LIFE EXTENSION of FPSO STRUCTURAL DETAIL USING ULTRASONIC PEENING

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ABSTRACT

Life extension has been achieved by the application of ultrasonic peening treatment to high stressed areas on the pallet stool welds on cargo deck of a FPSO installation.

This high stressed areas or welds, showed too short fatigue life in as-welded condition and the aim with the ultrasonic peening treatment was to avoid any further weld repairs during the remaining service life of the vessel at these specific locations.

Fatigue test results of treated relevant welded details for the specific stress ranges have been used to assess the possible life extension. The results showed that a four to six times fatigue life extension, would be possible to achieve by the treatment. The fatigue test was special designed to confirm that relaxation of the induced compressive stresses during treatment will not be relaxed during real load sequences.

The fatigue lives for the treated welds were extended to twenty years calculated from the theoretical fatigue life assessment and assuming the fatigue crack will start from weld toe between weld and deck plate.

Quality Assurance and Quality Control were covered by a Peening Procedure Specification, created for every treated weld. It ensures that the treatment is exactly reproduced to achieve the expected life extension.

Despite the variable weld quality encountered on the pallet stool welds the treatment was carried out at perfection and it showed to be relatively easy and straightforward application even in locations of difficult access.

KEYWORDS: life extension, fatigue improvement, crack arrest, ultrasonic peening.

INTRODUCTION

The application of fatigue life improvement techniques is gaining popularity in the last years. Classification Societies have been focusing more and more on these and the latest document dealing with it [1] presents recommendations for weld toe profiling by machining and grinding, weld toe grinding, TIG-dressing and hammer peening. The other important document in respect to execution of the improvement is the IIW Recommendations [2], which contains extensive reference data for various fatigue life improvements [3] and the quality assurance and control of their application.

Fatigue life improvement techniques can contribute to reduce maintenance cost by the avoidance of returning weld repairs. Furthermore life extension techniques are the only remedy when higher stress and/or fatigue cracks occur in a structure with many years remaining service life.

One other way to use the increased fatigue strength achieved during improvement is to increase the design stress for the structure. Higher design stresses mean either increased pay-load or extended life for retained design stresses for a specific structure.

Fatigue life improvement, or fatigue life extension by ultrasonic peening has been applied to high stressed areas on the pallet stool welds on cargo deck of a FPSO installation. The treated welds were located in two different frames at cargo deck. One of the treated frames has been repaired for a year ago and the other was repaired just before the application of the ultrasonic peening treatment.

The high stressed areas requiring special attention were the deck stools weld joints at bracket side, which showed to be more critical than the bracket free edge. These critical areas, where high stresses and varying weld quality come together, were selected for the post-weld treatment.

The fatigue life assessment of pallet stool weldments was based on stress plots. This assessment showed too short fatigue lives for the relevant welds before treatment and the aim with the ultrasonic peening treatment was to avoid any further weld repairs during the remaining service life of the FPSO at these specific locations.

EXPERIMENTAL PROCEDURE AND TEST RESULTS

Fatigue test results have been obtained on welded details, Class F (See Fig. 1) and Class F2 (See Fig. 5). The tested weld details reproduce the load cases (stress directions vs. crack grow path) and fatigue crack site expectation as in the existent brackets and deck plate.

Class F Detail

The fatigue life improvement by ultrasonic peening is normally achieved in part by the redistribution of weld induced residual stresses and in part by the change of the geometrical stresss concentration at weld toe, see Fig. 2. This redistribution of residual stresses, including possible introduction of compressive residual stresses which will act positively towards life extension, is supposed not to be relaxed during the service life because if so the ultrasonic peening treatment would not be as effective as expected. In order to document and study this effect the fatigue test has been designed to comply with the most severe fatigue load the weld could possibly see during its life.

