Fatigue Fract. Engng Mater. Struct. Vol. 19, No. 6, pp. 703–708, 1996
Printed in Great Britain.

8756-758X/96 $6.00 + 0.00

INFLUENCE OF STRESS RELIEVING BY VIBRATION ON THE FATIGUE BEHAVIOUR OF WELDED JOINTS IN COMPARISON TO POST-WELD HEAT TREATMENT

C. M. SONSINO[1], F. MÜLLER[1], J. DE BACK[2] and A. M. GRESNIGT[2]
[1] Fraunhofer-Institut für Betriebsfestigkeit (LBF), Darmstadt, Germany
[2] Delft University of Technology (TUD), Delft, Netherlands

Abstract—Constant amplitude fatigue tests with welded specimens under fully reversed four-point bending as well as under axial loading have shown that vibration stress relieving does not lead to a fatigue life improvement of welded parts when compared to the as-welded state. Thus, a substitution of thermal stress relieving by a vibration treatment is not successful. This was also proved by residual stress measurements in the welded parts studied in this paper.

Keywords—Weldments; Vibration stress relieving; Thermal stress relieving; Residual stresses; Fatigue strength; Endurance limit; *S–N*-curves

NOMENCLATURE

A_5 = elongation
f = frequency
F = force
k = slope of the *S–N*-curve
N_f = number of cycles to final failure
P_s = probability of survival
R = ratio between minimum and maximum stress
R_m = tensile strength
$R_{p0.2}$ = yield strength
t = vibration time
σ_a = stress amplitude
σ_t^{ES} = residual stress
$\Delta\sigma$ = nominal stress range
$\Delta\sigma_E$ = stress amplitude

INTRODUCTION

Tensile residual stresses induced during production very often lead to a distortion of welded components and they can also affect the fatigue strength. It is a well known fact, that the fatigue behaviour of welded parts can be improved significantly, if the residual stresses are removed by means of a post weld heat treatment [1]. However, thermal stress relieving can be very expensive in the case of large scale components. Since the heat treatment can also lead to a distortion of the component and to an oxidation of the surface, it is very often suggested, to replace post weld heat treatment by vibration stress relieving [2–4]. However it is not known, whether the vibration treatment can reduce significantly the influence of the tensile residual stresses on fatigue behaviour and so a research project, funded by the European Community for Steel and Coal (ECSC), with two partners (Technical University Delft (TUD), Netherlands, and Fraunhofer-Institut für

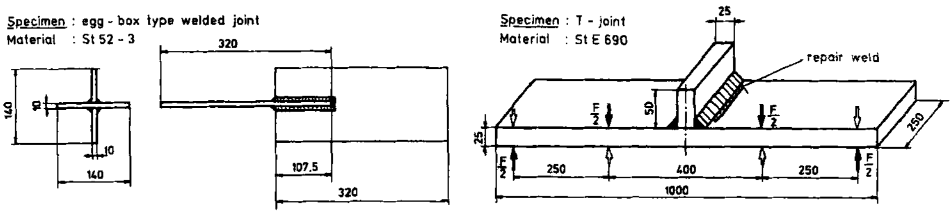

Fig. 1. Specimen geometries: all dimensions in mm.

Betriebsfestigkeit (LBF), Germany) was started. The aim of the investigation is to determine if a substitution of post weld heat treatment by a vibration treatment is possible.

MATERIALS, SPECIMENS AND TREATMENT

The fatigue tests were carried out with two types of specimens, see Fig. 1, namely T-joints of St E 690 and egg-box type cruciform joints.

While the second type is known for introducing high residual stresses during welding, the T-joints were fixed in a clamping jig and were additionally repair welded at the weld toe in order to obtain tensile residual stresses in this region.

The static material properties and the chemical composition of the two steels are listed in Table 1. The materials were selected due to their high yield strengths in order to obtain high tensile residual stresses after welding.

After welding the specimens were divided into three test series:

(1) as welded specimens,
(2) vibration stress relieved specimens, and
(3) heat treated specimens.

Reliable guidelines for the selection of appropriate vibration parameters are not available and so the vibration treatment was carried out by the national representatives of the manufacturers of the vibration devices on the basis of their own experiences. The parameters of the vibration treatment and the post weld heat treatment are given in Table 2. The details of the vibration treatment are described in the final report to the funding agency [5].

