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# LIFE EXTENSION of CLASS F and Class F2 DETAILS USING ULTRASONIC PEENING

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**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.

## THE ULTRASONIC PEENING TREATMENT

### *How the ultrasonic peening works*

The causes for the beneficial effect of ultrasonic peening in weldments can be summarized as follows:

- Crack-like flaws are effectively removed from weld toe zone introducing a fatigue crack initiation phase in the fatigue crack grow process. The total fatigue life, $N_{Total}$ ,of an untreated weld consists mostly of crack propagation i.e., the number of cycles for the crack to propagate from weld defects to failure. For a treated weld the total fatigue life is extended by the number of cycles it takes for the fatigue crack to initiate. The total fatigue life for a treated weld can theoretically be expressed as: $N_{Total} = N_{Initiation} + N_{Propagation}$ .

- Local stress concentration is reduced by the introduction of a weld toe groove at the weld toe.
- Relaxation or redistribution of tensile residual stresses to depth down to 12 mm as well as creation of compressive residual stresses to depths down to three mm. The exposure of HAZ to the ultrasonic oscillations simultaneously with the peening, causes the residual stresses at weld toe both to relax the tensile stresses and introduce compressive stresses, which positively contribute to extend the fatigue life of the weld.

### *The application of ultrasonic peening*

The ultrasonic peening treatment normally starts by treating the weld toe itself with a 3 mm diameter pin, tip radii of 1.5 mm, see Fig. 2. This operation will ensure that the crack-like flaws are effectively removed and the fatigue crack will need to start to grow on more or less plain material. By that we effectively introduce an initiation period in the weld joint.

This procedure would need to be applied even in welds toes produced in multi-pass welds in order to avoid adjacent stress raisers to the conventional weld toe, weld toe at parent plate location.

After the weld toe has been treated with a three mm pin diameter a four mm pin diameter is used. The weld toe groove created with this latest pin diameter give a smooth transition between weld and parent plate. As a result the geometrical stress concentration will be significantly reduced. This reduction in the geometrical stress concentration is optimal if all traces of the three mm pin are completely removed and the general weld toe groove shows a depth of 0.5-1.0 mm and a width of 2-4 mm. The geometrical weld parameters resulting from the ultrasonic peening treatment are documented in the ultrasonic peening procedure specification, see Fig. 8. This document which is produced for every treated weld, gives the possibility to check the weld its treatment and performance during subsequent inspections.

## 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 stress 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.

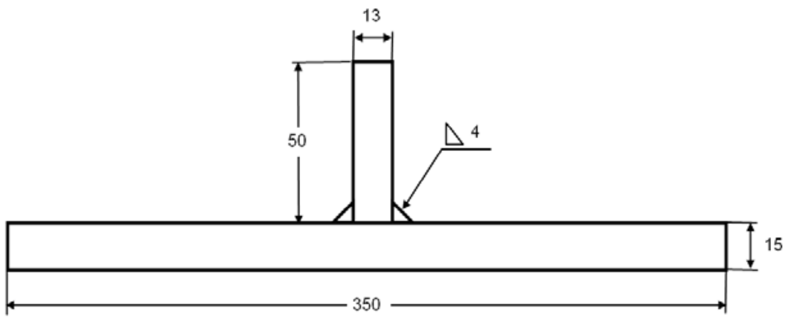


Fig 1 Fatigue test specimen Class F

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 pre-loading sequence was established in cooperation with DNV. The intention is to simulate overloading conditions during service which could produce local plasticity at the weld toe in compression and thereby relax residual stresses.

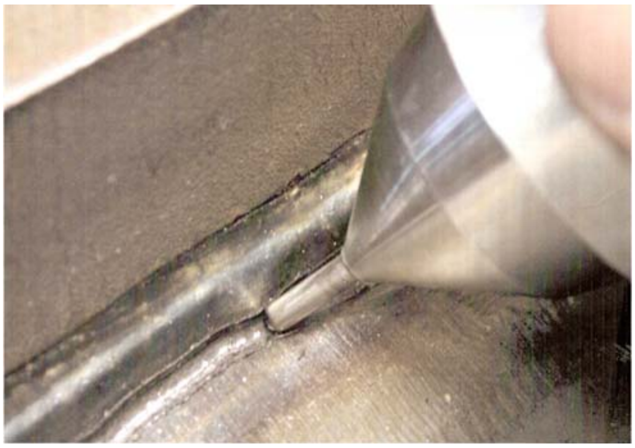

Fig 2 Ultrasonic Peening treatment of Class F fatigue test specimen

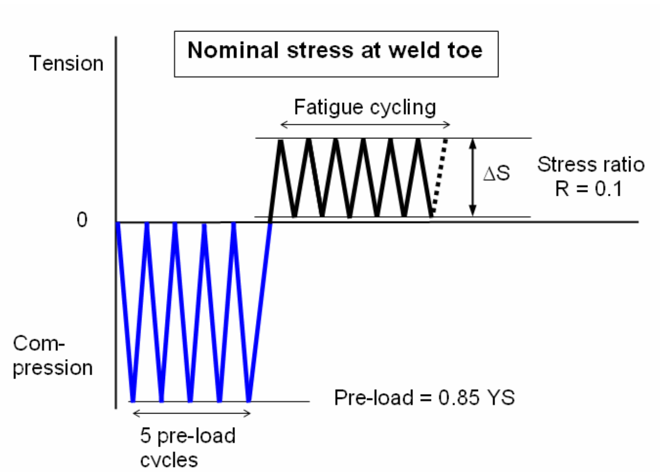


Fig 3 Pre-loading sequence performed applied prior to fatigue testing.

