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Structure and welding technologies for SPB LNG aluminum tank

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The IHI SPB (Self-supporting Prismatic shape IMO Type-B) aluminum tank (cargo containment) system is huge structure to store cryogenic liquefied natural gas safely. This system is an advanced version of this well-tested tank system, modernized by the most advanced technology of fatigue analysis and fracture mechanics to comply with the IMO Type-B requirements. These SPB tank is fabricated using aluminum alloy A5083-O and is specialized by the accurate estimation and guarantee of fatigue strength of aluminum tanks, hence, the stress concentration around welding bead has to be controls as well as welding process control are also required together with strict inspection to achieve highest reliability for the LNG tanks. From some superior features, SPB tank is strongly expected to apply to not only LNG carrier but floating-LNG storage structure recently. On the other hand, SPB tank is composed of a lot of aluminum rib and plate, then the cost for fabrication is tend to be more expensive than other tank system. To overcome this problem, IHI continue to develop the automated welding systems, for example one-side butt welding system for skin plate, and fillet welding robot systems without grinding process to guarantee the fatigue strength. In this paper, some features of IHI SPB aluminum tank and these improvements of welding technologies are reported.

Keywords: *SPB tank, LNG, floating-LNG storage structure, fatigue strength, welding*

1. Introduction

Tanks of the SPB type (self-supporting prismatic shape IMO type B) are realized by the LNG storage technology that has been developed through long-term linkage with IHI's LNG technology. Since a tank of this SPB type was first employed as an LPG ship in the 1960s, the technology has a long history. The tank technology, which was established as the type-B tank by combining the fatigue analysis technology and production technology, is superior in safety, economy, and future applicability [1].

The LNG ship shown in Fig. 1 was constructed at IHI in 1993 as an SPB LNG aluminum tank ship. The ship has been sailing for 16 years since the first sailing between Alaska and Japan, the hydrographic weather condition between which is known to be severe, without accidents. The ship gains, from customers, a high reputation for safety, a wide field of view from the pilothouse, which is achieved by the flat deck, and superior operability. The fact that the ship has been free from flaws demonstrates that the tank is highly reliable [2].

Recently, the demand for the natural gas is rapidly growing on a worldwide scale as clean energy that is environmentally benign. In addition to large-scale development project on the land, attention is also paid to development of relatively small-to-medium-sized maritime gas fields that is distant from the land. In view of these situations, floating LNG storage facilities on an ocean can be considered to be an economic solution, and it is strongly demanded that these facilities become a reality. Unlike LNG ships, a floating LNG storage facility is required to continuously operate in the sea area in which it is installed and periodic maintenance and inspection at a dock are not assumed, so the reliability of the tank becomes more important. IHI will satisfy requirements of the customers by taking advantages of the SPB type for which high reliability has been demonstrated.

Fig. 1 SPB LNG carrier "Polar Eagle"

