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Introductory fatigue tests on welded joints in high strength steel and aluminium improved by various methods including ultrasonic impact treatment (UIT).

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Abstract

This paper summarizes fatigue test on high strength steel specimens in the as-welded condition and specimens treated by ultrasonic impact treatment, TIG dressing and a combination of TIG dressing and ultrasonic impact treatment. Single lap joint specimens in 6 mm aluminium plate material were tested in the as-welded, hammer peened, needle peened and ground condition. Aluminium joints with longitudinal stiffeners in 8 mm plate were tested in the as-welded condition improved by ultrasonic impact treatment (UIT). Increases in fatigue strength at a life of 2 million cycles ranged from a negative influence for hammer peening of 6 mm aluminium lap joints to approximately 135 % for high strength steel specimens treated by TIG dressing plus UIT.

Introduction

Ultrasonic Impact Treatment (UIT) is a proprietary technology developed originally in the Soviet Union for use on naval ships to reduce welding stresses and deformations and introduce compressive stresses [1]. Further developments were made by Northern Scientific & Technological Company (NSTC) in Russia. Other peening techniques, e.g. hammer and needle peening, operate at relatively low frequencies, typically in the range 50 to 100 Hz, causing the tool to move in an unsteady manner, necessitating considerable effort to keep the tool aligned on the weld toe line. The high levels of vibration and noise make the peening methods uncomfortable, and prolonged use may pose health risks to the operator, similar to other tools with high vibration levels. In contrast the UIT method operates at a very high frequency, approximately 27 kHz, and the noise and vibration is much lower. The ease of use of the UIT method may result in considerable benefits in terms of quality of the treatment compared with conventional peening methods. The tests described below were undertaken to assess the potential benefits of the UIT method in terms of increased fatigue strength. The tests on welded high strength steels were made as an extension of previous work [2].

Experimental program

Materials

Steel
A high strength steel, Weldox 700, was used. While the minimum specified yield strength (YS) is 700 MPa for this material, the actual yield strength of the specimens was approximately 780 MPa, and the ultimate tensile strength approximately 800 MPa.

Aluminium

The aluminium specimens were fabricated from a typical ship plate material, AA5083 (or AlMg4.5Mn). The minimum specified yield and ultimate tensile strengths were 250 and 335 MPa, respectively, with a ductility of A_5 = 10%. The aluminium plates were supplied in 6 and 8 mm thickness.

Specimen

The steel specimen is shown in Fig. 1. This specimen has been used in a many investigations and consequently a large database is available for comparisons.

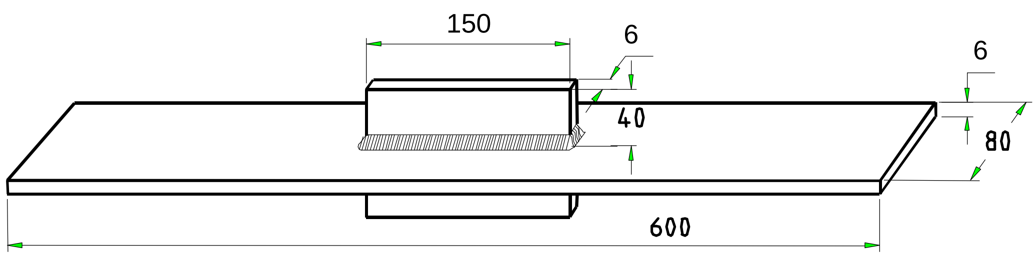


Fig. 1 Fatigue test specimen

Two basic types of aluminium specimens were tested. One is a lap type specimen shown in Fig. 2. Specimens of this type were made from two plate thickness, 6 and 8 mm as indicated in Fig. 2.

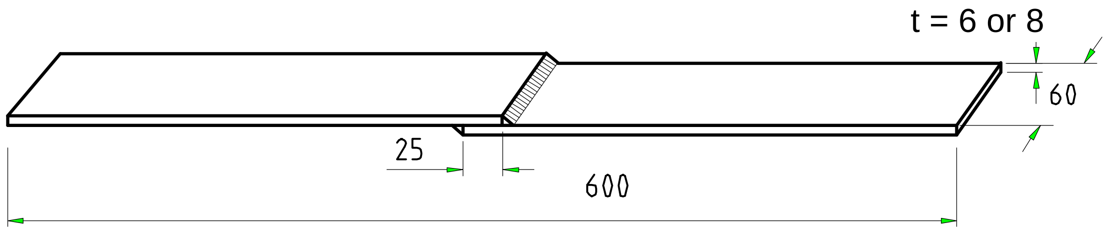


Fig. 2 Aluminium lap joint fatigue test specimen

The second type of aluminium specimen shown in Fig. 3 was similar to the steel specimens but made from 8 mm plate.

