Development Of Technology For Producing Thermally Strengthened Reinforcement Rolled

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Abstract: The article discusses the results of research on the development of the chemical composition and mechanical properties of reinforcement No. 12 made of steel grade 22C, as well as the development of a technology for obtaining thermomechanically hardened coiled rebar. It is shown that the proposed profile provides better hardenability of the rolled section and increases the efficiency of water cooling. The best results in terms of mechanical properties were obtained for rolled products made of steel grade 460B. A method of hot rolling of steel and a method of production of reinforcing bars of increased strength are proposed, one of the important components of which is microalloyed vanadium in the range of 0.04-0.10%, which will ensure an increase in the strength level up to 30%. The results of mechanical tests of coiled reinforcing bars and comparative data on the mechanical properties of reinforcement No. 12 rolled on mill 320 are also presented. It is shown that the use of steel microalloyed with vanadium makes it possible to obtain reinforcing bars with an effective profile with a nominal diameter of 5.5—8.0 mm, class A500C, in a temperature range acceptable for the equipment of mill 150.

1.Introduction

One of the main ways to ensure a set of quality indicators of rolled products with significant savings in metal in consuming industries is heat treatment immediately after hot deformation. Heat treatment of rolled products in the stream of high-speed small-section wire mills (strengthening and softening) has found wide application at present. The priority in the development and implementation of technological processes for heat treatment of rolled products from carbon and economically alloyed steels belongs to the scientific school of thermists - metallurgists of the Institute of Ferrous Metallurgy of the National Academy of Sciences of Ukraine [1-3].

The development of new economical types of products, including those in accordance with the requirements of foreign standards, also predetermined the conduct of research and development work with a comprehensive study of the mechanical, technological and service characteristics of rolled products after various processing modes.

At present, European countries have switched or are moving to the production and use in construction of only one class of welded periodic profile steel B500 according to the European standard EM10080. At the same time, the manufacturer has the right to independently choose the technological scheme for the production of such steel and the type of periodic profile with the obligatory provision of weldability properties, mechanical and anchor characteristics and taking into account such factors as production volume, reinforcement diameter, resource saving and economic efficiency of the technology [4-5].

Until 2010, the metallurgical industry produced coil rebar of classes A-I, A-I, A-1I in the rolling industry with a diameter of 6, 8, 10 and 12 mm in accordance with GOST 5781-82. These fittings have been widely used in design and construction practice. In recent years, the volume of construction has increased significantly, however, rebar rebar has been produced in small volumes due to low profitability. Due to the lack of rebar rebar with a diameter of 6 and 8 mm of class A400 in the domestic market of Uzbekistan and the CIS countries, manufacturers of precast and monolithic reinforced concrete were forced to switch to the massive use of reinforcing wire of class BP-1 with a diameter of 5 mm instead of reinforcement No. 6 of class A4 and bar reinforcement No. 10, 12 of class A400 instead of reel reinforcement No. 8 of class A400. This replacement led to an increase in labor intensity, metal consumption and, as a consequence, the cost of construction. The experience of using reinforcing wire of class Bp-1 shows that, due to its low plasticity, brittle ruptures are not uncommon in places of technological bends and welded joints [6-7].

The high ductility of reinforcing steel is an important indicator when choosing a class of reinforcement for mass consumption. The use of reinforcing steel with increased ductility significantly reduces the risk of progressive destruction of elements of reinforced concrete structures, which makes it possible to increase the reliability of buildings and structures.

In recent years, there has been an increase in the production of reinforced concrete, including for prefabricated construction. The production and use of welded A500C class reinforcement in reinforced concrete structures has been mastered, the introduction of which instead of the widely used A400 class reinforcement allows saving on average 10% of reinforcing steel. The assortment of reinforcement class A500C mastered in the CIS countries does not include diameters of 6 and 8 mm, the need for which is quite large. Scientific and technological developments in the heat treatment of reinforcing bars and wire rod were carried out mainly on steels smelted by the open-hearth or oxygen-converter method and cast into ingots. Therefore, with the development and introduction into production of the processes of intensive technology of electric arc smelting and continuous casting of steel into small-section billets, a number of unsolved problems have emerged in ensuring a set of qualitative and operational properties of rolled products subjected to heat treatment, which are urgent tasks of today.

