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Overview of residual stress measurement and fatigue test data for Pneumatic Impact Treated (PIT) joints

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Abstract

Pneumatic Impact Treatment (PIT) as High Frequency Mechanical Impact (HFMI) Treatment technique combines the three basic beneficial effects – improved weld toe topography, compressive residual stress state, and work-hardening of the surface-layer material within the post-treated area – leading to a significant enhancement of the fatigue performance of welded structures.
This paper provides an overview of residual stress measurement and fatigue test data for PIT-treated joints to present the current state of investigation and to proof the industrial applicability of this method. The fatigue test results are compared to the actual proposals for the fatigue assessment of HFMI-treated joints considering the base material yield strength and structural weld detail. Thereby, all performed comparisons illustrate that the PIT-treated joints exceed the proposed fatigue strength values, whereby an assessment of PIT-treated structures on the basis of the proposed values is recommended.

Keywords: Fatigue strength, High frequency mechanical impact (HFMI), Pneumatic impact treatment (PIT), High-strength steel joints, Fatigue test results

1 Introduction

The PIT method is a pneumatically operated, high-frequency peening method, which was developed for the post-weld treatment of seams and highly loaded non-welded areas of componenty. Both, the processing frequency, as well as the impact intensity can be adjusted independently, thereby making it possible to meet the different requirements of different materials and weld geometries justice. A pneumatic muscle in the device converts the pressure energy into mechanical impulses, which are transmitted by one or more hardened steel bolts on the surface to be treated.
In order to keep the vibrations during the treatment as low as possible, another spring system is included, so that the hand-held device is completely decoupled. This causes a slight hand vibration in the amount of approximately *5 m / sec²* for the operator and additionally results in a nearly constant impact force, whereby a high reproducibility is ensured.
The feed rate for steel is about *20 cm/min* at a frequency for the steel bolts of up to *80-120 Hz*. Via the compressed air can be the shock intensity adjust infinitely variable, which, unlike other methods, the device is already functional at a pressure of *4 to 6 bar* and therefore has a low air consumption of approximately *175 to 250 l/min*. The Exhaust air vented forward for processing location has the advantage that paint particles, metal chips and other contaminants are blown away and are not inadvertently pressed into the work-piece surface, and the flowing air cools the bolt and thus the service life is significantly increased.

Figure 1: PIT device (hand-held and control unit) and treatment of a test specimen

Compared to other treatment methods, such as grinding, shot-peening or stress-relief, an increase in fatigue strength and service life is usually achieved only by one or two effects of the following - the PIT process combines all three effects:

- Introduction of compressive residual stresses
- Reduction of the geometrical notch stress concentration
- Hardening of the material in the post-treated surface layer

This report provides an overview of residual stress measurement results and a summary of fatigue test data carried out in various institutions.

2 Residual stress measurement results

In addition to strengthening local compressive stresses are introduced which counteract to the fatigue-related loading tension stresses, thereby reducing the overall stress in the highly-stressed zone. For verification of the developing residual stress state through the post-treatment, measurements by means of X-ray diffraction or hole drilling method, as well as an estimate of the local residual stress state in a numerical simulation are possible.
Figure 2 shows a comparison of the residual compressive stresses of UIT and PIT treated surfaces for the material *S700MC*. It is interesting that the values achieved are virtually identical in both the UIT and PIT treated surface. The PIT treated surfaces were treated with different pin radii (*1.5 mm*, *2.0 mm* and *2.5 mm*). The measurements were carried out by the Technical University of Graz.