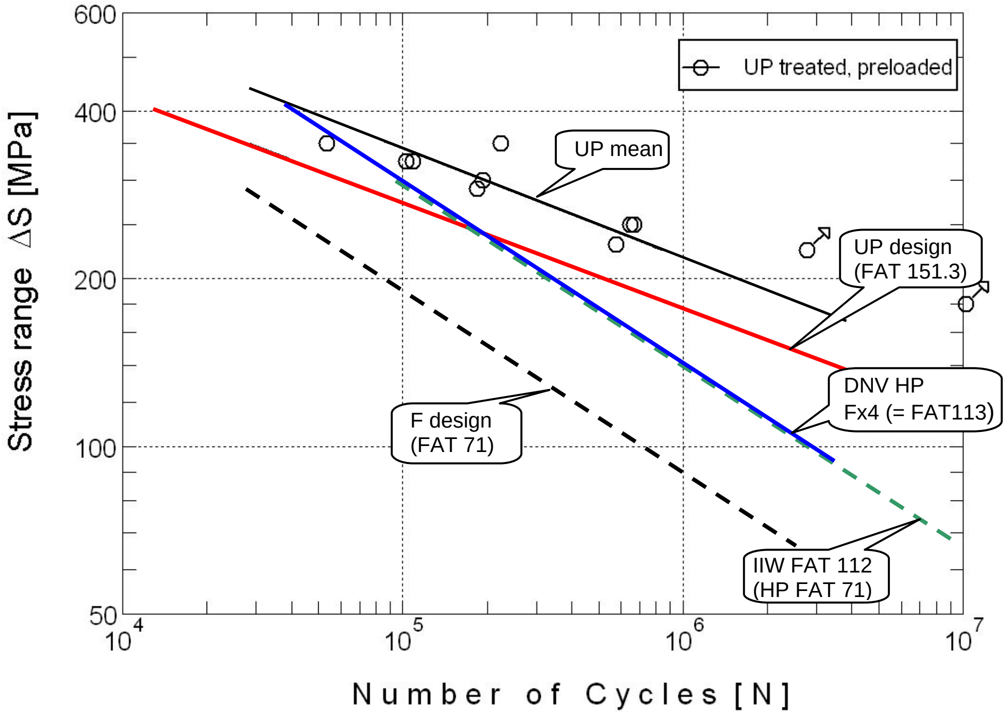


Fig 4 Fatigue test results for Class F

***Discussion of test results.***

All comparisons have been done against mean-curve minus two standard deviations calculated on fatigue test results. Fatigue testing was performed in four-point bending. The stress ratio R = $\sigma_{min}/\sigma_{max}$ of 0.1 was used for all tests.

***UP design***

This is the mean minus 2 st. dev. curve derived from the test data. The FAT value for this curve is 151.3 MPa. (Free slope m=5.1, C = $2.207 \cdot 10^{17}$)

**DNV HP Fx4**

This is the DNV design curve for hammer peened F-class joints, i.e. a factor of 4 on life.

***IIW FAT 112 ((HP FAT 71)***

This is the 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.