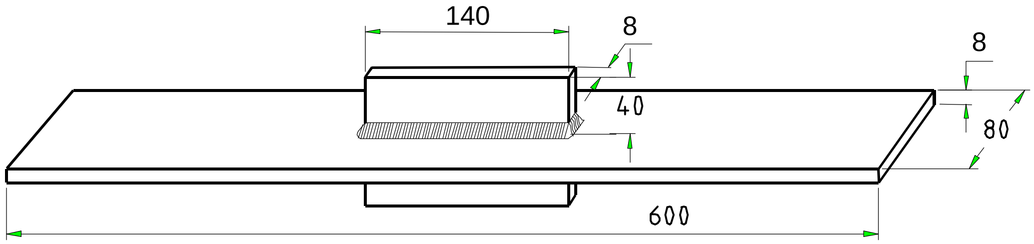
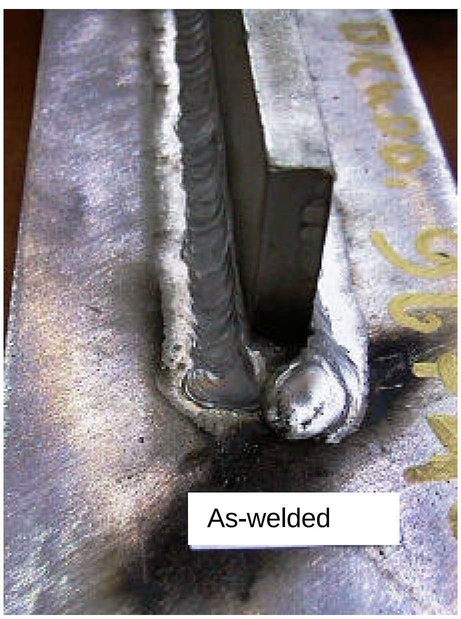


Fig. 2 Aluminium specimen with longitudinal stiffeners.

The specimens were fillet welded using standard shop practice, the aluminium specimens at Kvæ rner Fjellstrand shipyard, the steel specimens at SSAB in Oxelösund. The ultrasonic impact treatment was performed at Kvant in Severodvinsk according to standard practice as described in Ref. 3. The welds of the steel specimens were of normal quality for this type of weld, with a relatively smooth transition between weld and plate. The welded aluminium lap joints also had good quality welds. The aluminium specimens with longitudinal attachments, however, were weld at high production rates and had welds of poor quality at the ends of the attachments. A typical example is shown in Fig. 4a. Ultrasonic impact treatment, however improved the shape of the end of the weld considerably, as illustrated in Fig. 4b.

Some steel specimens were TIG dressed prior to ultrasonic impact treatment. The TIG dressing procedures are described in Ref. 1.



(a)

(b)

Fig. 4 Typical weld shapes of aluminium specimens with attachments; a) as-welded; weld toe improved by ultrasonic impact treatment.

Test conditions

All tests were made under laboratory air conditions in NTNU's civil engineering laboratory.

All specimens were tested in axial loading, constant amplitude at R = 0.1 The test frequency was in the range 3 to 10 Hz.
Failure was defined to have taken place upon complete separation of the specimen.

Results and discussion.

Steel specimens

Three types of fatigue failures occurred in the tests on steel specimens improved by UIT or the combined treatment of TIG dressing and UIT. In the majority of tests the normal failure mode was cracking from the weld toe. However, some failures initiated on the plate, away from the weld, an example is shown in Fig. 5

Fig. 5 Example of fracture in plate away from the weld, in specimen treated by TIG dressing plus ultrasonic impact treatment.

In another type of failure the crack initiated at the root of the weld at the end of the attachment, see Fig. 6.