INVESTIGATIONS

Residual stress measurements

In the case of the T-joints the residual stresses acting in the longitudinal direction (i.e. in direction of the loading stresses) were measured by means of X-ray diffraction along a line perpendicular to the repair weld, see Fig. 2. The residual stress distributions are shown in Fig. 3. While the resultant

Table 1. Mechanical properties and the chemical composition [%wt.] of the materials tested

	Mechanical Properties			Chemical Composition [%]							
Material	R_m [MPa]	$R_{p0.2}$ [MPa]	A_5 [%]	C	Si	Mn	P	S	Al	Cr	Mo
St 52-3	542	380	30	0.14	0.44	1.58	0.19	0.19	0.30	-	-
St E 690 (1. series)	869	774	18	0.19	0.67	0.67	<0.02	<0.01	-	0.71	0.03
St E 690 (2. series)	829	777	16	0.18	0.69	0.86	<0.02	<0.01	-	0.71	0.32

Table 2. The thermal and vibrational treatments given to the welded joints in this study

Thermal Stress Relieving		Vibration Treatment	
Material	Thermal treatment	Time for vibration treatment	Vibration frequency
St 52-3	650°C 1 h cooling in the furnace	t = 10 min. to 15 min.	f = 100 Hz
St E 690 (1. series)	550°C 1 h cooling in the furnace	t = 10 min. to 25 min.	
St E 690 (2. series)	600°C 50 min cooling in the furnace	t = 10 min. to 15 min.	

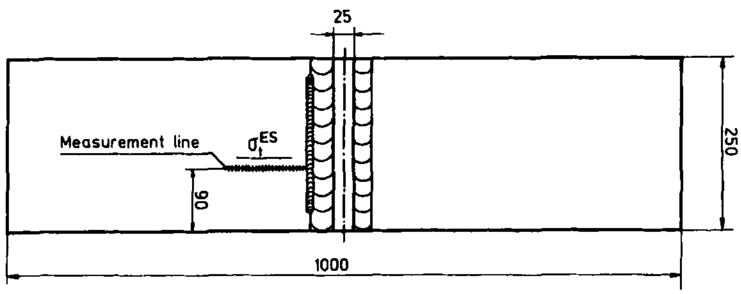

Fig. 2. Locations on the specimen surface where the residual stresses were measured.

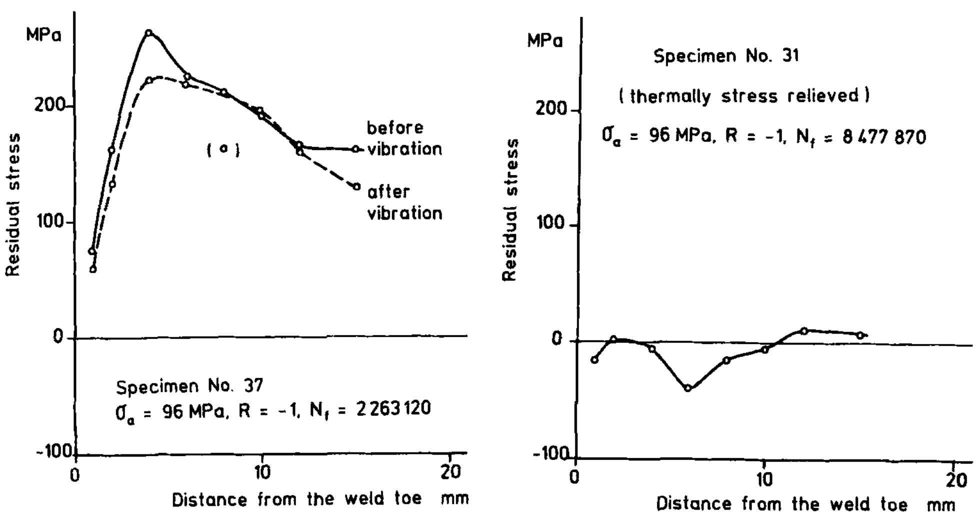

Fig. 3. The distribution of residual stresses perpendicular to the weld.

level of residual stresses in the thermally stress relieved specimens was negligible, the tensile residual stresses in the vibrated specimens were hardly reduced by the vibration treatment, when compared to the as-welded state. Thus, in this case the vibration stress relief could not substitute the heat treatment.

This was also proved, indirectly, by crack opening displacement measurements carried out by TUD on the vibrated egg-box type specimens. Due to the tensile residual stresses in the region of the weld toe the crack remained open even during the beginning of the compressive half-cycle of

