Microalloyed Steels for Car Parts

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Abstract. The composition and properties of three constructional microalloyed steel with vanadium, niobium and nitrogen is investigated. High strength and ductility steel in rolling mill products and in forgings were revealed, manufactured according to various flow diagram. The resistance of microalloyed steels to grain growth during heating to 1300 °C has been established. The opportunity of realization of the forging heat forgings in their heat treatment is shown. Output testing was carried out of steels in the manufacturing crankshaft and engine connecting rods. For heavily loaded machine components, the use of 38G2AF, AC40H2NMAF and AC30X3NMAFB steels is recommended. High resistance to grain growth is shown when heating steels microalloyed with vanadium, niobium and nitrogen. High properties of the steel AC40H2NMAF, AC30X3NMAFB and 38G2AF make it possible to recommend them for the manufacture of heavily loaded parts - crankshafts and connecting rods. The possibility of realizing forging heat of forgings made microalloyed steels with vanadium, niobium and nitrogen during their heat treatment to ensure a high level properties and structural requirements.

1. Introduction

Steel has been and remains the main structural material used in mechanical engineering, machine tool industry and other industries. Not only its technological and mechanical properties depend on the structural phase state of steel, but also the reliability and durability products in operation. Many indicators steel quality, including its structure, are laid at the stages of metallurgical production. A powerful factor affecting the alloy purity, changes in crystallization conditions, grain structure, homogeneity of the structure, and other property indicators are metallurgical technologies such as deoxidation, refining, modification, and alloying [1–5]. Thanks to alloying, it is possible to control the structure and steel properties in a very wide range. The degree of alloying is always determined by the level of the created properties and the functional belonging of the steel. For heavily loaded case-hardened products, a mandatory requirement is the hardening of the deep layers of the part, combined while maintaining of high plastic properties in these zones. In addition, such details are required to ensure minimal deformation and skellering, as well as the elimination cracks during their thermochemical treatment, which forces the use oil as a quenching medium [6–8]. The solution to these two problems in the complex is achieved by using alloy steels for the manufacture of such parts. The larger the cross section of the hardened product, the greater should be the degree of alloyed steel. At the same time, alloying should still be limited by the level at which the required hardenability and granularity are achieved in the adopted quenching technology. Excessive alloying, that is, exceeding that necessary to achieve the required hardenability, is irrational. This is due to the fact that the addition
of all (except nickel) alloying elements leads to a decrease in the reliability of steel under overload conditions and an increase in the cold brittleness threshold. As long as alloying increases hardenability in a given product, it helps to increase reliability, but if the content of alloying elements exceeds that required for through hardening in this section, the reliability of steel decreases [5, 9–11]. Alloying with several elements (complex alloying) more effectively increases hardenability than alloying with one element. It should also take into account the effect of steel alloying on the process diffusion saturation the surface of parts during thermochemical treatment, the formation of carbides and the amount of residual austenite in the hardened layer [12–14]. In selecting the steel, it is necessary to pay attention to the economic side of the issue: the more alloying elements it contains, the higher the cost [6–7].

Thus, it is indisputable that in most steel grades there is an irrational use of alloying elements, since only a certain amount of them is used for effective alloying of the die and the necessary formation compounds in the cross section products of a certain size [15–25]. In this case, the actual direction is the use of scientifically based sparingly alloyed and microalloyed steels for products of various functional purposes.

2. Working purpose
The study of the properties and experience of using microalloyed and sparingly alloyed steels in the manufacture of automobile parts.

3. Materials and research methods
Microalloyed steel vanadium, niobium and nitrogen were used in the work. Preference is given to steel AC40H2NMAF, AC30X3NMAFB, 38G2AF and sparingly alloyed steel 18HGR, in which the present chemical elements contribute to the hardening of alloys due to quench age hardening. Such steels have a reduced tendency to cracking and these elements can be introduced into steel with a wide range of carbon contents [17, 20]. Sample capture for the manufacture samples for mechanical and technological tests and for determining the chemical composition of steel was performed in accordance with GOST 7564 and GOST 7565. The content of chemical elements in steels was determined according to GOST 18895-97 on Spektrolab and AFS–51 spectrographs with specialized software SBP and Next and analyzers AN–7529 and AN–7560. Metallographic studies were performed using Neofo-21 and IM–7200 microscopes with a panoramic image analysis system and the Thixomet–PRO software product. The steel contamination with non-metallic inclusions was assessed according to GOST 1778, grain size was determined by oxidation (steel AC40H2NMAF, AC30X3NMAFB and 38G2AF) and cementation method (steel 18HGR and 20H2N4A) according to GOST 5639-82. Hardenability of steels was determined by end quenching standard samples according to GOST 5657-69. The microhardness was determined on a Durimet instrument at a load of 0.1 N (100 gf) with averaging the results measurements not less than 15 prints of the Vickers pyramid. Heat treatment of the samples was carried out in laboratory conditions using SNOL 1.6–2.5–1/11-V2 and SNOL 1.6–2.0–0.8/9–M1 heating furnaces, and gas furnaces were used in the production heating company “Holcroft” and units design “Teploproekt”. To determine the hardness used devices TSH–2M and TK–2M.

