Development of energy- and resource-saving production technology of high-strength strands

Parusov E.V.

PhD in Technical Sciences

Parusov V. V.

D.Sc. in engineering

Sagura L. V.

PhD in Technical Sciences
Institute of Ferrous Metallurgy of National Academy of Sciences of Ukraine

Derevyanchenko I. V.

Dolgiy S. V.

JSC Moldova Steel Works

Gremechev S. A.

Dem'yanova L. I.

HF PJSC "PA "Stalkanat-Silur" plant "Silur"

Abstract
In order to improve energy- and resource-saving efficiency of production of high-strength prestressing cables (strands), production technology of high-carbon wire rod without supplementation of vanadium and/or chromium was developed. It is shown that for a wire rod of steel grade 85-1 microalloyed by boron, the same structure (dispersion perlite) and mechanical properties as for wire rod with the addition of vanadium and/or chromium can be obtained.
Processing of wire rod of steel grade 85-1 with diameters 8.0, 10.0 and 11.0 mm under conditions

of HF PJSC “PA “Stalkanat-Silur” plant “Silur” showed satisfactory processability when drawing. Stabilized strands of high strength with diameters 9.3, 12.5 and 15.2 mm meet the requirements of prEN 10138-3:2005.
Keywords: HIGH-STRENGTH STRANDS, HIGH-CARBON WIRE ROD, CHEMICAL COMPOSITION, MECHANICAL PROPERTIES

High-strength strands are intended for perception of big tensile forces in the constructions and their transmission to support contours, anchor nodes and anchors. They are characterized by rather small cross section and weight. Such properties of strands are provided due to high strength characteristics of wire rod and wire, which strands are made of [1].

For obtaining high-strength wire and strands, high-carbon wire rod, which is subjected to patenting by hardware processing according to traditional technology for obtaining sorbitol structure, is used. At that, when drawing, the wire rod durability and technological plasticity increases.

Recently, the high-carbon wire rod, sorbitized from rolling heat is popular with domestic and foreign hardware enterprises as it allows reaching the considerable energy- and resource-saving.

The wire rod with strength ≥ 1150 N/mm^2 is necessary for production of high-strength strands by prEN 10138-3:2005 (temporal tearing resistance ≥ 1770 N/mm^2). As for production, wire rod of nominal diameter ≥ 8.0 mm is usually used, the problem of providing of the required durability of initial wire rod is complicated because of difficulty of obtaining the same degree of dispersion of perlite in this wire rod as in wire rod with diameter ≤ 5.5 mm.

Therefore, producers of the high-carbon wire rod intended for manufacture of high-strength wire for prestressing strands purposely add vanadium and/or chromium into steel for the purpose of increase of durability of wire rod.

In earlier published paper [2], comparative research of qualitative characteristics of the high-carbon wire rod applied for production of prestressing strands of the following leading producers was conducted: JSC “Severstal” (Russian Federation), FNsteel (Finland), ArcelorMittal (Germany), JSC “Moldova Steel Works” (MSW). It is established that wire rod of JSC “Severstal” production is microalloyed by vanadium (0.065%); FNsteel wire rod iron is microalloyed by vanadium (0.075%) also contains the targeted additive of chromium (0.18%); the wire rod of ArcelorMittal production contains only the targeted additive of chromium (0.22%).

From the point of view of resource-saving, alloying by chromium is more preferable than by vanadium.

The production technology of the high-carbon wire rod which does not contain components of chromium and/or vanadium and not requires patenting by hardware processing was developed for increase in energy- and resource-saving under the conditions of MSW. With use of specially developed technology, pilot batches of wire rod with diameters 8.0, 10.0 and 11.0 mm made of steel of grade 85-1 (TU U 27.1-4-519-2002) were produced.

The chemical composition and mechanical properties of wire rod are presented in Tables 1 and 2 respectively.

Table 1. Chemical composition of wire rod made of 85-1 steel

Wire rod diameter, mm	Chemical composition, % of mass												
	C	Mn	Si	Cr	Ni	Cu	Ti	Al	P	S	N	B	$C_э$
8; 10; 11	0,866	0,667	0,15	0,03	0,06	0,13	0,001	0,002	0,011	0,007	0,007	0,0013	0,999

Table 2. Mechanical properties of wire rod made of 85-1 steel

Wire rod diameter, mm	Mechanical properties *		
	Temporal resistance, N/mm^2	Percent elongation, %	Percent reduction, %
8	<u>1140-1250</u> 1200	<u>10-12</u> 11	<u>32-35</u> 33
11	<u>1140-1180</u> 1160	<u>8-9</u> 9	<u>26-32</u> 29

11	1140-1180 / 1160	8-9 / 9	26-32 / 29

* in numerator the minimum and maximum values, in a denominator – averages are provided

The detail metallographic analysis of wire rod was conducted. The evaluation of quantity of perlite of 1 point (sorbite) was performed by two techniques: according to appendix B TU 27.1-4-519-2002 and DIN EN ISO 16120-1:2011.