### *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 with 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.

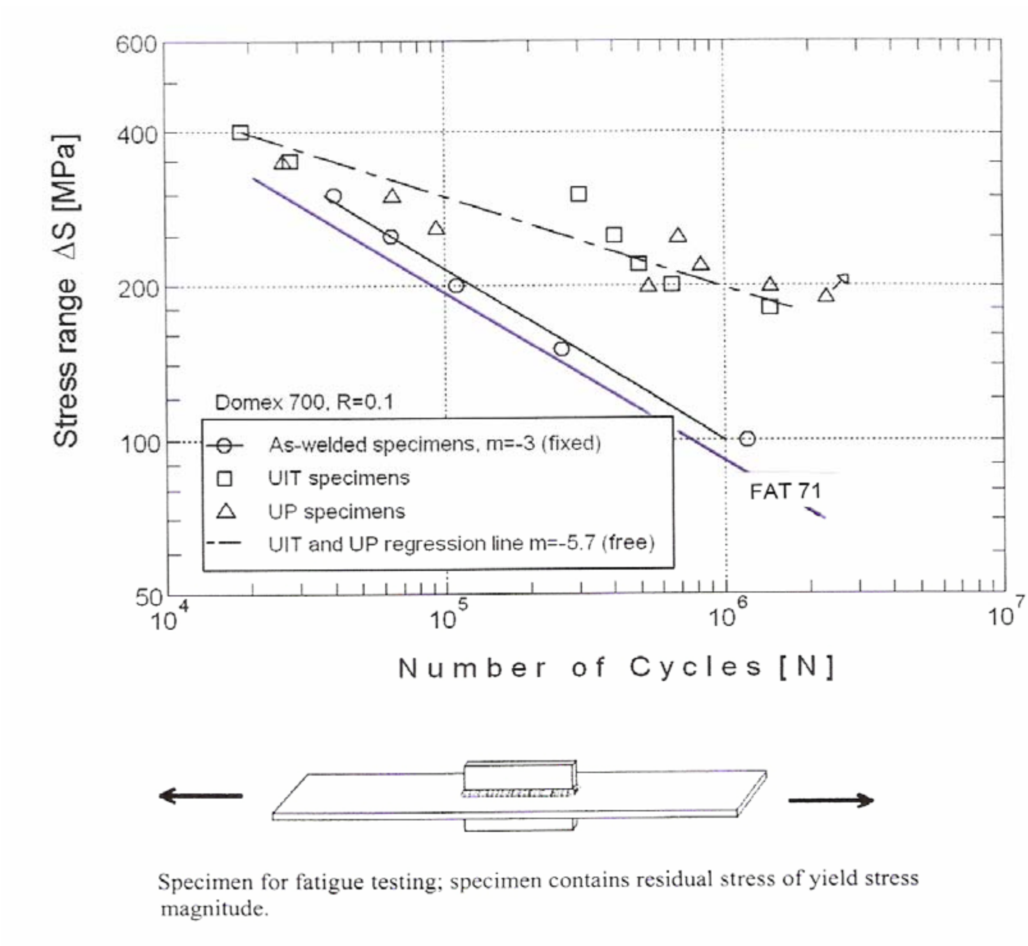


Fig 5. Fatigue test results and fatigue class F2 specimen

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 PROCEDURE SPECIFICATION and 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.

## FACTORS INFLUENCING THE RESULTS OF ULTRASONIC PEENING

### *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 main weld toe has been improved. Inter-pass weld toes in the vicinity of weld and parent plate are particularly sensitive for this 2$^{nd}$ link effect. To prevent this 2$^{nd}$ 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 parent 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$^{o}$ , will give a stress concentration factor of 6-7.5 or even higher whereas a 45$^{o}$ 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.

### *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 must be devoted to remove weld spatter from the treated welds although it is an extremely time consuming operation. The treated welds presented in Fig. 7 and in Fig. 9 shows spatter free weld reinforcements.

Fig 7 Ultrasonic Peening Treatment of multi-pass weld toe

## QUALITY ASSURANCE AND QUALITY CONTROL

The Ultrasonic Peening Procedure Specification, see Fig 8 is created for every treated weld and 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 a structure will be exactly reproduced.

| ***LETS-Engineering BV*** | | | | |
|---|---|---|---|---|
| **Ultrasonic Peening Procedure Specification** | | | | |
| **Welding Specification** | | **Weld joint identification** | | |
| Parent plate | | Type | | |
| Thickness | | Location | | |
| Filler metal | | Identification | | |
| Consumables | | UPPS-Number | | |
| Welding Proc Nr | | Rev. | | |
| **Equipment** | | Date | | |
| Make and Model | | **Photo of treated welded joint** | | |
| Power [kW] | | | | |
| Tip diam. [mm] | | | | |
| Weight [kg] | | | | |
| Impact frequency | | | | |
| Impact amplitude | | | | |
| Ultrasonic freq. | | | | |
| **Treatment data** | | | | |
| Position | | | | |
| Work angle side | | | | |
| Work angle ahead | | | | |
| Travel speed | | | | |
| Number of passes | | | | |
| Treated length | | | | |
| Time of treatment | | | | |
| Tool changes | | | | |
| Cause | | | | |
| **Operator** | | | | |
| Name | | | | |
| Experience [hrs] | | | | |
| Treated length | | **Remarks** | | |
| Date of treatment | | | | |
| **Inspection** | | | | |
| Visual | | | | |
| Photo | | | | |
| Measurement | | | | |
| Equipment | | | | |
| **Results** | | | | |
| Toe radius [mm] | | | | |
| Weld angle [deg] | | | | |
| Groovedepth[mm] | | | | |
| Groovewidth[mm] | | | | |
| **Approvals** | | | | |
| | **Contractor** | **Client** | **Survey Autho.** | |
| Name | | | | |
| Date | | | | |
| Responsible | | | | |
| Signature | | | | |

Fig 8 Ultrasonic Peening Procedure Specification

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 significantly. The preload sequence was designed to be the most severe load case for the weld.

### *Degree of life extension achieved for Class F detail*

The degree of improvement is 2 times in life for high stress ranges, $\sigma_R$ =300 MPa. For lower stress ranges, $\sigma_R$ = 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 $\sigma_R$ = 80 MPa in as-welded condition up to $\sigma_R$ =180 MPa for the ultrasonic peened specimens. The improvement is calculated as the difference between mean SN-curves for as-welded respective treated specimens.

## REFERENCES


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