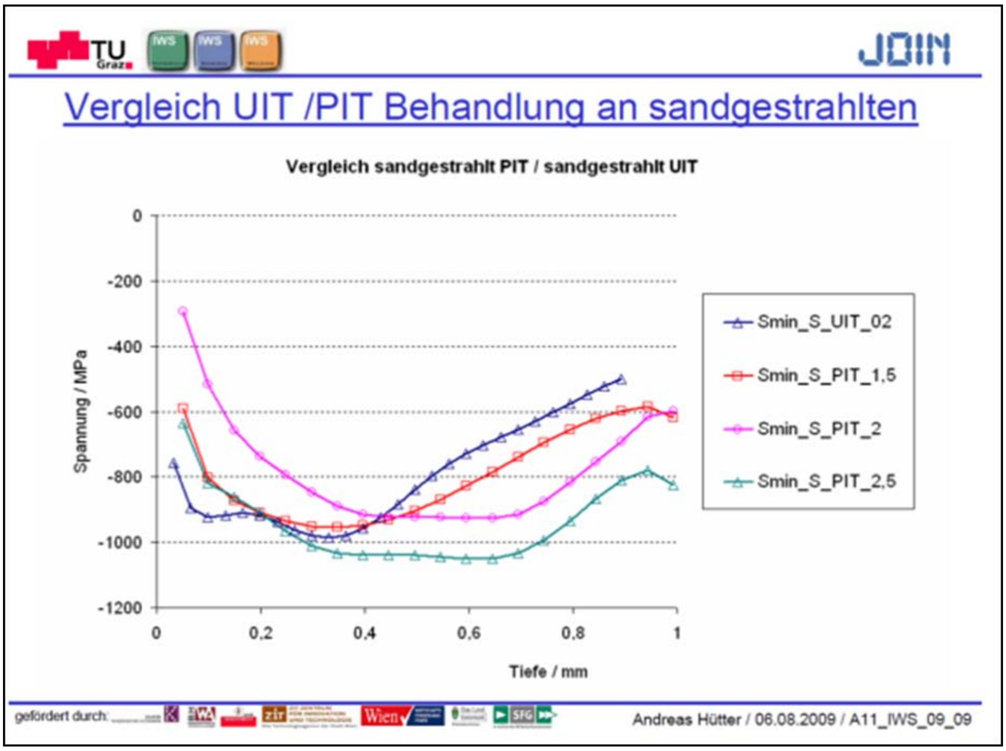

Figure 2: Residual stress measurements: Comparison of UIT and PIT

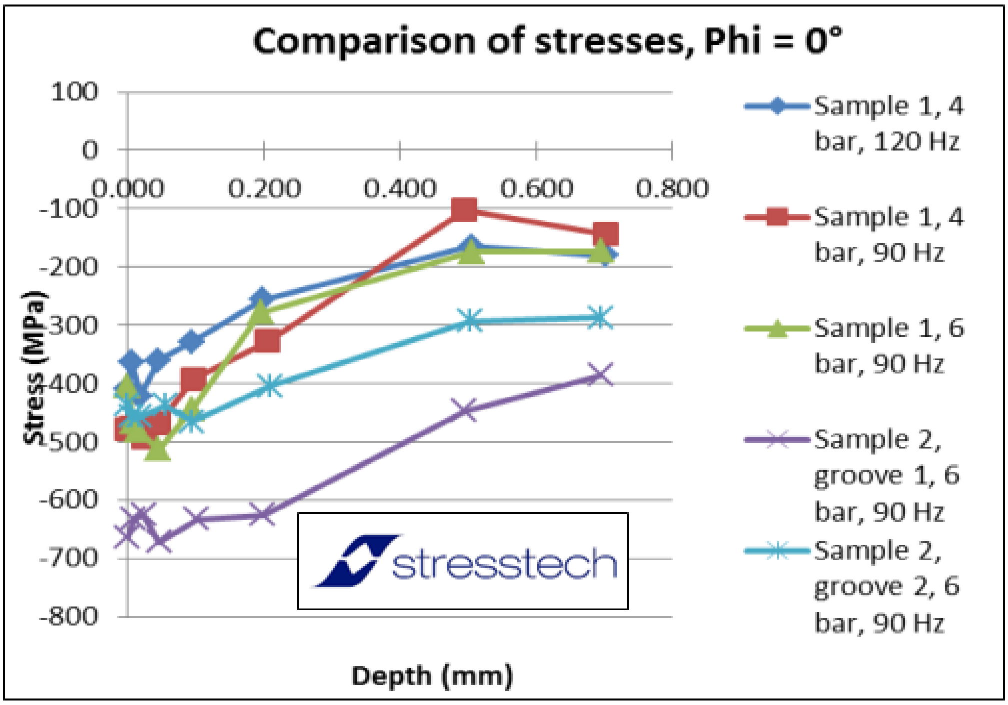

Figure 3: Residual stress measurements: PIT treatment with different parameters

Figure 3 shows a comparison of the residual compressive stresses of PIT treated surfaces with the material *S700MC*. The different curves show the values that have been treated with different parameters PIT namely *4 bar and 120 Hz, 4 bar and 90 Hz, 6 bar and 90 Hz and the root side 6 bar and 90 Hz*. The measurements were carried out at the company *Stresstech* on behalf of the Belgian welding Institute (BIL) and OCAS NV (Arcelor Mittal) within the European research project FATWELDHSS.

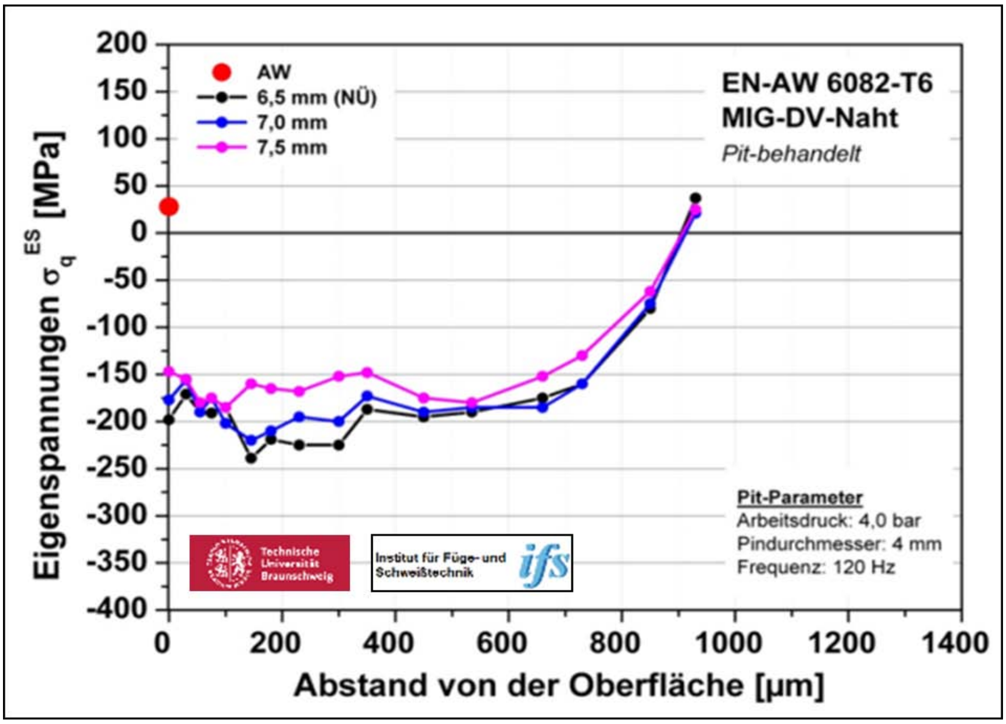

Figure 4: Residual stress measurements: Aluminum joints

Figure 4 shows the residual stresses on PIT-treated aluminum test specimen (material *6082-T6*) compared with the condition as welded. These tests were carried out as part of a research project at the Institute of Welding Technology (IFS) at the University of Braunschweig.

