Nitrogen segregation and blister formation of 316LN austenitic steel during electron beam welding tests for ITER gravity supports

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ABSTRACT

316LN has been widely applied in the design of ITER components, such as shield blanket and gravity supports, due to its excellent corrosion resistance and high strength. The behavior of nitrogen in this steel during welding is important for the mechanical properties of the components. In this study, a focused 150 kv high voltage electron beam with 300 mA beam current has been used to weld 316LN steel under vacuum condition. The microstructure and composition of the welding area were observed and analyzed. The influence of welding on the shock resistance and tensile strength at both room temperature and low temperature were examined. It was found that the mechanical properties are strongly related to the defects formed in the welding process.

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1. Introduction

316LN austenitic stainless steel has been widely applied in nuclear fusion devices, such as ITER [1], EAST and KASTAR [2], and chemical reactors, due to its excellent corrosion and fatigue resistance, high strength and low creep rate [3,4]. In ITER, the use of this material for most of the structural components, including vacuum vessel, shield blanket, cooling pipes and magnet supports system is being considered. The gravity supports are one of the key components to support the toroidal field (TF) coils of ITER. These components endure several large forces, such as dead weight (more than 100 MN), electromagnetic forces (normal operation, disruptions and vertical displacement events (VDE), thermal load (cooling of the coils from room temperature to 4 K) and seismic loads (in accident). Therefore, high strength of the support material is required. 316LN with high nitrogen content (preferably 0.12–0.22 wt%) has been recommended as one of the candidate steels for the support system [5], since the strength of 316LN increases with nitrogen content [6]. Based on the ITER design report, the maximum displacement of the TF coils is estimated up to 32 mm in radial direction during cool down, as shown in Fig. 1. In order to satisfy this requirement, each supports has been designed with 21 flexible plates welded to its upper and lower flanges, which makes displacement along the radial direction possible. Based on the structure analysis, the bending stress is very high in the flexible plate-flange junction zone. Therefore, welding technology plays a key role in manufacturing the support, especially for the structure safety. Needless to say, for welding the 316LN flexible plates to the two ends flanges, tungsten inert gas (TIG) welding would cause huge deformation due to large heat affects zones (HAZ), whereas laser beam could be focused to a small area, but welding depth would be limited [7]. Electron beam welding is the best choice for this structure, because it can not only be focused to a very small area, so that the deformation can be controlled to very small level, but also weld thick components. On the other hand, it is still suspected that the behavior of nitrogen, especially for high nitrogen content 316LN, may affect the welding property. Some research results show that the nitrogen can segregate or even react with other elements, such as chromium, and form a brittle phase [8]. Meanwhile, the formation of defects such as nitrogen gas voids may seriously affect the mechanical property of the components. The mechanism of nitrates precipitation has been investigated [9]. However, from the structure safety point of view, there is still a lack of data on 316LN components welding, which is essential for ITER construction, since all the supports will be operated under complex load conditions, including not only the dead weight, but also electromagnetic force and thermal loading.

In this report, the microstructure of electron beam welded 316LN and its effect on mechanical properties have been investigated.

2. Experimental

Thirty millimeters thick type 316LN austenitic stainless steel plate, with the composition shown in Table 1, was used for the present experiment. The plates was cut into 100 × 100 mm squares that, after polishing, ultrasonic cleaning and drying, where put into the vacuum chamber (generally at 10^{-3} Pa) for electron beam welding, as shown in Fig. 2. The electron beam energy is...