Fig. 6 Example of failure initiating at the root of the fillet weld in specimen treated by TIG dressing plus ultrasonic impact treatment.

A standard linear regression analysis was carried out; the results are listed in Table 1 below.

Table 1. **High strength steel, data from statistical analysis, regression model** $NS^m = C$

S-N curve	Slope *m*	Intercept *C*	Standard deviation *s*	Stress range (MPa) at N = 2 mill. cycles	Improvement at N = 2 mill. cycles (percent)
AW (for t = 6mm, from ref. 1)	3.02	1.39×10^{12}	-	86	-
Ultrasonic impact treatment (UIT)	6.54	1.66×10^{21}	0.452	190	121
TIG dressing	3.05	5.93×10^{12}	0.397	132	53
TIG + UIT	5.14	1.45×10^{18}	0.133	202	135

The test results are plotted in S-N diagrams with logarithmic axes, with mean life lines obtained by linear regression analyses. A few as-welded specimens were tested at NTNU to enable a comparison with the previous tests [1]. The results are shown in the S-N diagram Fig. 7, Also shown is the reference mean line obtained for similar specimens in 350 MPa yield strength steel [1]. This line is almost identical to the F2 mean curve.

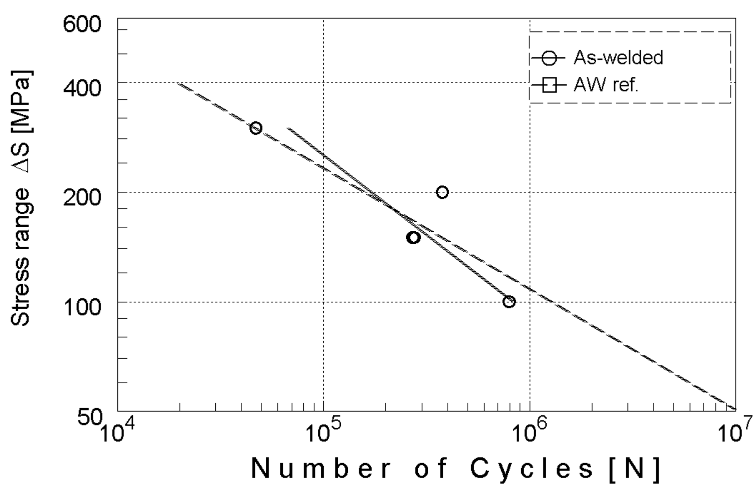


Fig. 7. Comparison of as-welded tests at NTNU with reference data [1].

With just four specimens tested the agreement between the two test series is good. The results from tests on improved specimens are shown in Fig, 8. together with the data for the untreated specimens.

