INVESTIGATION OF CHEMICAL COMPOSTITION AND MATERIAL STRUCTURE INFLUENCE ON MECHANICAL PROPERTIES OF SPECIAL CAST IRON

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Abstract

New wear-resistant special cast iron CHMN-35M was produced to be used for parts which are operated under the conditions of intense friction loads. Based on obtained results, technical requirements by chemical compounds and mechanical properties were determined. Wear resistant properties of experimental material in friction couples with a different type of steel were investigated. Experimental samples were tested by static and impact bending to evaluate strength and crack resistance of the material. Fractography investigations of samples after mechanical test were carried out. Influence of nickel and molybdenum on structure and mechanical properties of special cast iron CHMN-35M are presented in this work.

Keywords: Wear resistant cast iron, cast iron CHMN-35M, tribological properties, nickel and molybdenum influence, martensite in grey cast iron

1. INTRODUCTION

Nowadays, the Russian industry uses gray cast iron SCH10 - SCH35 (GOST 1412-85) for serial production of parts operating under the conditions of intense frictional loads. In comparison to steels, gray cast iron contains free graphite. Free graphite plays a role of solid lubricant which results in enhancing the lifetime of machines that are subject to wear [1-8]. However, to ensure the wear resistance of heavily loaded parts operating under the shock-frictional conditions, contributions of free graphite in gray cast iron is not enough. This was the reason to develop new high strength cast iron with an improved set of basic physical, mechanical and service properties (lower propensity to fracture, higher level of resistance to shock, etc.). The development of a new grade of cast iron was carried out on the basis of standard gray cast iron SCH35 (GOST 1412-85), which included the composition of alloying and modifying additives of nickel, molybdenum, zirconium, barium, calcium, aluminum. Added elements with high thermodynamic activity significantly influence the process of structure formation of cast iron and also positively influence the shape, size and dispersity of ferrite-pearlite, graphite and other structural components. After carrying out several experiments to determine the ratio of alloying and modifying elements, a chemical composition of cast iron having high strength and antifriction properties was developed [9]. The received iron is given the index of CHMN-35M. It is used in friction couples with various steels provided a significant reduction in wear of rubbing surfaces. The check for patent purity allowed to declare cast iron as an invention (patent for invention № 2562554) [10].

Based on results obtained, technological requirements (TU 0812-001-10036140-2014) by chemical composition and mechanical properties of a new grade of cast iron are summarized in **Table 1** and **Table 2**.

Table 1 Chemical composition of cast iron

Grade of the cast iron	Chemical elements [%]								
	C	Si	Mn	Mo	Ni	Cr	Cu	P	S
						not more than			
CHMN-35M	2.5 ÷ 2.8	1.3 ÷ 1.5	0.7 ÷ 1.0	0.6 ÷ 0.9	0.5 ÷ 0.8	0.3	0.3	0.2	0.1

Table 2 Mechanical properties of cast iron

Grade of cast iron	Tensile strength [MPa]	Brinell hardness [HB]	
		not less than	not less than
CHMN - 35M	≤350 (35)	250	300

2. MATERIAL AND METHODS

Experimental samples development and further evaluation of the influence of nickel and molybdenum on the strength and hardness of cast iron CHMN-35 and CHMN-35M was carried out under the conditions of LCC Altai steel plant (Barnaul, Russian Federation).

Microstructure of cast iron samples was observed using semiautomatic light microscope Axio Observer Z1m (Carl Zeiss).

Impact bending test of experimental samples was carried out on pendulum impact testing machine according to GOST 9454-78 at room temperature. Samples with U and V type of concentrators were utilized. Scanning electron microscope Carl Zeiss EVO50 XVP was utilized to provide fracture surface micrographs of the experimental samples after the impact bending test.

Investigation of fracture toughness parameters was done on samples with a sharp notch with a three-point bend on the universal test machine “Instron 3369” by static bending test (GOST 24648-90). The loading speed was 0.2 cm/min. According to the test result, tensile strength σ_d, yield strength σ_y, plastic bend deflection f_{pl} and destruction work A_d (work of crack initiation A_i and propagation A_p) were evaluated.

Wear resistance experiments were carried out on frictional testing machine UMT 2168. Samples in a form of a couple of “shaft-shoe” were provided for this test. Shaft samples were made from cast irons SCH35 and CHMN-35M. As a counter body, the shoes from steel 20GL, 30HGSA and 09G2S were used.

