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Unstable Fracture Preventive Design in Large Vessels and Offshore Structures

Gyu Baek An
Technical Research Laboratories, POSCO
Pohang, Korea

Recently, the requirements of oil and gas drilling in arctic regions have led to a significant increase in vessel size. This trend has led to increased safety requirements for materials such as high strength, good toughness at low temperature, and good weldability. Furthermore, crack arrestability has been a long-standing key issue for large container ships. Full-thickness weld joints of steel plates with 80-mm thickness were prepared through the use of two welding processes, namely Flux-Cored Arc Welding (FCAW) and a combined welding process of Electro Gas Welding (EGW) and FCAW. The effect of the joint design on crack arrestability was investigated to prevent a catastrophic failure along the block joint of the hatch side coaming in the container ship. A brittle crack-arrest technique was developed without a block joint shift on the basis of an arrest weld at the end of the hatch side coaming weld line.

INTRODUCTION

Recently, the size of the ship required to explore and produce oil and natural gas in the arctic offshore region has greatly increased the demand for large vessels. High performance steel plates are required by these industrial trends (Yamaguchi et al., 2006). As the usage of large-scale, high-strength metallic structures in various civil engineering constructions, shipbuilding, and other industries increases, higher standards and assessments are required for the integrity and performance of the components (Masubuchi, 1980; Ouchi, 2001). It is even more critical when the heavy-section or thick steel plate and pipes are welded because the inherently generated large residual stresses are detrimental to the safety of the structure and can lead to an abrupt crack initiation and fracture (Withers and Bhadeshia, 2001; Webster and Ezeilo, 2001).

In the shipbuilding industry, the container ship size has gradually increased for mass transportation and cost reduction in the shipping industry. Thus, thick and high-strength steel plates are used for the upper deck structure of container ships because of their large hatch openings (see Fig. 1) (Yamaguchi, 2006). It is expected that EH47 grade steel with minimum yield strength of 460 MPa and more than 80-mm thickness will be used to build the container ship above 18,000 TEU (Twenty-foot Equivalent Unit). In addition, offshore structures have been constructed with around 100-mm-thick steel plates. Due to the rapid increase in vessel and offshore structural size, the applied steel plate thickness has also increased. Thicker steel plates are usually used for the upper structure of a ship including the hatch side coamings, sheer strakes, and longitudinal bulkheads of large container ships. This is because of the restrictions on designing the hull girder strength for their large hatch openings.

The 147th Research Committee of The Shipbuilding Research Association of Japan (147th Research Committee, 1978) had investigated crack-arrest toughness of high heat input less than 30 kJ/mm welds with the thickness below 40 mm. They concluded that a long brittle crack can be arrested when the brittle crack that initiated from the weld joint propagates into the base metal. In addition, they concluded that plates of more than 40-mm thickness are more prone to fracture.

Recently, Inoue et al. (2007) suggested a large-scale full-penetration notch specimen for the determination of brittle crack arrestability and reported that it is not easy to arrest running brittle cracks in the high heat-input welds when the plate thickness is over 65 mm at −10°C due to the low fracture toughness inside the thick welds. However, there are limited studies that show the crack-arrest fracture toughness (K_{ca}) as a function of the crack-arrest temperature and crack propagation path in the high heat-input large-scale weld components. Although they propose restrictions on the use of thick steel plate for large structures, the susceptibility of unstable fractures tends to increase as the steel thickness increases, which is the so-called thickness effect (Nakano, 1992).

Hull structures have long been based on the concept of preventing hull separation and similar failures, with the focus on the prevention of the propagation of brittle cracks in rare events including crack initiation in welds. As the scale of many ships and offshore plants increases significantly in heavy industries, it is necessary to understand the brittle fracture phenomena for the full-scale components at low temperature (An et al., 2009). Numerous investigations of brittle crack-arrest performance of the base material

Element	12,000 TEU		19,200 TEU	
	Steel	Thick.	Steel	Thick.
Hatch coaming	EH40	75t	EH47	85t ↑
Deck plate	EH40	65t	EH40	90t ↑

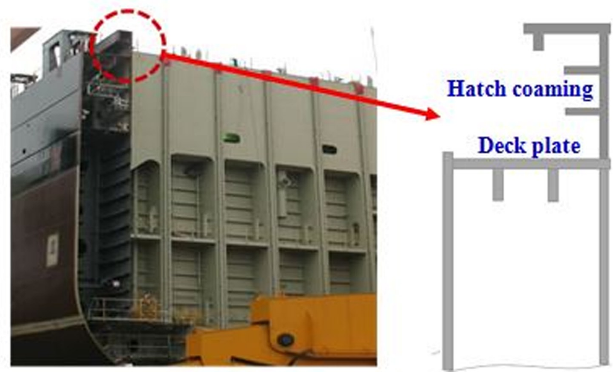

Fig. 1 The upper structure of a large container ship and applied steel plates

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