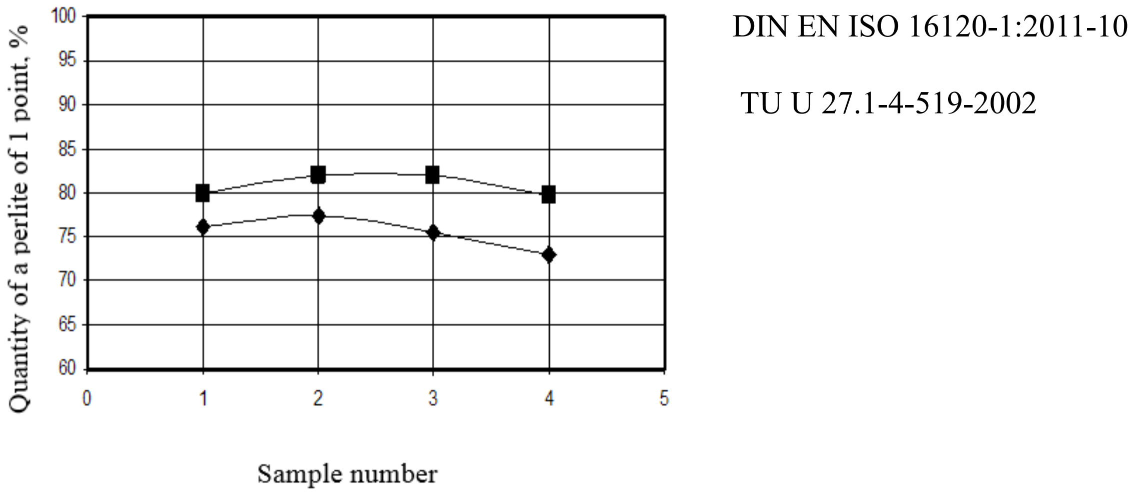
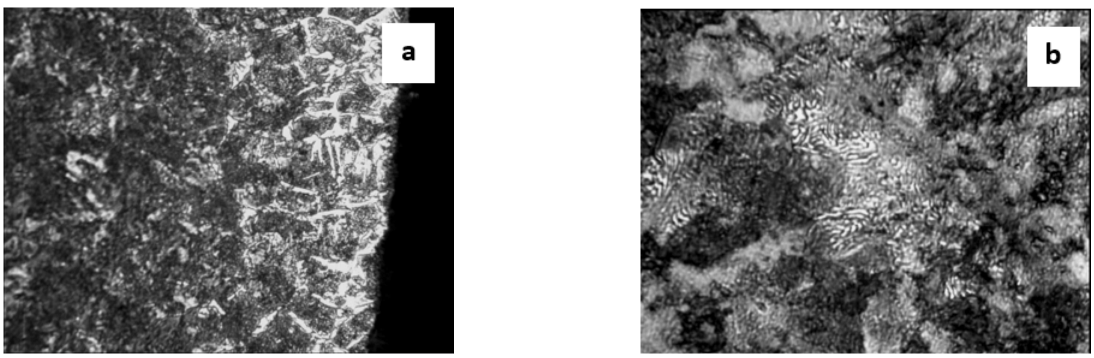


Figure 1. Quantity of perlite of 1 point which evaluation was carried out by two techniques

According to the first technique, average quantity of perlite of 1 point in the researched wire rod is 75.6%, according to the second technique, it is 80.9%. As is seen, distinction in evaluation of perlite of 1 point by domestic and European techniques is about 5% (Figure 1).

The microstructure of surface (a) and central zone (b) of section of wire rod is presented in Figure 2.

Average depth of decarburized layer (DL) of surface of wire rod of all diameters was 0.40-0.49%. Because of low value of DL depth, the wire rod is sensitive to formation of deformation martensite on surface. In this regard, measures for preventing of formation of deformation martensite are provided by DIN EN ISO 16120-1:2011. They consist in application of cross-beams made of soft steel, vertical rising of wire rod bundles, wood block fillers between wire rod bundles and concrete shop floor.



x500 x1000

Figure 2. Microstructure of wire rod with diameter 11 mm

The cementite network was evaluated by method of comparison with standards of microstructure of template III of NF A 04-114 standard. The cementite network corresponded to class B (trace of iron carbide).

