Mechanical Characteristics of Alloy Smelted from Ore of Kentik Ore Occurrence (Sakha Republic, Russia)

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Abstract. The present work evaluates the possibility of using local minerals to create foundry alloys used in conditions of low temperature. The feasibility of using iron ores from the Kentik ore occurrence in the Verkhnevilyuysky district of the Republic of Sakha (Yakutia) for the manufacture of new cold-resistant and high-strength steels was analyzed. The ore contains oxides of alkaline earth metals: MgO, CaO, SrO and BaO, the total content of that is 1.6%, that contributes to the process of deoxygenation of the melt during its cooling, and the deoxygenation product in the form of oxides and other chemical compounds based on Ca, Sr and Ba floats into slag. The content of rare earth yttrium oxide is 0.0058%. Alloy is smelted from Kentik enriched ore, samples for static tensile and impact toughness tests were machined in order to study the mechanical properties. The results of chemical analysis showed that the total content of rare earth oxides Eu₂O₃, Tb₂O₃, Dy₂O₃ and Er₂O₃ was 0.062%. Such concentration of rare-earth metals promotes the increase of strength properties, as well as the operational characteristics of the material. The fracture surface of impact toughness sample is investigated. Analogues for comparing the strength and plastic properties were given. Technical instructions for obtaining an experimental samples of a cold-resistant medium-carbon alloy with increased strength for castings using a charge of naturally alloyed ferroalloy have been formulated.

1. Introduction

The fundamental concept of the state industrial policy of Russia is modernization in mechanical engineering, welding technologies, construction of oil and gas pipelines, mining, etc. Modernization of companies is based on the regular introduction of new technologies and materials guaranteeing high-quality and competitive products manufacturing. At present, state programs for the social and economic development of the Arctic are being implemented in Yakutia, and the use of high-strength cold-resistant and wear-resistant steels of various purposes made on naturally alloyed iron alloys is rapidly becoming a critical subject[1-3]. Deposits of iron, ferromanganese, iron-titanium ores, rare and rare-earth metals of sedimentary origin have been explored in the Republic of Sakha (Yakutia) [4 -6]. Thus, it is certainly...
expected to develop own metallurgical cluster on the territory of the Republic, based on local raw materials and practically independent of external supplies [7].

2. Materials and experimental procedures

Ores were sampled and delivered from the Kentik ore occurrence in the Verkhnevilyuysky district (Yakutia) during the expedition. Samples were enriched by BB-200 jaw crusher. The chemical compositions of ore samples and melted alloy were investigated by using a SRS 3400 X-ray fluorescence spectrometer and a Foundry-Master optical emission spectrometer. Mechanical and metallurgical test samples were machined using an electric metal milling machine. The uniaxial tensile tests were performed using an Instron-1195 testing machine at room temperature with traverse speed 2 mm / min according to State Standard GOST 1497 – 84. KCU impact toughness tests (State Standard GOST 9454-78) were conducted on a Zwick / Roell pendulum impact tester.

3. Results and discussion

The test ore is red iron ore, mainly consisting of hematite (Fe₂O₃) oxides of the main alloying elements, oxides of transition metals representing the modifying mixture, and also oxides of rare-earth metals and alkaline earth metals.

As listed in table 1, the content of iron oxide in the ore is 76.53%, the titanium and aluminum oxides forming the composition of the modifying mixture are in the range of 4.81%, and the content of the rare-earth yttrium oxide is 0.0058%.

The ore contains oxides of alkaline earth metals: MgO, CaO, SrO and BaO, the total content of which is 1.6%, that contributes to the process of deoxygenation of the melt during its cooling, and the deoxygenation product in the form of oxides and other chemical compounds based on Ca, Sr and Ba floats into slag. Thus, the melt is purified of detrimental and non-metallic inclusions, gases, voids during crystallization process.

Table 1. Chemical oxide composition of enriched ore from the Kentik ore occurrence.

| Chemical oxides (wt.%) | Na₂O | MgO | Al₂O₃ | SiO₂ | P₂O₅ | SO₃ | Cl | K₂O | CaO | TiO₂ | Cr₂O₃ | MnO | CoO |
|-----------------------|------|-----|-------|------|------|-----|----|-----|-----|-----|-------|-----|-----|
|                       | 0.3  | 0.57| 4.64  | 10.6 | 1.6  | 0.17| 0.041 | 0.341 | 0.855 | 0.17 | 0.033 | 3.83 | 0.005 |
| NiO                   | 0.013| 0.007| 0.013 | 0.0086 | 0.0058 | 0.18 | 0.015 | 0.03 | 0.031 | 0.027 | 0.054 | 0.043 | 76.53 |

Tables 2 and 3 present the results of X-ray fluorescence analysis of melted alloy. The mass fraction of TiO₂ and V₂O₅ microalloying elements oxides is 0.01%, the total content of rare-earth compounds Eu₂O₃, Tb₂O₇, Dy₂O₃ and Er₂O₃ is 0.062%.

