HIGH-STRENGTH LOW-CARBON AND LOW-ALLOYED STEELS

EFFECT OF MANGANESE AND NIOBIUM ON THE PROPERTIES OF LOW-ALLOY STEELS

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INTRODUCTION

High-strength low-alloy steels have progressed considerably in the last decade after the determination of optimum proportion of alloying elements that ensures a good combination of strength and ductility characteristics, low-temperature toughness, and weldability at a low cost and simple enough production process.

The use of steels with higher strength parameters makes it possible to reduce the mass of ready structures. At the same time, growth in the strength is necessarily accompanied by growth in the toughness, as shown in Fig. 1 [1] for large-diameter gas conduit pipes. The figure presents an exponential dependence of the toughness of steels on the pressure of the pumped gas \( p \) and on the hoop stresses \( \sigma_h \) in the pipes.

The most expedient measure for the development of high-strength low-alloy steels is eliminating carbon as the hardening element due to its negative effect on both the weldability and the toughness of the steel (Fig. 2) [2]. Hardening by other mechanisms considered also has a negative effect on the toughness of steel except for the mechanism of grain disintegration, which enhances both the strength characteristics and the toughness of the metal. Grain disintegration is a necessary way for developing high-strength low-alloy steels.

As for the solid solution mechanism of hardening, its realization can influence differently the degree of hardening and the toughness of the steel depending on the alloying elements. Let us compare the most typical elements used for solid solution hardening, namely, Si and Mn. Silicon and manganese increase the strength characteristics of steel \( \Delta \sigma_y = 83 \text{ MPa}/1\% \text{ Si} \) and \( 32 \text{ MPa}/1\% \text{ Mn} \). At the same time, silicon additives raise the ductile-to-brittle transition temperature by \( 5^\circ \text{C} \) per every \( 10 \text{ MPa} \) on the average and

![Fig. 1. Relation between the impact energy \( KV \) not causing avalanche fracture and the gas pressure \( p \) and hoop stress \( \sigma_h \) in pipes with diameter of 1420 mm and wall thickness of 20 mm fabricated from different steels. The type of the test is given at the curves.](image-url)
manganese additives lower the temperature of the ductile-to-brittle transition by 3°C per every 10 MPa on the average [3]. Only several elements including manganese and nickel raise the ductility and are the most frequently used for alloying steels. They promote a decrease in the temperature of the transformation, thus causing additional disintegration of grains.

In addition to the chemical composition the properties of steels are affected by thermomechanical treatment (TMT) or “controlled” rolling. In this process the final deformation is conducted in a temperature range where the deformed austenite grains do not recrystallize and gradually acquire an elongated shape. In subsequent formation of ferrite grains and in the presence of fine particles dissolved in the ferrite matrix this makes it possible to disintegrate the microstructure to a considerable degree, which is presented schematically in Fig. 3.

The most effective element for hindering recrystallization of austenite is niobium. Under typical rolling conditions the addition of even 0.03% Nb into the metal fully suppresses the recrystallization of austenite at a temperature of about 950°C [4, 5]. As compared to microadditives of other elements (vanadium and titanium) niobium hinders recrystallization of austenite in a lower amount and at higher rolling temperatures.

The capacity of niobium to increase the strength and toughness has been proved by many researchers in microalloying of both traditional pipe steels with up to 0.18% carbon and of new steels with low carbon content (0.03 – 0.08%). It can be seen from Fig. 4 [6] that even low additives of niobium produce a high effect. Microalloying with 0.02% Nb increases the ultimate rupture strength by about 100 MPa, which is equivalent to alloying with up to 3% manganese. If we take into account the difference in the cost of the ferroalloys (FeMn and FeNb), the difference in the cost of 1 ton steel will become obvious (by $60 due to alloying with 3% Mn and by only $3 due to microalloying with 0.02% Nb). The Ural Steel JSC (Orsko-Khalilovskii Iron and Steel Works) has been working for many years at developing new grades of steel and advancing the traditional pipe steels for meeting the demands of the oil and gas industry for large-diameter pipes for various climatic conditions. We performed a complex study in order to determine optimum process parameters for the production of rolled sheets with specified mechanical and process properties at a specific chemical composition of the metal.