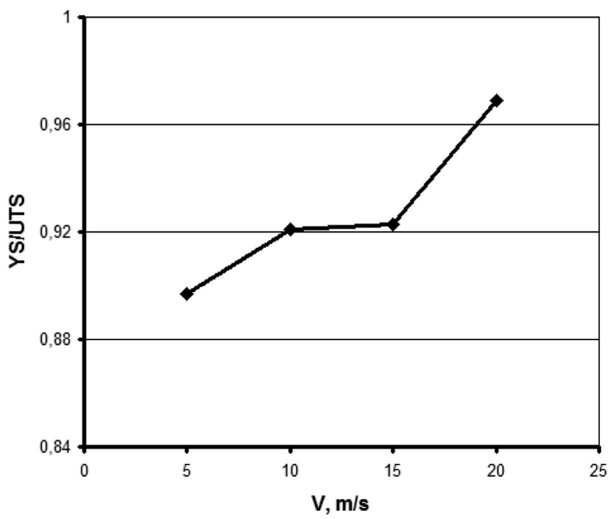

Fig. 4. Influence of drawing speed on coefficient YS/UTS

3. The mechanical-technological properties of drawn wires

In order to establish the effect of drawing speed on mechanical properties of wires, mechanical investigation was carried on by means of Zwick Z100 testing machine, according to PN-EN ISO 6892-1:2009 standard. For final wires ϕ1.6 mm, the following were determined: yield stress, YS; ultimate tensile strength, UTS; coefficient, YS/UTS; uniform elongation, EL_U; total elongation, EL_T; reduction of area, RA.

The changing of YS, UTS and YS/UTS in drawing speed function are presented in Fig. 2÷4.

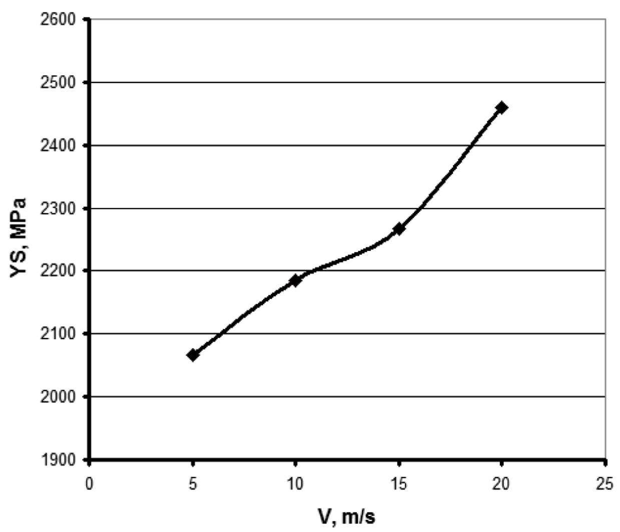

Fig. 2. Influence of drawing speed on yield stress

On the basis of Fig. 2÷4 it can be observed that the drawing speed influences essentially the strength properties of high carbon steel wires. The application of drawing speed V=20 m/s (variant D) results in an increase in their tensile properties, i.e. the yield stress and the ultimate tensile strength. The final wires from variant D (20 m/s), as compared to the wires from variants A (5 m/s), are distinguished by a yield point higher by 19% and an ultimate tensile strength higher by 10.1%, respectively.

Additionally in the work, the analysis of coefficient YS/UTS has been carried out. This parameter allows to estimate susceptibility of wire on plastic strain (smaller coefficient proves better plasticity properties of material). Fig. 4 proves the negative influence of drawing speed, especially above 15 m/s, on plasticity of wires. The wires from variant D have higher coefficient YS/UTS, approximately 8%. The parameters which can also prove the negative influence of drawing speed on plasticity properties were presented in Fig. 5÷7.