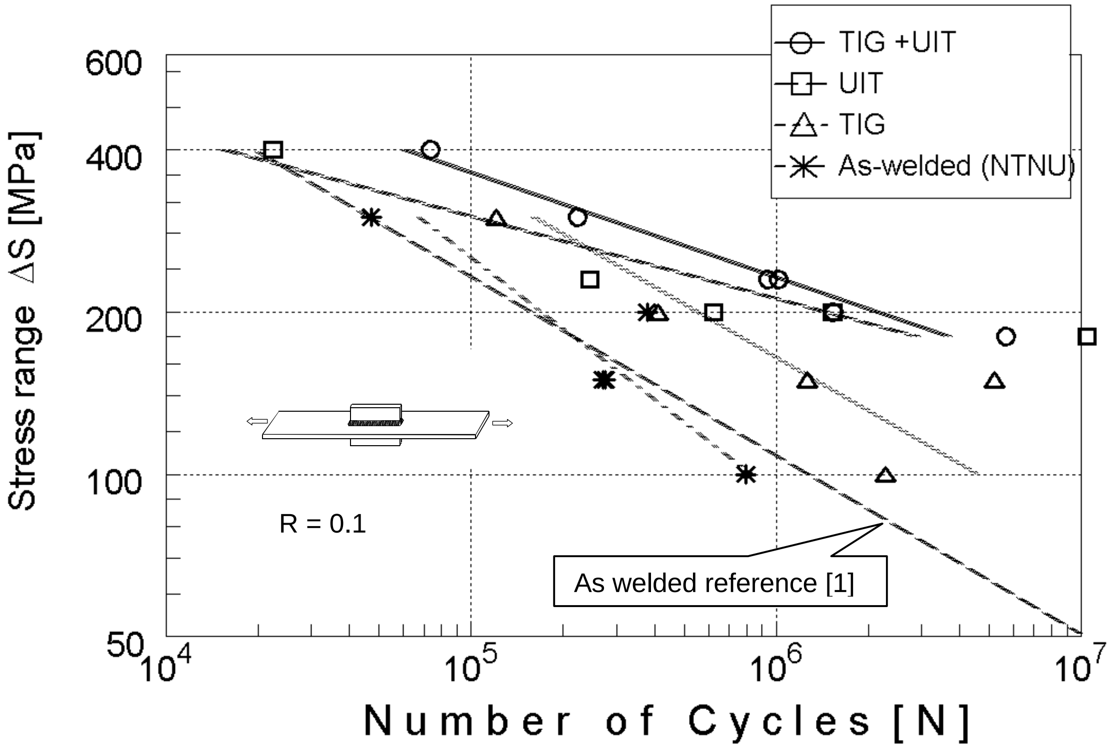


Fig. 8 Results from test on high strength steel specimens in the as-welded and improved conditions.

The results indicate that there is some difference between specimens treated by ultrasonic impact treatment alone and specimens treated by TIG dressing followed by in TIG dressing. But in the long life region the difference is small and probably not statistically significant.

Aluminium specimens

Specimens with longitudinal attachments

Results from the regression analysis are plotted in Table2.

The test results for as-welded and specimens improved by ultrasonic impact treatment are plotted in Fig. 9. Although the untreated weld had a very unfavorable shape at the stiffener ends the S-N curve for improved weld is quite high. Two of the specimens treated by ultrasonic impact treatment failed outside the weld, the cracks initiated at small defects on the plate. The improvement in fatigue strength at two million cycles is more than 90 %, corresponding to a factor on life of 20 over the entire range of the data.

Table 1. **Data from statistical analysis, aluminum specimens with longitudinal stiffeners, regression model** $NS^m = C$

S-N curve	Slope *m*	Intercept *C*	Standard deviation *s*	Stress range (MPa) at N = 2 mill. cycles	Improvement at N = 2 mill. cycles (percent)
As-weld	4.48	1.59×10^{13}	0.387	35	-
Ultrasonic impact treatment (UIT)	4.48	3.26×10^{14}	0.345	68	94