Tensile and toughness tests were carried out on a ZD-20 tensile testing machine and a PSW-30 pendulum head in accordance with GOST 1497 and GOST 9454. Heat treatment of billets from steel AC40H2NMAF and AC30X3NMAFB was carried out according to the regime: quenching from a temperature of 930°C to oil and tempering at 630 °C; for steel 18HGR – quenching from 860 °C into water and tempering at 200 °C with air cooling.

Fatigue strength of crankshafts was estimated by loading the cheeks with variable bending moment, and torsion by loading the connecting rod neck with variable torque. The connecting rods were tested according to an alternating loading cycle with reproducing hydrodynamics in the sliding bearing of the crank head with a tensile stress of 4 to 8 and a double amplitude of 14 to 20. Machining by cutting was evaluated in laboratory conditions and in production on automatic lines for the mechanical processing of crankshaft blanks, connecting rods and gears of the engine and bridges of the car.
4. Working results and their discussion

The content of chemical elements in the studied steels is shown in table 1. Steel AC40H2NMAF smelted in an open-hearth furnace, treated with synthetic slag and rolled into a square of 154 ± 2 mm at the Serov Metallurgical Plant; steel AC30X3NMAFB – melted and rolled to a circle of 70 mm at Izhestal Production Association; 18XFG steel – smelted at the Oskol Electrometallurgical Plant (OEMK) by direct reduction from metallized pellets and rolled into a circle of 90 mm from a continuously cast billet with a section of 360 x 300 mm; 38G2AF steel – melted and rolled into a circle of 150 mm at OEMK.

Table 1. The chemical composition of steels.

| Steel               | C     | Si    | Cr    | Ni    | Mn    | Mo    | V     | P     | S     | Nb | B  | N_2 |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----|----|-----|
| AC40H2NMAF          | 0.37  | 0.20  | 2.12  | 0.72  | 0.45  | 0.11  | 0.11  | 0.025 | 0.007 | -  | -  | -   |
| AC30X3NMAFB         | 0.31  | 0.24  | 2.54  | 0.74  | 0.40  | 0.20  | 0.07  | 0.021 | 0.011 | 0.03| -  | -   |
| 18HGR               | 0.18  | 0.28  | 1.22  | 0.26  | 1.21  | 0.09  | -     | 0.018 | 0.027 | 0.002| 0.0022| 0.010|
| 38G2AF              | 0.37  | 0.62  | 0.13  | 0.05  | 1.50  | 0.01  | 0.19  | 0.009 | 0.053 | -  | -  | 0.012|

Steel AC30X3NMAFB and 38G2AF are used for the manufacture connecting rods of an internal combustion engine, steel AC40H2NMAF – for crankshafts, and steel 118HGR – toothed parts of the engine and gearbox of the KAMAZ vehicle. In the delivery state, the contamination of steel AC40H2NMAF with oxides and sulfides does not exceed 2.5 points, and steel AC30X3NMAFB with oxides no more than 3 points, sulfides 2 points and nitrides 1 point. The mechanical properties of heat-treated steel in accordance with the recommendations of normative and technical documentation is at a high level and higher than that of commercially used steels 42HMFA and 40HN2MA for crankshafts and engine rods (Table 2).

Table 2. The mechanical properties of steels.

| Steel               | Property metrics |
|---------------------|------------------|
|                   | σ_0, MPa | σ_s, MPa | δ, % | ψ, % | KCU, J/cm² | HB  |
| AC40H2NMAF (connecting rods) | 1210     | 1080     | 12.5 | 56    | 110       | 302 |
| GOST 4543 40HN2MA (connecting rods) | ≥ 980   | ≥ 835    | ≥ 12.0 | ≥ 55 | ≥ 98    | 245-285 |
| AC30X3NMAFB (crankshaft) | 1110     | 1030     | 12.5 | 54    | 88        | 321 |
| Specification 14-1-5520 42HMFA (crankshaft) | ≥ 850   | ≥ 730    | ≥ 12.0 | ≥ 42 | ≥ 80    | 255-277 |

Note: Heat treatment of billets with a cross section of 25x25 for steels used for connecting rods - quenching from 850 °C to oil, tempering at 620 °C, cooling to oil; for steels used for crankshafts - quenching from 860 °C to oil, tempering at 580 °C, cooling to oil.

The manufacturability of steels with nitride-vanadium hardening was evaluated at the stages of forgings manufacturing (induction heating up to 1260 ± 20 °C, hot forging and heat treatment) and during the mechanical processing forgings at various cutting operations (turning, drilling, grinding). In the process of manufacturing forgings, steel showed its adaptability and after heat treatment, including quenching from 930 °C to oil and tempering at 630 °C, high strength and plastic properties.
were achieved. It should be noted that the heating temperature for hardening of forgings from steel AC30X3NMAFB and AC40H2NMAF is somewhat higher than that of steels 42HMFA and 40HN2MA – 930 °C instead of 860 °C, which is explained by the mechanism of their nitride-vanadium hardening.

