

# INVESTIGATION OF POSSIBLE CAUSES FOR APPEARANCE OF A CRACK IN THE WELDED JOINT OF THE SHIP WINCH FRAME

Miloš M. Matejić<sup>1</sup>, Ružica R. Nikolić<sup>1, 2,\*</sup>

<sup>1</sup> Faculty of Engineering, University of Kragujevac, Sestre Janjic 6, 34000 Kragujevac, Serbia

<sup>2</sup> Research Centre, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak Republic

\* corresponding author: tel.: +381 64 2303559, e-mail: ruzicarnikolic@yahoo.com

## Resume

Ship winches are one of the most important parts of the ship equipment since they perform the most responsible tasks on various ships. In the majority of cases, the ship winches are welded structures. All the necessary calculations according to required standards, that have to be done prior to actual execution of the structure, should also include the verification by the FEM. For the high reliability requirements to be met, the welded joints integrity of all the parts must be examined before they are assembled into the winch. After all the tests are conducted and the parts are assembled into the winch, the factory acceptance test (FAT) must be also done. During those tests all the flaws, which can appear during the manufacturing, must show.

An appearance of a very unusual crack in the ship winch frame, which happened during the FAT, is described in this paper. The simulation by the FEM was performed to obtain the stresses at which the crack appeared. The possible causes for that crack appearance are considered. Some measures for reducing appearance of such cracks to a minimum are proposed, as well as certain directions for further research of this problem.

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## 1. Introduction

Ship winches belong into a group of the most important ship equipment elements. They perform very responsible tasks on all kinds of ships. Winches' working tasks range from winches for catching fish to winches that are lowering extremely expensive research equipment into the sea or the ocean. They are mainly welded structures. Difference between the experimental investigations and analytical calculations should not exceed 10 % [1]. Very high standards are applied for sizing of the winches' elements (SAA – Standard Association of Australia, DNV – Det Norske Veritas, etc.). Besides verification by those standards, the checking of the critical parts of the structure is also done by the Finite Elements Method (FEM). Experimental investigations of winches are usually done by the Factory

Acceptance Tests (FAT), where the applied load is for 10 % higher than the calculated maximal one. In that way is ensured that if any flaw occurred in the manufacturing phase, the failure should occur immediately. If that should happen, eliminating the failure is far less costly on land than at open sea. The very important factor during those tests is maintaining the constant pulling force during the variable test conditions, [2]. Thus, the winch is tested for variable conditions that can arise during the open sea operations.

In paper [3] is presented testing of the welded corner joint, which appears in about 50 % of cases of the welded joint on winches. The crack usually appeared in the heat affected zone (HAZ). In [4] is presented an investigation of the V-notch of the S355JR steel, which is the most frequently used material for

manufacturing of the winch frame. Specimens taken from the welded joint sample were from the base metal (BM) zone, HAZ and the weld metal (WM) zone. Tests led to conclusion that the best characteristics in regard to preventing the crack opening has the weld metal. In papers [5-9] are presented investigations of corner joints subjected to different varying loads. All the flaws and cracks that were created, or appeared during investigations, or were artificially created, pointed to the fact that the most critical places causing the welded structures failure were within the heat affected zone.

In this paper is presented an exactly opposite phenomenon. During the factory acceptance test cracking of the welded joint occurred right in the middle of the weld. This was totally unexpected, so authors tried to find out what were the causes for such an uncommon behavior of the particular welded joint. Prior to that, the analysis was conducted by the finite elements method (FEM), which completely confirmed correctness of the calculations done during the design phase of the structure. Here is given the analysis of the structural part where the crack appeared. The procedure of investigation, the crack appearance, as well as the possible causes for this phenomenon, are presented in the paper. In the conclusions, authors tried to reason why this flaw appeared at all and proposed measures for preventing its repeating.

## 2. Factory acceptance testing (FAT)

Factory acceptance testing (FAT) represents investigation of the winch prior to assembling it into the ship structure in conditions similar to real – operational ones. Test is done in such a way that winch stand is being welded onto the platform, identically as it is imbedded on the ship. After that, the tests are done to verify that the winding systems are operating properly. The load carrying capacity of the winch is tested in such a way that it is subjected to maximal calculated load, with

additional 10 % of the variable load. The pulling force is then checked and so is the braking force. In Figure 1 is presented a sketch of the FAT station.

