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Influence of stress relieving on fatigue of heavy duty spot welded lap joints

by **J L Overbeeke*** and **J Draisma†**

In a previous investigation into the fatigue of heavy duty spot welded lap joints[1] the influence of the load ratio, R, as revealed by extensive testing, was analysed. For values of R between 2/3 and −1, the relationship between F_{max}, ($\Delta F = (1-R) F_{max}$) and N is represented by: $F_{max}^{0.5} \cdot F^{2.5} \cdot N$ = constant.

As the endurance of this joint is determined mainly by macro-crack propagation from the crack-like junction up to the critical crack length, it should follow that the negative part of the load cycle does not contribute to crack growth because of closure of the crack surfaces.

However, indications of crack closure were obtained only at an R ratio as low as R = −2. It was considered that positive residual welding stresses kept the crack open under negative loads.

In this investigation the tests as discussed above were repeated, but with the specimens in the stress relieved condition. The results are reported below.

Symbols

F	force or load, N
ΔF	load range, $F_{max}-F_{min}$
R	load ratio, F_{min}/F_{max}
N	number of cycles to failure

Specimens and testing machines

Great care was exercised to make these tests fully comparable with the previous ones. The shear test specimens were the same[1] (plate 7mm, nugget over 18mm), as was the material (56 KF steel, yield stress 470 N/mm²).

All specimens were stress relieved for 1hr at 500°C in an inert atmosphere. As it was established that normal cooling practice did not produce consistent results in endurance tests, the specimens were boxed to avoid temperature gradients. Cooling time to 50°C was 3hr. The mechanical properties of the material after stress relieving were within a few percent of those in the as-received condition.

The tests were carried out on the same Amsler 10 HFP fatigue machine. Testing frequency was 160–200Hz.

Test results and analysis

Fatigue tests were carried out at loads $F_{max} \leqslant$ 60kN and lives ranged from 10^5–10^8. The applied R ratios were 2/3, 1/2, 0, −1 and −2. The experimental data are plotted in Fig. 1. They were analysed by linear regression on the basis of:

$$\alpha \log F_{max} + \log N = C \text{ (R constant)}$$

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The results were as follows

R	α	C
2/3	(2.93)	20.05
1/2	2.93	19.61
0	2.92	18.91
−1	2.39	16.38
−2	2.07	14.89

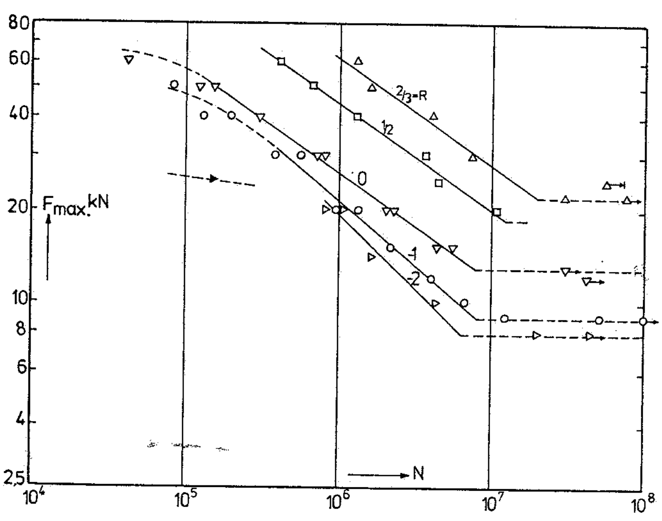
Standard deviations in life were below 15%.