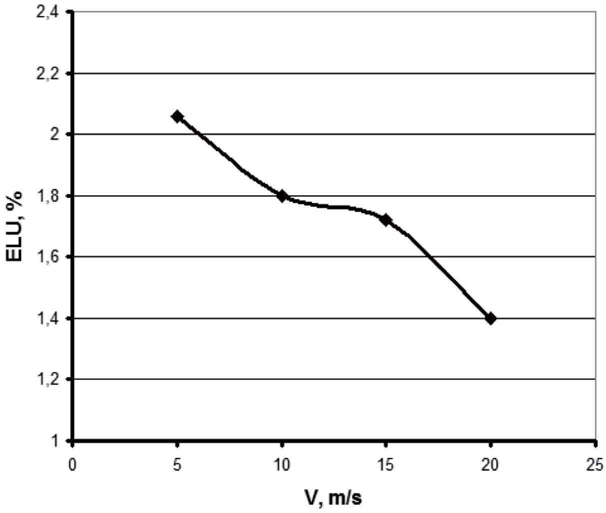

Fig. 5. Influence of drawing speed on uniform elongation

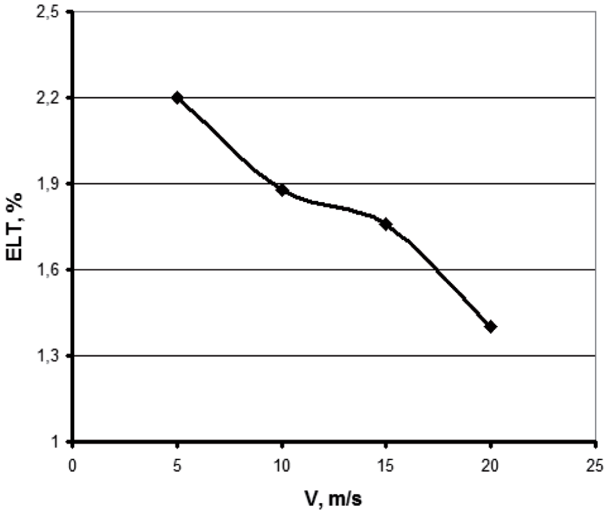

Fig. 6. Influence of drawing speed on total elongation

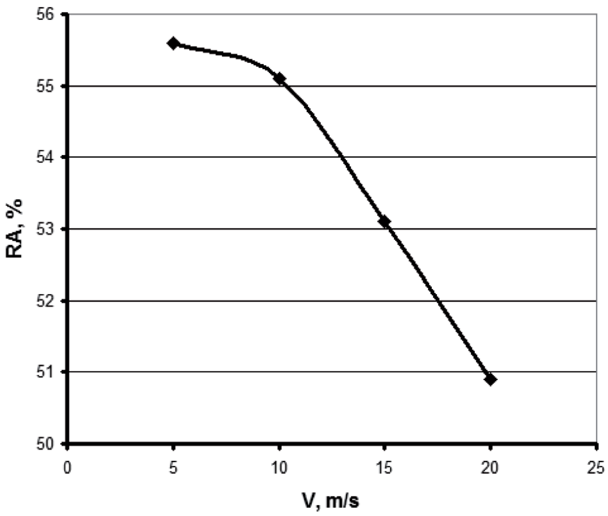

Fig. 7. Influence of drawing speed on reduction of area

It can be observed from Fig. 5÷7 that the increase of drawing speed deteriorates essentially the plasticity properties of high carbon steel wires. The final wires from variant D (20 m/s), as compared to the wires from variants A (5 m/s), are distinguished by an uniform elongation lower by 32%, a total elongation lower by 36% and a contraction lower by 8.5%, respectively. The worse plasticity properties for wires from variant D are related to their bigger work hardening (Fig. 2÷3).

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 manner, like 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. 8÷9.