3. RESULTS AND DISCUSSIONS

According to the specifications for this material, the nickel content should be from 0.5 % up to 0.8 %. The hardness is between 296-300 HB (**Figure 1**). The nickel content below the limit leads to decrease the mechanical properties (e.g. hardness and tensile strength), doping above the limit does not have any significant influence (**Figure 1**).

Strength studies of the samples with 0.5 - 0.8 % of Ni showed that tensile strength was 368 - 380 MPa which met the requirements of the material specification.

The concentration of molybdenum according to the technical specifications for CHMN-35M should be in the range from 0.6 % up to 0.9 %. This concentration provides the hardness of 298 - 303 HB. The decrease of the concentration leads to a significant reduction in hardness (**Figure 2**), while the increase of Mo leads to enhance the hardness of more than 300 HB, which is unacceptable by the requirements.

The tensile strength of samples containing 0.6 - 0.9 % of Mo was 378 - 385 MPa, what met the requirements. With increasing of Mo, the tensile strength is greatly reduced due to the increase of hardness.

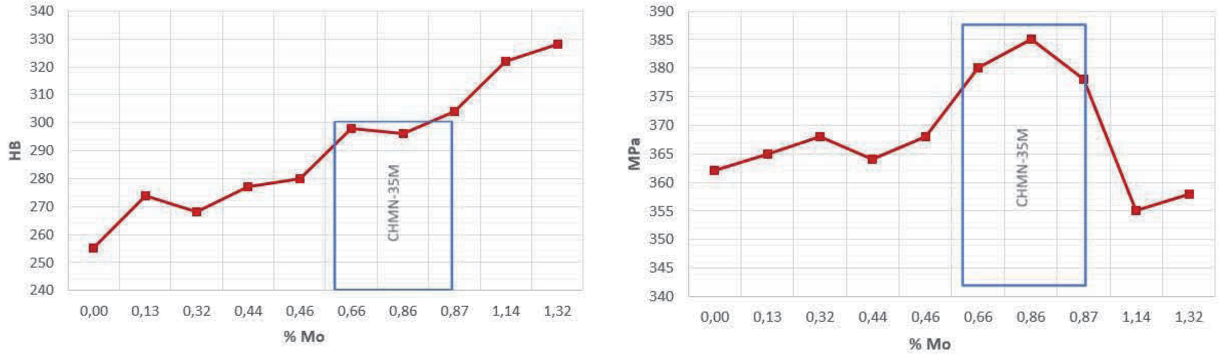

Figure 1 Influence of nickel on hardness and tensile strength of cast iron CHMN-35M

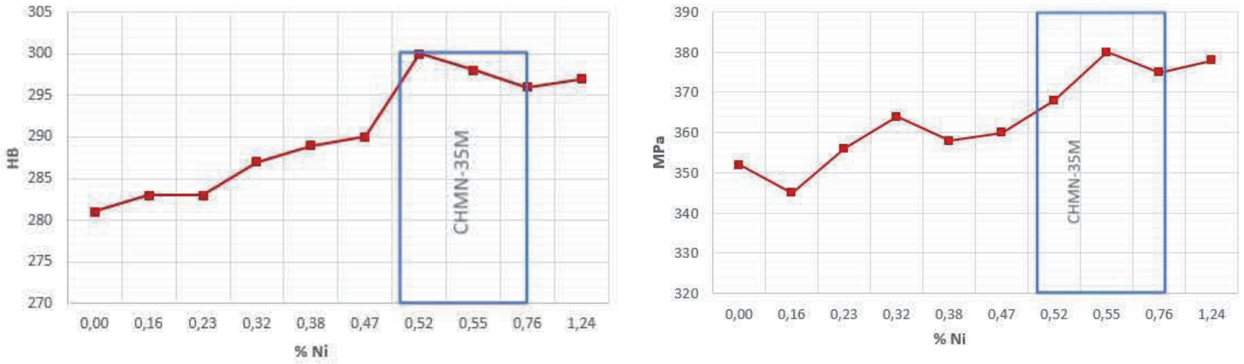

Figure 2 Influence of molybdenum on hardness and tensile strength of cast iron CHMN-35M

The main differences in the microstructure between cast iron experimental samples (CHMN-35 and CHMN-35M) and conventional cast iron SCH-35 are characterized by the graphite inclusions. The cast iron SCH-35 had mixed interdendritic lamellar and uneven distribution of graphite (**Figure 3a**). In the cast iron CHMN-35, the distribution of graphite was mixed by sections of uniform and uneven distribution (**Figure 3b**). The microstructure of CHMN-35M had ferrite-pearlite metal base with uniformly distributed inclusions of lamellar, vortex or nest-like graphite. Microstructure of SCH-35 cast iron was perlitic (**Figure 4a**), while the microstructure of CHMN-35M cast iron was perlitic-ferrite (**Figure 4b**).