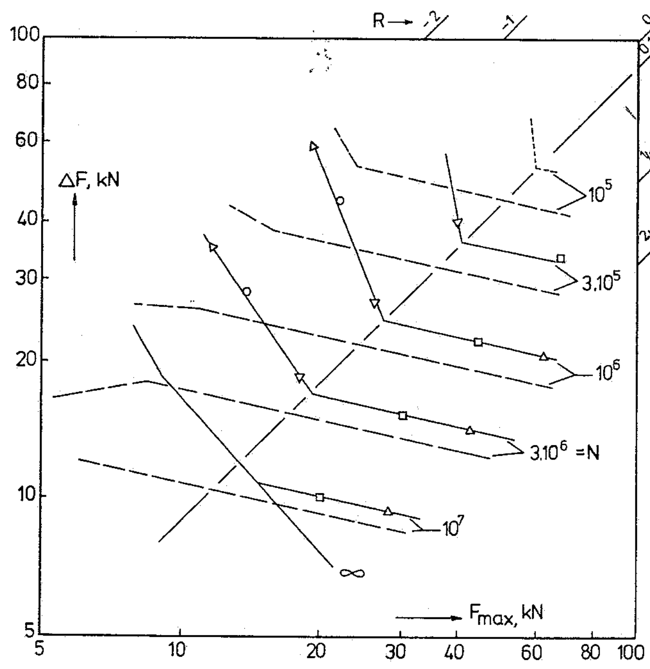
The results show that the deviation from linearity of the log F_{max}–log N line, observed in Ref. 1 only at R = −2 (α = 2.53), here also takes place at R = −1.

A cross plot of log ΔF versus log F_{max} is given in Fig. 2. In this Figure, a stress range ΔF that is independent of F_{max} shows up as a horizontal line. A vertical line means that F_{max} is independent of the range ΔF. The former line is a first approximation to crack propagation at R > 0, the latter for crack propagation at R < 0, when crack closure is fully effective.

Figure 2 shows that a changeover in dependency from ΔF to F_{max} takes place at about R = 0.12 (lines of R = constant are at 45° to the abscissa). For R < 0.12, F_{max} is the dominant parameter, but it is also clear that this influence becomes less at longer lives.

Below **1** *Fatigue life of stress relieved specimens at different values of R.*
Right **2** *Cross plot of lines of constant endurance on the base of log ΔF versus log F_{max}*
——— *stress relieved* – – – – *as welded*[1]





Apparently the crack surfaces degrade as a result of repeated hammering and sliding, so that the closure of the crack surfaces becomes the less effective, the longer the life is.

In Fig. 2 the endurances for the same specimens in the as-welded condition[1] are also shown. The influence of the residual welding stresses can be seen very clearly. At low endurances the residual stresses can be accounted for by a shift in F_{max}, but this is not possible at higher endurances.

Other welded joints

Although crack propagation measurements on mild steel[2,3] also indicate that crack closure is only partly effective at negative R ratios, the results reported here should be regarded as valid for this joint only. In principle, each type of (welded) joint will have its own crack closure pattern depending on geometry, type of loading, crack mode, endurance and the material used. Nevertheless, the observed type of behaviour—crack closure effects that decrease with increasing endurance, with a corresponding decrease of the inverse slope of the log F_{max}–log N line—may be typical for joints with partial wedge-type loading. Most welded joints with interrupted welds or with local attachments are of this type.

If this interpretation were correct a number of reported differences in the inverse slopes of the log S–log N lines of welded joints,[4] would become explicable in terms of residual stresses and crack closure phenomena.

Conclusions

The conclusions which may be drawn from this and previous investigations into the fatigue behaviour of spot welded lap joints are:

—When no crack closure takes place the FRN diagram can, to a first approximation, again be represented by ..

$$F_{max}^{0.5} . \Delta F^{2.5} . N = \text{constant}$$

—In the stress relieved condition crack closure is effective below $R \sim 0.1$. In the as-welded condition this changeover is below $R = -1$.

—Crack closure effects depend on load ratio and endurance and cause large changes in the inverse slope of the log F–log N lines.

—Fields of residual welding stresses cannot be replaced by an additional external static load, except when endurances are low.

—The above may also be valid for certain other types of welded joints.

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Abstract

The evaluation of possible crack closure effects was carried out by testing stress relieved specimens. Results show that crack closure effects depend on load ratio and endurance. In the stress relieved condition crack closure is effective below $R \sim 0.1$. In the as-welded condition this changeover is below $R = -1$. Details of the F R N diagram equation are given. Fine grain steel was used in testing.

(for full version see *Welding Research International* 1977 **7**(3) 241-253)

Keywords

SPOT WELDING; LAP JOINTS; STRESS RELIEVING; FATIGUE LOADING; CRACK PROPAGATION; MEASUREMENT; FINE GRAINED STEELS; THEORETICAL INVESTIGATION.