Evaluation of Microstructural and Mechanical Properties of SA508 cl.3 Heat Affected Zone Produced by RPV Cladding

J.S. Lee[1], I.S. Kim[2] S.C. Kown[3]

1) Center for Advanced Reactor Research, KAIST 373-1, Daejon 305-701, jslee2@kaist.ac.kr
2) Department of Nuclear and Quantum Engineering, KAIST 373-1, Daejon 305-701, iskim@kaist.ac.kr
3) Korea Atomic Energy Research Institute, P. O. Box 105, Daejeon 305-600, sckown@kaeri.re.kr

1. Introduction

The inner wall of LWR reactor pressure vessel (RPV) was overlay cladded with 300 grade austenitic stainless steels of a few millimeter thicknesses to prevent the general corrosion attack and the radioactive contamination problems in main coolant systems. As the results, the heat affected zone (HAZ) was produced on the RPV steel under the stainless cladding, showing relatively complex microstructural characteristics [1]. The assessment and understanding of mechanical properties of HAZ of reactor pressure vessel (RPV) steel is an important factor associated with safe operation and extended service life of the reactor.

2. Experimental

The309L stainless steel was deposited on SA508cl.3 plate by submerged arc welding with a heat input rate of 188.5 kJ/cm. The microstructure of the RPV HAZ was examined using optical microscope, scanning electron microscope (SEM) and transmission electron microscopy (TEM). Small size tensile (gage length = 5 mm, $1.2^w \times 0.25^t$ mm) and disk type ($3\varphi \times 0.28^t$ mm) small punch (SP) specimens were sampled from 0, 3, 6, 9 and 20 mm away from the weld fusion line. Tensile tests and SP tests were performed at a cross-head speed of 0.2 mm/min. at room temperature and temperatures from 77 to 293 K, respectively. More detailed information about the material preparation and SP tests could be found in Ref. [2].

3. Results

3.1. Microstructural characteristics

The HAZ of SA508cl3 is "scallop-shaped" and maximum width is approximately 10 mm. The HAZ was composed a variety of microstructures with various sizes of grain and precipitates [3]. Figure 1 presents the optical microstructures as a function of distance from overlay weld fusion line. The base metal consists of tempered bainite structure, and ASTM grain size number and RT_{NDT} of the material is 7.0 and -30 F respectively. As the cladding is approached, the base metal experiences slight changes of microstructure, which is the result of slight heating into the austenite region. Closer to the cladding, the material is heated further during cladding, so more of the ferrite is transformed to austenite. Finally, the entire structure is heated into the austenite region transforming it into fine grains of ferrite and bainite as it cools. Close to the fusion line, the material is heated to higher temperature, and forms coarse austenite grains, which transform to an acicular baintic structure on cooling. In addition, along the weld fusion line there formed a heavy carbide precipitation zone in the width of 20~30 μm.

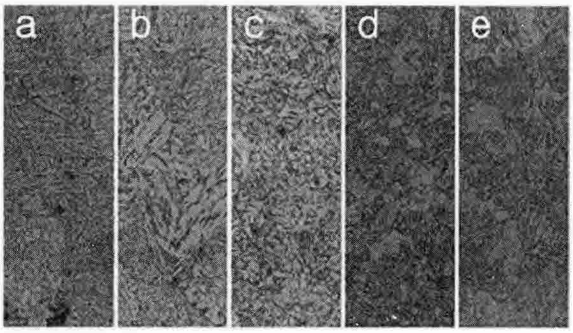

Figure 1. Optical microstructures of HAZ in SA508cl.3 RPV steel, sampled from (a) 0 mm (coarse-grained), (b) 3mm (fine-grained), (c) 6 mm (intercritical), (d) 9 mm (subcritical) and (e) 20 mm (base metal) away from weld fusion line. Nital etching.

3.2. Tensile properties

The each HAZ shows different tensile properties since it has completely different microstructures.

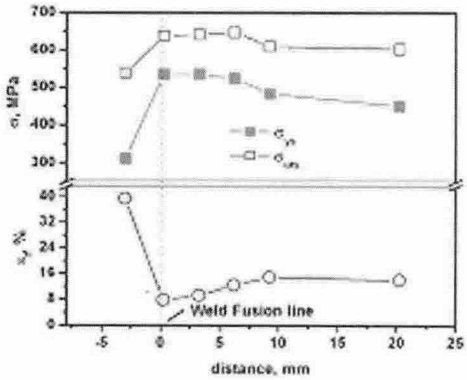

Figure 2. The changes in yield (σ_{ys}), tensile strength (σ_{uts}) and plastic fracture strain (ε_{pf}) as a function of distance from weld fusion line.

Figure 2 presents the yield (σ_{ys}), tensile strength (σ_{uts}) and plastic fracture strain (ε_{pf}) as a function of distance from weld fusion line. As the cladding is approached, the yield and tensile strength increased gradually from 450 to 530 and 600 to 640 MPa, respectively. Meanwhile, the plastic fracture strain reduced to approximately half percent, from 14 to 8 percent.

3.3. SP energy

The ductile to brittle transition behaviors of specific SP energy of each HAZ as a function of test temperature are shown in Figure 3. In 9 (subcritical HAZ) and 20 mm (base metal) condition, they revealed the exactly same ductile to brittle transition behavior, showing an increase in SP energy with decreasing temperature up to a maximum temperature at around 113 K. As the test temperature decreased further, a sudden drop of SP energy was observed. However, the lower shelf SP energy could not be obtained until the test temperature reached up to 77 K. In case of 6 mm (intercritical HAZ), it showed very similar SP energy with 20 and 9 mm condition until the test temperature reached to 153 K, and SP energy decreased with further cooling. The lowest SP energies in the HAZ regions were observed at the specimens sampled from 0 and 3 mm away from the fusion line, which corresponded to coarse- and fine-grained HAZ, respectively. They revealed the lowest toughness at all test temperatures and highest ductile to brittle transition temperature compared to the others.

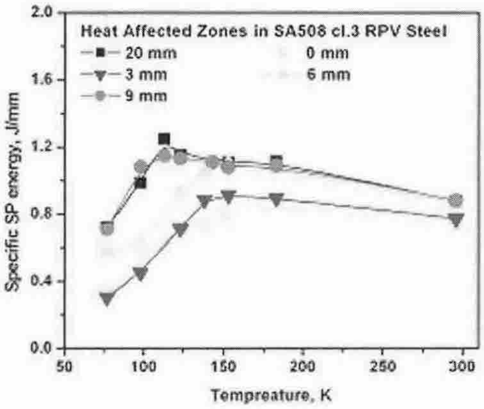

Figure 3. The changes in specific SP energy in SA508cl.3 RPV steel HAZ as a function of test temperature.

4. Summary

1. The maximum width of HAZ of SA508cl.3 steel produced by overlay RPV cladding was approximately 10 mm and it was composed of variety of microstructures with various grain size and precipitates. In addition, along the weld fusion line there formed a heavy carbide precipitation zone in the width of 20~30 μm.

2. As the specimen sampling position approached to the weld fusion line, the increase in yield and tensile strength was approximately 90 and 40 MPa, respectively. Meanwhile, the plastic fracture strain reduced from 14 to 8 percent.

3. The lowest SP energy and the highest ductile to brittle transition temperature in the HAZ were observed at the coarse- and fine-grained HAZ.

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