During this test, all the flaws that could appear during construction and manufacturing of the winch could be noticed. Each of the welded joint is then loaded in conditions, which are more strenuous than the real working conditions, so that any flaw, even the smallest one, can surface. This type of testing is very dangerous (due to overloading of the structure above the maximum calculated load). The special security measures must be undertaken, what includes that presence of workers at a distance smaller than the safe one is not allowed. The safe distance is being defined taking into account the size of the winch. This test is done according to the DNV standard, [10].

## 3. Failure during the FAT

The tested winch frame was made of steel S355JR. This is a steel of unwarranted chemical composition, with tensile strength 500 – 590 N/mm<sup>2</sup>, carbon content of 0.24 %, maximal content of sulfur of 0.06 % and phosphorus of 0.06 %. Percentage of the V-welds on the tested winch frame was about 40 %, while the corner joints were about 50 %; the rest of the welds were prepared as the U and X welds. The applied welding procedure was GMAW, protective gas was CO<sub>2</sub>. The wire used for welding was VAC (mark by "Jesenice" ironworks). Its chemical composition is: C 0.1 %, Si 0.9 %, and Mn 1.5 %. This wire is used for welding thin sheets and profiles of the ship equipment, made of steels with tensile strength up to 590 N/mm<sup>2</sup>. Welding was done after operations: thin sheets and frame profiles cutting by gas cutter, cleaning of the cut positions, preparation of grooves for welding, stapling (pre-welding joining of parts) and sand blasting. After the welding was done, the operation of welds heat treatment – normalizing was skipped. Then the penetrating test was performed. No flaws

were detected with this probe. Finally, the finishing protection and painting of the frame were done. The final operation of the FAT was mounting of the winch onto the FAT station. During the testing, a crack was noticed at the place where the carrying plate is connected to the device for proper winding-up of the rope, Figure 2.

The crack appeared at a point which is not subjected to the maximum load intensity. It appeared in the middle of the weld, what is

a very rare case, both in exploitation and in tests. The crack length was about 120 mm. If the crack has opened completely, that would cause fracture of the system for rope guiding around the winch. Flaws of this type could lead to catastrophic consequences during the winch operation at open seas. Due to appearance of this crack, the safety of the winch operator would be automatically compromised, as well as pulling up or lowering down the cargo and the total failure of the winch would be immanent.

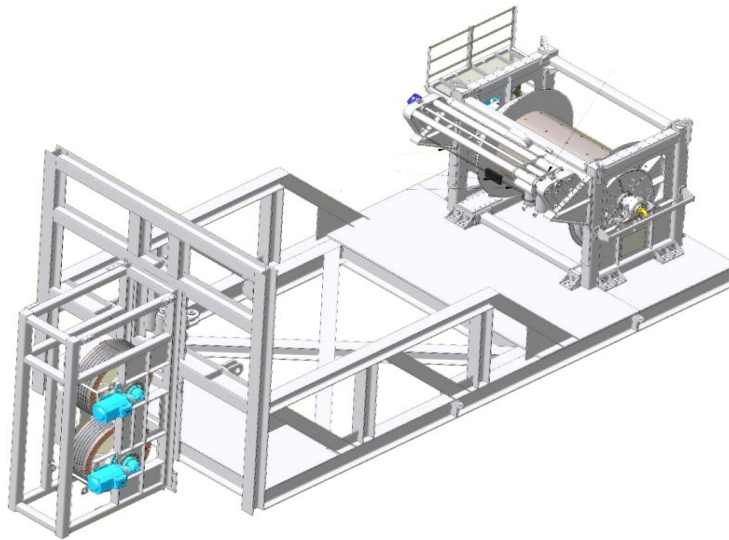


Fig. 1. The FAT station.  
(full colour version available online)

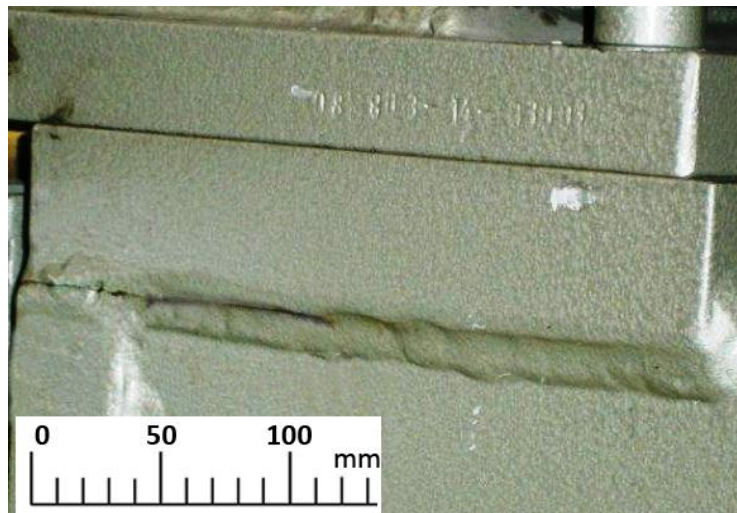


Fig. 2. Crack in the middle of the welded joint – Failure at FAT.  
(full colour version available online)

