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Welding assessment of a damaged crane pedestal of a container ship

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Abstract

A structural integrity assessment of a damaged crane pedestal/column of a container ship is presented. Crane cabins and pedestal/columns are subjected to fatigue coupled with sudden overloads during cargo operations and corrosion effects due to sea environment. Significant number of surface cracks was detected around the pedestal/column, at inner and outside of the crane foundation, close to the main weld seam and, in consequence, the ship-owner ordered a survey. The main weld seam and the sites where cracks were found are evaluated in the present study. For the purpose, the sample material (hot rolled steel plate and upper ring) of the pedestal was provided by the shipyard and macro and micrographics were observed. Results did not show any cracks, although they have been found by the NDT technical services of the shipyard which have decided to remove them by the grinding process. The weld seam did not also show relevant defects, whereby the replacing of the pedestal/column by a new one would not had been necessary. Regardless of some occasional overloads, the surface cracks found on the pedestal/column could be a consequence of the normal operation conditions of the crane during the last 5 years and also due to poor maintenance.

Keywords: structural failure survey, weld macrostructures, structural integrity, pedestal/column of container ship.

1. Introduction

Container ships have cranes to handle loads in ports. They include the supporting structure and their foundations. The pedestal/column are subjected to sudden loadings as result of the crane operating coupled with corrosion effects due to sea environment which can cause damages in the structural integrity. Ships are exposed to a range of corrosion environments and, as result, the patterns of corrosion can vary widely. Corrosion and corrosion-related problems have been considered to be the most important factors which lead to age-related structural degradation of ships and their equipment. Corrosion can lead to thickness decrease, fatigue cracks, brittle fracture and also unstable failure. Literature reviews [1-4] have identified the main corrosion mechanisms that can be found in ship structures as well as the main environmental factors that affect them. In the practice to monitor the growth of corrosion during the ships lifetime is to obtain thickness measurements at regular inspections for maintenance and classifications according to the requirements of International Association of Classification Societies (IACS) [5]. The design of steel ships typically incorporates a corrosion allowance, i.e. an amount of corrosion loss that can be tolerated before the structural system is considered compromised [6]. Repairing and replacement of structural details may be necessary, incurring very considerable cost penalties due to direct repair and delay costs.

Residual stresses play also an important role in the performance materials, parts and structural elements. The effect in the engineering properties of materials such as fatigue and fracture, corrosion resistance and dimensional stability can be considerable, whereby should be taken into account during design, fatigue assessment and manufacturing [7]. This study was carried out on a container ship (five years old), where the cabin crane No.1 (fore crane ship) presented some structural deformation combined with corrosion effects. Fig. 1 shows a general view of the container ship and the handling equipment (3 cranes, 45 ton each one).

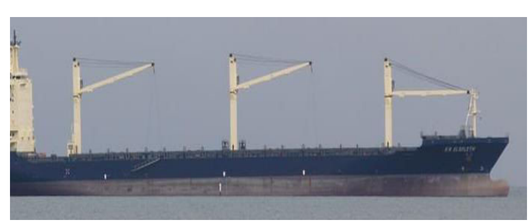

Fig. 1 Container ship with the 3 cranes and its pedestals.

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When the ship was at shipyard to replace the damaged crane cabin, NDT tests were performed in the crane foundation (pedestal/column) by ultrasonic and magnetic particles close to the main weld seam between the flange and the crane pedestal/column. Twenty surface cracks were detected by a dye check inspection around the pedestal, at inner and at outside the pedestal, being the extension and depths evaluated. However, the size of cracks found was considered acceptable by the shipyard and therefore was decided to remove them by grinding of the material on the affected areas. The NDT report delivered by shipyard to the ship-owner considered that the foundation could have been eventually affected by sudden overloads under cargo operation which could have caused some local deformation on the pedestal/column. In the following the Class Surveyor also recommended the replacing of crane pedestal. Taking into account the shipyard report, the Manufacturer Technical Services and ship-to-shore (STS) Competence Cranes have also concluded that the foundation was affected by the found cracks and therefore could have caused changes in the material structure. The grinding of the cracks could have not been successful and therefore strongly recommended the replacing of pedestal/column by a new one.