2.Materials and methods

For the study, we used steel grades St3sp., St3Gsp., 460V, 25G2S, microalloyed vanadium, the method of hot rolling of steel and the method of cold deformation of steel.

3.Results and discussion

The most common method for producing periodic profile reinforcement of the A500C class with a diameter of 3-12 mm is cold deformation of steel, which, as a rule, is combined with the manufacture of reinforcing meshes and other finished products. Obtaining cold-deformed reinforcement of class A500C with a diameter of 5.5, 8.0, 10.0, 12.0 mm from wire rod of low-carbon steel grade is quite difficult. As shown by earlier studies, in JSC "Uzmetkombinat", when the required level of strength is reached, the elongations are significantly lower than the permissible ones. Along with the development of the production of cold-deformed reinforcement class A500C, a number of metallurgical enterprises in the CIS are making attempts to roll production of this reinforcement [8-10].

We, together with the engineering and technical workers of JSC "Uzmetkombinat" and carried out research on the development of technology for obtaining thermomechanically hardened coiled rebar. Were investigated the chemical composition of the metal melt No. 120449 22C, which are shown in table 1.

Table 1. Chemical composition of heat No. 120449 22C of reinforcement No. 12 in accordance with GOST 34028-2016

Mass fraction of elements in%, no more										
C	Mn	Si	P	S	Cr	Ni	Cu	Ti	As	Al
0,23	0,73	0,98	0,019	0,028	0,10	0,14	0,22	0,031	0,054	0,009

A new chemical composition of reinforcement No. 12 of class A, 500C microalloyed with vanadium has been proposed. The introduction of 0.05-0.12% vanadium (V) provides an increase in the strength of steel by 20-50%, both in hot-rolled, normalized, and after heat hardening. Microalloying with vanadium reduces the carbon content of the steel, thereby improving ductility, toughness and weldability. The presence of an increased nitrogen content in vanadium steel (characteristic of an electric furnace metal) further enhances disperse hardening. Dispersed precipitation of vanadium nitrides provide a higher level of strength in a lower (by 20%) vanadium content and this is economically beneficial for the production of thermomechanically hardened coiled rebar. Table 2 shows the proposed chemical composition of reinforcement No. 12 of class A 500C microalloyed with vanadium.

Table 2. The proposed chemical composition of reinforcement No. 12 of class A 500C microalloyed with vanadium

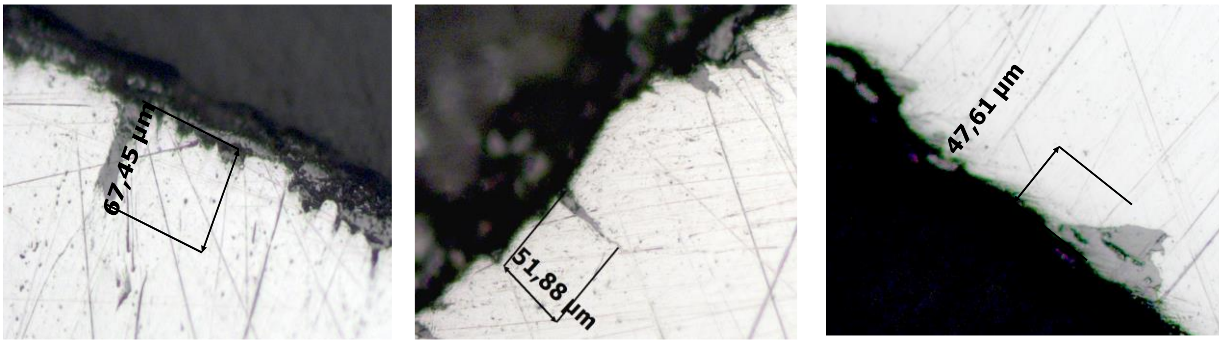
C	Mn	Si	P	S	Cr	Ni	Cu	Al	N	V
			no more							
0,23-0,27	0,73-0,82	0,6-0,70	0,030	0,030	0,30	0,30	0,22	0,009	0,03	0,10-0,12

The microstructure of longitudinal specimens was also investigated in accordance with GOST 5639, GOST 21014. For this, three specimens of rolled round Ø 12.0 mm from steel grade St 22S from heat No. 120449 were selected, the results of which are shown in Figure 1 and in Table 3.