#### 4. Finite elements analysis of the broken winch frame part

After the performed FAT and appearance of a crack at the winch's frame, the FEM analysis of the part of the frame where the crack appeared, was conducted, [12]. This analysis was done so that the reason why the problem appeared could be identified – whether the crack appeared due to poor design solution and inadequately prescribed technology, or there was some other reason for that.

The part of the frame, together with the level wind support, was modeled. Those two welded assemblies were connected by screws, as in the original structure. Appearance of this model is given in Figure 3. The winch plates were 20 mm thick, except for the plate for connecting the level wind support, which was 30 mm thick. The level wind support's plates were also 20 mm thick, except for the support's housing plate, which is obtained by bending of the thin sheet, 10 mm thick. The connection between the frame and the support was done with four M 16 × 40 screws with cylindrical heads.

The constraints of the winch frame were set in such a way that the sides of the model that belong to the winch frame part with the crack, were taken as fixed. Such constraints simulate behavior of that part of the frame as if it still were at the winch frame. Loading that is transferred to it comes through the screws' connection, which receives the loading from the wind level support. The remote force, which stems from pushing the cable for the proper winding on the winch's drum, acts on the wind level support. That force amounts to 10 % of the pulling force; in this case, that is 8 kN. Coordinates of the point of the remote force most unfavorable action are ( $x = 100$ ,  $y = 400$ ,  $z = 800$ ) mm. Before the simulation, types of finite elements, which correspond to plates, were set, as well as the connections between the plates that simulate the welded joints.

After the FEM simulation was performed, the part at which the crack appeared during the FAT was singled out for easier viewing of results. The simulation results are shown in Figure 4.

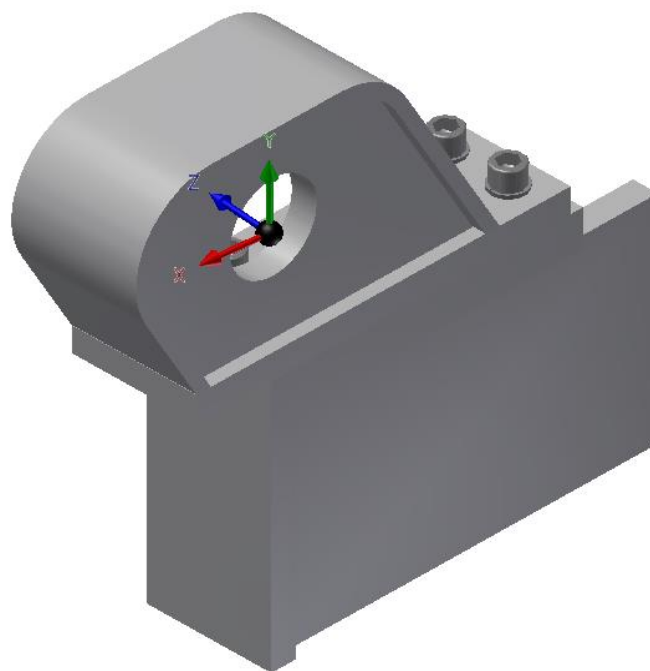
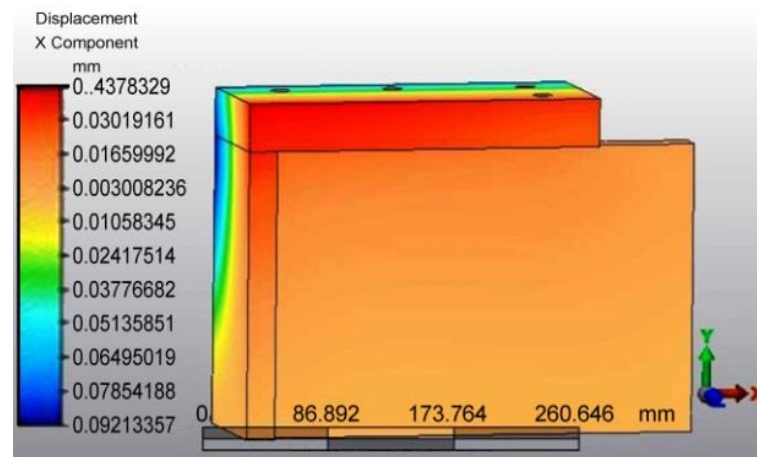
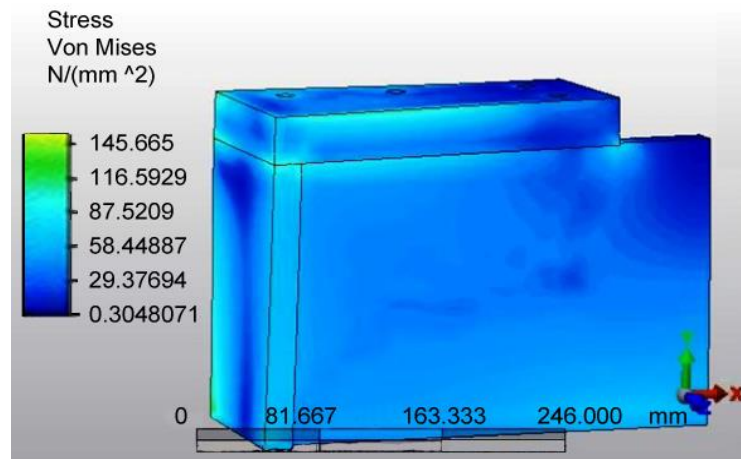