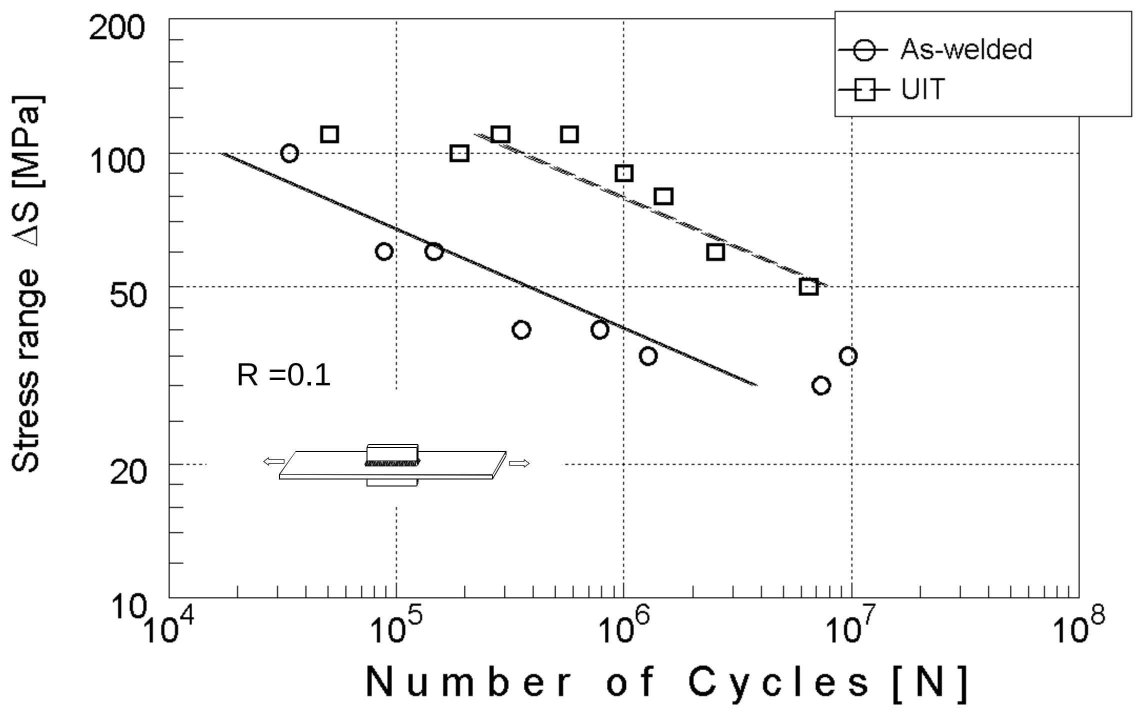


Fig. 9 Results on aluminium specimens in the as-welded and UIT improved conditions.

Single lap joint specimens, 6 mm plate thickness

The 6 mm lap joint were tested in as-welded, needle peened, hammer peened and ground conditions.