Then the manufacturer has sent a new pedestal/column, but this one came with a new design and a thicker steel plate. The costs of this replacing could be attributed to the Ship Insurance or Protection and Indemnity (P&I) if the damage was a consequence of a sudden overloading by negligence of the crane operators. Hence the ship-owner ordered a damage analysis report to a scientific laboratory for determining damage's cause.

The aim of this research work is to evaluate if the damage of pedestal/column was mandatory for the replacing by a new one, and also if the damage (cracks found) of the pedestal/column was a consequence of sudden overloads or not. In the following sections, the material characterization is presented firstly, and then both laboratory examination and results are presented and discussed.

2. Material and procedures

2.1 Chemical composition and mechanical properties

The pedestal/column is a hot rolled steel plate, see Fig. 2 (a) and (b). The material of flange (upper ring, iii) is steel S355NL (27 joules/-40 ºC) (a), and the hot rolled steel plate is the S355N (27 joules/-20 ºC), as can be seen in the sketch, Fig. 2 (b). The flange cross-section is 112 mm x 84 mm, and the hot rolled steel plate is 25 mm thickness.

Table 1 shows the chemical compositions in weight percent [%] and Table 2 shows the mechanical properties of the flange and hot rolled plate steel presented by the manufacturer.

Anisotropic properties of rolled steel plates are related to pancake inclusions in the rolling direction, residual stress and mechanical fibering [8]. The S355N is a type of high strength and low-alloyed normalized steel, which is widely used at ship structures, being the weldability the more important parameter at the soundness of construction.

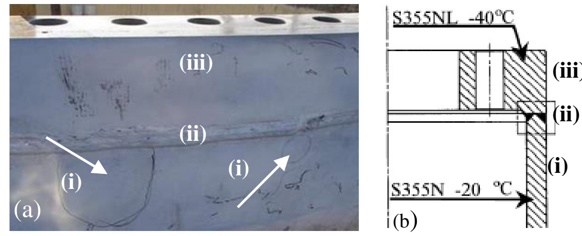

Fig. 2. (a) Crane base pedestal/column surface where cracks were localized (i); (b) column sketch with the upper ring (iii), shell plate (i) and the weld seam (ii).

Table 1. Chemical composition (W %).

Grade	C	Si	Mn	P	S	N
S355N	0.20	0.5	0.9-1.65	0.03	0.02	0.015
S355NL	0.18	0.5	0.9-1.65	0.02	0.02	0.015
Grade	**Al**	**Cu**	**Ni**	**V**	**C_E**	
S355N	0.02	0.55	0.50	0.12	0.43	
S355NL	0.02	0.55	0.50	0.12	0.43	

Table 2. Mechanical properties.

Grade	min. yield strength MPa	tensile strength MPa	min. total elongation [%] $L_O = 5.65\sqrt{S_O}$
S355N	355-345	345	470-630
S355NL	355-345	345	470-630

According to the shipyard report, surface cracks were found at inside and outside of the hot rolled steel plate (25 mm thickness), close to the main weld seam, as is shown in Fig. 2 (a) (i), and some ones also appeared on the welding seam. Most of cracks were found to starboard of the crane. The cracks size ranged between 50 mm and 100 mm long and between 1 mm and 5 mm deep. Cracks were detected by NDT, i.e. magnetic particles and ultra-sounds test. As the cracks size were considered acceptable by the shipyard, the technical services for ship repairs removed them by grinding of the material as it is shown in Fig. 3 (a) and (b) indicated with white arrows.

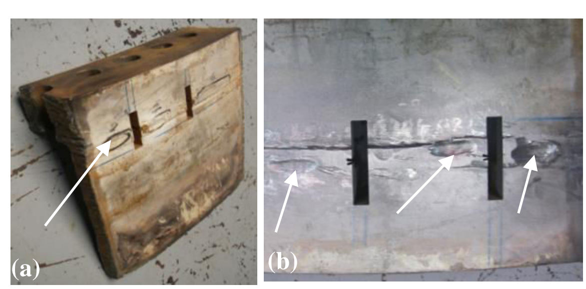

Fig. 3. (a) Flange and (b) hot rolled steel plate, with two holes from where the samples were cut.