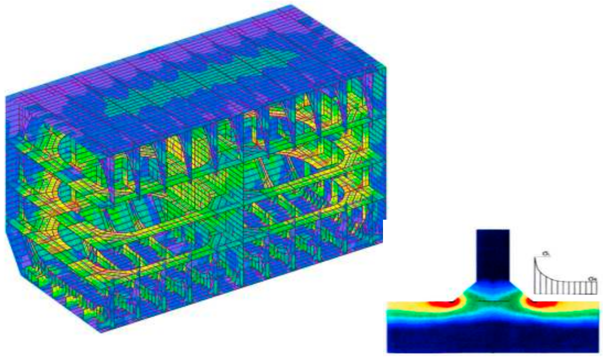

Fig. 2 FEM analysis examples of SPB tank

2. Structure of the SPB tank and development to the floating LNG structure

The SPB tank belongs to self-supporting type B in the tank classification stipulated in the IMO rule, and tanks having a prismatic shape are referred to as SPB tanks [1]. There are two types of large self-standing tanks having a plasmatic shape; type A and type B (there is also type C that is mainly applied to small-capacity tanks designed by the design technology as with pressure tanks). For type A, tanks are designed through ordinary strength calculation based on allowable stress. For type B, tanks are designed according to precise strength analysis and fatigue and destruction analysis. Fig. 2 shows an example of stress analysis performed for the interior of a tank by using a computer [2]. LNG is at an extremely low temperature of -162℃. If the LNG in the tank leaks and comes into contact with the body of the ship, there is a risk that a crack may be caused in the body, resulting in serious damage. For type A, therefore, it must be assumed that if a crack occurs, the tank is excessively destructed, so complete secondary barriers are required under the assumption that the total amount of loaded LNG leaks. By contrast, type-B tanks are reliable because they are designed based on an advanced analysis technique. It is assured that even if a crack occurs, only a small amount of LNG leaks and thereby the tank is not excessively destructed. Therefore, the type-B tanks satisfy the concept "Leak before Failure" indicating that it suffices to provide partial secondary barriers according to the assumed amount of leak, so they can be said to be most suitable for LNG storage for which high reliability is required.

Fig. 3 shows the cross section of the body and tank of an LNG ship at the center [3]. The tank has a plate structure similar to the ordinary ship structure, so a swash bulkhead can be generally placed at the center of the tank. Although aluminum alloys, 9%-nickel alloys, and austenitic stainless steel, which do not cause brittle fracture even at extremely low temperatures, may be considered as LNG storage tank materials, tanks made of aluminum alloys are most lightweight and have a track record as SPB LNG storage tanks.

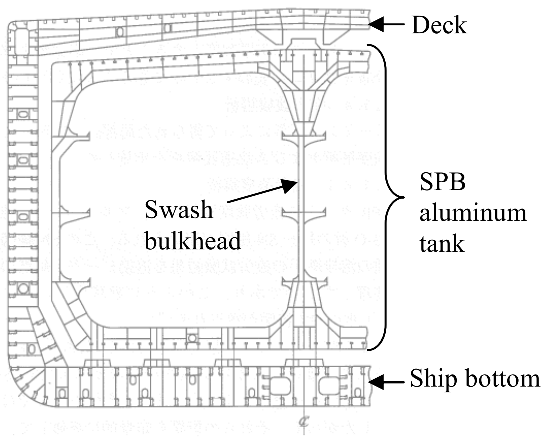

Fig. 3 Midship section of SPB LNG carrier

Fig. 4 is a conceptual diagram of a floating LNG storage facility [4]. For floating LNG storage facilities on an ocean as well, three LNG storage tank types [4], which are the SPB type, moss type, and membrane type (shown in Fig. 5) used for large LNG ships, are available as candidates. In a floating LNG production facility installed in a gas field on an ocean, it can be considered to be most suitable that the production plant of the facility is placed on the deck. SPB tanks are prismatic, so they can have an optimum tank shape suited to the ship and enable a flat deck to be formed as in the LNG ship shown in Fig. 1, resulting in a high freedom in production plant placement.

A floating LNG production facility needs to produce LNG according to a plan based on a LNG demand prediction. Unlike an LNG ship, the storage tank in the floating LNG production facility needs to assume operations at all liquid levels from the empty level to the fully loaded level. As a problem in this paper, the sloshing phenomenon of loaded liquid must be considered. In the sloshing phenomenon, the loaded liquid causes resonance with the movement of the ship due to ocean waves and thereby causes very large wavy movement. This phenomenon may give a large load to the tank and its internal equipment. The SPB tank can have an internal swash bulkhead as shown in Fig. 3, so the cycle specific to the loaded liquid can be shifted from the cycle of ship motion at any liquid level, preventing the sloshing phenomenon.

Fig. 4 Schematic illustration of LNG FPSO

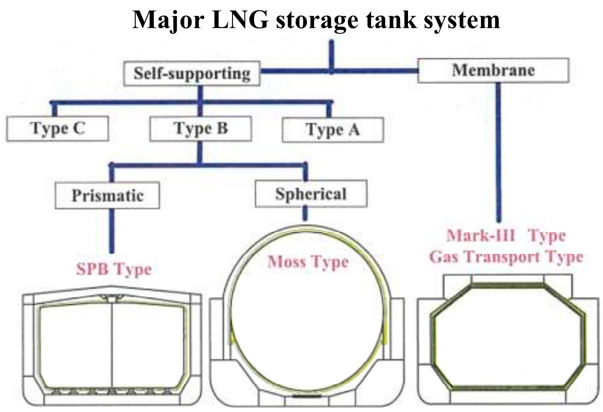

Fig. 5 Comparison of typical LNG Containment systems

3. Requirements for SPB tank design and welding management

The reliability of the SPB tank is attained through detailed analysis. Therefore, prerequisites for the analysis must be assured before a tank is actually structured. Fatigue strength analysis is now taken as an example. Prerequisites for the analysis and the concept of quality control in welding are described below.