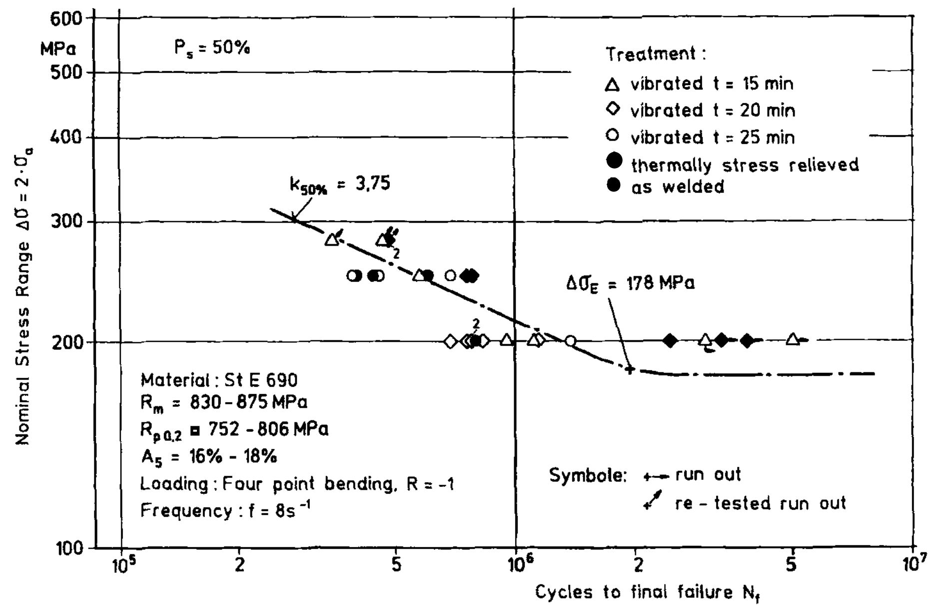

Fig. 4. First series of fatigue results on T-joints.

loading. If the specimens were thermally stress relieved, the crack was closed as soon as the compressive half-cycles of loading began.

Fatigue testing

The T-joint specimens were submitted to fully reversed four point bending ($R = -1$). All fatigue testing results lay around a common S–N-curve, Fig. 4, although the level of the residual stresses was different. Due to the stress concentration at the weld toe the locally acting stresses are higher than the yield strength of the material and the local yielding at the weld toe caused a relaxation of the tensile residual stresses during the initial loading cycles. Thus, the fatigue behaviour of the different samples was similar. Only a slight tendency of the thermally-stress-relieved specimens toward higher fatigue lives could be observed, while the as-welded and the vibrated specimens were mainly exhibiting shorter fatigue lives.

In a second series of specimens the temperature during the heat treatment was increased from 550°C to 600°C in order to improve the level of reduction of the residual stresses. Additionally, some specimens were investigated at a lower stress level to avoid the removal of residual stresses due to local yielding at the weld toe. Figure 5 shows that in this case the thermally-stress-relieved specimens attained higher fatigue lives at final failure, while the fatigue lifes of the vibrated specimens are lower.

In order to avoid the removal of the tensile residual stresses at the weld toe under higher loading amplitudes the egg-box type specimens were cycled at stress ratios of $R = -1.5$ and -2.5, where the influence of tensile residual stresses on fatigue behaviour should be noticeably higher since the level of the applied tensile loading stresses are much lower and thus local yielding only occurs in the case of very high loading amplitudes. Figure 6 shows that the fatigue life of the vibrated specimens is the same as was observed for the as-welded specimens, while the fatigue strength of the heat treated specimens is much higher.

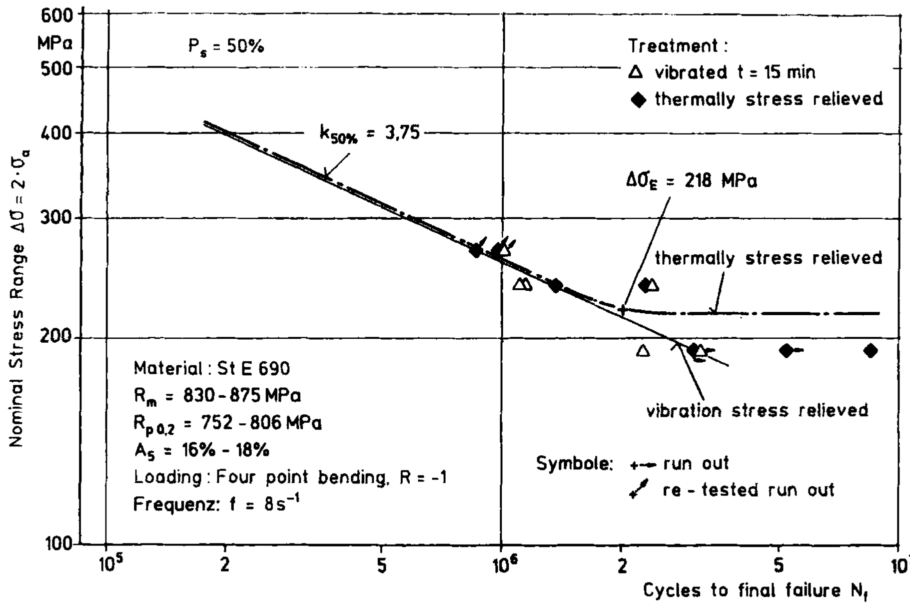

Fig. 5. Second series of fatigue results on T-joints.

