Prospects of high-tensile reinforcement in manufacturing of large diameter wire rod at «MMK-METIZ» - Magnitogorsk Hardware and Sizing plant

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Railway transport in Russia plays a key role in the transport service of the country (more then 80% of public transport and 40 % of passenger miles) and in the state economics. In light of the existing situation there was confirmed a Federal objective program entitled "Modernization of the transport infrastructure" (2002–2010). The main objectives of this program are the extension of train system, removal of the lag in railway techniques, development of native high-technology manufacturing which can satisfy all needs of railway sector, putting the quality and security of railroading in accordance with international standards. Forthcoming development of train system and modernization of the plants which works for supporting Open Joint Stock Company "Russian Railways" (RRW) will cause essential demand for the high-tensile reinforcement which is used for manufacturing reinforced concrete sleepers.

Sleepers made from pre-strained concrete are used in the construction of rail tracks in many countries for 50 years. That's why "RRW" need in steel reinforcement will grow continuously. There is wide spread occurrence of reinforced concrete sleepers with high-tensile reinforcement of large diameter wire in Europe. In different ways when anchoring as reinforcing elements two U-figured cap-bolts from high-tension smooth steel with diam. 9.4 mm and with carving on both ends, 8 rods of shaped fittings with diam. 7.5–8.0 mm, 4 rods of shaped fittings with diam. 9.4–10.5 mm are used. Fittings with diam. 9.4 and 9.5 mm makes in average about 80 % of total volume (20,000 tons a year) of procurement from "NEDRI" (one of the leading producers of high-tensile reinforcement and stands in Europe). In the foreign countries appliance of high-tensile stabilized reinforced large diameter wire rod expands in the manufacture of reinforced concrete sleepers.

Up to the present moment, periodic profile wire of grade VR-2 with diam. 3 mm has been applied in Russia according to the All-Union standard GOST 10629-88 as fittings in reinforced concrete sleepers. But, according to global track record, "Russian railways" plans to increase the proportion of sleepers with high-tensile steel reinforced large diameter rod. Production of sleepers with steel reinforced rod (9.6 or 10.0 mm in diameter) is notable for good fabricability and allows to increase capacity by two times comparably with conventional technology applied at "Russian railways" (for 3.0 mm diameter). The decision about organization of production of national high-tensile stabilized reinforced wire with diam. 9.6 mm for the modern reinforced concrete sleepers in conditions of Magnitogorsk Hardware and Sizing Plant («MMK-METIZ») was reached at first on the meeting of spokesmen from this plant and "Russian Railways". «MMK-METIZ" has a large long-term experience of producing high-tensile reinforcement.

However, specific requirements for stabilized fittings, missing national experience in cold deformation and processing of strip and plates of such diameters and limited opportunities of adaptation and usage of foreign developments didn't allow to produce such type of production via copying traditional methods applied on the plant when manufacture other types of reinforced materials. That's why «MMK-METIZ" required in conceptually new developments to achieve set level of production quality.

Experts from «MMK-METIZ" and scientists from Magnitogorsk State Technical University developed co-joint project for creation high-technology manufacture of high-tensile reinforced rod with diam. 9.6 mm for concrete sleepers which are used in highways. This project was approved by the Ministry of Education of Russian Federation. The main idea of this project is to form nano-patterned conditions for manufacture of high-carbon steel in long workpieces. It will allow to raise significantly operating capabilities of metal products which includes high-tensile reinforced rod with diam. 9.6 mm for concrete sleepers of new generation [1, 2].

There is a big variety of semi-theoretical researches which are made inside the scientific field "Industry of nanosystems and materials". They confirm high efficiency of applying nano-materials made from steel. Despite this fact most of developments couldn't be applied because of non-availability of continuous production schemes and necessary industrial equipment for their realization in the conditions of major industrial production facilities. Significance of this project for the development of science and engineering in Russian Federation consist of getting modern knowledges about formation of nano-structure in carbon steel based on complex strain impact processes under high temperature. Formation of nanostructure in carbon steel is a conceptual new scientific lead-up. It opens perspectives of creation a type of crystalline material with high level of merit rate.

The processes with strain impact under high temperature allows to achieve long workpieces with nano-structure in distinction from known methods which have restriction to the size of obtained workpieces. This engineerable high-technology production is based on the strain impact processes under high temperature. This impact forms in carbon steel submicrocrystalline and nanocrystalline grains which provide the development of high-test substance and special properties of

the fittings with diam. 9.6 mm. Realization of this technology is based on the effective modular units of strain impact processes under high temperature. In foreign countries, high-tensile reinforced rods with diam. 10.0 mm for concrete sleepers are made with usage of mechanical hardening technology of sorbitized hot-rolled rod. It consist of multi-pass cold rolling. There are many companies such as «Koch», «Karl Fuhr», «Properzi», «Eurorolls», «Pittini» , «Elin Union» in this industry which have strong positions and prestige on the international markets.