When stress concentration at a weld bead on an aluminum tank is defined as in the equation indicated below to represent local stress, the strength of the welded portion can be evaluated by a single integrated S-N curve shown in Fig. 6, instead of a joint type [5].

$$\sigma = K_\tau \cdot \sigma_N \qquad (1)$$

σ : Local stress at the weld toe

K_τ : Stress concentration coefficient

σ_N: Nominal stress

When stress concentration coefficient Kt of all weld joints is controlled to a certain value or less, the lower limit of a fatigue life can be estimated by inferring the nominal stress of the structure through detailed analysis. With the aluminum tank of a structured LNG ship, weld bead shape data was collected by manufacturing a partial mockup [6]. Since the stress concentration coefficient corresponding to 98% cumulative probability was determined to be 2.17 from the result, an allowable value of stress concentration coefficient Kt was set to 3 with variations in welding taken into consideration. That is, it is necessary from the viewpoint of welding to assure this value for all weld beads. Fig. 7 schematically shows a weld bead in fillet welding [7]. It was found that stress concentration coefficient Kt at the bead toe was largely affected by toe radius ρ and flank angle θ and that Kt became equal to or less than 3 when ρ was equal to or more than 1.0 mm and θ was equal to or more than 120 degrees [5]. This consideration suggests that welding in actual tank construction be managed with emphasis placed on toe radius ρ and flank angle θ. As shown in Fig. 8, uniform high-quality weld beads were obtained in both (a) automated horizontal fillet welding and (b) robotic welding [7], and these weld beads were satisfied with both aforementioned ρ and θ.