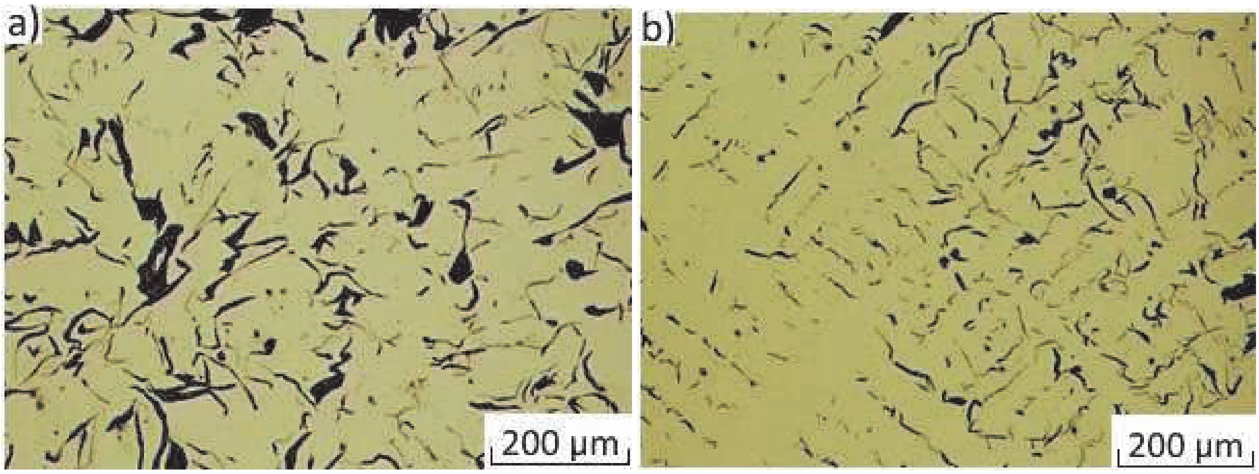

Figure 3 Distribution of graphite in cast iron (a) SCH35 and (b) CHMN-35M

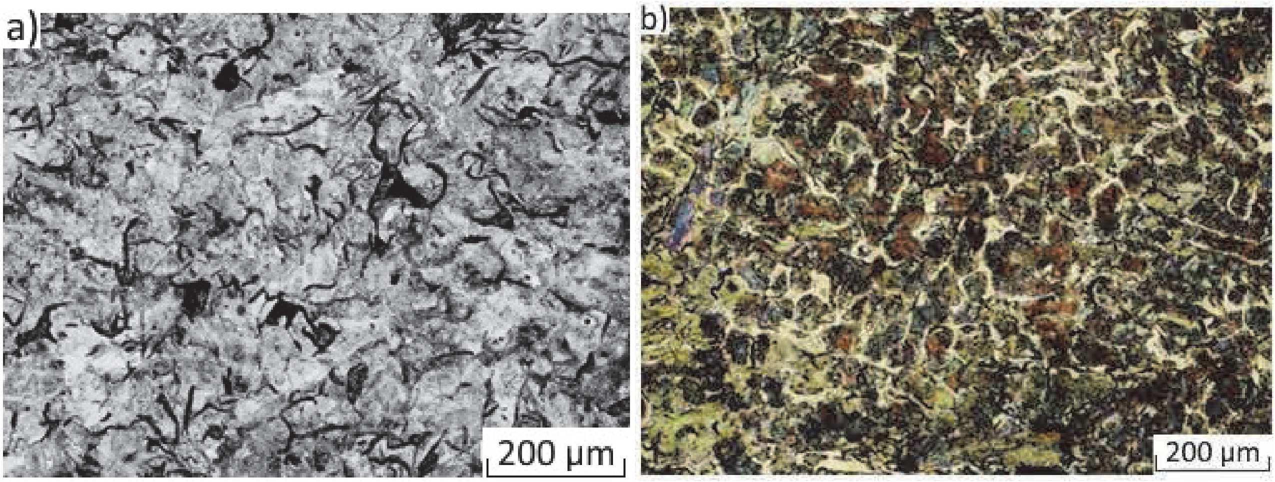

Figure 4 Microstructure of (a) perlitic cast iron SCH35 and (b) perlitic-ferrite cast iron CHMN-35M

Impact bending test results are presented in **Table 3**. Samples had macro-fragile fracture pattern. From the given data, it can be seen that the cast iron CHMN-35, as well as cast iron SCH-35, were not sensitive to stress concentrators. It is explained by the presence of graphite inclusions, which can be considered as micro-cracks due to low fracture strength of the graphite.

