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SYMBOLS

F	force, kN.
ΔF	force range, kN.
F_{rms}	standard deviation of a random load sequence.
N	number of cycles to failure.
R	load ratio, $R = 1 - \Delta F/F_{max}$.

Previous research on the fatigue of heavy duty spot welded lap joints has revealed very systematic results in fatigue behaviour. It was shown[1] that welding variables and grade of material did not influence the endurance, and that the fatigue strength was equal to the fatigue strength of a crack.[2]

In reference 3 the influence of the R ratio was shown to be

$$F_{max}^{0.53}.\Delta F^{2.61}.N = \text{constant}$$

where $\Delta F = (1 - R)F_{max}$.

No closure of the crack surfaces was operative as low as $R = -1$ because of residual welding stresses. In reference 4 the influence of residual welding stresses was analysed and information regarding the effectiveness of crack closure was obtained.

Although constant amplitude results are still the usual basis for design purposes, service loads have variable amplitude and therefore an additional test programme was carried out to establish the influence of variable amplitude on the endurance.

Among all load histories possible, those that can be described by simple statistical parameters are preferable. So the loading patterns used here are either Gaussian or derived from a Gaussian time distribution. Furthermore, it is, to reveal the influence of different parameters more clearly, very convenient to use a repeatable pseudo-random excitation to be sure that each specimen gets the same sequence of peaks and troughs.

TEST PROGRAMME

The aim of this random load fatigue programme was to gather information regarding:

- the inverse slope of the endurance line.
- the influence of the R ratio (mean load) both as compared with constant amplitude tests.
- a comparison of wide band against narrow band loading (response of damped versus undamped structures).
- the influence of high peaks.
- the influence of very low amplitudes by using different peak distributions under narrow band loading.

The number of specimens used per series was 6 to 8. This number was sufficient, as the standard deviations in life were in general below 10%.

The total number of specimens tested was a hundred.

TEST SPECIMENS

The test specimens (plate 7mm, nugget over 18mm) were the same as used before[3] as was the material (56KF steel, σ_y = 470 N/mm²). All specimens were used in the as-welded condition.

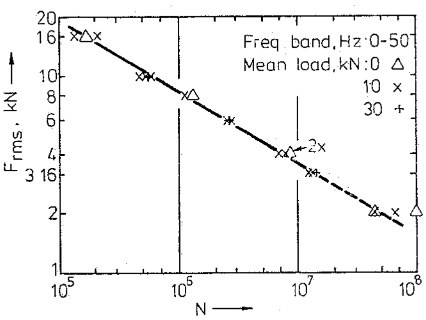
EQUIPMENT

Tests were carried out on two MTS systems and on two Vibrophores. The latter were also provided with complete servo-control and suitable for narrow band loading. Pseudo-random generators (HP 3722A) were used throughout. For the wide band tests the generator output was fed directly into the MTS systems. For the narrow band tests this output was first modulated by a much higher frequency, thus providing a pseudo-Gaussian distribution of peaks.

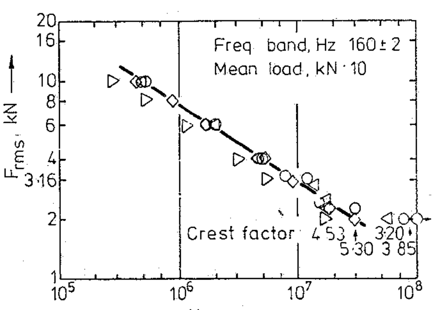
The pseudo-Rayleigh distribution of peaks was generated by shaping the Gaussian output of the generator, according to statistical rules, before modulation. The distributions were checked by counting methods and all tests were monitored by true-RMS voltmeters.

The used frequency bands are:

0 — 50 Hz wide band—MTS
40 ± 5 Hz narrow band—MTS
160 ± 2 Hz narrow band—Vibrophore



1 *Influence of the mean load, frequency band 0-50 Hz.*



2 *Influence of crest factor, frequency band 160 ± 2 Hz. Values of crestfactors are indicated.*

RESULTS AND ANALYSIS

Inverse slope and mean load

At mean loads of 0, 10 and 30kN the endurances were determined at lives varying from 2.10^5 to 5.10^7 cycles.