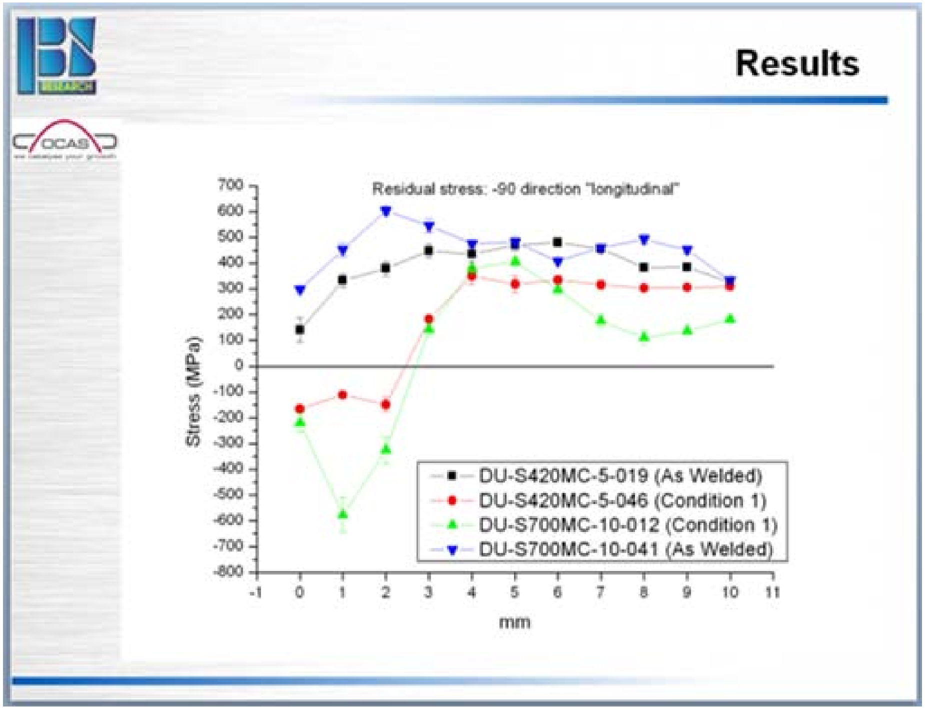

Figure 5: Residual stress measurements: Comparison of *S420* and *S700*

Figure 5 shows the residual stresses in welded condition and PIT treated from two different materials *S420MC* and *S700MC*. These results were part of the research project DURIMPROVE.

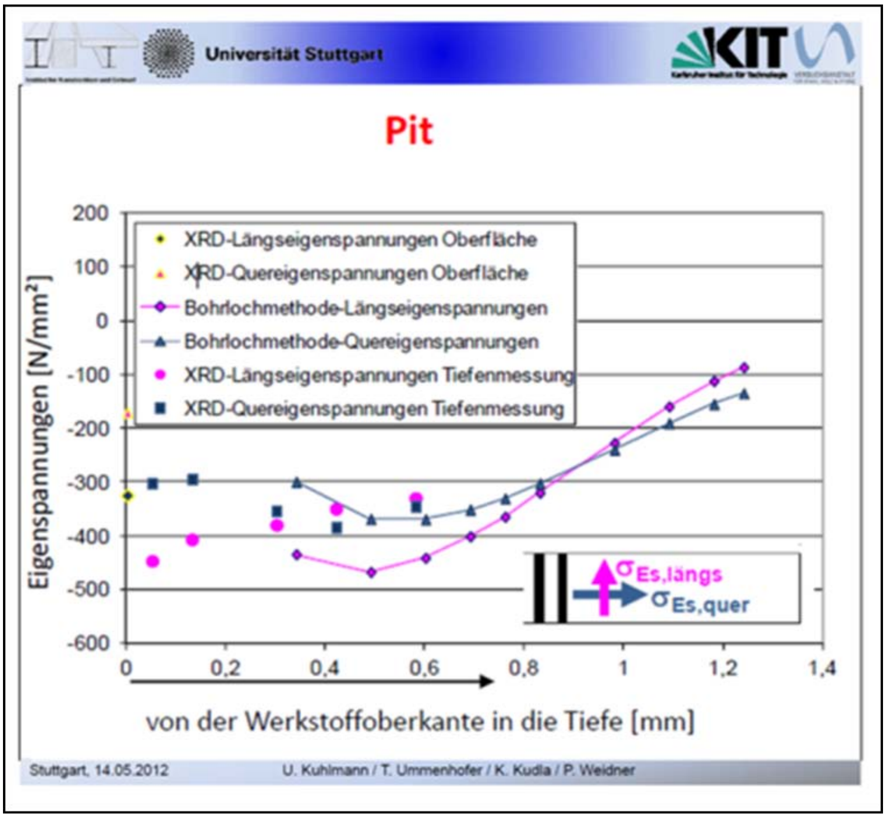

Figure 6: Residual stress measurements: Comparison of X-ray diffraction and hole drilling method

Figure 6 shows the results of PIT-treated samples of the material *S235*. The measurements were performed with the X-ray diffraction and with the hole drilling method in order of the Federal Office for Hydraulic Engineering (BAW) Karlsruhe carried out at the Universities of Karlsruhe and Stuttgart.

3 Fatigue test results

3.1 Overview of fatigue test data

Up to now numerous research projects focusing on the fatigue improvement of welded joints by PIT-treatment are successfully executed, whereat some of the results are still confidential. However, subsequent an overview of the considered data involving steel specimen fatigue test results is provided:

- [1], denoted as Lei2014
- [2], denoted as Ber2014
- [3], denoted as Iss2008
- [4], denoted as Kuh2013
- [5], denoted as Baa2014

The test series include butt, transverse as well as longitudinal welds with different base material strengths ranging from *S235* to *S1300*. In sum, about *200* data points for PIT-treated steel joints are included in this evaluation. The data points are compared to the proposed FAT-values for HFMI-treated joints given in [6] implying a survival probability of *97 %*. The analysis is performed up to two million cycles as not all test series include fatigue test data points in the high-cycle fatigue region. However, also for available data points in this region a comparison shows that the PIT-treated specimens exceed the proposal. A detailed presentation of the proposed values is provided in the following chapter.
Further fatigue test data incorporating other specimen types, base materials and component applications is investigated in [7, 8, 9, 10, 11, 12, 13] and basically shows the beneficial effect of the PIT-method as post-treatment technique.