The test results from single lap joints in 6 mm plate are shown in Fig. 10

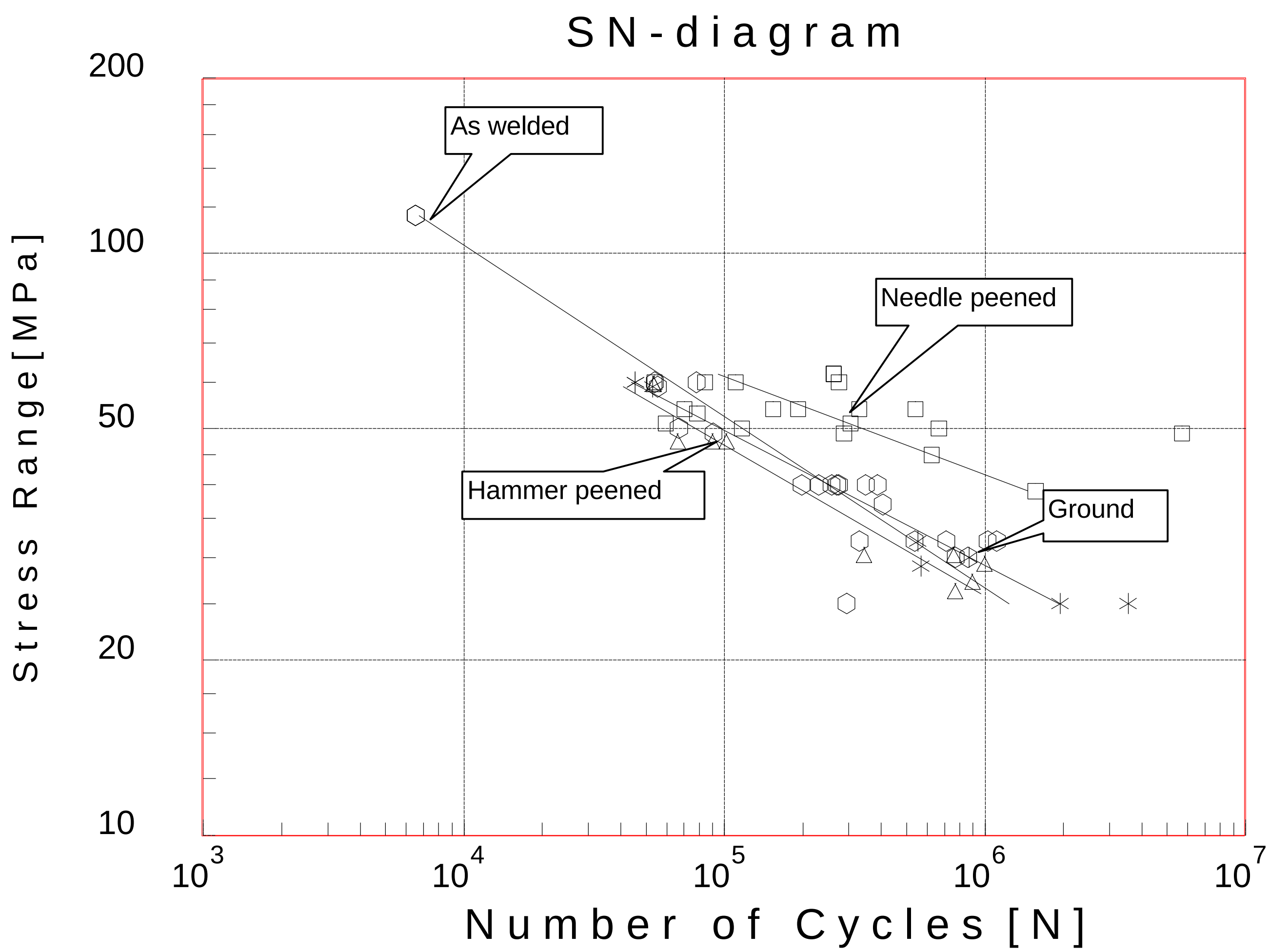


Fig.10 Results from tests on 6 mm lap joints with different weld treatments.

It is evident from Fig 10 that only needle peening gives a significant improvement in fatigue strength.

Since the results in Fig 10 are limited to a fairly narrow range of fatigue lives the slope of the S-N curves is somewhat uncertain, and the data were re-analyzed with a forced slope of m = 4.0 for all curves. In Fig 11 the S-N curves are re-plotted with a slope of m = 4.0 and without the data points.

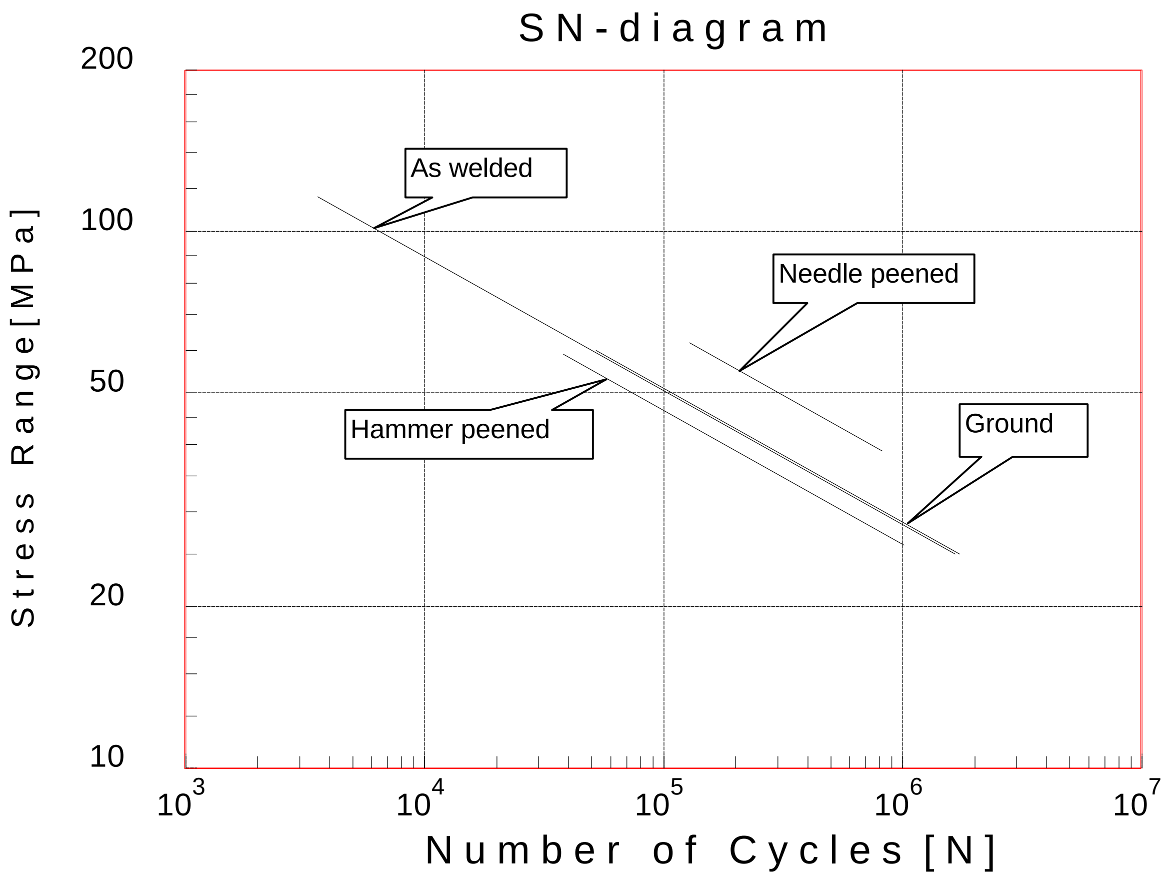


Fig.11 Mean line results from tests on 6 mm lap joints with different weld treatments; slope fixed at 4.0.