Table 3. Microstructure of longitudinal reinforcement specimens No. 12

Room sample	Microstructure	Surface defects

1.	perlite-ferritic, grain size - G_8, G_7	- inclusions of rolled scale up to 0.07 mm deep (Figure 1a)
2.	perlite-ferritic, grain size - G_8, G_7	- inclusions of rolled scale up to 0.05 mm deep (Figure 1b)
3.	perlite-ferritic, grain size - G_8, G_7	- inclusions of rolled scale up to 0.05 mm deep (Figure 1c)



a b c

Fig. 1. Microstructure, X 200. Inclusions of rolled scale: a - sample No. 1; b - sample No. 2; c - sample no. 3.

For the reinforcement of reinforced concrete structures, the mechanical properties of reinforcement No. 12 made of steel grade 22C were investigated. The results are shown in Table 4.
On the basis of the above studies, a technology was developed for obtaining thermomechanically hardened coiled rebar without significant changes in rolling technology and productivity. The solution to the problem is to obtain a profile of a special cross-sectional shape with a more developed surface compared to a circle of equal cross-sectional area (square, hypocycloid)

Table 4. Mechanical properties of reinforcement No. 12 made of steel grade 22C

Modes	$\sigma_т$ н/мм^2			$\sigma_в$ н/мм^2			δ_5, %		
	start	middle	end	start	middle	end	start	middle	end
1 hot-rolled	440 445	440 445	445 450	605 610	600 610	610 615	31,2 30,2	29,0 32,0	30,5 31,0
middle	442,5	442,5	447,5	607,5	605	612,5			
2 5 – 10	640 630	635 615	645 585	730 730	735 710	700 685	24,0 22,0	22,5 23,0	24,0 28,0
middle	635	625	615	730	722,5	692,5	23,0	22,75	26,0
3 15 – 10	795 820	805 815	735 755	855 885	870 880	825 835	15,0 14,5	12,0 в/з	16,6 8,3
middle	807,5	807,5	745	870	875	830	14,75	-	12,45
4 8 – 15	765 755	745 780	685 695	840 830	820 850	755 775	13,0 17,6	16,6 14,6	20,0 17,6
middle	760	762,5	690	835	835	765	15,3	15,6	18,6
5 5 – 10	580 570	570 630	640 610	630 650	665 710	735 715	27,0 24,2	20,0 21,5	19,0 21,6
middle	575	600	625	640	687,5	725	25,6	20,75	20,3
6 5 - -	495 480	480 505	515 515	615 630	650 650	635 640	28,3 28,6	28,0 30,8	25,8 24,6
сред	482,5	492,5	515	622,5	650	637,5	28,45	29,4	25,2
7 - - -	450 460	460 460	470 470	610 615	615 615	625 625	28,3 31,6	28,6 29,1	30,3 27,0
middle	455	460	470	612,5	615	625	29,95	28,85	28,65
GOST 10884	No less 500			No less 600			No less 14		
Ат500	600			800			12		

Ат600 Ат400	440	550	16

The proposed profile provides better hardenability of the rolled section, increases the efficiency of water cooling. To assess the effectiveness of the new profile, a test rolling of a square and a circle with a diameter of 5.5 mm of the same size in cross-sectional area of St3sp steel grade was performed. The results of mechanical tests showed that only by changing the shape of the cross-section of thermomechanically hardened wire rod with a nominal diameter of 5.5 mm, the yield strength can be increased by 60–70 N / mm. Taking into account the results obtained, technical requirements were developed and temporary technical conditions were prepared for pilot batches of thermomechanically hardened rolled products with an effective cross section. The values of the yield point and ultimate strength in technical conditions must be at least 420 and 550 N / mm2, respectively. It was decided to test the influence of the new profile on the mechanical properties of heat-strengthened reinforcing bars on different grades of steel, namely St3sp, St3Gsp, 460V, 25G2S [11-12].

