The development of the high-strength corrosion resistant austenitic steels for the oil equipment shafts

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Abstract. The work proposes to use corrosion-resistant austenitic Fe-Cr-Mn-Ni-Mo-N steel with a nitrogen content of ~ 0.4-0.9% as a material for the shafts of the oil equipment. The steel was hardened by the solid-solution hardening. Previously, such materials in this area were not used.

1. Introduction
To manufacturing oil pump shafts, RPS shafts (reservoir pressure station) and other shafts, working in aggressive environment, such as:
- centrifugal pump installations (CPI);
- gas separators and water protection;
- reservoir pressure pumps
traditionally using nickel alloys monel and inkonel Alloy 925, Alloy 718, Alloy K-500 types. At first, these alloys was developed in USA to jet engine production. Unto the temperature 900°C this alloy differ by high percussive viscosity and strength, and at low temperatures (until -78°C) is not sensitive to incision. All these alloys austenitic class with dispersive strengthening [1-5].

Using such nickel alloys to the oil equipment shafts explained by their high corrosion resistance and good strength indicators. This obtaining by high nickel containing and high cost elements alloying – molybdenum, copper, niobium, titanium. The shafts operating temperature lay in the interval from -50 to 180°C, and operating temperature interval of nickel alloys is excess for they.

Manufacturing shafts of these alloys is coupled with range of metallurgical problems. It is very difficult to provide a homogeneity of chemical compound at smelting at titanium and aluminum insertion, and exposure, which require to mixing, is adduct to high metal pollution by the products of their furnace lining interaction. For the same reason it is impossible to use own refuses in the melt charging. It is necessary to smelt alloys in vacuum. Otherwise atmosphere nitrogen will rough titanium and aluminum nitride formation, and, as a result, to plasticity and percussive viscosity loses.

Even greater difficulties causes by sensitivities of these alloys to slow cooling. Wherein it is flow an alloy dispersion hardening, accompanied by the volume reducing. A stresses arising from this lead to the many defects formation, up to the ingots or forging destruction. Therefore at all operating phases, up to 25 mm section they are necessary in hardening (cooling in water).
The heat treatment of alloys including the hardening and two-stage continuous tempering. To high strength obtaining it is necessary to provide a cold deformation additionally.

The main requirements to the materials – the high strength and corrosion resistance.

To the oil shaft pumps operating, working in aggressive environments, at present time using nickel corrosion resistance alloys Alloy 925, Alloy 718, Alloy K-500 types. The other way to obtain the necessary combination of high strength and corrosion properties is exist. It appeared relatively recently and till not widely used in Russia. This is alloying the corrosion resistant steel by nitrogen. Standard for the recommended materials for the oil and gas mining ISO 15156-3:2015 is recommend for working in this condition as well as tradition dispersion hardened nickel alloys the steels S-20910 (03Kh23G5N12M3 with nitrogen containing 0.2-0.4%), J95370 (03Kh25N18G2AM6D6V3 with nitrogen containing 0.7-0.8%), S32654 (03Kh25N23G4AM8D with nitrogen containing 0.45-0.55%).

Nitrogen steel from Fe-Cr-Mn-Ni-Mo-N system alloying with chromium containing ~25% and nitrogen ~0.7-0.9% mass. allows [6, 7]:

- to decrease in 8-10 times the product cost price, relatively to the inkonnels, and in 2-3 times relatively the steels from the standard ISO 15156-3:2015;
- to reach the more high category of strength – the liquidity limit up to 1800 MPa (alloy K-500 using for the shafts with the liquidity limit up to 1100 MPa, alloys 925 and 718 up to 1500 MPa, the steels from the standard ISO 15156-3:2015 can provide the strength category up to 1400 MPa because of not high enough nitrogen containing or the system of metal strengthening – nitrogen connected with a wolfram (the dispersion strengthening));
- to simplify the shafts operating technology (smelting without vacuum, exclude the hardening after each operation and the steel temper) [8-10].

2. Steels for the oil equipment shafts.

The job offers using as a material for the oil equipment shafts the corrosion resistant austenitic steel of alloying system Fe-Cr-Mn-Ni-Mo-N with nitrogen containing ~0.7-0.9%. Steel will strengthening by the hard-solution mechanism of strengthening from the impurity of implementation of nitrogen. Earlier such materials in this area was not applied. Nitrogen steels from the standard ISO 15156-3:2015 J95370 (03Kh25N18G2AM6D6V3 with nitrogen containing 0.7-0.8%), S32654 (03Kh25N23G4AM8D with nitrogen containing 0.45-0.55%) are dispersion-hardening and strengthening take a place due to allocation in them nitrides. Steel S-20910 (03Kh23G5N12M3 with nitrogen containing 0.2-0.4%) does not contain enough a number of nitrogen to obtain high strength categories and corrosion resistance, and high nickel containing are negatively affects on it cost.