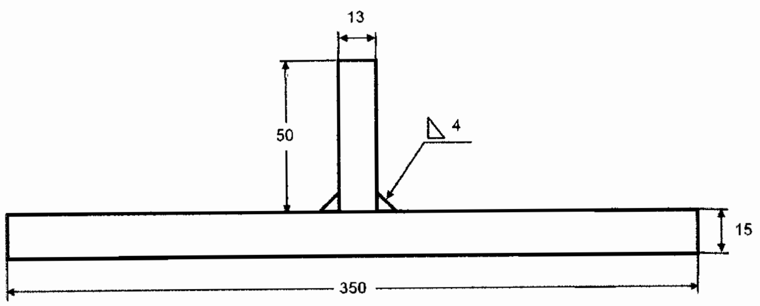


Fig 1 Fatigue test specimen Class F

As a result the welds were preloaded in compression bending 5 times up to 85% of yield strength (nominal stress) before fatigue testing, see Fig. 3.

Since the ultrasonic peening treatment is responsible for certain redistribution of residual stresses, as previously explained, it is critical to document how the mechanical relaxation by compressive loads of by the treatment induced residual stresses affects the degree of improvement.

The design of the pre-loading sequence has been established in cooperation with DNV. The intention is to produce local plasticity at the weld toe by the application of overloads in compression and by that achieve relaxation of residual stresses.

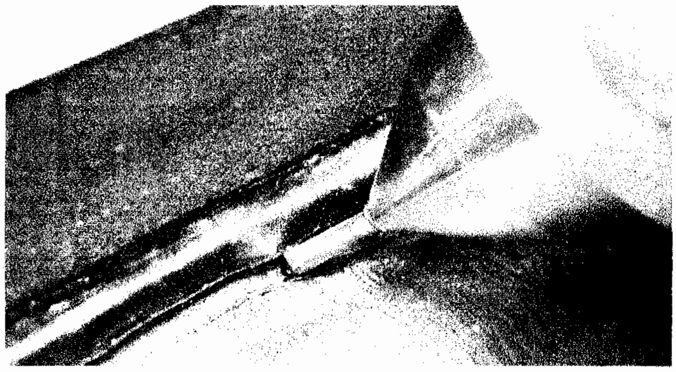


Fig 2 Ultrasonic Peening treatment of Class F fatigue test specimen

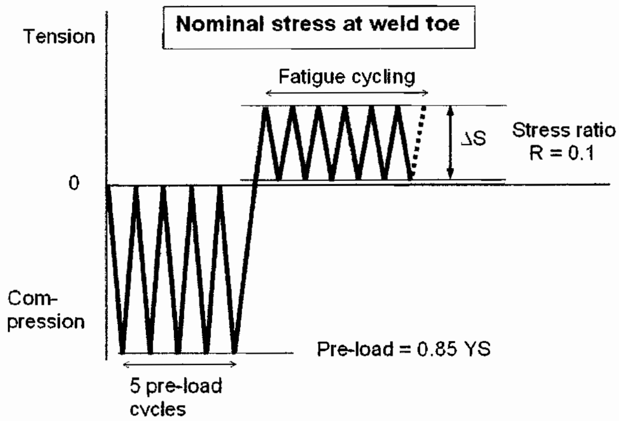


Fig 3 Pre-loading sequence performed previous to fatigue testing

Test Rig and Test Procedure

Fatigue testing was performed in four-point bending. The stress ratio $R = \sigma_{min}/\sigma_{max}$ of 0.1 was used for all tests.

Results and Correlation to Relevant Codes

All comparisons have been done against mean-curve minus two standard deviations calculated on fatigue test results.

Key to SN-Curves in Fig. 4: Fatigue test results for Class F

UP Design: The FAT value for this curve is 149 MPa.

DNV HP Fx4: This is the DNV design curve for hammer peening F-class joints i.e. factor of 4 on life.

IIW FAT 112 (HP FAT 71): IIW design curve for hammer peened F-class joints, i.e. apply a factor of 1.6 on strength and choose next curve below which is FAT 112.

For grinding the corresponding factor on strength is 1.5 and the curve for ground or TIG-dressed FAT 71 class joints would be FAT 100.

The influence of the preloading has been extensively studied [4] in connection to spectrum loading of tension/compression type for TIG-dressed specimens where same, even beneficial, effect has been detected. The compressive preloading applied to the ultrasonic peening treated specimens does not reduce the expected life extension of the treated weldments.