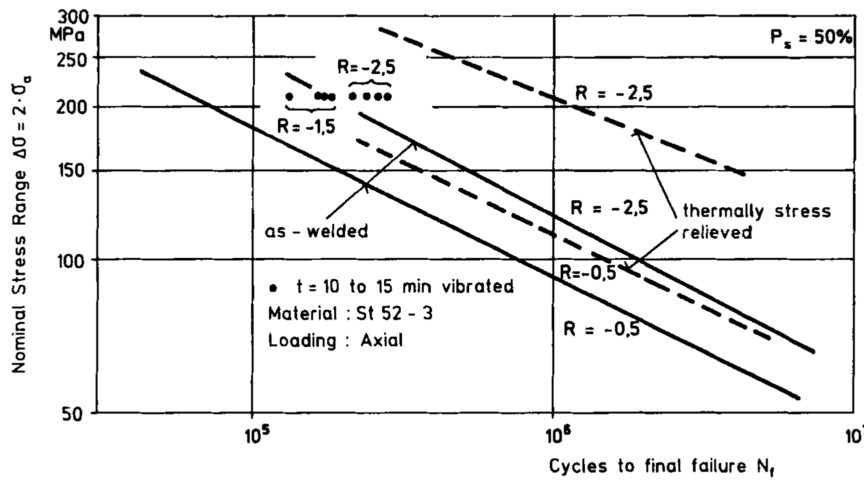

Fig. 6. Comparison of results. The endurance curves are according to J. L. Overbeeke and J. de Back.

A SUMMARY STATEMENT

The investigations have shown that a vibration stress relief cannot act as a substitute for a thermal stress relief since the residual stresses in the welded specimens could not be removed by the vibration treatment. Thus the vibrated specimens only reached the fatigue life of the heat treated specimens in the case of high applied stress amplitudes, where the tensile residual stresses were reduced during the initial loading cycles due to local yielding at the weld toe.

From a literature survey it can be noted that a vibration treatment can be applied successfully to large scale welded components, where the distortions could be reduced and the geometric form improved. However only in a few cases was a slight reduction of residual stresses observed [6,7] which is in contradiction to the name given to the "stress-relieving" vibration procedure. In this present investigation also no significant reduction of residual stresses could be measured. On the other hand it has to be mentioned that the T-joint specimens, with a weight of 50 kg, were lying close to the lower bound of application for a vibration treatment; this information being given by the distributors of the vibration devices.

If all results of the present investigation are taken into account, a post-weld heat treatment cannot be replaced by a vibration stress relieving technique. Additionally, reliable guidelines for successful applications of vibration treatments to welded joints are still required.

REFERENCES

1. C. M. Sonsino, C. Kulka, D. Boehme and R. Helwig (1987) Slope of the *S–N*-curve and high-cycle fatigue behaviour of longitudinal stiffeners in as-welded and stress-relieved states. IIW-Document No. XIII-1242-87.
2. A. Rappen (1972) Vibration nach dem VSR-Verfahren zur Verminderung des Eigenspannungsverzuges Lasttechnik **38**(10), 223–233.
3. E. Döbler (1981) Abbau von Eigenspannungen durch Vibration Werkstatt und Betrieb **114**(7), 459–461.
4. A. Rappen (1982) Verringerung von Schweißeigenspannungen durch Vibration zur Erzielung von Maß- und Formgenauigkeit von Maschinen Deutscher Verlag für Schweißtechnik GmbH, Düsseldorf, DVS-Bericht, Band 74, 191–202.
5. J. de Back, A. M. Gresnigt, C. M. Sonsino and F. Müller (1993) Influence of stress relieving by vibration as compared with post weld heat treatment on the fatigue behaviour of repaired welds. Report EUR 14484 EN, Luxembourg. Commission of the European Communities.
6. J. O. Nøkleby, T. B. Larsson and J. P. Tronskar (1984) Influence of vibration stress relieving on welding stresses and cracking susceptibility. VERITEC Marine Technology Consultants, Høvik (Norway). Technical Report No. VT-84-3158.
7. P. Sedek (1983) Können mechanische Schwingungen das Spannungsarmglühen geschweißter Maschinenelemente ersetzen? Schweißen und Schneiden 35, Heft 10, 483–486.
8. J. L. Overbeeke and J. de Back (1982/1983) The effect of residual stresses and *R*-value on the service life of welded connections subjected to fatigue. Report of the Netherlands Institutions for Welding Technology. Report No. NIL-TC-XIII-164-82 (1982), Delft, IIW-Doc. XIII-1095-83 (1983).