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Influence of Reheating Temperature and Vanadium Content on Transformation Behavior and Mechanical Properties of Medium Carbon Forging Steels

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The influence of vanadium and nitrogen on microstructure and mechanical properties of medium-carbon steels has been studied by means of metallography and mechanical testing. Vanadium addition to the low nitrogen steel suppresses the formation of ferrite–pearlite following the low reheating temperatures and microstructure consists of bainitic sheaves. Increasing nitrogen at the same vanadium level promotes the acicular ferrite formation. For high reheating temperatures, dominantly acicular ferrite structure in both the low nitrogen and the high nitrogen vanadium steels is obtained. The results suggest that vanadium in solid solution promotes the formation of bainite. The effect of nitrogen is related to the precipitation of VN particles in austenite with high potency for intragranular nucleation of acicular ferrite and to the precipitation of V(C, N) particles in ferrite with high potency for precipitation strengthening. Addition of both vanadium and nitrogen considerably increases the strength level, while CVN_{20} impact energy increases on changing the microstructure from bainitic ferrite to the fine ferrite–pearlite and acicular ferrite.

KEY WORDS: V-microalloyed steels; medium-carbon steels; bainite; acicular ferrite.

1. Introduction

The main purpose of vanadium addition to high-strength microalloyed steels is the precipitation strengthening by V(C, N) particles. It is commonly accepted that particles precipitated in ferrite on continuous cooling from the austenitization temperatures during and after the austenite/ferrite transformation are the most effective. However, at high nitrogen contents precipitation of VN particles can occur already in the austenite.[1–3)] Those VN particles are proved to be highly potent for intragranular nucleation of acicular ferrite, which could effectively improve toughness of high strength steels.[1)] In this manner vanadium addition indirectly enhances the formation of acicular ferrite structure and improves toughness. The effect of nitrogen on microstructure and mechanical properties is primarily related to the interaction with vanadium, as with other alloying elements, such as titanium and niobium.

However, there is some disagreement in literature regarding the effect of dissolved vanadium on transformation behavior of microalloyed steels. It is generally believed that vanadium atoms segregate to austenite grain boundaries rendering them less effective as ferrite nucleation sites. Although many authors suggest that vanadium increases hardenability by preventing grain boundary nucleation, thus suppressing ferrite–pearlite formation,[4,5)] there are opposite opinions, that vanadium actually does not suppress grain boundary reaction and even decreases hardenability.[6,7)]

The aim of this work was to examine the influence of vanadium and nitrogen contents on microstructure and properties of medium-carbon steels, in attempt to clarify the effect of vanadium on transformation behavior and mechanical properties.

2. Experimental Procedure

Three medium carbon forging steels with varied content of nitrogen and vanadium were melted in a laboratory vacuum furnace and cast into 60 kg tapered ingots. Chemical compositions of the steels are given in **Table 1**, where inscriptions "High-N", "Low-N" and "V-free" indicate vanadium and nitrogen content. The as-cast ingots were reheated to 1 200°C and press forged into 80×80 mm bars. The bars were subsequently reheated to 1 150°C, hot rolled

Table 1. Chemical compositions of experimental steels [wt%].

Steel	C	Si	Mn	P	S	Cr	Ni	Mo	V	Ti	Al	N
High-N	0.26	0.30	1.48	0.0080	0.0080	0.29	0.16	0.03	0.12	0.01	0.02	0.0166
Low-N	0.25	0.34	1.47	0.0060	0.0080	0.29	ND*	0.01	0.12	0.01	0.02	0.0057
V-free	0.25	0.32	1.46	0.0070	0.0080	0.28	0.16	0.03	-	0.01	0.02	0.0059

* ND – Not determined