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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

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Selection and justification of a technology for improving the wear resistance of ball mill liners

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Abstract: Under conditions of intensive abrasive and impact wear, typical of ball mill operation, the use of conventional high-manganese steel 110G13L as a lining material proves to be insufficiently effective. This study substantiates the feasibility of using M1-grade chromium-molybdenum steel as an alternative material for mill drum lining. Laboratory investigations of the composition, microstructure, and properties of M1 steel were conducted, along with an analysis of the production technology and heat treatment. The results confirm the potential of the proposed alloy in enhancing wear resistance and operational reliability of the lining.
Keywords: chromium-molybdenum steel, mill lining, wear resistance, ball mill, abrasive wear, heat treatment

1. Introduction

Ball mills are widely used in the mining and metallurgical industries for fine grinding of ores and other abrasive materials. A major factor limiting the service life of such equipment is the wear of the lining, which is subjected to cyclic impact and abrasive loads. The most commonly used lining material is high-manganese steel 110G13L; however, under increasingly aggressive operating conditions, this material shows insufficient resistance to wear. Therefore, there is a pressing need to identify new structural materials that offer a combination of superior mechanical and performance properties. One promising candidate is chromium-molybdenum steel, known for its high strength, resistance to abrasive wear, and thermal stability [1-3].

2. Research methodology

K. Nagel and M. Schreckenberg's "Road Design" textbook is dedicated to exploration and road design. The first part describes the main requirements for road elements in plan and profile, methods for ensuring the stability of the roadbed, determining the thickness of the road surface and laying the axis of the road on the ground, and calculating small water-conducting structures [10].

U. Yuldashev and others wrote in the textbook "Labor Protection" based on the general rules of labor protection, industrial sanitation, equipment safety techniques, fire safety issues, as well as regulatory documents adopted in the Republic of Uzbekistan.

2.1. Material

The primary material used in this study was M1-grade chromium-molybdenum steel, produced under laboratory conditions (Figure 1) at the Academic Foundry of NUST "MISIS". The chemical composition of the studied steel is presented in Table 1 [4-5].

Fig. 1. Melting process of M1-grade chromium-molybdenum steel

Table 1
Chemical composition of chromium-molybdenum steel, %

No.	Material Name	C	Si	Mn	P	S	Cr	Mo	Cu
1	M1 grade	0.35	1.11	0.31	0.009	0.009	1.07	0.57	0.50
2	Obtained steel	0.12	0.10	0.18	0.018	0.024	0.36	0.39	0.50

2.2. Melting Procedure

The steel was melted in a laboratory induction crucible furnace using a graphite crucible. The alloying sequence was as follows: iron and carbon were added first, followed sequentially by silicon, manganese, chromium, and molybdenum. Copper was added at the final stage to minimize evaporation losses. The melting temperature was maintained in the range of 1550–1600 °C [6-8].

2.3. Heat Treatment

To achieve the desired microstructure (martensite + carbides), the following heat treatment regime was applied [9]:

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– quenching: Heating to 870–900 °C, holding for 1 hour, followed by oil cooling.

– tempering: Heating to 500–550 °C, holding for 2 hours, followed by air cooling.

2.4. Metallographic Analysis

The microstructure was studied using optical microscopy. Samples were ground and polished, then etched in a 4% nitric acid solution in ethanol [10]. The microstructure of M1 steel after heat treatment is shown in Figure 2.

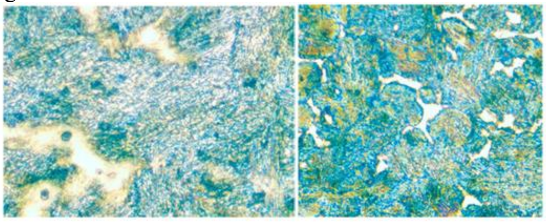

Fig. 2. Microstructure of M1 steel: a) 800× magnification; b) 200× magnification

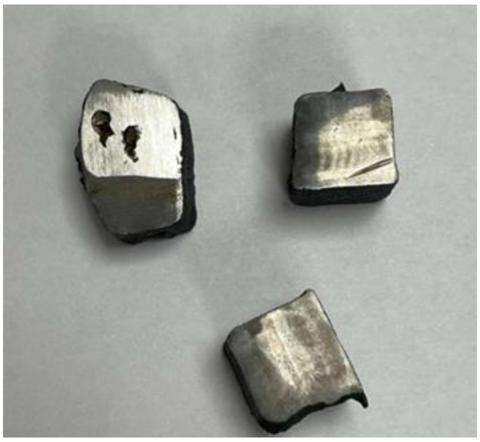

Fig. 3. Sample surface after grinding

3. Results and Discussion

Metallographic analysis showed that after quenching and tempering, the structure of M1 steel consists of martensite with uniformly distributed carbides. This contributes to increased hardness and wear resistance.

The measured hardness reached 450–520 HB, significantly exceeding the typical values of conventional rubber or low-alloy steel linings. This combination of strength and toughness is particularly important under conditions involving intensive interaction between the lining, metal grinding balls, and abrasive ore.

Due to the presence of chromium (0.8–1.2%) and molybdenum (0.8–1.2%), stable carbides are formed in the steel structure, enhancing resistance to both abrasive and impact wear. The additional alloying with copper improves corrosion resistance and reduces susceptibility to cracking.

4. Conclusion

The conducted study confirms the promising potential of using M1-grade chromium-molybdenum steel as a lining material for ball mills. Based on the analysis of chemical composition, microstructure, and heat treatment, the following conclusions can be drawn:

1. M1 steel possesses a combination of properties ensuring high wear resistance and impact toughness under abrasive conditions.

2. The martensitic structure strengthened by carbides provides hardness in the range of 450–520 HB, surpassing conventional lining materials.

3. The proposed technology can be recommended for implementation at industrial facilities operating ball mills in highly abrasive environments, particularly at JSC "AGMK".

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