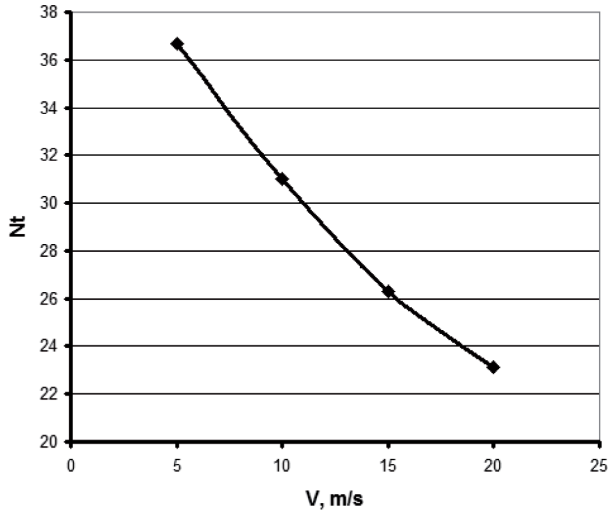

Fig. 8. Influence of drawing speed on number of twists

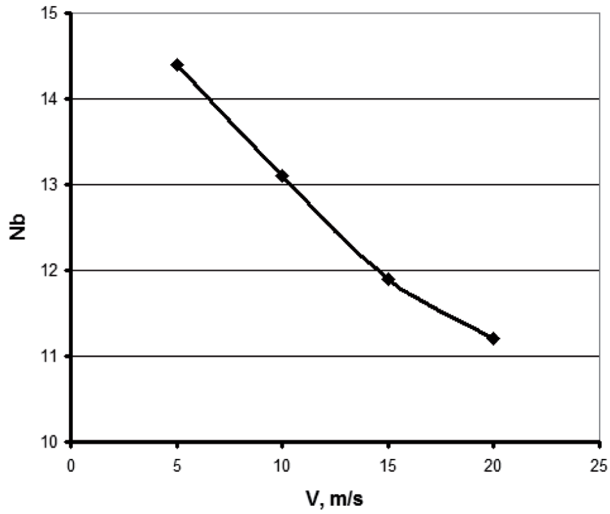

Fig. 9. Influence of drawing speed on number of bends

The tests carried out have shown that the drawing speed in the drawing process influences significantly the obtained number of twists and the number of bends of high carbon wires. Fig. 8÷9 indicates that increasing the drawing speed has an unfavourable effect on the technological properties. The wires from variant D (V=20 m/s), as compared with the wires from variants B (V=5 m/s), exhibit a number of twists lower by 37% and a number of bends lower by 22.2%, respectively. It should be underlined wires from variant D do not comply with the inner standard (i.e. PN-68/M-80021 standard), because for this variant obtained too small number of twists and number of bends.

The one of the factors which have a significant influence on mechanical-technological properties of drawn wires is the effective strain (intensity of strain). Therefore, the effect of the drawing speed on the effective strain in the high-carbon wire drawing process has been established within the present work.

4. The theoretical analysis of wiredrawing process

The experimental determination of the distribution of effective strain on the cross-section of wire being drawn is difficult to accomplish, therefore the present work proposes a theoretical analysis of this problem based on the software Drawing 2D [7]. Used in the program a model of multi passes drawing 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.

Simulation of the multi-stage drawing process was performed for a wire with plastic properties corresponding to those of the pearlitic-ferritic steel C72 (~0.72%C). It was assumed that the drawing process took place with the identical distribution of individual and total drafts to that of the experimental tests (Table 1÷2), with a friction coefficient of μ=0.065÷0.09 [6].

Fig. 10 shows the effective strain distributions on the cross-section of ϕ1.6 mm wires drawn according to variant A÷D.