3.2 Proposed values for HFMI-treated joints

In [6, 14] a proposal to assess the fatigue strength of HFMI-treated steel joints is presented. Based on an extensive number of fatigue test data points it is observed, that the FAT-class increases with a higher base material strength. Therefore, an enhancement of one fatigue class (about *12.5%* in fatigue strength) for every *200 MPa* increase in static yield strength is proposed and is shown to be conservative with respect to the investigated data. In order to achieve high quality post-treatment, specific recommendations for the application of HFMI is developed, see [15]. As stated, this paper includes fatigue test results of butt, transverse as well as longitudinal welds, for which the proposed S/N-curve values are shown in Fig. 7 in case of a nominal stress assessment.

f_y (MPa)	Longitudinal welds	Transverse welds	Butt welds
	As-welded, $m = 3$ [2]		
All f_y	71	80	90
	Improved by hammer or needle peening, $m = 3$ [1]		
$f_y \leqslant 355$	90	100	112
$355 < f_y$	100	112	125
	Improved by HFMI, $m = 5$		
$235 < f_y \leqslant 355$	112	125[a]	140[a]
$355 < f_y \leqslant 550$	125	140	160
$550 < f_y \leqslant 750$	140	160	180
$750 < f_y \leqslant 950$	160	180[a]	–
$950 < f_y$	180	–	–

[a] no data available.

Figure 7 — Proposed S/N-curve values for HFMI-treated joints [6]

3.3 Butt welds

In Fig. 8 to 10 the data points of the involved butt weld fatigue test results in comparison with the proposed design S/N-curve for HFMI-treated joints for different base material yield strength is presented.