Table 3 Impact bending test results

Grade of the cast iron	Impact bending strength KCU [J / cm^2]	Impact bending strength KCV [J / cm^2]
CHMN-35M	107 - 112	102 - 108
SCH35	89 - 95	95 - 101

Static bending test results are summarized in **Table 4**. This test provided us the information that the iron cast CHMN-35M strength was higher than iron cast SCH35. The tensile strength was higher by 23 - 25 %; and the yield strength was up by 30 - 33 %. The total work of destruction of cast iron CHMN-35M was 1.5 times higher. This difference is mostly based on increased work of crack propagation, since the work of crack initiation had low absolute values.

Comparative fractographic studies of cast iron SCH35 and CHMN-35M showed that destruction mechanism of both of the samples was the same. Both in the region of initiation and in the region of propagation of the crack, fracture proceeded by a fragile mechanism with a clear predominance of intercrystalline failure. There also were the facets of a brittle fracture on the failure surface. The size of the facets in the region of crack initiation and propagation for a particular grade of cast iron was almost the same. It should be noted that the structure of surface fracture was much more homogeneous. The facets size of the chip was about 1.5 times smaller (**Figure 5**).

Table 4 Static bending test results

Grade of the cast iron	σ_d	σ_y	f_{pl}	Ai	Ap	A_{Σ},
	[N / mm^2]			[J / cm^2]		
CHMN-35M	524 - 559 541.5	559 - 559 559	0 - 0.02 0.01	0 - 0.13 0.06	2.08 - 2.29 2.18	2.21 - 2.29 2.25
SCH35	429 - 448 439	415 - 434 425	0.03	0.13 - 0.15 0.14	1.40 - 1.47 1.44	1.55 - 1.60 1.58

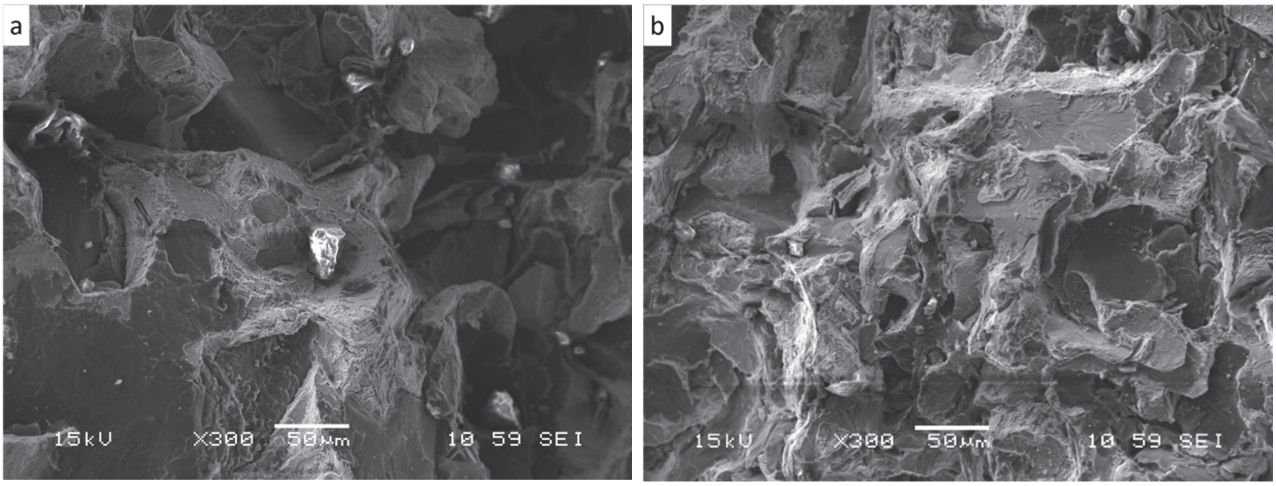

Figure 5 Fracture surface of the samples after impact bending test (KCU) (a) cast iron SCH35, (b) cast iron CHMN-35M

A number of comparative tribo-technical studies have been carried out to establish the dependence of the weight wear on a length of a trace due to interaction of the rubbing surfaces. Wear resistance experiment results are presented in **Table 5.**

Analysis of shafts and shoes wear showed that the wear resistance of shafts made from cast iron CHMN-35M was approximately 1.5 times higher than the SCH35 cast iron shafts.