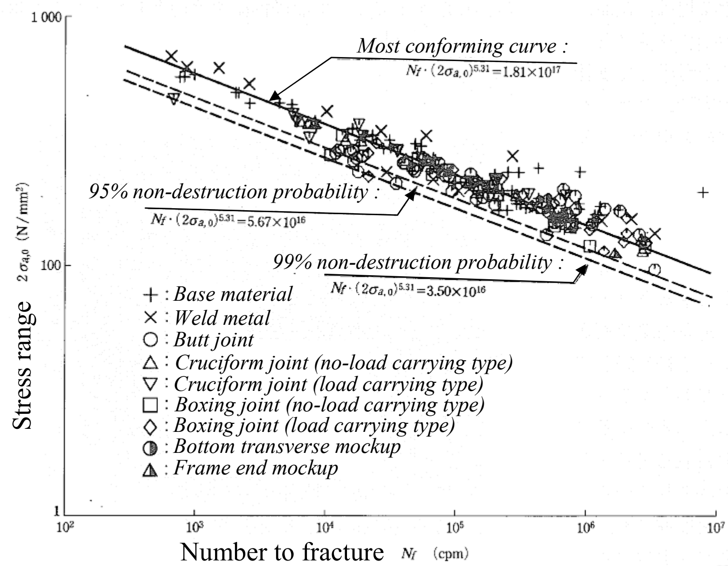

Fig. 6 S-N curve of aluminum alloy

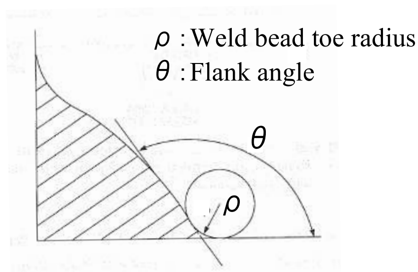

Fig. 7 Toe radius and flank angle in weld bead shape

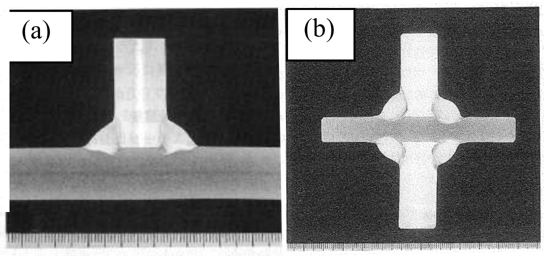

Fig. 8 Macrosection of (a) automated horizontal fillet weld and (b) robotic weld

4. Efforts for development of a new weld technology in SPB tank manufacturing

As descried above, the SPB tank is characterized by its superior performance, and development not only to LNG ships but also to floating LNG storage facilities on an ocean can be greatly expected. For structural reasons, however, the interior of the tank has a plate structure, that is, it is formed by many longitudinal and transverse materials, so the cost of the tank is likely to be higher than that of tanks of other types. To address this problem, efforts have been made for higher efficiency and automation as described below. The effectiveness of the developed technology is being demonstrated through manufacturing of a large mockup shown in Fig. 9 [8].

4.1 One-side butt welding

In conventional LNG ship construction, high-current MIG welding has been applied as the butt welding for large aluminum plates. Of the welding methods with aluminum alloys, the high-current MIG welding is regarded as one of most reliable welding methods. Since two-path welding is carried out from both the front and back of a plate as shown in the macrosection in Fig. 10 [7], however, a process for inverting a large aluminum panel measuring ten-odd meters by ten-odd meters is needed after one-side butt welding. To eliminate this inversion process, a butt welding apparatus having three welding torches was developed to enable butt welding from only one side in one run, thereby reducing the construction period.

4.2 Continuous welding by a fillet welding robot

SPB tanks employ fatigue design, so it is important to control the shape of the bead toe that affects stress concentration of the weld joint. Reduction in cost can be expected by achieving stable welding quality and assuring values required for design before welding is performed. To achieve this cost reduction, welding is required to be automated. With the SPB tank, a structure (frame) in which transverse and longitudinal materials are assembled as a frame can be well welded even at a narrow portion by using a fillet welding robot. A welding robot is also used even at a welding stage at which horizontal fillet welding is performed between a plate and a frame, as shown in Fig. 11. The newly developed fillet welding robot can perform welding even at a portion where three plates are mutually orthogonal, and at a boxing portion with good bead shapes by optimizing welding conditions and unique weaving; these portions are difficult to weld by an automatic welding carriage. Fig. 12 shows beads at a portion at which three plates are mutually orthogonal.

Fig. 9 Mock-up Aluminum panel

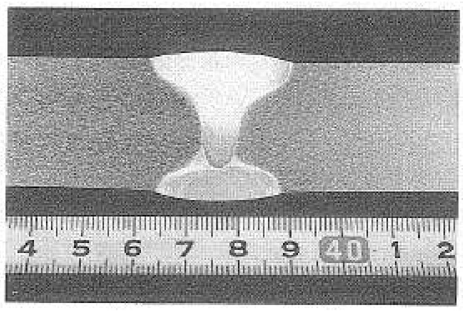

Fig.10 Macrosection of high current MIG weld (Conventional)

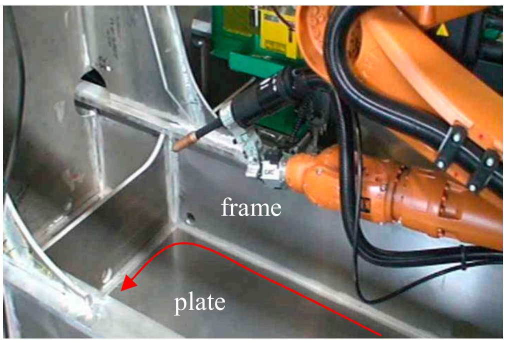

Fig.11 Developed fillet welding robot

Fig. 12 Bead appearance welded by robot

5. Conclusion

This paper has generally described characteristics of the SPB tank originally developed by IHI. On the basis of high tank reliability that could be proven by operation of the LNG ship, IHI will enhance introduction of factory facilities that utilize the newly developed welding technology, and will aggressively strive to realize floating LNG storage facilities at an early stage in response to the increasing natural gas demand.

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