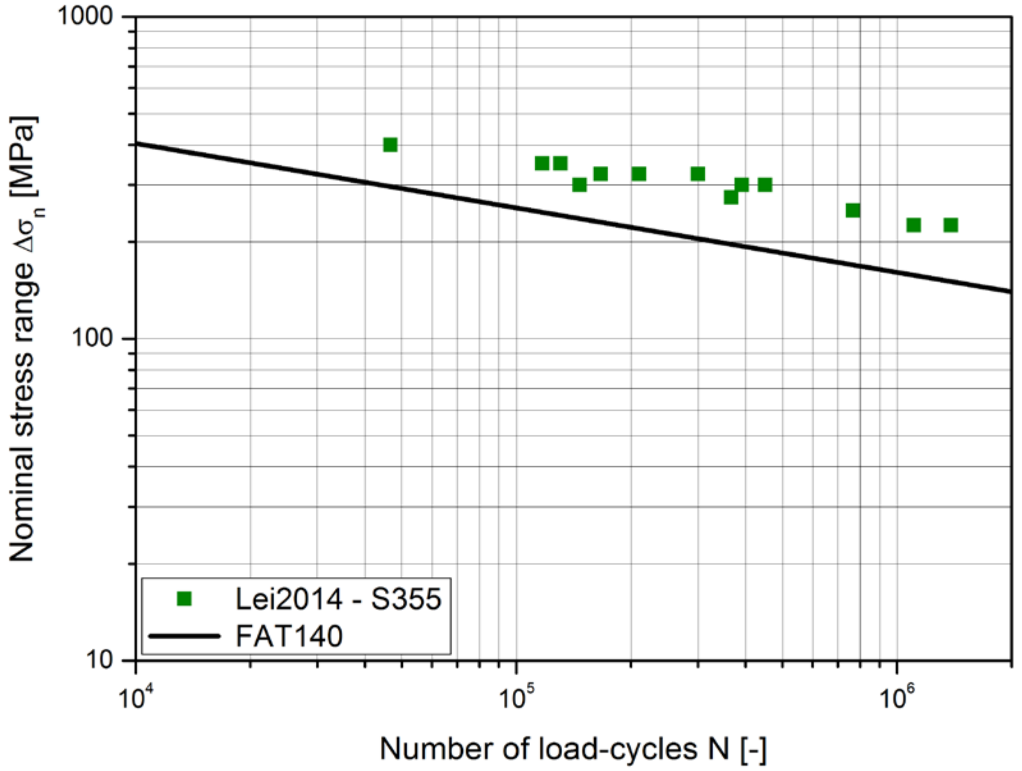

Figure 8 — Butt welds with 235 < f_y ≤ 355

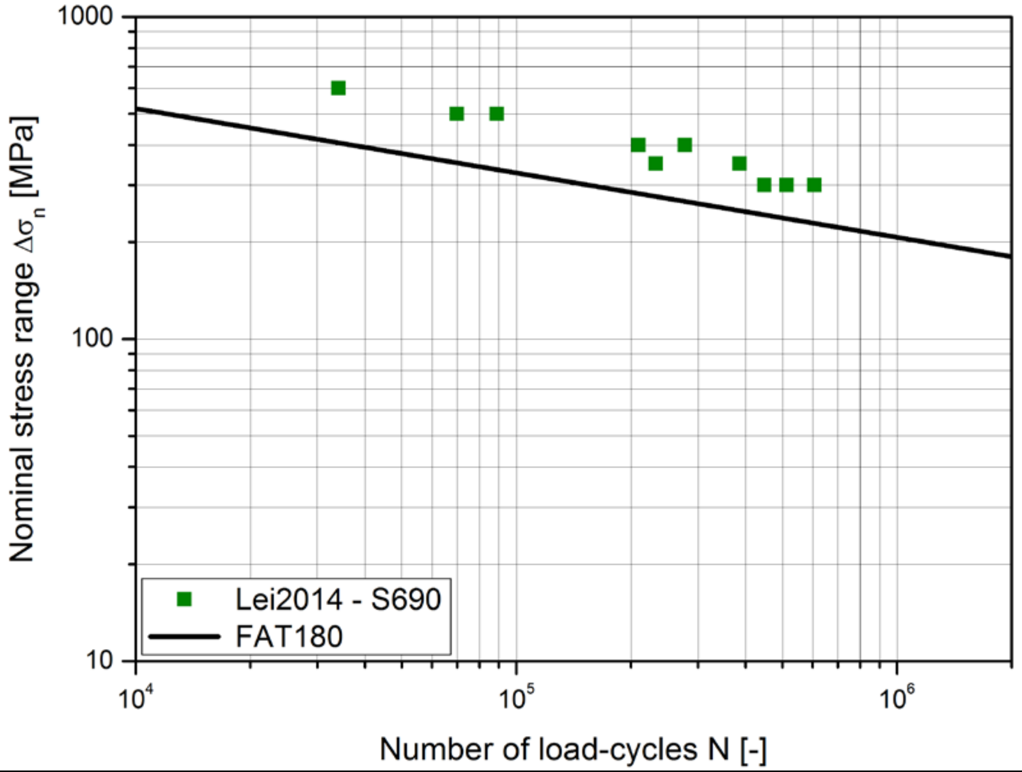

Figure 9 — Butt welds with 550 < f_y ≤ 750

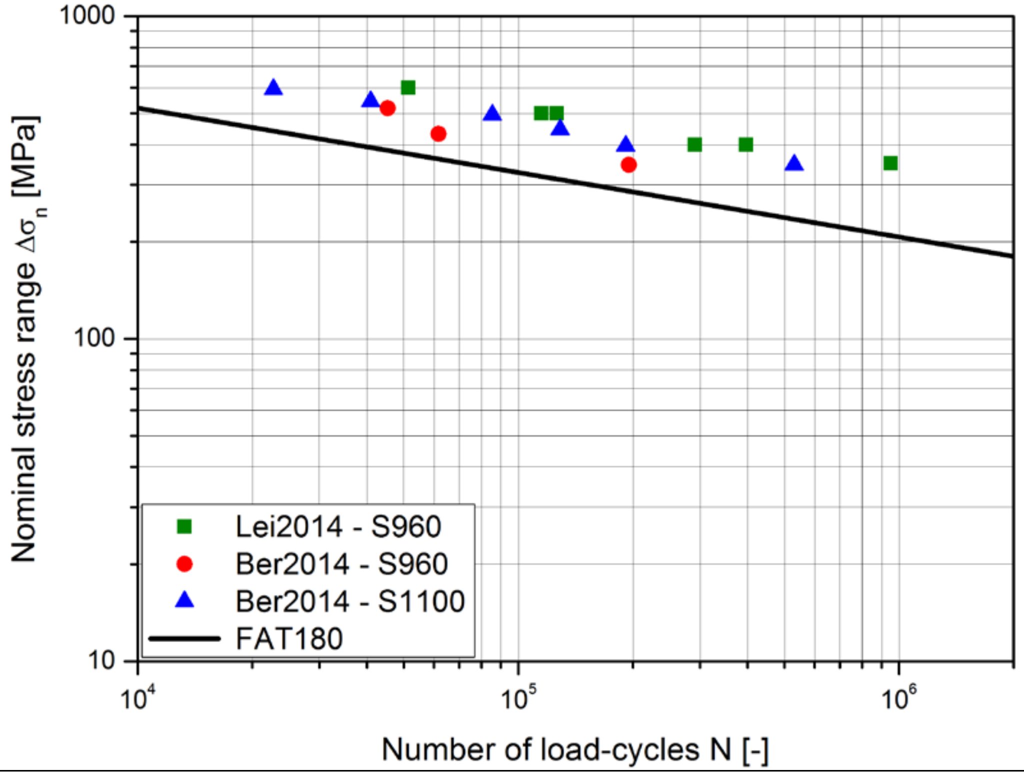

Figure 10 — Butt welds with 950 < f_y

3.4 Transverse welds

In Fig. 11 to 13 the data points of the involved transverse weld fatigue test results in comparison with the proposed design S/N-curve for HFMI-treated joints for different base material yield strength is presented.