The evaluation of impurity of wire rod with non-metallic inclusions (NI) have shown that the silicates and oxides, which do not exceed 0.5 points in accordance with GOST 1778-70, are found out in the wire rod.

Processing of wire rod with diameters 8.0, 10.0 and 11.0 mm was carried out under the conditions of HF PJSC "PA "Stalkanat-Silur" plant "Silur" (hereinafter "Silur" plant) by method of direct drawing, i.e. without application of heat treatment (patenting).

After wire rod etching treatment and surface preparation drawing was carried out according to the following schemes: 8.0 mm → 3.05 (3.20) mm; 10.0 mm → 4.10 (4.25) mm; 11.0 mm → 5.0 (5.25) mm. Mechanical properties of finished wire are given in Table 3.

Table 3. Properties of wire made of rod with nominal diameters 8.0; 10.0 and 11.0 mm

Nominal diameter of wire rod, mm	Wire diameter*, mm	Temporal tearing resistance **, N/mm²
8,0	3,05 (3,20)	2030-2160 / 2090
10,0	4,10 (4,25)	1890-2130 / 2040
11,0	5,0 (5,25)	1940-2020 / 1980

* diameters of peripheral wires are specified without brackets, central ones are specified in brackets;
** in numerator the minimum and maximum values, in a denominator – averages are provided

As is seen from Table 3, properties of wire meet the requirements of technological instruction TI 285-MT-PR-109-2010 of "Silur" plant.

From the data provided in paper, it follows that degree of dispersion of perlite of steel 85 (TU U 27.1-4-519-2002) is almost the same as of C82D2 steel (HARDWARE 518/71915393-2010) microalloyed by vanadium [3]. Because of this, temporal resistance of wire with diameter 5.0 (5.25) mm applied for production of prestressing cables (strands) of steel 85 and S82D2 is also almost identical, despite lower level of deformation of wire rod in the first case (diameter of wire rod made of steel 85-1 is 10 mm; diameter of wire rod made of steel C82D2 is 12 mm) [3].

From wire of diameters shown in Table 3, lay of 7-wire high-strength strands by prEN 10138-3:2005 was carried out; strands were subjected to stabilizing.

Mechanical properties of the high-strength stabilized strands are presented in Table 4.

Table 4. Mechanical properties of prestressing strands made of 85 steel

Wire rod diameter, mm	Cable diameter, mm	Strength group, N/mm²	Breaking strength Fm, kN	Temporal resistance, N/mm²	Effort at conventional yield strength $F_{p0,1}$, kN	Complete relative lengthening before breaking, %
8	9,3	1860	102,1-102,9 / 102,6	1968-1979 / 1972	87,4-89,4 / 88,6	5,3-7,1 / 6,2
10	12,5	1860	178,7-181,6 / 180,4	1922-1953 / 1940	150,5-160,5 / 153,7	6,3-7,1 / 6,7
11	15,2	1770	254,2-257,5 / 256,6	1829-1852,6 / 1845,8	211,8-215,8 / 214,4	6,1-6,7 / 6,5

* in numerator the minimum and maximum values, in a denominator – averages are provided

From Table 4, it follows that 7-wire strands with diameters 9.3; 12.5; and 15.2 mm completely meet the requirements of European standard prEN 10138-3:2005.

Conclusions

1. It is shown that for a wire rod of steel grade 85 produced by specially developed technology, the same structure (dispersion perlite) and mechanical

properties as for wire rod C82D2 microalloyed by vanadium.

2. It is shown that because of lower depth of decarburized layer, the wire rod produced by special technology is more sensitive to formation of deformation martensite on surface that requires observance of safety precautions provided by DIN EN ISO 16120-1:2011.

3. Processing of wire rod with diameters 8.0; 10.0 and 11.0 mm by hardware processing showed satisfactory technological efficiency when drawing and compliance of temporal resistance to requirements of TI 285-MT-PR-109-2010 that is necessary for production of high-strength strands by prEN 10138-3:2005.

4. The stabilized high-strength strands with diameters 9.3, 12.5 and 15.2 mm made of wire rod of steel 85-1 produced by specially developed technology meet the requirements of prEN 10138-3:2005.

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