In the work were developed and studied such models of the steel as in table 1 (numbers of lines 1-4). For comparison a mechanical properties of alloys Alloy K-500 and Alloy 925 are given. A typical austenitic microstructure of these steels after hot deformation is shown in Figure 1.

Steel 08Kh18AG10N2 and 05Kh20AG10N8M2F were tested to the resistance to the hydrogen sulfide cracking under stress (HSCS). Investigations were carried out by the standard NACE TM 0177-2005 method A (STO Gazprom 2-5.1-148-2007 (GOST9.901.1, GOST9.901.4). As a corrosion substance was a water solution 5%NaCl+0.5%CH3COOH, saturated by H2S, pH≤3.5, the temperature of solution - 24±2°C. Tests were carried out on the installation PN-16-4 at constant weight. The results of tests are showed in the table 2.
Table 1. Mechanical properties of the investigated models of steel.

| №  | A model of steel  | Type and rate of deformation | σ0,2, MPa | σd, MPa | δ, % | Ψ, % | KCU |
|----|-----------------|----------------------------|---------|---------|-----|------|-----|
| 1  | 08Kh18AG10N2    | H/d                        | 560     | 850     | 45  | 56   | 18,3|
|    |                 | C/d 25%                    | 1093    | 1143    | 22  | 59   | 14,4|
|    |                 | C/d 50%                    | 1308    | 1359    | 18  | 55   | 12,4|
| 2  | 05Kh20AG10N8M2F | H/d                        | 730     | 1010    | 38  | 64   | 22,8|
|    |                 | C/d 22%                    | 1230    | 1290    | 18  | 55   | 9,9 |
|    |                 | C/d 52%                    | 1510    | 1630    | 10  | 46   | 6,1 |
| 3  | 05Kh23AG11N5    | H/d                        | 950     | 1170    | 24  | 50   | 13,6|
|    |                 | C/d 20%                    | 1290    | 1380    | 15  | 34   | 1,9 |
| 4  | 05Kh25AG10N5    | H/d                        | 893     | 1152    | 39  | 56   | 6,7 |
|    |                 | C/d 22%                    | 1380    | 1430    | 20  | 59   | 17,1|
|    |                 | C/d 54%                    | 1790    | 1902    | 11  | 49   | 7,3 |
| 5  | Alloy K-500     | C/d+aging                  | 1074    | 1412    | 31  | 53   | 19,3|
| 6  | Alloy 925       | C/d+aging                  | 1400    | -       | 8   | 25   | 6   |

* H/d – hot deformation, C/d – cold deformation

Table 2. The results of tests of the steels 08Kh18AG10N2 and 05Kh20AG10N8M2F.

| №  | A model of steel  | Type and rate of deformation | Load, MPa | Test result |
|----|-----------------|----------------------------|-----------|-------------|
| 1  | 08Kh18AG10N2    | C/d 50%                    | 0,5 from σ0,2 | Stand       |
| 2  |                 | C/d 50%                    | 0,7 from σ0,2 | Not stand   |
| 3  | 05Kh20AG10N8M2F | H/d                        | 0,7 from σ0,2 | Stand       |
| 4  |                 | C/d 22%                    | 0,7 from σ0,2 | Stand       |
| 5  |                 | C/d 50%                    | 0,7 from σ0,2 | Stand       |

3. Conclusions.

Analyzing data of tables 1, 2 and data from literary sources [11, 12] can conclude that nitrogen steels of alloying system Fe-Cr-Mn-Ni-Mo-N with chromium containing ~18-25% and nitrogen ~0,4-1,0 % mass, allows:

- in 8-10 times decreases cost price of product, comparison to inconells, and in 2-3 times comparison to the steels from the standard ISO 15156-3:2015;

- to get more higher category of strength (T18), i.e. limit of liquidity up to 1800 MPa. (For comparison: alloy K-500 using for shafts with limit of liquidity up to 1100 MPa, alloys Alloy 925 and 718 – up to 1400 MPa; steels from the standard ISO 15156-3:2015 can provide category of strength up to 1300 MPa due to insufficient high nitrogen containing or fastening of nitrogen to nitrides);
Figure 1. Typical austenitic microstructure of steels from table 1 after hot deformation.

- to simplify a shafts operating technology (smelting without vacuum, exception after each operation hardening and tempering);
- using new steel will allow to open new directions of development and improvement of technics for a hydrocarbon production and transportation.

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