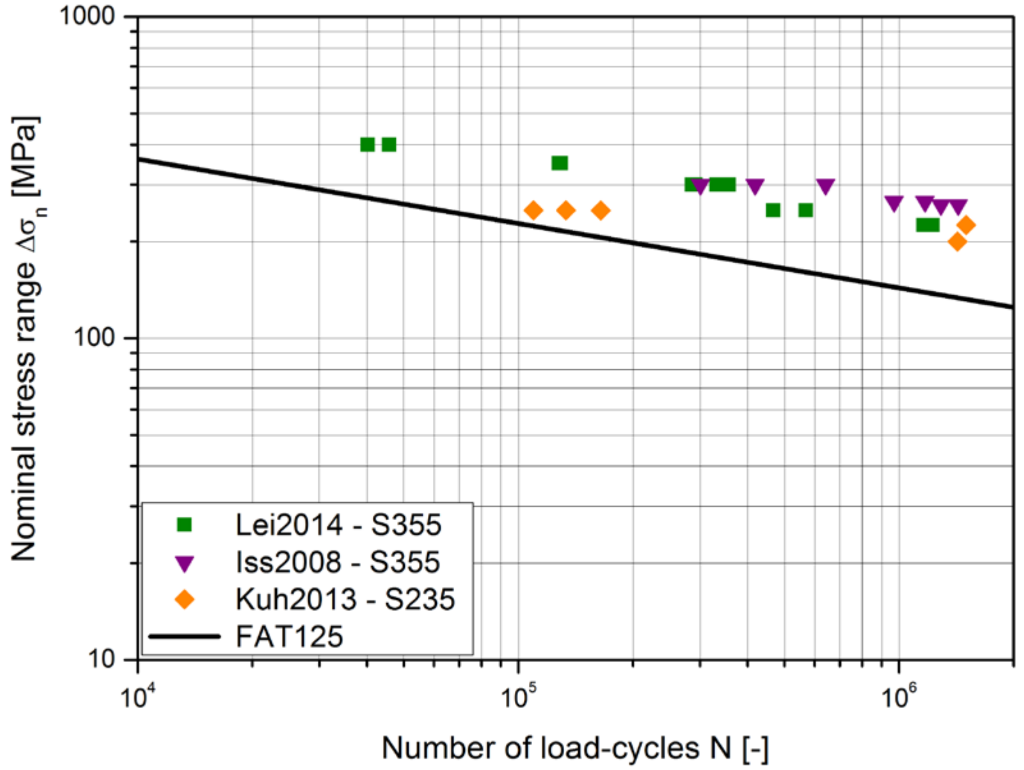

Figure 11 — Transverse welds with 235 < f_y ≤ 355

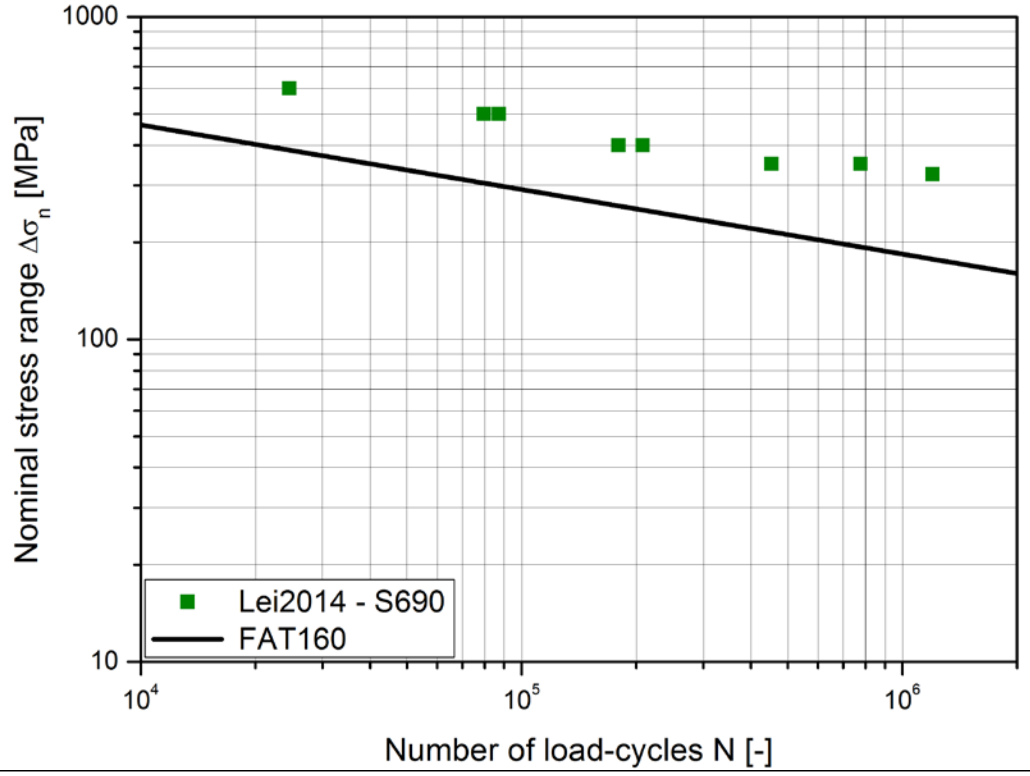

Figure 12 — Transverse welds with 550 < f_y ≤ 750

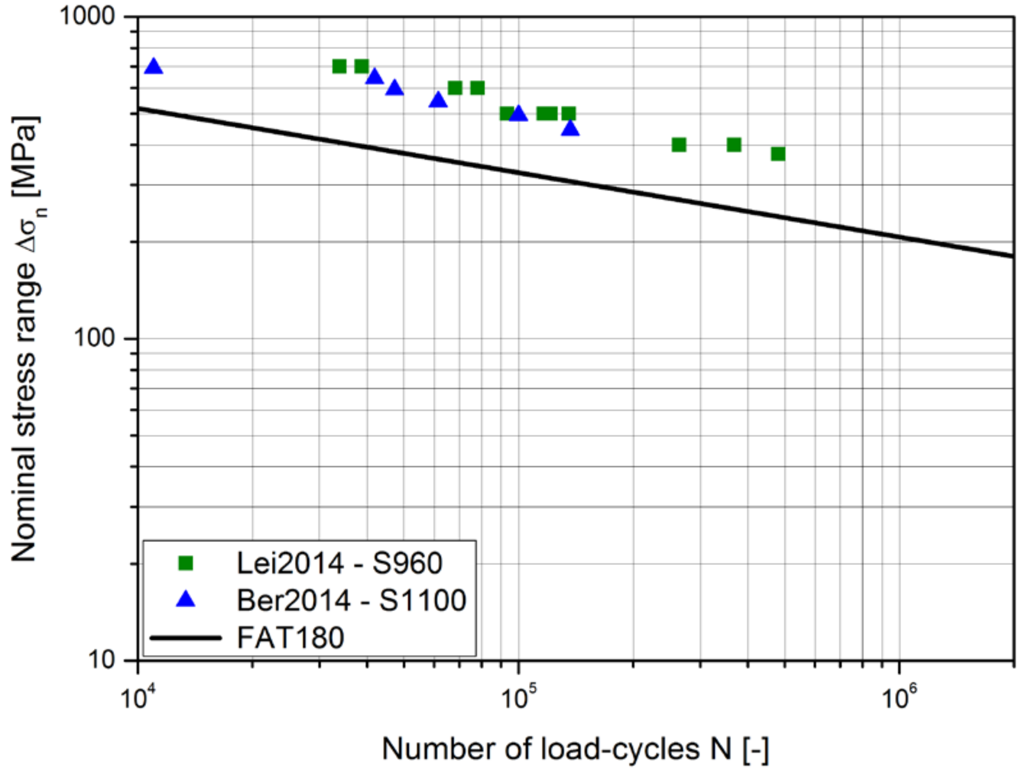

Figure 13 — Transverse welds with 950 < f_y

3.5 Longitudinal welds

In Fig. 14 to 17 the data points of the involved longitudinal weld fatigue test results in comparison with the proposed design S/N-curve for HFMI-treated joints for different base material yield strength is presented.

