



Microstructure characterization and hardness distribution of 13Cr4Ni multipass weld metal

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ABSTRACT

Multipass welding is a common method for fabrication and repairs of large industrial steel parts. In the hydroelectric industry these parts are commonly made with 13Cr4Ni steels that present outstanding performances. In this research the microstructures and crystallographic textures of a multipass weld have been studied. The microstructure was found to be complex and heterogeneous, consisting of several regions affected by adjacent weld passes. The study showed that austenite parent grains modification happened in areas close to the subsequent weld passes. However, parallel and low angle interface laths were observed inside martensite sub-blocks over different regions. The hardness profile was explained by overlaying the simple three regions heat affected zone. In some regions a tempering heat treatment effect was observed while in some other regions a double-quenching has happened.

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1. Introduction

13Cr4Ni belongs to the low carbon martensitic stainless steels. They have lots of applications in hydroelectric, power generation, offshore and petrochemical industries. Multipass welding processes are common for the fabrication and repair of this steel as the carbon content is low enough to avoid loss of toughness and compressive residual stresses built in the weld after each pass [1–3]. Generally the composition of the electrode is similar to the base metal in order to produce weld metals with similar properties [4]. 410NiMo filler metal family is the best choice among available electrodes.

13Cr4Ni steel solidifies to δ -ferrite, then starts to transform into austenite at around 1300 °C and ends, in a thermodynamically equilibrium conditions, at around 1200 °C [1,5]. At temperatures lower than 1200 °C austenite decomposes and if a thermodynamically equilibrium is achieved; ferrite and carbides are expected to be the stable phases at room temperature. However in cooling conditions which are typical of production, the very slow rate of ferrite-carbides formation maintains

the austenite existence at low temperature and then austenite is subjected to the martensitic transformation.

The fully martensitic microstructure expected after cooling to room temperature, may be very complex. Alloying elements segregation in-between dendrites at the final stages of solidification can stabilize δ -ferrite phase which can remain in the microstructure even at room temperature [1]. Furthermore, the transformation of austenite to martensite can be incomplete and small amounts of retained austenite may remain between martensite laths [6–9].

The microstructure of a multipass weld is even more complex as the thermal cycles of subsequent passes act as several quick heat treatments which can affect the microstructure. As a result, some carbides and austenite can be formed or modified locally. It has been shown that the reformed austenite can be stable at room temperature and it improves toughness and fatigue properties. However, in cases of receiving excessive heat from adjacent weld passes, the reformed austenite transforms back to fresh martensite on cooling and it significantly reduces the impact properties [10–14].

The focus of this study is on the heterogeneous nature of as-welded multipass microstructures such as various heat affected regions inside weld beads and hardness distributions in order to better understand microstructure features characteristics, formations, and evolutions. Previously, and as a first step toward the goals of the current study, a

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Table 1
Welding parameters.

Method	Interpass temp. (°C)	Pre-heat temp. (°C)	Voltage (V)	Current (A)	Torch speed (mm/s)	Filler deposit rate (kg/h)	Heat input (J/mm)	Welding position	Gas
Flux-core arc welded (FCAW)	200	180	21.1	209	4.5	3.9	980	1G	Argon-25% CO ₂

Table 2
Nominal and measured composition of substrate metal and welding electrode (wt.%).

Grade	Cr	Ni	Mo	Si	Mn	C	P	S	Cu	N
CA6NM (ASTM)	11.5–14	3.5–4.5	0.4–1.0	<0.1	<0.5	<0.06	<0.04	<0.03	<0.05	–
CA6NM (As measured)	12.5	4.17	0.467	0.43	0.7	0.04	0.027	0.005	0.02	–
E410NiMo (ASTM)	12.46	4.39	0.56	0.37	0.36	0.021	0.008	0.011	0.03	–
E410NiMo (As measured)	11.6	4.5	0.529	0.44	0.38	0.023	0.01	0.01	0.014	0.003

comprehensive study on a single pass weld microstructure has already been conducted [15].