The results from the statistical analysis are given in Table 3.

Table 3: Details from statistical analysis, regression model $NS^m = C$. p Plate thickness 6 mm.

SN-curve	Slope m	Intercept C ($*10^{10}$)	Standard deviation s	Stress range at $N=2*10^6$ (MPa)	Strength improvement (percent) at $N=2*10^6$
As-welded, 6 mm.	3.40	6.91×10^{10}	0.203	21.7	-
Needle peened	5.90	359000	0.444	37.0	70.5
Hammer peened	3.86	2.77×10^{11}	0.149	21.5	-1.0
Ground	4.32	2.09×10^{12}	0.169	24.8	14.3
As-welded, 6 mm, fixed slope	4.0	6.48×10^{11}	0.217	23.9	-
Needle peened, fixed slope	4.0	1.90×10^{12}	0.441	31.2	30.5
Hammer peened, fixed slope	4.0	4.62×10^{11}	0.141	21.9	-8.3
Ground, fixed slope	4.0	6.77×10^{11}	0.163	24.1	1
As-welded, 6 mm, two points left out	*4.04*	*7.79×10^{11}*	*0.138*	*24.3*	-

It is interesting to note that while needle peening gives approximately 70 % increase in fatigue strength, weld toe hammer peening of 6 mm plates actually seems to give a reduction in fatigue strength whereas weld toe grinding gives no effect.

Single lap joint specimens, 8 mm plate thickness

The test results for 8 mm lap joints are presented in Fig. 12. These joint were tested in the as-welded condition or improved by ultrasonic impact treatment. Regression data are given in Table 4.

