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Microstructure and Mechanical Properties of Cryogenic High-Manganese Steel Weld Metal

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Extant studies have focused on the development of high-manganese austenitic steel, which is a potential cost-effective alternative to commercial cryogenic materials such as 9% Ni steels, 304 stainless steels, and Al5083 alloys. The development of suitable welding consumables is of significant importance in the commercial application of this new material for cryogenic applications. Specifically, flux-cored arc welding consumables that allow all-positional welding for high-Mn steel are required to fabricate liquefied natural gas (LNG) tanks. Hence, a welding wire alloyed with austenite-stabilizing elements (e.g., C, Mn, and Ni) was developed for cryogenic toughness. The microstructure and mechanical properties were evaluated as a function of the alloy composition. This unique combination of strength and toughness demonstrated the potential of this newly developed high-Mn steel for cryogenic services.

INTRODUCTION

Recently, global energy consumption and demands are underlined by a steady increase. Energy sources include oil that has played a major role in the energy supply. However, the role of oil is expected to gradually reduce in the future. Coal is abundant and cheap, but it faces environmental problems. Conversely, natural gas is an attractive clean energy source that has been in use for a long time. Generally, natural gas is projected as the fastest growing major fuel with an increase in global demand by 60% from 2010 to 2040. It is expected that by 2025, natural gas will overtake coal and become the second largest worldwide energy source after oil (ExxonMobil, 2016). Furthermore, the discovery of shale gas has significantly affected the global energy composition. The circumstances of the traditional energy supply are affected by China, USA, Argentina, and Mexico as these countries possess a tremendous amount of shale gas sources. It is expected that the golden age of natural gas will dawn in the near future with the development of shale gas (International Energy Agency, 2012).

The volume of natural gas at cryogenic temperature (−163°C) is decreased by approximately 1/600, and this dramatically simplifies its storage and transportation (Kotzot, 2003). It is generally accepted that liquefied natural gas (LNG) transport is economically advantageous with respect to structural cryogenic alloys such as 9% Ni steels, austenitic stainless steels, aluminum, nickel alloys, and Invar alloys (ASM International, 1993). Recently, POSCO developed a new high-manganese steel that provides cost-saving opportunities in cryogenic applications (Choi et al., 2012).

This study involved the development of flux-cored welding consumables that allowed all-positional welding for high-Mn steel in the fabrication of LNG tanks. Specifically, the microstructure and mechanical properties of weld metals were evaluated by the chemical component variation of welding consumables.

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KEY WORDS: High-manganese steel, austenite, cryogenic, liquefied natural gas (LNG), flux-cored arc welding (FCAW).

AUSTENITIC HIGH-Mn WELDING CONSUMABLE FOR LNG TANK

Development Concept of Welding Consumables

Currently, with the exception of 9% Ni steel, most cryogenic alloys involve a face-centered-cubic (FCC) crystal structure as an FCC crystal structure does not normally exhibit a ductile-brittle transition, unlike that of materials that possess a body-centered-cubic (BCC) or body-centered-tetragonal (BCT) crystal structure. Special heat treatments are necessitated by 9% Ni steel to achieve a favorable microstructure of fine retained austenite dispersed in a tempered martensite structure that is essential for low-temperature toughness (API Standard 620, 2013; ASME, 2010; IMO, 1993). Most welding consumables for cryogenic applications consist of predominantly FCC crystal structures to ensure good low-temperature toughness required for cryogenic structures. To date, Ni base or austenitic stainless base welding consumables are widely used in extant studies. The present study involved the investigation of high-Mn steel welding consumables with an FCC crystal structure for cryogenic LNG tank applications.

The mechanical properties of the commercial cryogenic base metal and welding consumables are compared in Table 1. The commercialized welding consumables for various tank alloys are included in Table 1.

Table 2 gives the target properties of high-Mn steel for LNG tanks. ASTM A1106/A1106M-17 defines the tensile strength (> 400 MPa) at room temperature and the Charpy impact energy at cryogenic temperature of high-Mn steels (ASTM International, 2017). This is followed by the establishment of the objective of developing welding consumables at a level similar to that of the base metal.

With respect to the mechanical properties of the base metal, the yield and tensile strength are determined by rolling and heat treatment processes. Conversely, welding consumables are composed