

## **Microstructure Development of Ultra-High Strength Steel Weld Metal for Avoiding Hot and Cold Cracking**

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### **ABSTRACT**

Supermartensitic steel was applied to the weld metal for ultra-high strength steel. Toward saving the pre-heating, PWHT, degassing, controlling of interpass temperature, the best balance of martensite, delta-ferrite and austenite should be searched in solidification process and the final microstructure. In the present work, the phase evolution of weld metal during welding was in-situ analyzed by using x-ray diffraction experiments as a useful technique to design the chemical composition of weld metal for ultra-high strength steel.

**KEY WORDS:** Welding, In-situ analysis, Martensite, Retained-austenite, Cracking, Efficiency, Solidification.

### **INTRODUCTION**

Ultra-high strength steels (~1000 MPa) has been applied to weld structures such as offshore structures and linepipe (Komizo, 2006). The main microstructure of the weld is martensite. The pre-heating, controlling of interpass temperature and PWHT are essential for avoiding weld cracking problems and increasing toughness (Karlsson et al, 2002, Deleu and Dhooge, 2002). Then the efficiency of the welding of ultra-high strength steels is the point at issue.

Using supermartensitic steel (13CrNiMo) as a weld metal for ultra-high strength steels will improve the problem of efficiency without the pre-heating and PWHT. Controlling the amount of Cr, Ni and Mo, the three phases: martensite, ferrite and austenite phases could be used in the weld metal in as-weld condition. For preventing the cold cracking, the presence of austenite phase is effective due to its nature of hydrogen absorption and the existing of austenite phase increases toughness of weld metal. On the other hand, for preventing the hot cracking, the delta-ferrite phase is effective due to its nature of high solubility for the minor elements. Thus, controlling the amount of delta-ferrite phase in solidification process and austenite as a retained phase is an important technique to achieve an excellent weldability for the weld metal in as-welded conditions. For controlling the microstructure, it is essential understanding the microstructure along thermal-cycle of fusion

welding: rapid heating, melting, solidification and solid-state phase transformation, in chemical composition being designed. However, it is difficult understanding the microstructure under the high temperature, rapid heating and cooling circumstance. For example, the delta-ferrite may disappear in room temperature.

In order to break the problem, we observed the microstructure formation of weld metal (13 Cr-9 Ni-0.5 Mo mass% steel) along weld thermal-cycle by using the system consisting of synchrotron radiation, welding system and novel two-dimensional x-ray detector (Eikenberry et al, 2003). The ultra-bright X-ray generated from undulator beam line at SPring-8 and the X-ray detector made it possible that measuring the diffraction pattern for the weld in very high time-resolution. It is called as 'In-situ observation system of welding' (Komizo et al, 2005). As a result, diffraction patterns during welding were in-situ recorded in high time-resolution. The diffracton patterns for the delta ferrite crystallization and pritectic reaction in solidification process were presented as a function of welding torch position. Furthermore, behavior of martensite formation with retained-austenite is clearly shown in-situ. Those observations for microstructure evolution was being related to TEM micrograph of weld microstructure in the room temperature. Those diffraction patterns in time-series during welding of ultra-hgih strength steels were measured at first time and provided the useful kinetic information in order to design the tough and strong weld metal by using delta-ferrite, austenite and martensite phases.

### **EXPERIMENTAL PROCEDURES**

#### **Materials and welding**

Gas tungsten arc welding (GTAW) was produced on plate (150 mm\*50 mm\*12 mm) of supermartensitic steel since it is planned that the weld metal is formed in the clean welding process to avoid the oxide formation in future. A chemical composition of the steel was 13 Cr-9 Ni-0.5 Mo (mass %) with the balance Fe. The sample was restrained on the water-cooled copper anode to avoid warping due to the plasma heating. The shielding gas was pure argon. The arc plasma current was 150 A and the arc length was kept in the length of 2 mm. It corresponded to the arc voltage of 10 V. Fixing the plasma torch with stepping motor stage, the welding speed was controlled in constant speed of 1 mm/sec. The welding system consisting of the plasma torch,