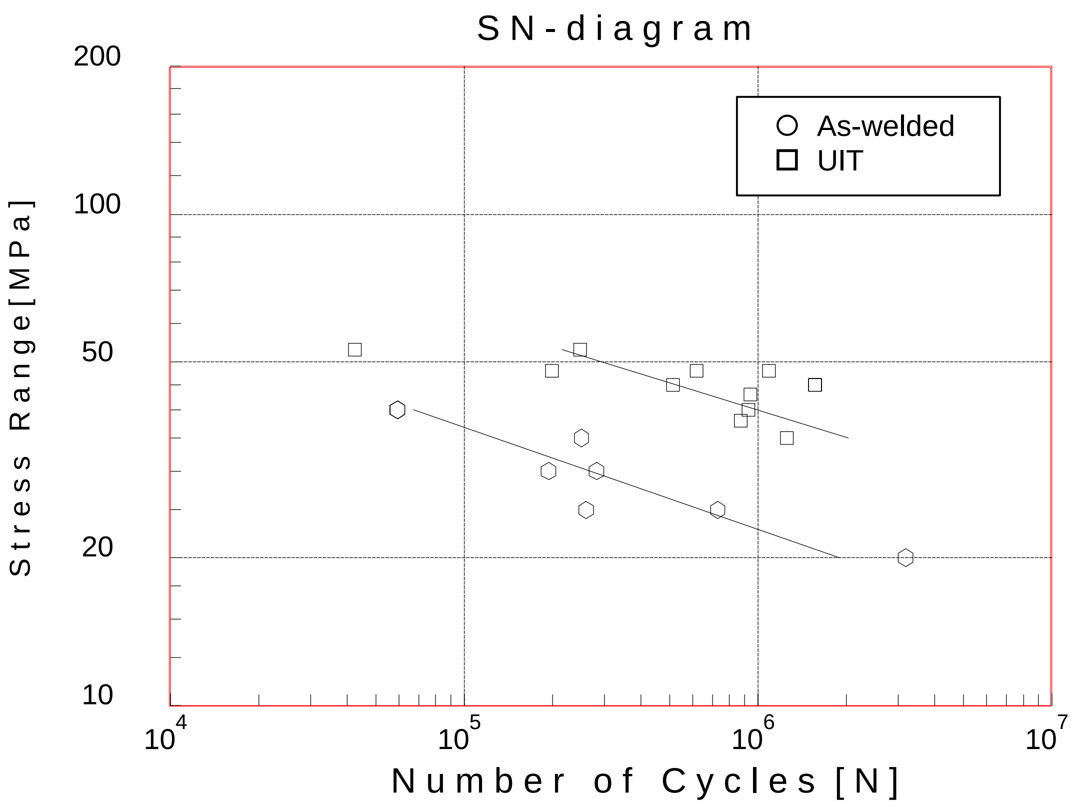


Fig.12 RS-N data for as-welded and ap joints with different weld treatments.

Table 4: Details from statistical analysis, regression model $NS^m = C$

SN-curve	Slope m	Intercept C ($*10^{10}$)	Standard deviation s	Stress range at $N=2*10^6$ (MPa)	Strength improvement (percent)
AW	4.81	3.43×10^{12}	0.253	19.8	-
UIT	5.40	4.37×10^{14}	0.360	35.1	77

The improvement due to ultrasonic impact treatment is somewhat lower than for the aluminium specimens with longitudinal attachments. The reason is probably that the as-weld S-N curve is quite high so further improvement is not possible. This assumption is substantiated by the fact that several failures initiated on the plate; an example is shown in Fig. 13.

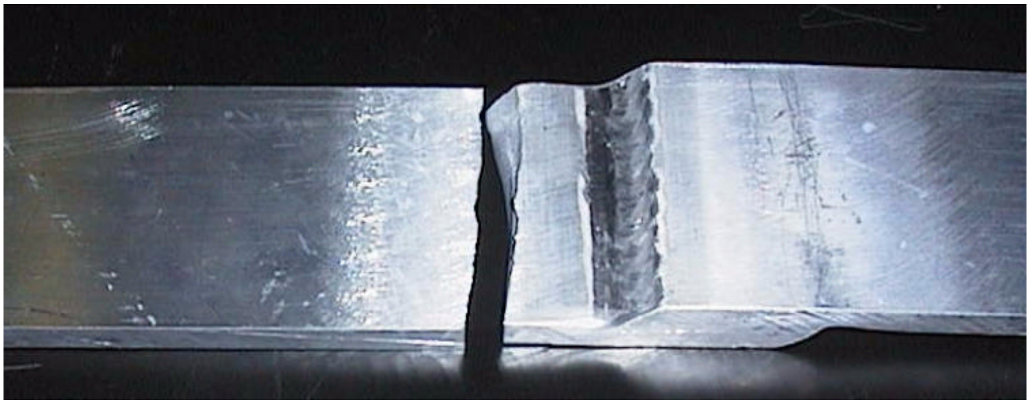


Fig.13 Example of plate failure for lap improved by ultrasonic impact treatment, crack initiated at grinding marks.

Conclusions

Based on a limited number of tests in this investigation the following tentative conclusions are drawn:

1. Ultrasonic impact treatment (UIT) gives consistently large increases in fatigue strength, particularly at long lives, for welded high strength steel specimens as well as for welded AA5083 aluminium plates.

2. The improvements in fatigue strength at long lives due to UIT varied from about 120 % for high strength steel specimens to about 80 % for aluminium 8 mm lap joint and aluminium specimens similar to the steel specimens.

3. Weld toe grinding of 6 mm lap joints gave no improvement whereas needle peening resulted in an improvement of approximately 70 %. Hammer peening reduced the fatigue strength by 8 %.

4. The combined treatment of TIG dressing followed by ultrasonic impact treatment gave the highest improvement in fatigue strength at 2 mill. cycles of 135 % for steel specimens.

Acknowledgement

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References

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2. M. Lopez-Martinez et al., *Fatigue behaviour of steels with strength levels beteen 350 and 900 MPa. - Influence of post-weld treatments under spectrum loading.* Paper D in *Fatigue Behaviour of Welded High-Strength Steels,* Report No. 97-30, Royal Institute of Technology, Stockholm, Oct. 1997.

3. E. Statnikov et al., Specifications for weld improvement by ultrasonic impact treatment. IIW Doc XIII-1617-96.