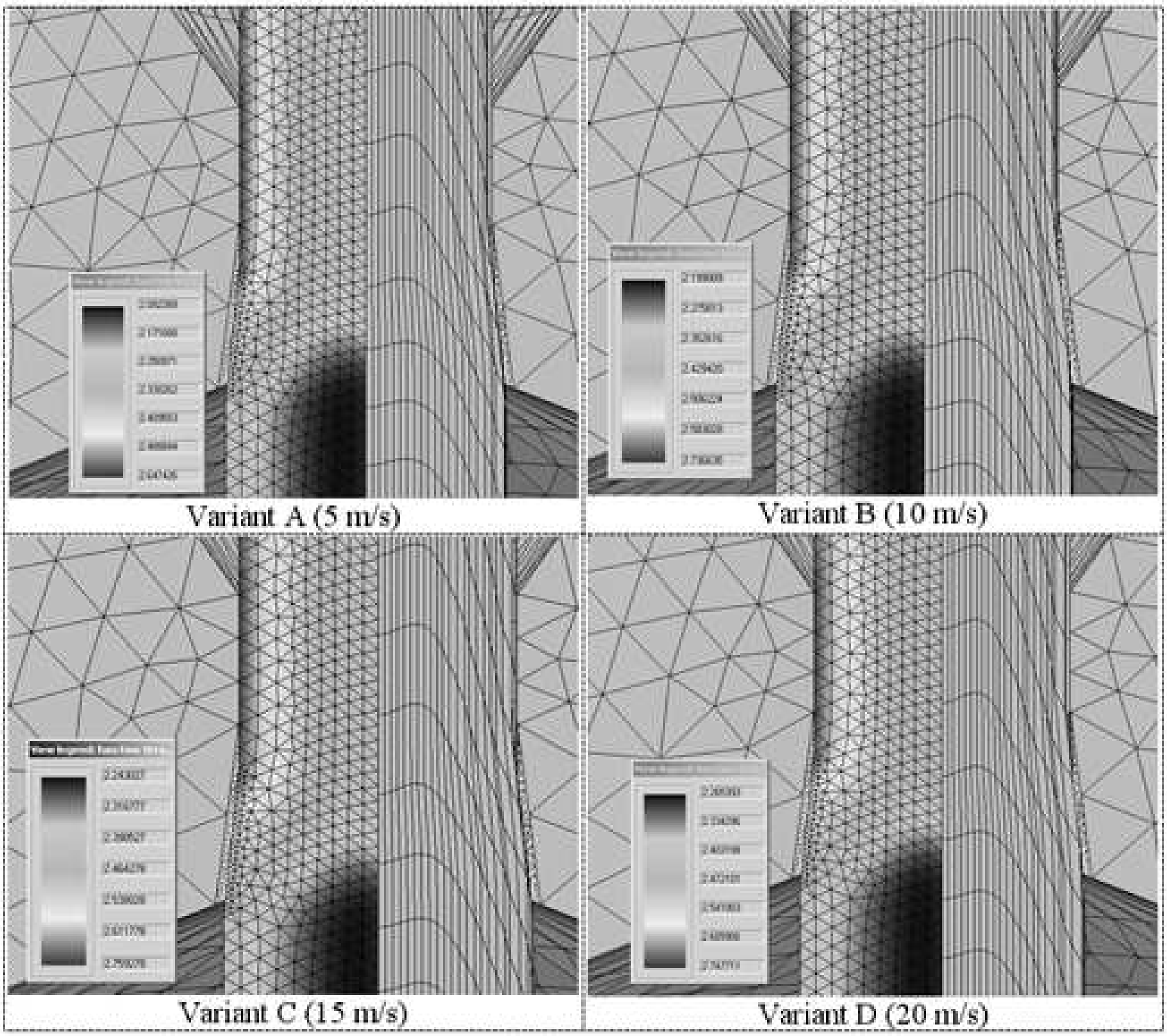

Fig. 10. Effective strain distributions on the cross-section of ϕ1,6 mm wires drawn according to variant A÷D

As the Drawing 2D software, with the visualization of distribution of a particular parameter, provides the possibility of reading out the numerical value of that parameter for each of the triangular grid nodes, the effective strain on the wire surface was determined in the work. The results have been shown in Fig. 11.

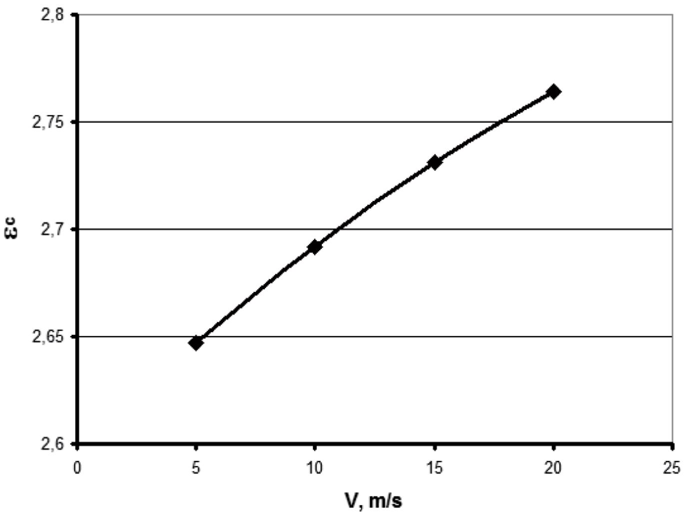

Fig. 11. Influence of drawing speed on effective strain ε_c on wire surface

On the basis of data investigation shown in Fig. 11 it was found that the drawing speed have the influence on effective strain. The biggest differences were found in the sub-layers of drawn wires. Wires from variant D (V=20 m/s), as compared with the wires from variants B (V=5 m/s), exhibit an effective strain higher by 4.5%. The increase of effective strain in wires drawn with drawing speed 20 m/s provides no doubt connected with a non-dilatational of strain, which can cause additional work hardening.

5. Conclusions

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

1. The drawing speed influences essentially on the mechanical properties of high carbon steel wires. The wires from variant D (V=20 m/s), as compared to the wires from variants A (V=5 m/s), are distinguished by a yield stress higher by 19% and an ultimate tensile strength higher by 10%, respectively. The increase of strength properties of wires from variant D caused their deterioration of plasticity properties, an elongation lower by 34% and a reduction of area lower by 8.5%, respectively.
2. The increase of strength properties in wires drawn with high drawing speed is related to the occurrence of their bigger effective strain.
3. The technological properties, i.e. the number of twists and the number of bends, are significantly influenced by the drawing speed. In the case of the wires from variant D the decrease of a number of twists by 37% and a number of bends by 22.2%, have been noted as compared to variant A.
4. The wires drawn with the speed 20 m/s do not comply the inner standard connected with tortional strength of wires, and despite having high strength properties, they cannot be used as the material for ropes, tyre cords or springs.
5. The obtained data of investigations can be applied in wire industry while implementing the new technologies of high speed drawing process of high carbon steel wires.

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Received: 10 February 2011.