EFFECT OF CARBON AND MANGANESE CONTENT ON THE MECHANICAL PROPERTIES OF HADFIELD STEEL

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Despite the fact that Hadfield steel (110G13L) has been used worldwide for over 120 years, and many scientists have studied its composition and properties, the basic chemical composition of this steel remains unchanged. This is due to significant fluctuations in the main elements in the steel, which ultimately provide the necessary properties that differ from each other. The chemical composition of steel plays an important role in determining its mechanical characteristics. Various additives can significantly affect the strength, hardness, plasticity, and impact toughness of the material. The structure and grain size also have a significant impact on the mechanical behavior of steel. The influence of alloying elements such as manganese, chromium, nickel must be considered to achieve optimal properties. Heat treatment plays an important role in improving the mechanical properties of steel. Therefore, it is important to consider both the chemical composition and the internal structure of the steel when designing materials. The wide range of carbon and manganese content and ratios plays a defining role in the stability of the composition of Hadfield steel. The opinion of many scientists about the influence of the amount of carbon on the mechanical properties of Hadfield steel is similar, with differences only manifesting depending on the conditions of use. Carbon, being part of the solid solution, in any case affects the strength properties, hardness, and plasticity. This dependency is explained by the reduced mobility of dislocations due to interaction with carbon atoms. As the carbon content increases from 0.63% to 1.5%, the strength properties and hardness increase, while plasticity decreases due to the increase in size and number of excess carbides. According to the conclusions of N.G. Davydov and V.V. Sitnov, a carbon content above 1% increases the hardness and strength properties of steel, but the impact toughness, narrowing, and elongation (plastic properties) decrease and reach a minimum value at a carbon content of more than 1.18% [1,2]. It should be noted that these dependencies are valid only without heat treatment after casting. With a carbon content of 1.06% to 1.48% after quenching, the impact toughness decreases [3].

After the quenching process, the relationship between carbon content and mechanical properties is maintained, but the tendency to reduce the indicators of relative elongation and narrowing weakens due to the transition of carbon into the solid solution. At low temperatures and a carbon content of less than 0.8%, the plastic and strength properties of steel decrease due to the formation of deformation martensite. As a result, the lower limit of carbon content in Hadfield steel is set at 0.9%.

Manganese, like carbon, expands the range of stability of the γ-phase and contributes to the formation of austenite. When manganese and carbon are present in steel simultaneously, they enhance the formation of a substitutional solid solution in iron. Manganese at high temperatures increases the ability of austenite to dissolve carbon. The main purpose of adding manganese to steel is to remove oxygen and sulfur. Manganese positively affects the weldability and plasticity of steel, reducing the likelihood of red brittleness. In addition, manganese improves the cold resistance and plasticity of steel.

For high-carbon steels, certain minimum concentrations of manganese are characteristic. A carbon content of 1.2% and manganese of more than 5% provides the steel with a purely austenitic structure after cooling in water, as confirmed by the structural diagram of manganese steels by E.S. Bain [4]. According to GOST 2176–77, with a manganese concentration of more than 10%, the steel acquires high strength and plasticity. At the same time, with a manganese content of 8 to 10%, its influence on the wear resistance of steel is small. Research at URALMASH has shown that a manganese to carbon ratio of 11–11.5 provides resistance to bending until cracks appear. For thin-walled parts made of 110G13L steel with a thickness to length ratio of 100:1 to 150:1, a manganese content of 10.5–11.5% is recommended to avoid carbide contamination and cracks after casting and heat treatment. Reducing the manganese content from 13.8% to 10.75% increases hardening with little deformation. Parts with 9–11% manganese are more durable by 35–40% compared to 12–14% manganese [5].

A manganese concentration of 10–14% does not affect the mechanical properties with a carbon content of up to 1.5%. The manganese to carbon ratio should be no less than 10. A high content of both elements provides a stable austenitic structure. A ratio of 8–8.5 eliminates problems with quenching and hot cracks, maintaining impact toughness and increasing shrinkage and the tendency to form burning cracks with an increase in manganese in the composition and a constant amount of carbon.[6]

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