Modern tendency of science, engineering and technology in the area of manufacture of high-tensile reinforced rods with diam. 9.6 mm for the concrete sleepers is marked by searching for effective complex of impact on the microstructure which combines processing methods of different physical nature (microalloying of steel, special methods of thermal and deformational treatment). The main purpose of such impact is to achieve high-test condition of tillable material and add to it a complex of special properties which will meet requirements of service environment on modern railway highways for high-tensile reinforced rods which are used for concrete sleepers. Over the range of technologies for manufacturing high-tensile reinforced rods the tendency for creation of manufacturing complexes based on modular approach to the organization of production which has functional flexibility and mobility has been found out. Project proposal completely answers the current trend of science, engineering and technology development in the area of manufacturing high-quality production.

Steel reinforced die-rolled section with diam. 9.6 mm represents rods with equispaced toolmarks on its surface. It has complex of high strength properties and at that keeps plastic properties of carbon steel with nano-structure.

According to exploited technology, steel reinforced products having 9.6 mm diameter with nano-structure will have increased strength properties: rupture strength – not less than 1,600 MPa; proof load – 1,450 MPa; elongation at break- not less than 6 %; alternating bending on the 90° holder-adapter with diam. 100mm – not less than by 3 times.

Stress relaxation in the fittings for 1,000 hours at a temperature 20 °C and tension $\sigma_0 = 0.8\ \sigma_{0.2}$ are totally not less than 4.5 %. Long-term strength $2\ \sigma_A$ by $2 \cdot 10^6$ work cycles and tension $\sigma_0 = 0.65\sigma_B$ are totally not less than 180 MPa. Such complex of applying properties for finished products with diam. 9.6 mm is a conceptually new kind of product which can't be obtained using tradition approaches to manufacture fittings for various applications.

The main advantages of reinforcing of steel rod with nano-structure and with diam. 9.6 mm are higher merit rates by lower production expenditures. Higher production merit rates will deplete fittings breakage by tension, cut power capacity of the reinforcing process for sleepers, increase productivity. Increased indexes of relaxation and long resistibility will afford higher service life and working time of railroad sleepers and consequently trunk railways.

Feedstock for high-tech manufacture of reinforced rod will be hot-rolled bar with diam. 15 mm from Magnitogorsk Iron and Steel Works - leading member of the holding which includes implementing organization. It will enable to realize more flexible pricing policy and provide additional competitive advantages.

In such a way building up technologically intensive production will assure integral level of quality, maintainability and competitive advantages of national production of reinforced steel with nano-structure and with diam. 9.6 mm.

The main difference between merit rates of national and foreign operated fittings are determined by achievement of nanocrystalline structure in carbon steel (Table 1). Steel reinforcement with high temperature hardening producing by national and foreign manufacturers has strongly marked coarse-crystalline structural inequality. It considerably reduces operating factors of the product especially at repeated stresses which influence reinforced concrete sleepers in the operational process.

Steel nano-structured reinforcement via die-rolled section will excel the analogous production manufactured of coarse-grained material in terms of the level of mechanical properties, fatigue and relaxation resistance, reliability and construction durability (Table 2). In comparison with foreign and domestic analogues, the following changes are expected: increasing of reinforcement plasticity level by 1.7 times, rise of relaxation resistance by 1.5 times, elevation of durability by 1.4 times. In this case nano-structured reinforcement will have the minimum variation of properties.

The following high technologies are used in the established manufacturing processes for achievement of the necessary properties required for high-tensile reinforced rods with diam. 9.6 mm for the new generation of concrete sleepers.

1. The special kind of heat treatment of carbon steel, ensured obtaining of ultrafine-grained and nano-structured materials, characterized by high strength and ability to the subsequent deformation with high total deformation.

For the purpose of producing submicro-crystalline and nano-structured components in the primary structure of a billet with diam. 15.0 mm, it is expedient to use the special kind of heat treatment - patenting - consists of steel heating to austenitic state (to temperatures higher than point A_{C3}) with the subsequent cooling in any media (salt, lead, boiling bed) at temperatures in the range 450–500 °C.

Table 1. Existing and perspective kinds of high-tensile reinforcement

New scientific intensive production planed to be produced	Foreign technological analogues	Domestic technological analogues
Production of high-tensile nano-structured reinforced rods with diam. 9.6 mm via die-rolled section for concrete sleepers of new generation	Production of high-tensile heat-treated reinforced rods with diam. 9.5 mm in conformity with the requirements of EN 10138 international standard	Production of high-tensile heat-treated reinforcd rods with diam. 10.0 mm in conformity with the requirements of specification 14-125-704-96

Table 2 – Properties of high-tensile nano-structured reinforced rod

Designation of parameters of the main production process	Values for designing properties of products	Relative values for foreign analogues of products in accordance with EN 10138	Relative values for domestic production analogues of products in accordance with the specification 14-125-704-96
Nominal diameter. mm	9.6	9.5	10.0
Tensile strength, MPa	Not less than 1.600	1.57	1.47
Conventional yield strength, MPa	Not less than 1.450	Does not normalize	1.33
Failure elongation, %	Not less than 6.0	3.5	3.5
Reversed bending by 90^{o}	Not less than 3	3	Does not normalize
Stress relaxation at 1,000 h under temperature of 20 ^{o}C and loading	Not less than 4.5	3	3
Durability at $2 \cdot 10^{6}$ cycles of processing under loading	Not less than 180	Does not normalize	Does not normalize

2. Highly productive multi-drawing, activating free glide planes in every deformation cycle, which leads to additional fragmentation of material structure and provides maximal strengthening of the processed fittings. Deformation treatment modes are set to activate new free glide planes in every deformation cycle, which leads to additional dispersion of utrafine-grained stricture and fragmentation of ferritic solder pads in pearlite.