Two large samples were cut by oxy-cutting from the rejected pedestal/column at shipyard. From one of them, two small samples were cut by water jet, close to the welding seam cross-section. Fig. 3 (a) and (b) shows the holes from where samples were obtained, as well as the visible zones where cracks were removed by grinding pointed by the white arrows.

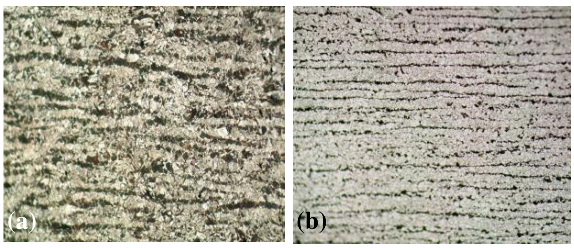

Fig.4. Microstructures of the flange ring (a) and hot rolled steel plate (b), both with 100 X magnification.

The small samples were prepared at laboratory in order to obtain macros and micrographs of weld seams, as well as the EDS chemical analysis.

3. Results

3.1 Flange (upper ring) and hot rolled steel plate micrographs

Microstructures of the crane upper ring and rolled steel plate were obtained by etching (2% Nital solution) after sample polishing, being observed by optical microscopy. Micrographs are shown in Fig. 4, both with 100 X magnification, being a typical microstructure of these steels, S355NL and S355N.
The image of optical microscopy shows a ferrite-perlite structure with grain bands parallel to the welded seam due to the mechanical treatment. The microstructure does not show any subsequent heat treatment for improving the mechanical properties.
It is noteworthy that when working with thick plates, the welding generates a high level of residual stresses, hence it is necessary to perform a heat treatment in order to relieve those residual stresses. In some few cases, when the steel is hot or cold worked, it is necessary to perform a normalizing heat treatment for recovering the original mechanical properties.

3.2 Welding metal micrographs

Fig. 5 shows the weld seam cross-section where is possible to observe the micrographs of different weld seams, as well as the fusion limits among them and the heat affected zone (HAZ).
Micrographs show a typical microstructure for this multi-pass welding. Some weld defects such as inclusions and voids were found but are not significant. However the welding defects found at the weld seam are acceptable and cracks were not found.

3.3 Electron diffraction analysis (EDS)

The chemical analysis of the material obtained by electron diffraction (EDS) shows a Mn (%) of 2.18 ± 0.5 which reveals that both materials (upper ring and hot rolled plate) are reasonably within the earlier indicated range of chemical composition for the material under consideration (steel S355N and S355NL).

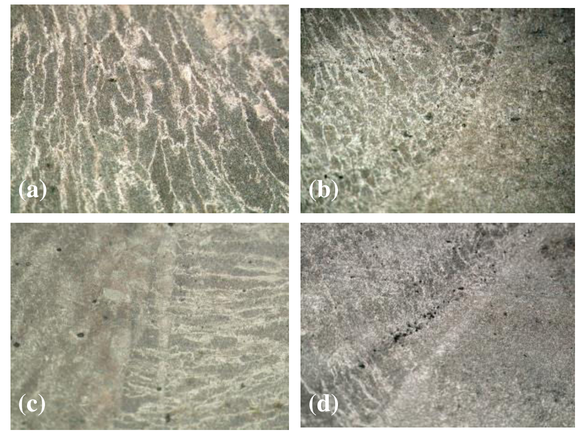

Fig. 5. (a), (b), (c) and (d) welding microstructure and seam limits, with 100 X magnification.

3.4 Cross-section of the weld seam (double bevel) macrographs

Four macrographs of two double bevel weld joint samples were carried out: in each one, two macrographs (front side and back side). The double bevel weld seam macrographs are shown in Fig. 6 and Fig. 7. In these weld cross-section it is possible to observe the macrographs of different weld seams, as well as the fusion limits among them and the heat affected zone (HAZ).