Table 2. Chemical oxide composition of melted alloy from the Kentik ore occurrence.

| Chemical oxides (wt.%) | Na₂O | MgO | Al₂O₃ | SiO₂ | P₂O₅ | SO₃ | Cl | K₂O | CaO | TiO₂ |
|-----------------------|------|-----|-------|------|------|-----|----|-----|-----|-----|
|                       | 0.30 | 0.098 | 0.13 | 0.28 | 0.11 | 0.038 | 0.05 | 0.0081 | 0.054 | 0.0047 |
| CoO                   | 0.005| 0.035 | 0.018 | 0.0065 | 0.024 | 0.021 | 0.073 | 0.017 | 0.017 | 0.016 |
| Cr₂O₃                 | 0.005| 0.023 | 0.004 | 0.012 | 0.038 | 0.045 | 0.033 | 0.012 | 0.0091 | 85.66 |
Table 3. Chemical composition of melted alloy from the Kentik ore occurrence.

| Chemical elements (wt.%) | Na   | Mg   | Al   | Si   | P    | S    | Cl   | K    | Ca   | Ti   |
|-------------------------|------|------|------|------|------|------|------|------|------|------|
| Na                      | 0.22 | 0.059| 0.82 | 0.13 | 0.049| 0.015| 0.05 | 0.073| 0.038| 0.0028|
| Co                      | 0.004| 0.028| 0.014| 0.0049| 0.024| 0.15 | 0.014| 0.014| 0.011| 0.038|
| Cr                      | 0.0034| 0.017| 0.002| 0.045| 0.021| 0.021| 0.012| 0.069| 0.033| 59.91 |

The results of optical emission analysis of melted alloy are presented in table 4. Melted ferroalloy belongs to medium carbon alloy with a minimum content of detrimental inclusions of phosphorus and sulfur.

Table 4. Chemical composition of melted alloy from the Kentik ore occurrence.

| Chemical elements (wt.%) | C    | Si   | Mn   | Ni   | W    | Cu   |
|-------------------------|------|------|------|------|------|------|
| C                       | 0.59 | 0.44 | 0.03 | 0.02 | 0.01 | 0.006|

Alloy contains microalloying elements Ti, V in thousandths of a percent. These strong carbon-nitride-forming elements are components of naturally alloyed ore. Ti and V microalloying promotes the optimal combination of mechanical (strength, cold resistance), technological (weldability) and service properties (structural strength, reliability, durability, wear resistance, weight reduction, etc.) of machine parts working in difficult climatic conditions of the North.

Samples for mechanical tests were machined from melted alloy (figure 1).

Figure 1. Samples for: a) uniaxial tensile tests; b) impact toughness tests.

The results of uniaxial tensile and impact toughness tests of melted alloy are listed in table 5. Samples of the first group after heat treatment by annealing at T = 720°C; t = 1 hour (treatment time), were tested for static tension according to GOST 1497-84 and impact toughness according to GOST 9454-78. The second group of samples after heat treatment in the form of quenching at 800°C was highly tempered (table 5). The melted alloy in terms of carbon content and mechanical properties of forgings (GOST 8479-70) belongs to construction carbon steels of ordinary quality of grades St30 and St45. Increases of 15-20 % in mechanical properties of melted alloy compared to analogues were observed.
Table 5. The mechanical properties of melted alloy.

| Materials                      | Yield strength [MPa] | Tensile strength [MPa] | Elongation [%] | Contraction [%] | KCU [kJ/m²] | Hardness [HB] |
|--------------------------------|----------------------|------------------------|----------------|-----------------|-------------|--------------|
| Melted alloy after annealing   | 388                  | 588                    | 13             | 47              | 450         | 195          |
| Melted alloy after quenching + tempering | 500      | 982                    | 7              | 28              | 500         | 213          |
| Analog St30                   |                      |                        |                |                 |             |              |
| (State Standard GOST 8479-70) |                      |                        |                |                 |             |              |
| USA C1030                     |                      |                        |                |                 |             |              |
| Analog Si45                   |                      |                        |                |                 |             |              |
| (State Standard GOST 8479-70) |                      |                        |                |                 |             |              |
| USA 1045                      |                      |                        |                |                 |             |              |

The type of fracture is crystalline, the fracture surface is light gray with a metallic sheen, indicating fracture along grain boundaries, as depicted in figure 2. Contractions on the fracture sides are very small, that characterizes a slight plastic deformation (in 7-13 %) of the metal during its destruction (table 5).

Figure 2. Fractograph of impact sample.

Pullouts observed on the fracture surface are formed due to partially preserved segregation heterogeneity during forging.

In this way, the melted alloy from Kentik ore occurrence ore in the Verkhnevilyuysky district (Yakutia), according to its mechanical properties and chemical composition, belongs to medium-carbon high-quality structural steels.

4. Conclusions

1. Technical instructions for obtaining an experimental samples of a cold-resistant medium-carbon alloy with increased strength for castings using a charge of naturally alloyed (Ti, V, Mn, W, rare earths and alkalines) ferroalloy have been formulated. Ferroalloy was obtained by direct reduction of ores from the Sredniy Vilyui ore field of Yakutia.

Titanium, vanadium (strong carbonitride-forming elements) and rare-earth elements microalloying in a quantity of 0.01% and 0.062%, respectively, promotes the optimal combination of mechanical (strength, cold resistance), technological (weldability) and service properties (structural strength, reliability, durability, wear resistance, weight reduction, etc.) of machine parts and mechanisms operating in difficult climatic conditions of the North.

2. New alloy has been created from local naturally-alloyed iron ore from the Kentik ore occurrence in the Verkhnevilyuysky district of the Republic of Sakha (Yakutia). This alloy belongs to the grade of
low alloy medium carbon quality structural steels. Mechanical characteristics and operational properties of the alloy are higher by 15-20% than the properties of the cited similar serial steels.

5. References

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