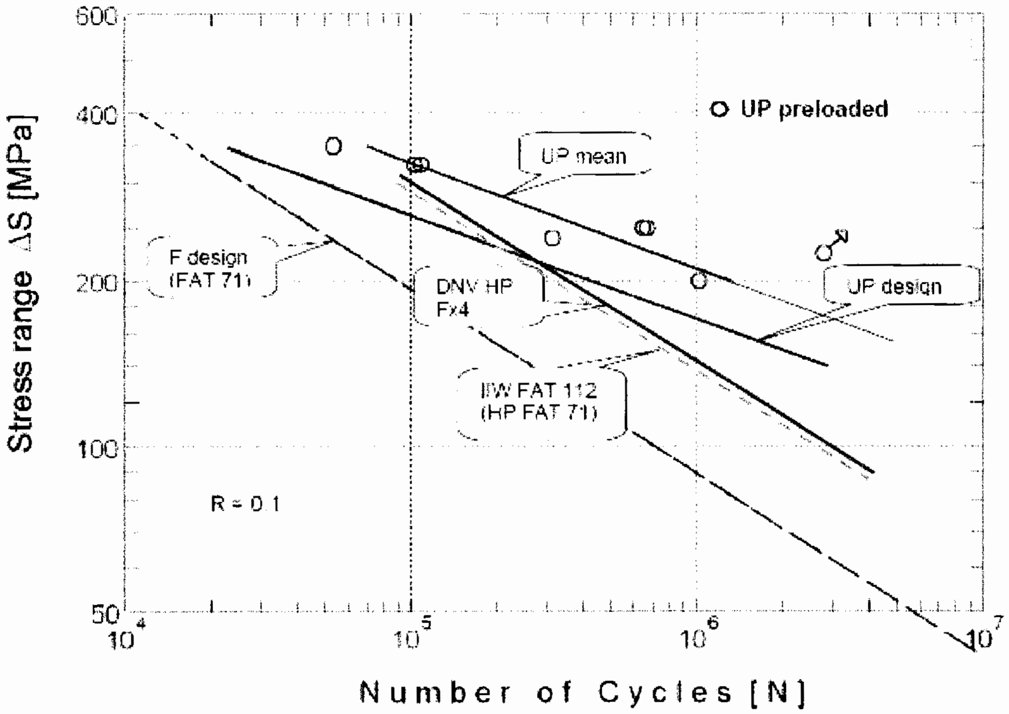


Fig 4 Fatigue test results for Class F

Class F2 Detail
The Class F2 test specimen is shown along the test results in Fig. 5. The specimen has a non-load carrying fillet weld attaching a longitudinal stiffener on both sides of the plate. One feature, which makes this fatigue test specimen particular, is the high degree of residual stresses concentrated at the crack site, which is designed to be the weld toe at the stiffener. The fatigue test results in Fig. 5 have been compared to literature data [5] but not yet correlated to DNV recommendations.