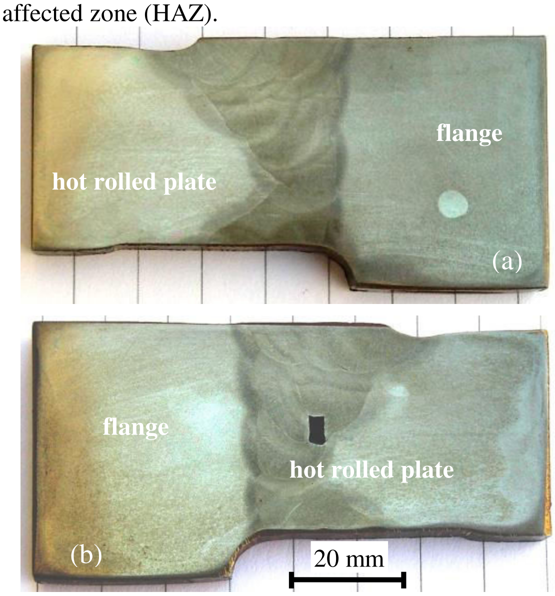

Fig. 6. (a) Weld seam cross-section (double bevel weld seam), where multi-pass weld is observed, and (b) a weld defect (void) at the opposite side of the sample (a).

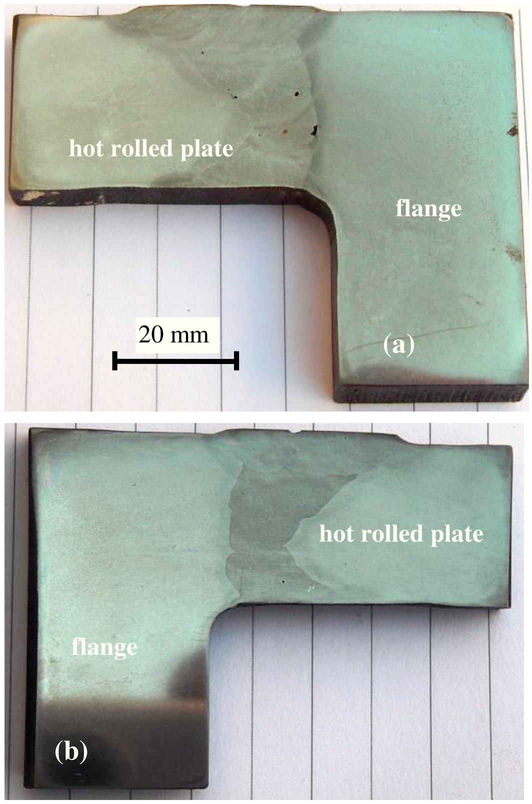

Fig. 7. (a) Weld seam cross-section (double bevel weld seam), where multi-pass weld is observed, and (b) the opposite side of the sample (a).

Some defects such as inclusions and voids were found but they are not of significant importance and may be considered acceptable. Cracks were not found in these macrographs, taking into account the cracks which were eliminated by grinding at the shipyard. It should be also noted that an exhaustive dye check was done at the laboratory before cutting these samples and surface cracks were not found.

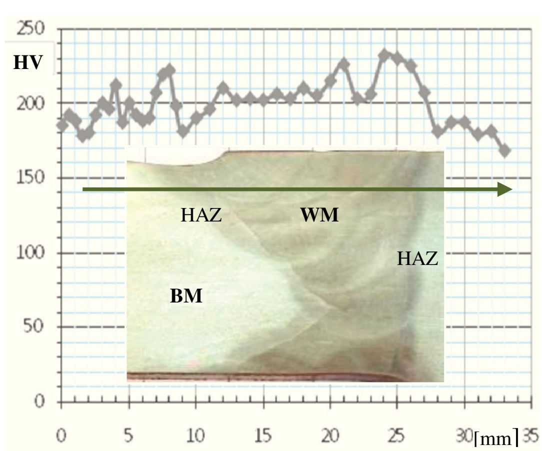

Fig. 8. Cross-section Vickers hardness obtained on the weld metal (WM) according to the arrow direction.