In accordance with the technical conditions, a pilot batch of reinforcing bars with an effective profile with a nominal diameter of 5.5 and 8.0 mm was carried out. The best results in terms of mechanical properties were obtained for rolled products made of steel grade 460B. The values of the yield point of reinforcing bars with a diameter of 5.5 and 8.0 mm averaged 470 and 465 N / mm2, respectively. The relative spread (the difference between the maximum and minimum values, referred to the minimum value), characterizing the uniformity of properties along the length of the loop, for the yield strength and ultimate strength is the smallest for rolled steel 460V (for 5.5 mm σt / σw = 24/15 N / mm2; for 8.0 mm σy / σw = 21/16 N / mm2) and the largest of steel 25G2S (for 5.5 mm σy / σw = 66/84 N / mm2; for 8.0 mm σy / σw = 37 / 99 N / mm2). Attention is drawn to the high level of relative elongation, the average value of which exceeds 30% for reinforcement made of 460B steel, which indicates a certain margin of plasticity of the resulting rolled products. At the same time, for reinforcement made of 25G2S steel, the average relative elongation is 20%. The achieved level of mechanical properties of reinforcing bars of pilot batches exceeds the requirements for reinforcement class A400 according to STO ASChM-7-93, especially in terms of plastic properties. A significant reserve of plastic properties allows, while maintaining the required level of plasticity ($\delta 5 \geq 14\%$), to increase the conventional yield stress [13-14].

To facilitate the introduction of reinforcing bars with an effective cross-section into construction practice without revising existing standard designs of reinforced concrete structures, it is necessary to solve the problem of interchangeability of reinforcement of one strength class for reinforcement of another class, taking into account the entire complex of requirements for reinforcing steel.

For this purpose, taking into account the technological capabilities of Uzmetkombinat JSC, it is proposed to expand the range of reinforcing bars in comparison with GOST 5781-82 and STO ASChM 7-93 and take the force corresponding to the yield point and breaking strength as the criteria for the interchangeability of reinforcement of different classes. For reinforcing bars of a periodic profile, taking into account the tolerances for the geometric dimensions of the cross-section, the concept of the calculated cross-sectional area is introduced, which is used in the design of reinforced concrete structures.

The calculated cross-sectional area is controlled during product acceptance by standardizing the linear density of rolled products. The use of reinforcing bars without recalculating cross-sections will allow a steel saving of about 16%.

The development of the production of rebar with an effective cross-section was carried out at a rate lower by about 20-30% relative to the design rolling speed, which is due to the technical capabilities of the existing equipment.

High hydraulic resistance at the first stage of water cooling with an increase in the rolling speed and, accordingly, additional cooling intensity leads to an increase in the difference between the rolling and water flow rates and, as a consequence, to a deterioration in the stability of the process - the rolling stock gets stuck. The tested technology did not provide an output to the design productivity of the mill when rolling reinforcing steel of the A500C class [15-16].

The production of reinforcing bars is possible in various ways, depending on the technical capabilities of the manufacturer. But at this stage, the most acceptable method for the production of reinforcing bars of increased strength is the method of hot rolling of steel microalloyed with vanadium in the range of 0.04-0.10%, which will ensure an increase in the strength level by 10-30%. Obtaining fine grains and evenly distributed dispersed particles of vanadium carbonitride allows achieving high strength values, which brings significant advantages to the construction industry without compromising other performance properties. A low sensitivity of mechanical properties to the temperature of the end of rolling of steel microalloyed with vanadium is noted. Vanadium-containing steels weld well and retain a high level of toughness in the heat-affected zone. Replacing carbon steels with vanadium-containing steels with increased strength should be beneficial for both the manufacturer (obtaining higher profits) and the consumer (products with higher strength, making it possible to reduce the weight of the structure). For the production of a pilot batch, rebar with an efficient and economical profile was rolled in coils No. 7 of steel microalloyed with vanadium. When rolling blanks, the modes of cooling the reinforcement with water before and after the wire block, the intensity of air cooling, and the rolling speed were changed. The weight of a running meter of reinforcement specimens varied within 0.300-0.313 kg with permissible values of 0.287-0.317 kg. To determine the variability of the mechanical properties of coiled reinforcing bars, samples were tested along the length of one turn from coils rolled under the most extreme cooling conditions. The results of mechanical tests of rebar rebar are given in table.5.