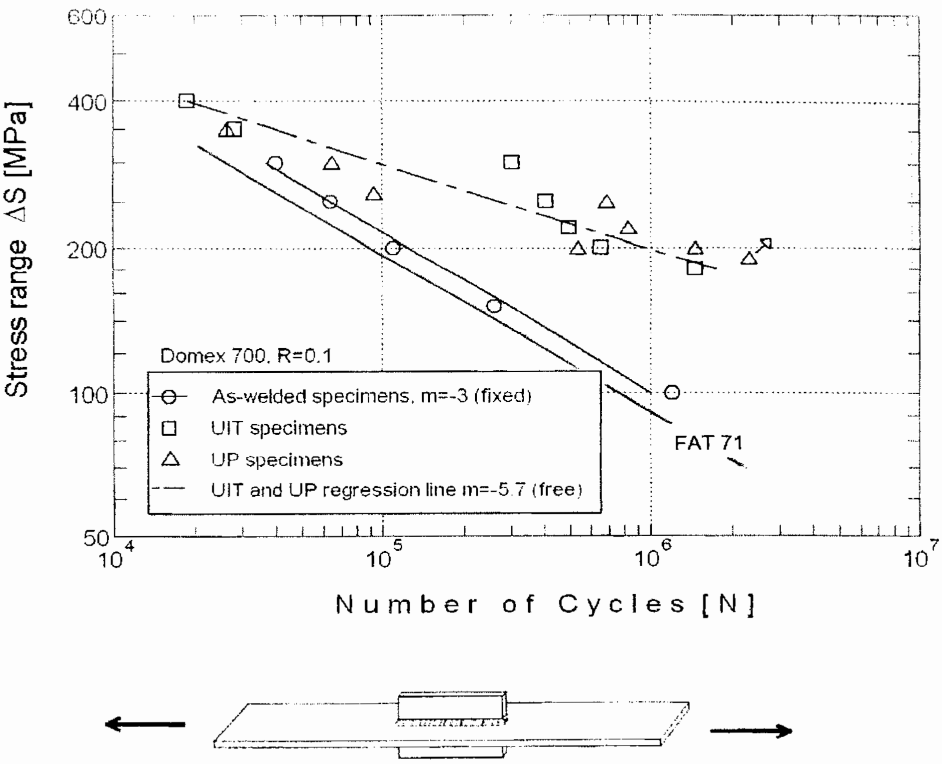
The slope of the curve for the fatigue test results for treated specimens in Fig. 5 (Class F2) shows almost the same change in the slope as for the treated specimens Fig. 4 (Class F). The change in the slope of the SN-curves origins as the residual stress is redistributed (or relaxed) due to the ultrasonic peening treatment.

Without going into discrepancies about how much or how deep the residual stress field is modified by the ultrasonic peening treatment, it is a well accepted fact that the change of slope in the SN-curves indicates redistribution of weld induced residual stresses.

ASSESSMENT OF FATIGUE LIFE IMPROVEMENT FOR THE RELEVANT WELDS

Detail FEA calculations have been used to obtain information about the values of the principal stresses at the relevant weld toes in the FPSO installation. The principal stresses directions have been selected perpendicular to crack grow direction.

FEA calculated principal stresses have been correlated to the relevant σ_R in the SN-Diagram in Fig. 4. As a result the life extension has been predicted using the Class F Design Curve for treated welds and σ_R obtained from the principal stresses located at the high stressed areas.



Specimen for fatigue testing: specimen contains residual stress of yield stress magnitude.

Fig 5 Fatigue test results and fatigue class F2 specimen

All the fatigue tests were carried out at the fatigue test laboratory of NTNU in Trondheim in Norway under the supervision of Prof. Haagensen. The analysis of fatigue test data has been independently carried out at the same laboratory.

WELD QUALITY

The predicted level of improvement assumes the crack will start at the weld toe and grow from it until failure occurs. Thus, we assume full penetration welds joining the brackets against the deck plate. Normally this needs to be established against previous NDT procedure results before ultrasonic peening treatment is applied. Although this could satisfactory be verified the weld geometry and shape will determine the weld quality and hence its endurance.

Influence of multi-passes

When dealing with multi-pass welds it is crucial to ensure that weld toes located in between the weld passes do not constitute alternative stress raisers after the weld toe (bracket and deck plate) has been improved. Inter-pass weld toes in the vicinity of weld and deck plate are particularly sensitive for this 2nd link effect. To prevent this 2nd effect, the ultrasonic peening treatment has been also applied to weld toes located in between the weld passes see Fig. 6.