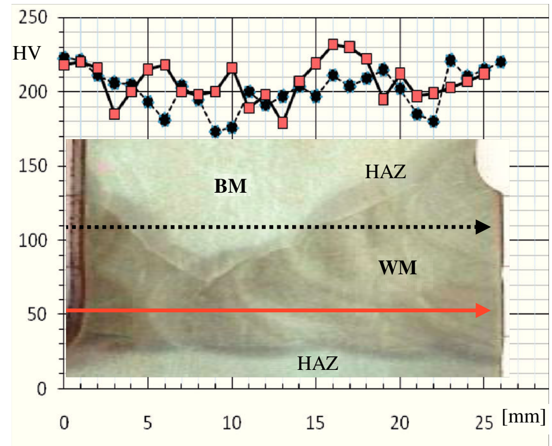

Fig. 9. Longitudinal Vickers hardness obtained on the weld metal (WM) according to the arrows direction.

Macrographs do not show any subsequent heat treatment of the weld seam in order to improve the mechanical properties of the weld metal.

In Fig. 7 (a) shows the heat affected zones (HAZ), and some defects, like inclusions and voids in the bevel weld seam. However these defect sizes are considered acceptable in welding. Cracks or corrosion effects were not also found.

3.5 Vickers hardness

The Vickers hardness measurements were performed to evaluate the mechanical properties of the welding metal (WM). Fig. 8 and Fig. 9 show the Vickers hardness of the weld seam according to the direction lines on the macrographs. The base metal hardness (BM) shows to be lower than in the weld metal (WM). The highest hardness (peaks) occurs at the heat affected zone (HAZ). The Vickers hardness obtained on the cross-direction is uniform without significant peaks among the multiple weld seams.

As was formerly said, a total of twenty cracks were reportedly by the shipyard around the upper welding joint, between the upper ring (flange) and the crane column (hot rolled steel plate), at shipyard. As they were removed by grinding, cracks were not detected by a careful dye-check at the laboratory.

Vickers hardness values obtained on the weld seam at the cross-direction have no significant peaks among the weld seams and from this one may conclude that the residual stresses are not significant, see Fig. 8, Fig. 9.

4. Discussion

Sudden overloads on the pedestal/column of the crane may generate an overstressing in the weld seam between the upper ring and the hot rolled steel plate, but is very unlikely that such overloads can produce cracks, as those found by the ultrasonic and magnetic particles tests performed at shipyard. As the localized plastic deformations were not found, this is an indication of non-existence of overloads during the crane operation. However it is clear that the crane No. 1 being more affected by the sea conditions, the vessel's movement can eventually be more prone to corrosion under tension.

Therefore cracks found could have developed as a consequence of a fatigue process during the crane operation in the last five years, and probably assisted by corrosion under tension. Furthermore if cracks were a consequence of the crane operation, despite some occasional overloading, the crane design can be undersized.

The characterization of the root cause of detected cracks requires a careful analysis for one short or long crack by optical microscopy or by the scanning electron microscope (SEM). This unfortunately was not possible since no cracks were detected on the samples sent to the laboratory by the shipyard, once all found cracks were removed by grinding before.

It should also be considered that crane No.1 is more hit by the sea water and therefore some corrosion under tension could occur by the crane operation during the last 5 years. Plastic deformations were not found close to the weld seam which does not reveal any overstressing due to sudden loads of the crane in service.

Regardless some occasional overloads, if the cracks were the result of the normal crane operation, an inadequate maintenance of the pedestal /column surface should not be excluded. The crane and pedestal/column should be painted with shorter intervals. Therefore the pedestal/column should not be replaced by a new one, such as the others were also not replaced.

5. Concluding remarks

Macrographs and micrographs of the weld seam do not show any cracks despite of some weld defects found. The upper ring (flange) and the hot rolled plate micrographs show a typical microstructure for these S355N and S355NL steels. The mean Vickers hardness measurements on the cross-section weld seam is about HV 200 which shows that the welding process was well done. The surface cracks found by the shipyard on the crane pedestal/column plate, close to the welding seam to the upper ring, were probably originated by a fatigue process assisted by corrosion due to the sea aggressive environment, and not due to sudden overloads of the crane operation or material defects. An inadequate maintenance points out for the origin of the cracks found, being the replacing of the pedestal/column by a new one clearly unnecessary.

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