Effects of Molybdenum and Vanadium Addition on Tensile and Charpy Impact Properties of API X70 Linepipe Steels

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This study is concerned with the effects of V and Mo addition on tensile and Charpy impact properties of API X70 linepipe steels. Twelve kinds of steel specimens were produced by varying V and Mo additions and rolling conditions. The addition of V and Mo promoted the formation of acicular ferrite (AF), banitic ferrite (BF), and martensite-austenite (MA) constituents, while suppressing the formation of polygonal ferrite (PF) or pearlite (P). The tensile test results indicated that the tensile strength of the specimens rolled in the two-phase region increased with the addition of V and Mo, while the yield strength did not vary much in these specimens except the water-cooled specimens, which showed the increased yield strength with addition of Mo. The tensile strength of specimens rolled in the single-phase region followed by water cooling increased with increasing V and Mo contents. The yield strength, however, did not vary much with increasing V content or with addition of Mo to the low-V alloy. In these specimens, a substantial increase in the strengths was achieved only when Mo was added to the high-V alloy. The specimens rolled in the single-phase region had higher upper-shelf energy (USE) and lower ductile-brittle transition temperature (DBTT) than the specimens rolled in the two-phase region, because their microstructures were composed of AF and fine PF. According to the electron backscatter diffraction (EBSD) analysis data, the effective grain size in AF was determined by crystallographic packets composed of a few fine grains having similar orientations. Thus, the decreased DBTT in the specimens rolled in the single-phase region could be explained by the decrease in the overall effective grain size due to the presence of AF having smaller effective grain size.

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I. INTRODUCTION

LINEPIPE steels have been used for transporting crude oil or natural gas from oil fields to ports or refineries and have been denominated as API X65, API X70, *etc*., based on strength in accordance with the American Petroleum Institute (API) specifications. Recently produced linepipe steels have become stronger, tougher, thicker, and larger in order to increase the transportation efficiency under high pressure and to reduce the long-distance transportation cost. As many drilling activities have been undertaken in severe conditions such as extremely cold or deep regions, the demands for much stronger and tougher linepipe steels have been increasing.[1–5]

In linepipe steels, strength is mainly represented by yield strength, while toughness is largely considered in terms of ductile-brittle transition temperature (DBTT) and absorption energy at a specified temperature or upper-shelf energy (USE). Thus, high-strength high-toughness linepipe steels require high yield strength, low DBTT to prevent brittle fracture at service temperatures, and sufficient absorption energy to prevent unstable ductile fracture propagation in ductile fracture regions above DBTT. It is generally known that the absorption energy and strength depend on microstructural factors such as type, volume fraction, and morphology of secondary phases, reinforcing phases, grain size, and matrix microstructure, and that DBTT primarily relies on the distance between grain boundaries, *i.e.*, effective grain size, which work as a barrier against the cleavage crack propagation.[3–13] The effective grain size of ferrite-pearlite steels is identified as ferrite grain size; however, those of high-strength acicular ferritic steels, bainitic steels, dual-phase (ferrite-martensite) steels, and complex steels with these microstructures coexisting are still exposed to serious controversies.[12–17]

Because the increase in strength can be accompanied with deteriorating toughness, systematic understanding of various microstructural factors affecting tensile and Charpy impact properties is needed in order to produce high-strength high-toughness linepipe steels. Therefore, API X70 linepipe steels having different microstructures depending on rolling and cooling conditions and alloying elements such as V and Mo were produced in the

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