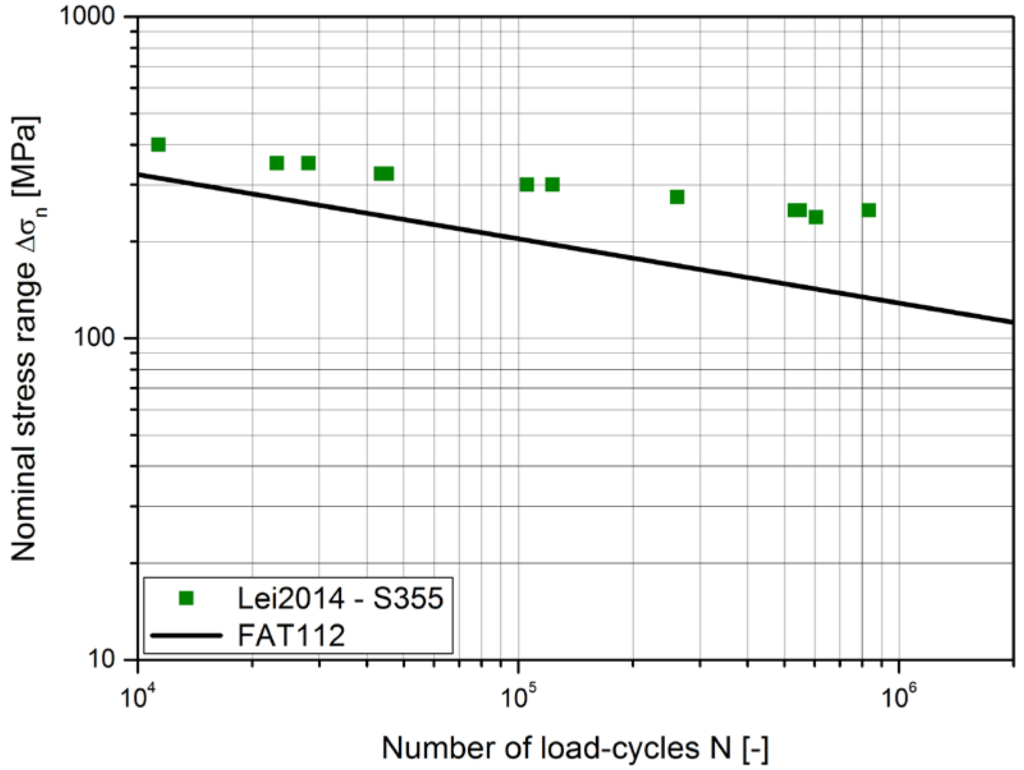

Figure 14 — Longitudinal welds with 235 < f_y ≤ 355

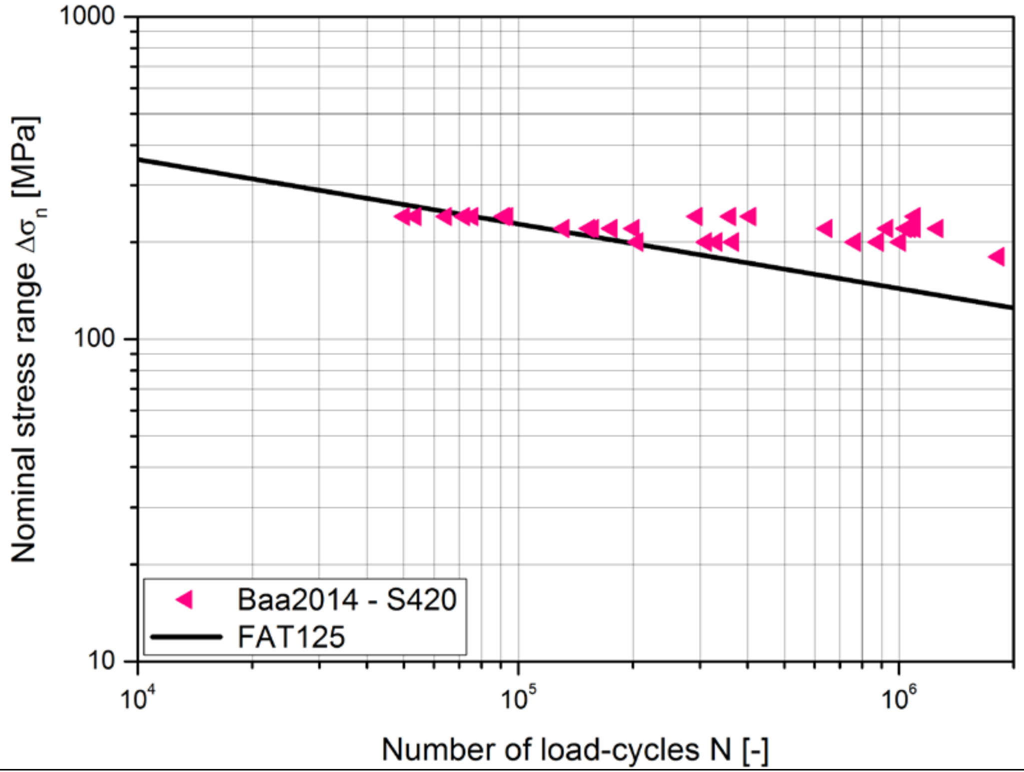

Figure 15 — Longitudinal welds with 355 < f_y ≤ 550

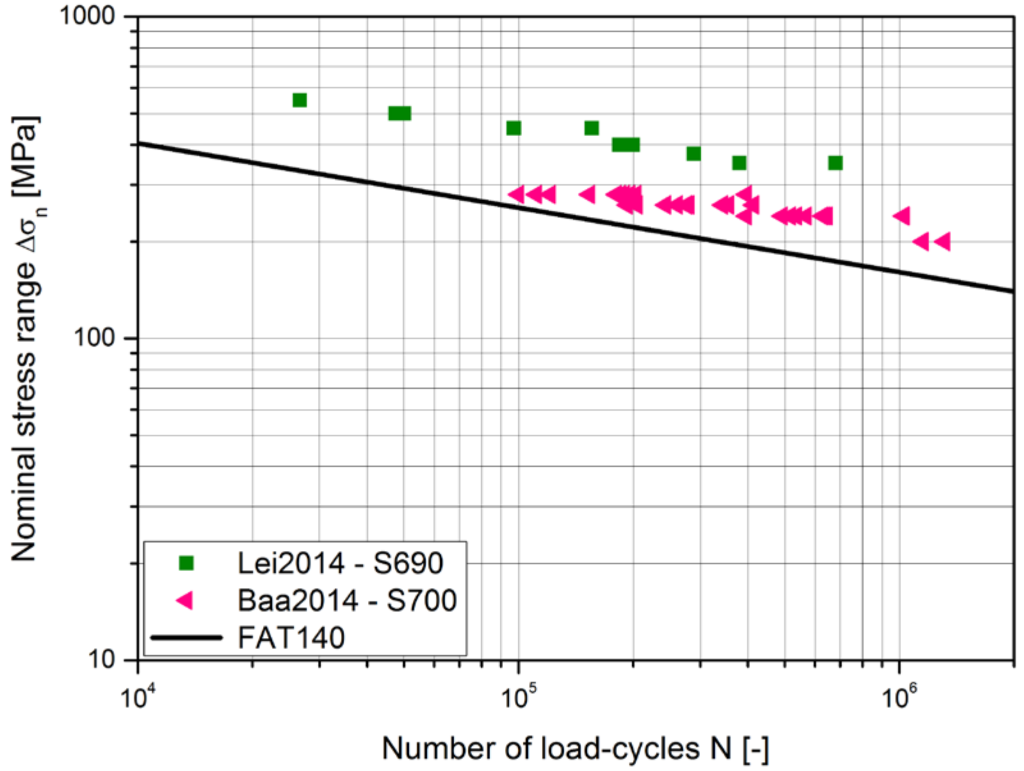

Figure 16 — Longitudinal welds with 550 < f_y ≤ 750

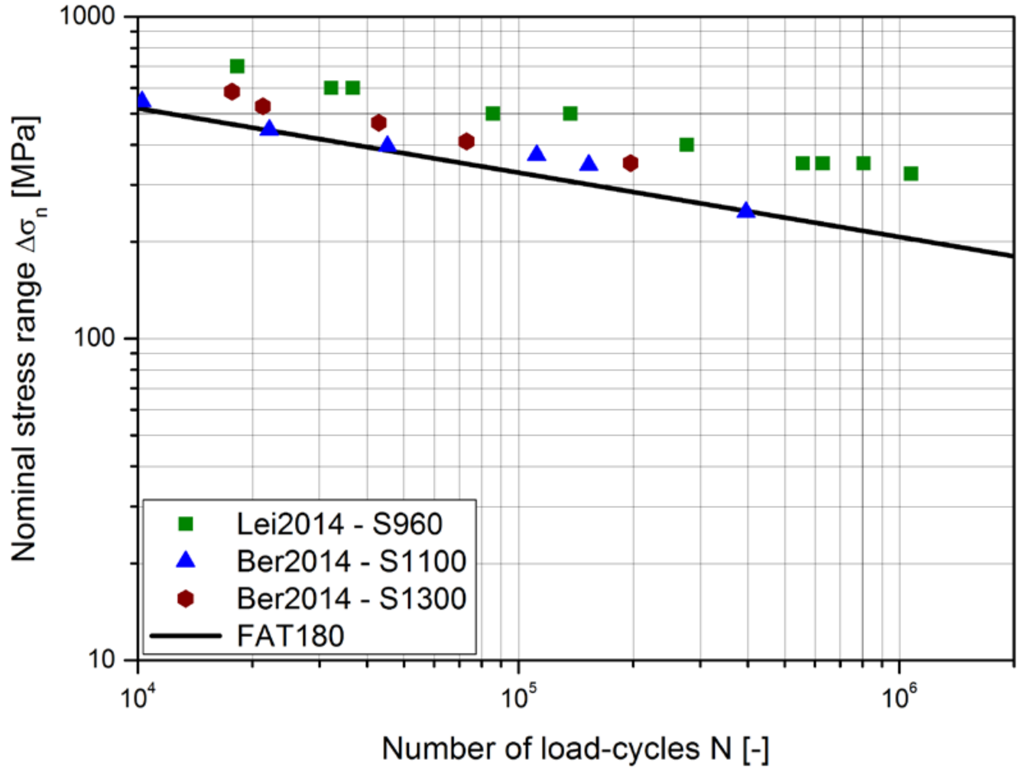

Figure 17 — Longitudinal welds with 950 < f_y

3.6 Discussion

A comparison of the included fatigue test data points to the design recommendations shows, that almost all HFMI-treated specimens exceed the proposed S/N-curve. The marginal number of data points, which under run the proposal in Fig. 15, can be explained by a minor increased scattering of the investigated results. However, the proposed S/N-curves are valid for a survival probability of *97 %* and therefore, all the investigated fatigue test series fulfil the recommendation. Summarized, this study shows that the proposed fatigue assessment values given in [6, 14] are in a good agreement to the incorporated data points for PIT-treated weld seams.

4 Conclusion

Extensive residual stress measurement results for PIT-treated specimens basically proof the reproducible introduction of compressive residual stresses due to the post-treatment. A comparison of over *200* fatigue test specimens results are compared to the proposed values for HFMI-treated joints showing a good agreement, whereat most of the PIT-treated data points exceed the recommendation.
Therefore, the basic applicability of PIT to increase the fatigue strength of welded structures and a fatigue assessment based on the actual proposals is proven.

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