Table 5 Wear resistance test results

№	Shape of the sample	Material	Coefficient of friction	Weight of worn material [g]	Total wear of friction couples [g]
1	Shoe	30HGSA	0.11 - 0.13	0.12	1.13
	Shaft	SCH35		1.01	
2	Shoe	30HGSA	0.10 - 0.12	0.05	0.56
	Shaft	CHMN-35M		0.51	
3	Shoe	20GL	0.12 - 0.13	0.04	1.02
	Shaft	SCH35		0.98	
4	Shoe	20GL	0.11 - 0.12	0.12	0.78
	Shaft	CHMN-35M		0.66	
5	Shoe	09G2S	0.13 - 0.14	0.45	0.80
	Shaft	20GL		0.35	
6	Shoe	09G2S	0.11 - 0.12	0.13	0.69
	Shaft	CHMN-35M		0.56	

The presence of molybdenum (0.6 - 0.9 %) and nickel (0.5 - 0.8 %) in the chemical composition of the CHMN-35M cast iron led to the stabilization of the perlite and ensured the martensite formation in the microstructure (**Figure 6**). Martensite positively influenced wear resistance by reducing the wear.

Based on the tests result, it can be stated that the cast iron CHMN-35M fully meets the operating requirements for the parts working under the long cyclic shock-friction conditions.

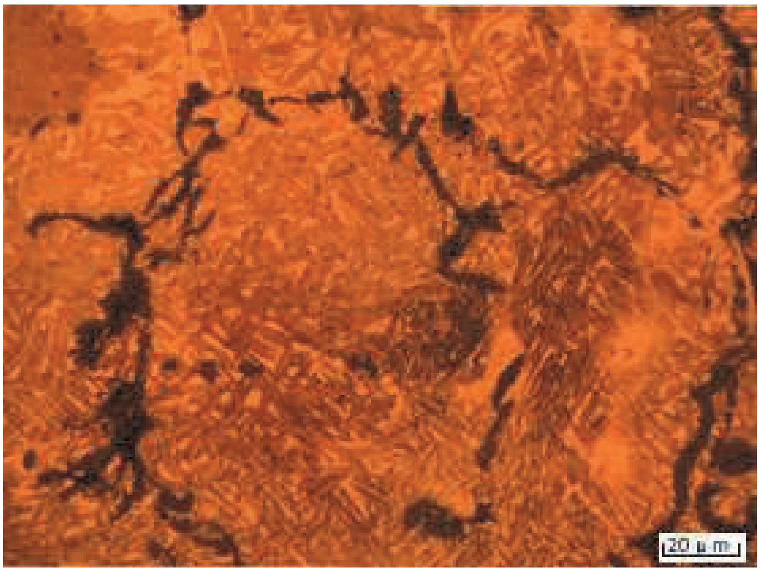

Figure 6 Marensitic formation in microstructure of cast iron CHMN-35M

4. CONCLUSIONS

The influence of nickel and molybdenum on mechanical properties of cast iron CHMN-35M was determined. With decreasing of nickel (<0.5 %) and of molybdenum (<0.6 %), the hardness and the strength decreased. With increasing of nickel (>0.8 %), the mechanical properties relatively did not change. The increase of molybdenum more than 0.9 % led to increase of the hardness and high decrease of strength due to formation of molybdenum carbides. The content of Ni from 0.5 % to 0.8 % and of Mo from 0.6 % to 0.9 % in the cast iron CHMN-35M provided the formation of martensitic structure, which also had positive influence on strength and wear resistance of material. Experimental sample CHMN-35M showed higher mechanical properties in comparison to serial cast iron SCH35: the tensile strength was higher on 23 - 35 %, the yield strength was higher on 30 - 33 %, and the total destruction work was 1.5 times higher. Fractography investigations of cast irons SCH35 and CHMN-35M showed that fracture occurred by the same way both in the region of crack initiation and in the region of crack propagation. Fracture proceeded by a brittle mechanism with a clear predominance of intercrystalline failure. The facets of a brittle fracture on the failure surface were observed. The size of facets of cast iron CHMN-35M was 1.5 times less than the facets of serial cast iron SCH35.

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