When machining 1000 pcs. connecting rods with a hardness in the range of 255–302HB, the high technological effectiveness of the steel used in all cutting operations is established. The test results of connecting rods made of steel AC30X3NMAFB after various types of heat treatment (Table 3) showed that the fatigue limit of all experimental and industrial parts was 6 tons compression with a double cycle amplitude of 24 tons, which is 50% higher than the similar performance parts made from 40HN2MA steels. A slight decrease in hardness and the presence of ferrite (less than 10%) in the steel structure is observed in the part, the heat treatment of which included the implementation of forging heat from the billets (cooling after stamping). To neutralize the decarburized layer, inherited by the parts from the operation of induction heating of billets for stamping and heat treatment in an oxidizing atmosphere of forgings, shot blasting is used. Thanks to this treatment, the endurance of the connecting rods is increased, which is confirmed by metallographic studies, the study surface microhardness and fatigue strength tests [22].

**Table 3. Properties of steel AC30X3NMAFB after heat treatment.**

| Heat treatment schedule | T<sub>auto</sub>, °C | Cooling means | T<sub>temp</sub>, °C | Cooling means | Structure | Hardness, HB |
|-------------------------|---------------------|---------------|---------------------|---------------|-----------|-------------|
| 940                     | Air                 | 650           | Air                 | Sorbite       | 285       |
| 930                     | Oil                 | 650           | Oil                 | Sorbite       | 302       |
| 930                     | Air                 | 705           | Oil                 | Sorbite       | 278       |
| 950 (stamping end temperature) | Air (2-5°C/c) on the line | 705 | Air | Sorbite + Ferrite | 255 |

The mechanical processing the billet of the crankshaft on an automatic line showed that the deepest drilling operations are the limiting stage of the cutting process. The reason for the low resistance of drills is ø5.5÷10.0 mm. the sticking of the billet material to the cutting tool and the formation of poorly removed chips from the cutting zones served as Taking into account the relationship between machinability by cutting and material properties, parameters of the cutting mode and design features of the tool, the possibility of improving machinability in drilling operations billets from complex alloyed heat-optimized steel AC40H2NMAF is investigated. It was found that the optimal parameters when drilling billets from new steel are:

- for drills ø 5.5 mm and ø 5.7 mm – inputting 0.1 mm / rev at a speed of 660 rpm;
- for drills ø 8.5 mm and ø 8.7 mm - inputting 0.17 mm / rev at a speed of 400 rpm;
- for drills ø 9.0 mm and ø 10.0 mm – inputting 0.15 mm / rev at 360 rpm.

The main attention during the pilot industrial testing is given to indicators of the service part properties – their fatigue strength. Bench tests parts made of experimental steel showed that the endurance limits of crankshafts are: bending – 1000 kg · m, torsion - 900 kg · m, which exceeds these properties for currently used 42HMFA steel (900 and 800 kg M, respectively). The advantages of steels microalloyed with such elements include their high resistance to grain growth during heating, as evidenced by the temperature dependence of grain size changes in 38G2AF steel (Figure 1). In comparison with the 20H2N4A and 18HGR steels widely used in automotive industry, 38G2AF steel retains a fine-grained structure over the entire temperature range of alloy deformation (1000–1250 °C), which indicates the possibility of its quenching from temperature after deformation processing. A good example is the AC30X3NMAFB structural steel chilled immediately after completion of hot plastic deformation and having a grain size of 7–8 points (table 3). Similar results were obtained with the forging heat of forgings of a connecting rod made of 38G2AF steel. During controlled forging of the connecting rod forgings, the following indicators took place: the temperature of the onset of deformation –1220 °C, the end of the deformation – 940 °C, cooling
with cold compressed air (3.0–3.5 atm.) To a temperature of 450–550 °C and beyond in workshop conditions, to room temperature in calm air, the steel acquired a ferrite-pearlite structure (ferrite is less than 10%), grain size 6–7 points and hardness 285–293 HB.

![Figure 1](image_url)

**Figure 1.** Temperature dependence of grain growth in steel.

On the metal the connecting rod parts, the following strengths were achieved: tensile strength of 980 MPa, yield strength of 840 MPa, elongation of more than 19% and relative narrowing of more than 45%, which indicates the possibility of implementing residual forging heat for heat treatment forgings.

**Conclusions**

- High resistance to grain growth is shown when heating steels microalloyed with vanadium, niobium and nitrogen.
- High properties of the steel AC40H2NMAF, AC30X3NMAFB and 38G2AF make it possible to recommend them for the manufacture of heavily loaded parts – crankshafts and connecting rods.
- The possibility of realizing forging heat of forgings made of steels microalloyed with vanadium, niobium and nitrogen during their heat treatment to ensure a high level of properties and structural requirements.

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