2. Materials and characterization methods

A 50 mm thick weld metal was deposited on a 50 mm thick CA6NM substrate (25 cm × 50 cm) using 13Cr4Ni flux-cored welding electrodes (E410NiMo) and a Scompi robotic welding machine [16] according to AWS A5.22 in order to reproduce the industrial condition. The welding parameters are presented in Table 1. The nominal and measured compositions of substrate and the welding electrode are shown in Table 2. The deposited weld metal was the result of 10 layers of 40 adjacent and parallel weld passes, for a total of approximately 400 passes as shown schematically in Fig. 1. Each pass was deposited in the longitudinal (X) direction beside previous pass and over the layer beneath. The welding direction was always positive X. In producing each complete layer (about 40 passes), the torch moved along the Y direction, +Y and –Y in subsequent layers. Samples used in this study have been taken from the middle of the weld.

Microstructure, chemical composition, and hardness were determined in the as-welded condition. The actual chemical composition of the weld metal and base metal were measured by a Glow Discharge Atomic Emission Spectrometer on an average surface of 4 mm². The elements C, N, O, and S were measured by combustion/fusion determination methods. A spectrometer operated at 15 kV with the working distance of 15 mm was used to perform chemical composition analysis of the weld layer regions, phases and inclusion particles using ESPRIT analytical software (Bruker Corporation, Germany). To reveal

microstructure and austenite particles, samples were polished mechanically and then electro-polished with a solution of 65 ml HClO₄, 550 ml ethanol, 70 ml butyl-cellulose, and 70 ml H₂O using an electropolishing device at 25 °C, 25 V for 20 s. The austenite volume fractions in samples were measured by X-ray diffraction from a Rietveld analysis with an X-ray diffractometer machine [17]. Hardness evaluations on large maps have been done using an automatic micro-hardness testing machine with a load of 300 g and a loading time of 10.2 s. A scanning electron microscope (SEM) operated at 5 kV to 20 kV was used to observe the samples microstructures. Electron backscattered diffraction (EBSD) technique was used to determine the grains orientations in the weld metal. The integration time was 5 ms and 2 × 2 binning was used for the acquisition and grain orientation maps were made using Tango software. Then, austenite grains reconstructions were done on EBSD maps using specific reconstruction technique [18]. Optical and SEM images were used to quantify determine dilutions and inclusions distributions in weld layers. For this, ImageJ software using threshold filtering methods was applied [19].

3. Results and discussions

3.1. Chemical composition

The measured chemical compositions of the base metal and weld metal given in Table 2 show that there are some chemical differences between the base metal and the weld metal, however they can be

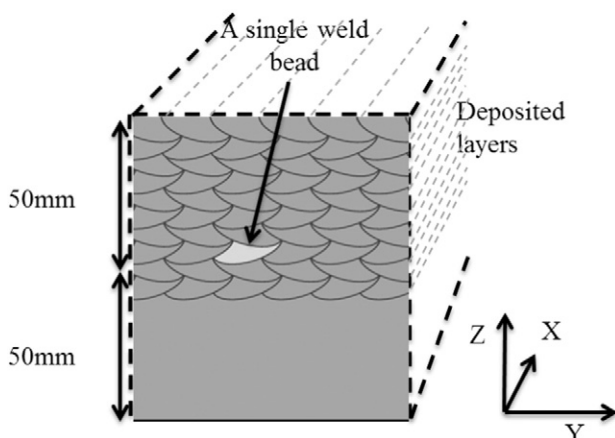


Fig. 1. Schematic cross-section of the weld layers.

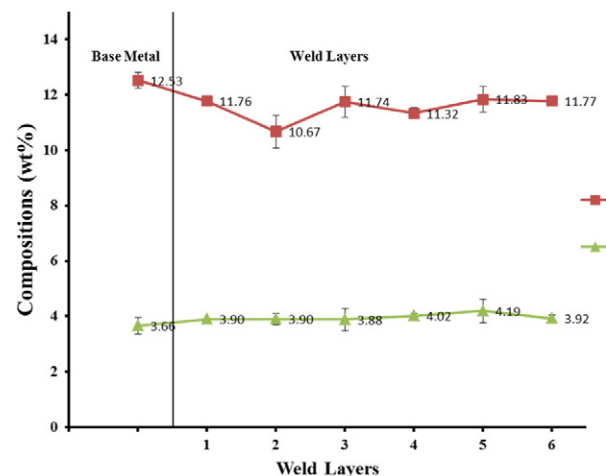


Fig. 2. Chromium and nickel contents of the base metal and the successive weld layers measured on average surfaces of 1 μm².

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