The test results were analysed by linear regression on the basis of: $\alpha \log F_{max} + \beta \log \Delta F_{rms} + \log N = C$.

In accord with the definitions of constant amplitude loading, $F_{max} = F_{mean} + F_{rms}\sqrt{2}$.

The results are shown in the Table.

From the above it is clear that the influence of F_{max}, expressed by α, can be neglected, at least technically speaking (Fig. 1). Furthermore the inverse slope β is almost the same for random as for constant amplitude loading. (It should be remembered that for $R \geqslant -1$, as applied here, the surfaces do not close.)

High peak loads

Wide band Gaussian tests were performed at short block lengths (266 cycles) and a maximum peak value of 3.2 F_{rms} (so a crest factor of 3.2) and block lengths of 26 000 cycles together with a crest factor of 3.85.

No influence of block length and/or crest factor could be detected. Narrow band tests with crest factors ranging from 3.2 to 5.9 and block lengths up to 262 000 cycles did not show influences of block length except in those cases where the life of the specimen was less than four times the block length. No influence of the crest factor (clipping ratio) was noted, except at a crest factor of 4.85 which behaved in an anomalous manner (Fig. 2) for unknown reasons.

Low amplitudes

The influence of low amplitude cycles was analysed by using two different narrow band loadings, viz a Rayleigh versus Gaussian distribution of peaks. For the former, only 22% of all cycles have peaks below 0.5 F_{rms} (note that the fatigue limit under constant amplitude is 4–6kN)

Test results

Test	α	β	C	Machine
Wide band Gaussian	0.10	2.72	9.439	MTS
Narrow band Rayleigh	0.16	2.69	9.204	MTS
Narrow band Rayleigh	0.06	2.58	9.149	Vibr
Constant amplitude 3	0.53	2.61	10.237	Vibr

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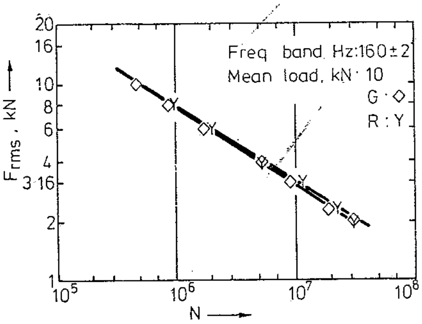

3 *Influence of peak distribution*
Y Rayleigh peak distribution
◇ Gaussian peak distribution.

while this value is 38% for the Gaussian one. On the basis of F_{rms} the former showed 8–10% longer life than the Gaussian distribution of peaks (Fig. 3). So, based on F_{rms} the peak distribution, as such, seems to be rather unimportant, as was also reported[5] with regard to crack propagation.

Damage calculations based on Miner's rule and $F_{rms}^{2.6}.N = C$ result in a 9% longer life for the Rayleigh distribution, which is equal to the measured difference in life. However, analysing differences in life of the order of 10% seems highly artificial as they are within the experimental error; but anyhow Miner's rule yields good results here.

DISCUSSION

From tests under block programme loading and from tests with high single overloads it is known that the load sequence can cause large differences in life and, consequently, Miner's rule does not yield reliable results. Here, the lack of influence of the mean load and of the maximum peak load, together with the measured influence of low amplitudes, show that the stress history is not important for a random load sequence. Reasons for the absence of load history effects could be:

- the absence of crack closure
- the high residual stress together with a maximum gross stress caused by loading below 90 N/mm² ($= 0.2\ \sigma_y$) .
- the rather low crest factors for wide band loading or the gradual change per cycle of the amplitude for narrow band loading.

CONCLUSIONS

From a design point of view, this type of spot welded joint allows a simple method of life estimation, *viz*:

- neglect of the mean load
- neglect of a fatigue limit
- the use of F_{rms} of the load spectrum or the use of Miner's rule to compare different load spectra.

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METCON FILE

Author OVERBEEKE J L
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Abstract
Joints made of 7mm thick high grade mild steel using 25mm electrodes were tested under random loading conditions. Tests were carried out under wide and narrow frequency band conditions. The results showed that the frequency had almost no effect on the endurance, and the crest factor can be neglected. The inverse slopes of the log F_{rms} – log N lines were equal under random and constant amplitude conditions. F_{rms} results and definition are discussed.
(for full version see *Welding Research International*, 1977 **7** (3) 254-276).