The mechanical properties of reinforcing bars along the length of the coil change little. Thus, the yield point and strength varied in the range 13-19 N / mm2 with an average value of 546 N / mm^2, and the elongation in the range 2.6-4.8% with an average value of 26.6%.

Table 5. Physical and mechanical properties of reinforcing bar No. 7 along the length of the turns

Statistical indicator	Yield point, Н/мм^2		Tensile strength, Н/мм2		Relative extension, δ_5, %	
	Riot 1н	Riot 10н	Riot 1н	Riot 10н	Riot 1н	Riot 10н
	541	559	689	702	29,2	25,9
	547	556	695	702	24,2	27,3
	545	559	698	700	27,2	27,8
	540	549	697	686	27,3	28,1
	537	556	687	695	25,2	26,7
	544	542	684	699	24,3	26,4
	545	554	688	688	25,3	26,8
	545	540	699	693	25,2	26,9
	550	544	700	689	26,0	28,2
	542	544	698	685	25,3	27,0
	546	540	694	694	25,3	28,5
	546	540	687	698	26,9	27,4
	544	544	693	698	26,2	26,8
Max	550	559	700	704	29,2	28,7
Min	537	540	684	684	24,6	26,1
Scatter	13	19	16	17	4,9	2,7
Average	544	548	692	695	26,1	27,3
St. Deviation.	3,34	7,61	4,92	5,96	1,37	0,82

Moreover, to assess the efficiency of microalloying steel with vanadium, part of the billets were rolled on mill 320 by triple slitting onto bar reinforcement No. 12. For comparison, in table. 6 shows the statistical data of the results of mechanical tests of a similar grade of steel of melt No. 25732 (without vanadium), rolled on mill 320 with billets of melt No. 25733 in one mode.

The table shows a significant effect of microalloying steel on the mechanical properties of reinforcement No. 12. The difference in mechanical properties between the maximum and minimum values for reinforcement made of steel microalloyed with vanadium is much smaller.

In addition, the data in the table show the reserve for increasing the yield strength (reinforcement class) when using microalloying steel with vanadium. With the maximum use of water cooling in mill 150, results comparable to those obtained in mill 320 can be obtained. However, existing water nozzles in mill 150 have a noticeable braking effect on cooling of the periodic reinforcement, lead to "drilling" of the roll in the wire block and thereby limit increased water supply.

Table 6. Comparative data of mechanical properties of reinforcement No. 12, rolled on mill 320

Statistical indicator	Yield point $\sigma_в$, Н/мм^2		Tensile strength $\sigma_в$, Н/мм2		Relative extension δ5, %		Full elongation δ5, %	
	№712	№713	№712	№713	№712	№713	№712	№713
Max	576	663	657	741	25,9	21,9	14,6	12,2
Min	520	641	601	729	22,8	18,0	10,0	9,0
Scatter	58	19	44	14	3,7	5,2	4,7	3,1
Average	544	655	634	731	24,1	20,2	11,9	9,9

The use of steel microalloyed with vanadium makes it possible to obtain reinforcing bars with an effective profile with a nominal diameter of 5.5—8.0 mm, class A500C, in a temperature range acceptable for the equipment of a mill 150 and practically at a nominal capacity.

4.Conclusion

This study made it possible to obtain new technological solutions for the production of coiled reinforcing bars, the implementation of which will increase the reliability of reinforced concrete structures of buildings and structures. It should be noted that fittings with an effective profile with a nominal diameter of 5.5—8.0 mm of class A500C are one of the most necessary in the implementation of construction and industrial work of any complexity. The proposed technology has its own specifics and manufacturing technology. The reinforcement obtained by these technologies, due to the increased physical, chemical and mechanical properties of the properties, effectively enhance the strength and reliability of structures, and also increase the service life.

5.References

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