Fig. 3. Assembly of the winch frame and the level wind support.  
(full colour version available online)



a)



b)

Fig. 4. Results of FEM simulations: a) displacements; b) Von Mises stresses. (full colour version available online)

From Figure 4 a) one can see that the largest displacement, during the force action, amounts to 0.04 mm. This zone of displacements is shown in red and it is in the zone of the crack. Value of this displacement is at least four times less than the maximum allowed value, what would imply that this displacement is within the elastic region. Thus, this could not have been the reason for the cracking of the weld. From Figure 4 b) can be seen that the highest stresses in the winch frame act in the region of the crack. They are shown with light blue color and amount to 120 N/mm<sup>2</sup>. The value of stress in that zone is more than four times lower than the allowed value, what would imply that even

after the large number of repetitions of the operational cycles of the winch, no crack whatsoever should appear. The much higher stress (over 300 N/mm<sup>2</sup>) appeared in another part of the model, which is not shown in Figure 4 b), since it does not have effect on the weld and the crack appearance in it.

Thus, the FEM simulation has confirmed the design calculations, what implies that the design errors could be excluded as possible causes for appearance of the weld crack.

## 5. Discussion

Appearance of such a crack could be caused by several reasons. Specifically, in this case of a crack on the winch frame, the highest

influence could have been imposed by the following factors:

1. Insufficiently cleaned surfaces prior to welding;
2. Lower pressure of the protective gas and
3. Poor quality of the welding wire.

Insufficient and improper cleaning of surfaces prior to welding creates a possibility for appearance of impurities in the weld metal. Those impurities cause inhomogeneity of the weld metal and appearance of eventual inside cracks. At the lower loads, those cracks propagate and connect to each other and form a large crack.

Lower pressure of the protective gas facilitates penetration of the oxygen in the weld metal; that prevents proper joining of the weld metal and the base metal.

Wire that was used for welding is completely adequate for this purpose, according to characteristics provided by the manufacturer's catalogue. However, it is the most probable that an error occurred and that this wire was replaced by the wire, which does not possess adequate characteristics, necessary for these purposes.

It is also possible that the welder played a partial role in appearance of this flaw – crack. However, due to previously stated reasons, that role would be negligible.

The conducted FEM analysis has shown that the largest stresses in that part of the winch frame and largest displacements in the elastic region appear at the place of the welded joint. However, those stresses, as well as displacements, though the largest possible, are still three to four times smaller than the largest permissible values, obtained by calculations. This is an excellent indicator that causes for crack appearance were not in the prescribed technology, but rather in its execution

In order to avoid appearance of such cracks in the future, it is necessary to introduce the following measures:

1. Cleaning of surfaces prior to welding and their degreasing at the highest quality level;
2. Checking of the protective gas bottle and pressure of the gas in it, and
3. Changing of the welding wire supplier.

By executing such measures, flaws like the considered crack, could be reduced to a minimum. Combinations of the three factors, mentioned as possible causes for flaw, are highly improbable. However, if they would coincide and/or if the FAT (or some other form of similar tests) were not performed, the consequences would have been catastrophic and could result in fast appearance of winch frame failure immediately after the first crack appearance.

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