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Failure Analysis of Ship-borne Mast Based on Finite Element Method

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Abstract:

A large number of shipboard mast failure accidents show that fatigue damage is the biggest hidden danger of mast structure. Based on finite element method and experimental method, this paper analyzes the main failure factors and prevention methods of ring weld fracture of a mast. The results show that the structure welded by stiffeners to the mast base retains a high welding residual stress level, so the fatigue resistance of the mast is reduced. In addition, the multi-directional wind load will cause the stress in the circumferential weld zone of the mast to exceed the fatigue strength, and promote the initiation of fatigue cracks. The influence of stiffener thickness on the stress level of mast was analyzed. The results show that increasing the stiffener thickness can effectively reduce the stress level in the circumferential weld zone, that is, the stiffness of mast structure increases. The correctness of the finite element analysis is verified by comparing the finite element calculation results with the actual experiment.

Influence of welding on mast structure:

The welding started from the packing area, and the heat source moved uniformly around the girth weld. After cooling, the stress distribution at the root of the mast was obtained, as shown in Figure 2. The stress distribution shows a series of concentric circles centered on the heat source, and the closer to the heat source, the greater the stress gradient. The maximum stress appears at the position where the boundary line between the ring plane perpendicular to the mast and the mast barrel is slightly above, that is, near the boundary line of the packing area, which is basically consistent with the actual fracture position.

Influence of wind load on mast structure:

When the surface ship sails on the waves, the load on the mast mainly consists of the gravity of the mast structure and its equipment, the inertia force caused by the ship's swaying, and the wind force. Stiffeners welded to the base of the mast can not only increase the stability of the mast, but also avoid deformation. The thickness of the mast and stiffeners was changed to 3mm, 3.5mm, 4.5mm, and 5.5mm respectively, and the calculation was performed under the same loading conditions. The calculation results are shown in Figure 4.

Test Verification:

In order to verify the validity of the finite element analysis, metallographic microstructure observation, scanning electron microscope observation and mechanical properties testing of the failed samples were investigated. Due to the uneven heat input, the α phase in different regions has different growth trends, and the grains are coarse and unevenly distributed. When temperature reaches the phase transition temperature, the α grains are transformed into β grains, and β-phase stabilizing elements are precipitated at the same time, so that the β-phase grows by merging the surrounding fine α-phase grains. Subsequently, upon rapid cooling, the β phase undergoes a martensitic transformation to form α bulk grains with jagged edges of large size. Fatigue strips shown in Fig 5 indicate that under the action of alternating loads, the weld at the bottom of the mast is locally overloaded and cracks are formed on the outer surface.

Conclusion:

- (1) When the mast is welded to the stiffener, the large and uneven heat input leads to different micro-structure transformation in different areas of the weld, which forms different microstructure after cooling and generates residual stress. This inhomogeneity leads to the reduction of mechanical properties and fatigue resistance in the weld area.
- (2) During sailing, the mast is subjected to inertial loads and wind loads, and fatigue damage occurs in the weld area with poor fatigue resistance, which eventually leads to fatigue fracture.
- (3) By increasing the thickness of the mast, the stress level of the mast can be significantly reduced.