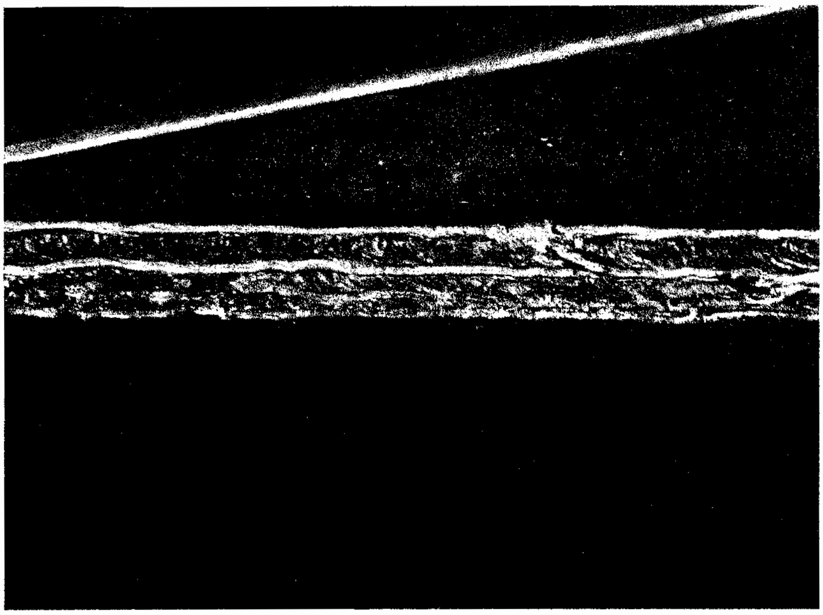


Fig. 6 Treatment of inter-pass weld toe and weld spatter

Weld profile

The number of weld passes influences the fatigue strength by influencing, increasing or decreasing, the sharpness of the transition of weld and deck plate. The steeper the weld profile, the highest the geometrical stress concentration will be. As an example a weld profile showing an angle of 83°, will give a stress concentration factor of 6-7.5 or even higher whereas a 45° angle will normally give a geometrical stress concentration of 3.5 to 5. As a result the number of weld passes does have a relation to the stress concentration and hence a rather high influence on the fatigue strength.

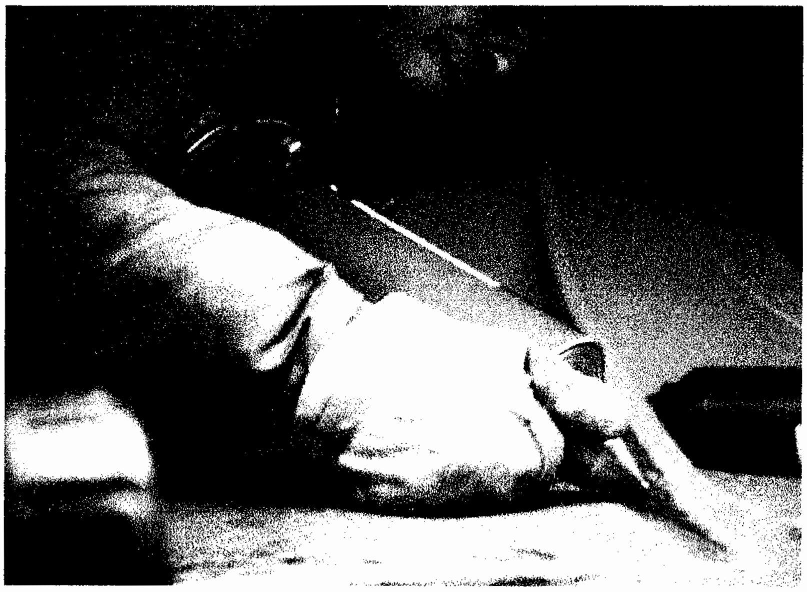


Fig 7 Ultrasonic Peening treatment of weld

Influence of Weld Spatter

Weld spatter could act as an effective stress raiser if located close to a treated weld toe. As a result it is necessary to remove the weld spatter and to treat the location in order to ensure the site will not represent a potential fatigue crack spot. Every effort has been devoted to remove weld spatter from the treated welds although it is an extremely time consuming operation. The treated welds presented in Fig. 8 and in Fig. 9 shows spatter free weld reinforcements.