The main advantages of metal deformation in monolithic dies are precision and stability of dimensions of products along finished shapes and simplicity of deformation tool. The established shortcoming of this feedstock deformation method is caused by heavy-friction conditions on metal and tool contact area. This shortcoming stipulates the low deformation ratio in one pass, surface defects such as tearing, relatively low mechanical properties of the finished products and high wear of the tool.

Comparison of characteristics of semi-finished steel rolled products with diam. 15–16 mm manufactured using feasible deformation treatment methods for rods high-strength steel rods with diam. 9.6 mm is presented in the Table 3.

It seems to be reasonable to take drawing in monolithic die using modern and high-performance equipment of direct-flow type as the main method of forming on the base of the above-presented analysis of advantages and shortcomings of the existing methods of forming of round steel billets for their following reprocessing to high-tensile reinforced rods with diam. 9,6 mm.

3. The special type of thermal deformation treatment which consists of simultaneous effect of plastic deformation during forming of die-rolled section on the reinforced surface and thermal effect under high tension, which ensures good complex of special properties of nano-structure reinforcement: adhesion with concrete, relaxation resistance and cyclic strength. Structure of high-

Table 3. Comparison of characteristics of the technological process with regard to manufacturing process of nano-structured rods with diam. 9.6 mm

Process features	Rolling	Drawing in monolithic dies	Drawing in roller dies
Technological			
Metal workability	good	satisfactory	medium
Sectional shape	arbitrary	arbitrary	arbitrary
Workpiece dimensions	medium	up to 20 mm	medium
The finished shape precision	low	high	medium
The finished shape geometry	limited	good	bad
Process speed	high	limited	limited
Reduction	simple	small	high
Oiling conditions	high	simple	simple
Power consumption	n.a.	high	medium
Irregularity of mechanical properties and metal structure	low	high	high
Internal stress	low	high	low
Quantity of intermediate heat treatment	low	high	low
Ability of steady multiple treatment	limited	unlimited	limited
Constructive			
Complex primary equipment	high	low	medium
Complication of operating tool production	medium	low	medium
Ability of process hermetic encapsulation	medium	easy	easy
Ability of process automation	medium	easy	easy
The occupied area	large	small	small
Economical			
Capital outlays	high	low	low
Unitary tool cost	low	high	low
Intermediate heat treatment and etching costs	small	considerable	considerable
The required manning level	high	medium	medium
Lubrication cost	low	high	low

Table 4. Comparison of the main technologies for production of high-tensile reinforced rods

	Foreign technologies analogues	Domestic technologies analogues
Developed technologies	Technology of Nedri Spanstaal BV (Netherlands)	Technology of Omutninsky Metallurgical Plant (Russia)
Innovation technology of thermal deformation of carbon steel with nano-structuring	Technology based on thermal strengthening of medium-alloy steel grades in hot-rolling metal production line [5]	Technology based on thermal strengthening of hot-rolled silicon steel with independent heating [6]

carbon steel reinforcement obtained as result of realization of high thermal diffusion treatment corresponding to nanomaterials with platelet shape of constituent.

Using of thermomechanical treatment method (TMO) in manufacturing of reinforcement for pre-stressed concrete constructions with enhanced apparent elastic limit and conventional yield strength enables to reach these values respectively not less than 80 and 90 % of sorting ultimate strength minimum. In these conditions reinforcement maintains sufficiently high ultimate elongation δ before rupture (not less than 4 %). Stress relaxation in reinforcement reduces sharply and do not exceeds 2 % at 1000 h under 20 °C and accounts for $\sigma^{0}_{рел}$ = 75 % of tensile strength.

Thereby, realization of above-mentioned approaches provides achievement of high-tensile reinforcement state at the expense of reinforcement material ultrafine-grained and forming of nano-structure based on influence of complex thermal diffusion on carbon steels using of highly productive units of thermal and deformation treatment (Table 4). Combination of these treatment methods opens up high technological possibilities for enhancement of strength and special reinforcement properties keeping their high uniformity without steel alloying. This technology is less sensitive to quality of semi-finished rolled products.

The established high-technology production of high-tensile reinforced rods and wire with diameter of 9.6 mm for reinforcing of concrete sleepers for modern highways possesses the necessary characteristics of innovation technology. It's the first time of complex usage of modern scientific intensive thermal deformation methods for making influence on carbon steel structure with forming nanostructured state. Commercialization of the results of this innovative theoretical and practical project will enable to establish scientific intensive production of reinforcement for concrete sleepers of new generation for the first time in the conditions of Russian hardware metallurgical plant.

The research corresponds with realization of complex project for high-technology production development. This project has been performed with participation of Russian higher education institute (contract 13.G25.31.0061).

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