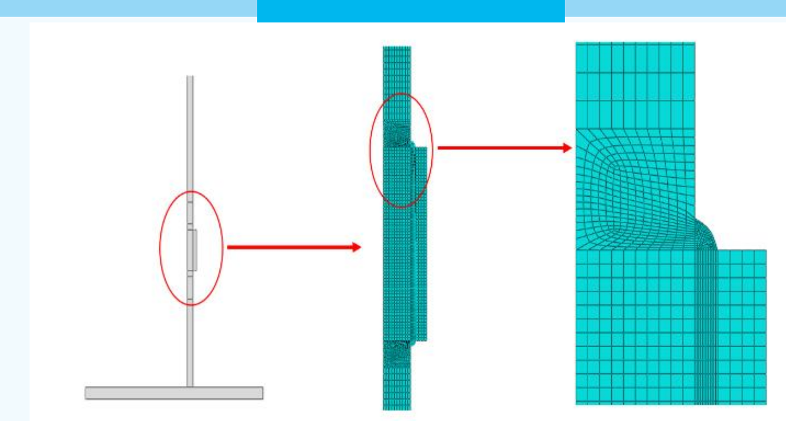

Figure 1. The finite element calculation model of the mast for welding

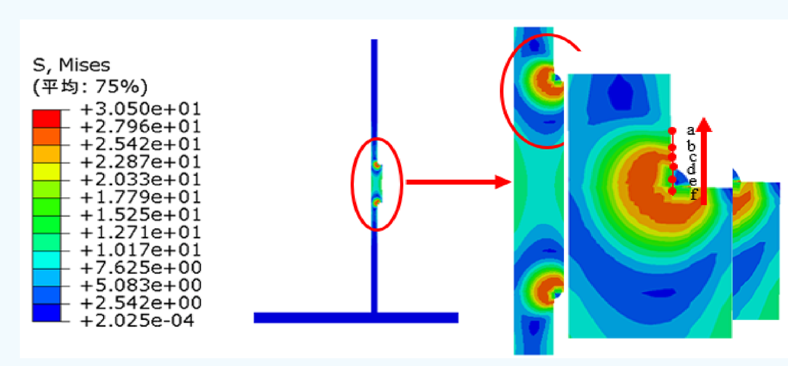

Figure 2. The welding residual stress after cooling

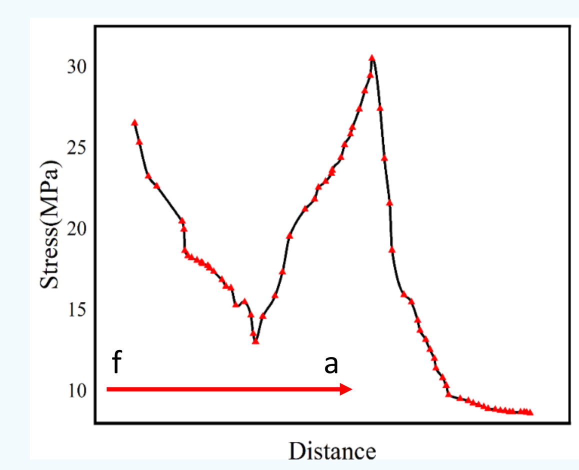

Figure 3. equivalent stress distribution of Heat-affected zone

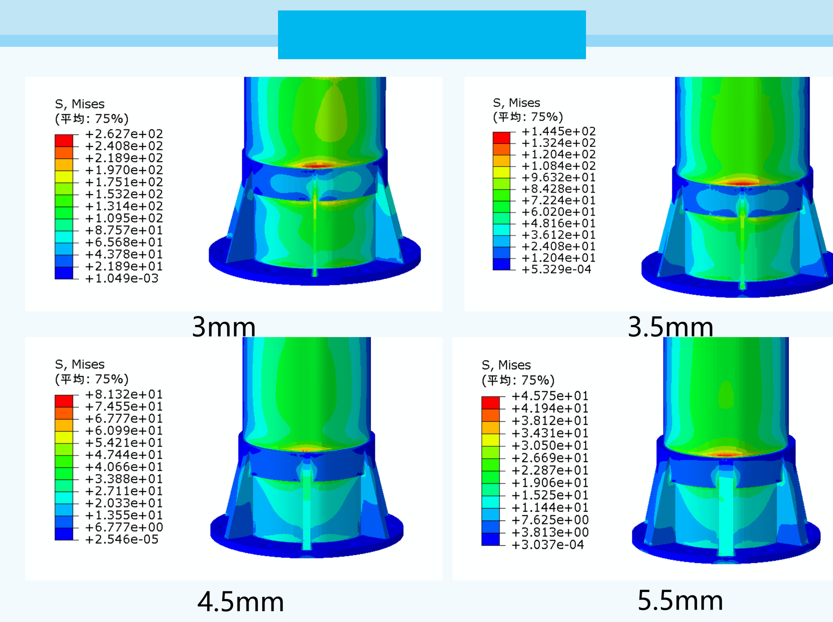

Figure 4. The stress distribution of different thicknesses

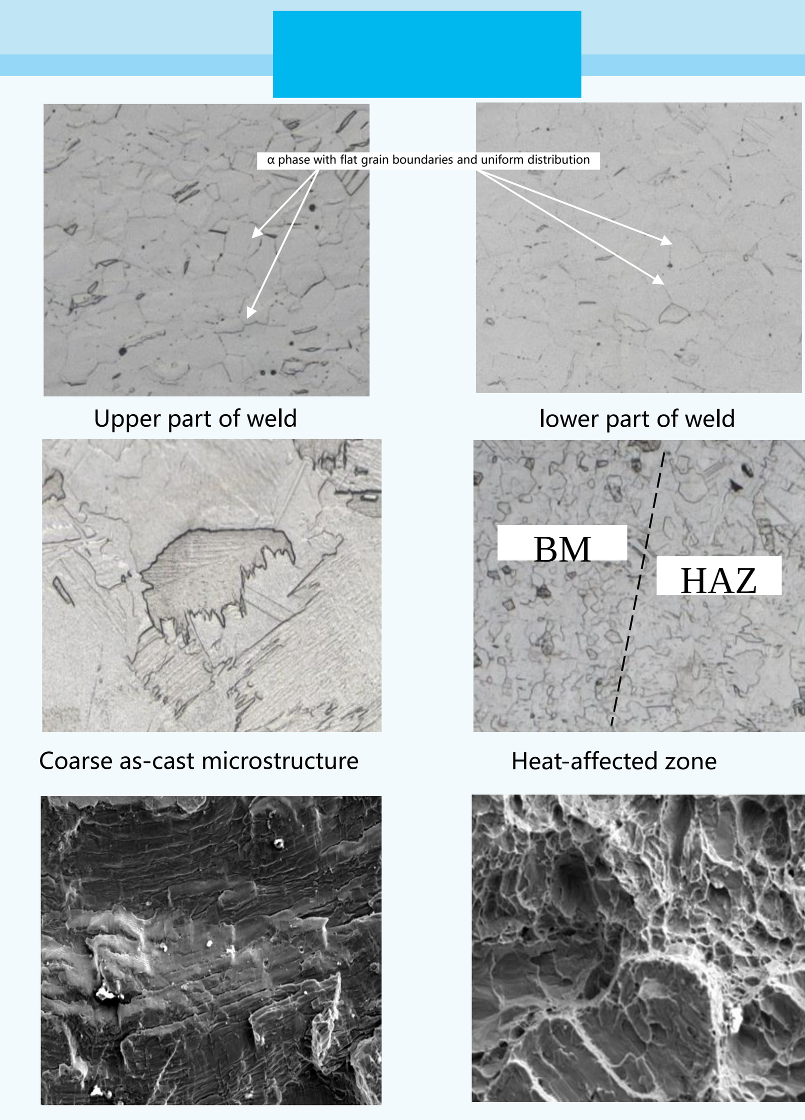

Figure 5. Microstructure analysis of the mast