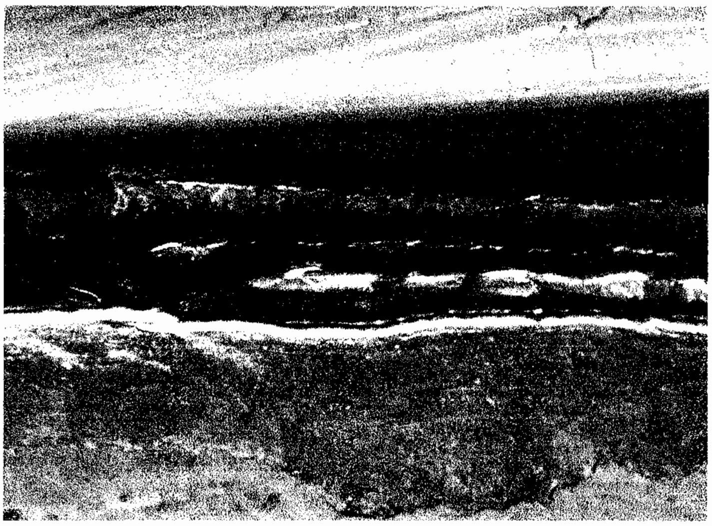


Fig 8 Ultrasonic Peening Treatment of multi-pass weld toe

QUALITY ASSURANCE AND QUALITY CONTROL

The Ultrasonic Peening Procedure Specification, produced for every treated weld, assures that the treatment is applied exactly in the same way as when it produced life extension in laboratory experiments. Furthermore this specification assures that the treatment applied at different locations in the vessel will be exactly reproduced.

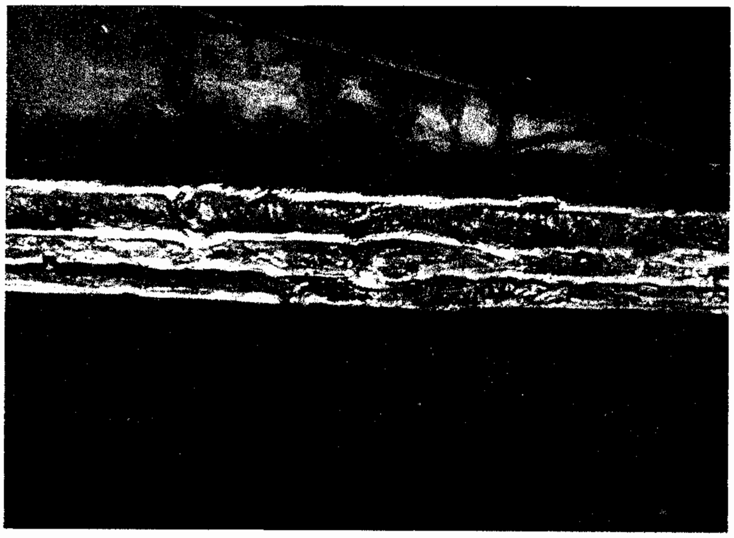


Fig 9 Treatment of weld spatter, multi-pass weld toe and start/stop locations.

CONCLUSIONS

Preload influence on improvement
It has been demonstrated that the application of preloads to the treated weldments previous to fatigue testing does not decrease the degree of improvement. The preload sequence was designed to be the most severe load case for the weld.

Degree of life extension achieved Class F detail
The degree of improvement is 2 times in life for high stress ranges, σ_R=300 MPa. For lower stress ranges, σ_R=140 MPa, the degree of improvement is 12 times in life. The improvement is calculated as the difference between Design curves for treated weldments and FAT 71.

Degree of life extension achieved Class F2 detail
The degree of improvement at $2 \cdot 10^6$ cycles in stress is 2.25 times. From σ_R=80 MPa in as-welded condition up to σ_R=180 MPa for the ultrasonic peened specimens. The improvement is calculated as the difference between mean SN-curves for as-welded respective treated specimens.

Degree of life extension predicted for pallet stool welds
The life extension expected for the ultrasonic peening treated welds on the installation is not less than five times in life. According to the previous fatigue life assessment this life extension will bring the service life up to the design requirement which is twenty years.

The predicted life extension for the pallet support stools welds is well within previous extensive test results of improved welds with the same technology.

It is important to note that the predicted improvement assumes the crack will start in all cases at the weld toe and grow from it until failure occurs. We assume full penetration welds joining the brackets against the deck plate.

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