FATIGUE 84

FATIGUE STRENGTH OF SINGLE-SPOT AND MULTI-SPOT WELDED JOINTS

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In order to establish a method of estimating the fatigue strength of single-spot and multi-spot welded joints, fatigue tests of single-spot and multi-spot welded joints of 0.8 mm mild steel sheet were carried out and the results were compared with those obtained from stress analyses by means of FEM and a graphical method.

INTRODUCTION

This investigation was designed to obtain data required in order to establish estimation methods relating to the fatigue strengths of single-spot and multi-spot welded joints, arranged perpendicular to the load direction under repeated tensile shear load. The estimation method for multi-spot welded joints is based on the fatigue test results for single-spot welded joints having the same nugget diameter. These estimation methods deal mainly with the case of high cycle fatigue of about $2x10^6$ cycles when we can consider the stress of spot welded joints to be elastic.

First, in order to test the influence of basic factors (plate width, lap length and spot space, etc.) related to joint shape on the fatigue strength, fatigue tests of single-spot welded joints with various plate widths and lap lengths, and of multi-spot welded joints with various spot spaces and lap lengths were carried out. Although the load bearing of each spot weld of a multi-spot welded joint is an important factor in the fatigue strength (1, 2), in this report we can consider the case of even

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distribution of load bearing as the first stage of this investigation.

Next, in order to give wider generality to the results obtained by the fatigue testing, the influences of the basic factors mentioned above on the maximum stress in the neighborhood of spot welds were investigated using elastic stress analysis by means of FEM.

Finally, in order to obtain data for the estimation method for the fatigue strength of the multi-spot welded joint, which is based on the fatigue test results of single-spot welded joints, the relationships between stress distributions, that is, fatigue strengths of single-spot and multi-spot welded joints, were investigated by using the graphical method developed in this investigation.

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The specimen used is of mild steel sheet of 0.8 mm thickness. The chemical composition and mechanical properties of the specimen material are shown in Table 1. As the sample of a multi-spot

TABLE 1 - Chemical composition and mechanical properties of specimen used

Chemical composition (%)				Mechanical properties		
C	Mn	P	S	Y.S.(MPa)	T.S.(MPa)	Elong.(%)
.019	.25	.01	.012	265.6	343.0	52.7

welded joint, a 3-spot welded joint was used. The plate widths (W) of the single-spot welded joint were 50 mm, 25 mm and 15 mm respectively, and the lap lengths (L) were 25 mm, 10 mm and 3 mm. As regards the 3-spot welded joint, this had lap lengths (L) the same as for the single-spot welded joint, and spot spaces (p) of 50 mm, 25 mm and 15 mm. For each specimen, the spot welding conditions were based on the recommendations of the RWMA A-class, with the aim of obtaining a 5 mm nugget diameter. Fatigue tests were carried out under 0-tension load (stress ratio R=0), with a constant load amplitude and frequency of 40 Hz. Fatigue testing for 3-spot welded joints was carried out with the greatest case so that the load bearing of each spot weld becomes as even as possible.

We define the fatigue life of the spot welded joints as the number of cycles for a fatigue crack with a length of the same order as the diameter of spot indentation to become visible around the spot indentation, based on JIS Z 3138-1983 "Method of Fatigue Testing for Spot Welded Joint". The fatigue life of a multi-spot welded joint was taken to be the number of cycles at which the first fatigue crack was observed in a spot weld.

Fatigue strengths for single-spot and multi-spot welded joints at 2×10^6 cycles are shown in Table 2. From Table 2, it can be seen that the fatigue strength of single-spot welded joints decreases with decreasing plate width and/or lap length and that of the 3-spot welded joints decreases with decreasing spot space and/or lap length. It was found from the Load - Number of cycles curves that this tendency because more marked with the increase in the number of cycles to failure.

TABLE 2 - Fatigue strength of single-spot and 3-spot welded joints at 2×10^6 cycles

(kN)

		Single-spot welded joint			3-spot welded joint		
		W (mm) 50	25	15	p (mm) 50	25	15
L (mm)	25	1.20	1.05	0.86	3.29	2.94	2.47
	10	1.10	1.02	0.83	3.18	2.84	2.06
	3	0.90	0.82	0.76	2.59	2.23	2.12

2-DIMENSIONAL ELASTIC STRESS ANALYSIS OF SPOT WELDED JOINTS BY MEANS OF FEM

The influence of plate width and lap length of a single-spot welded joint and of the spot space and lap length of a multi-spot welded joint on the maximum stress of each spot welded joint was investigated by 2-dimensional elastic stress analyses of single-spot and multi-spot welded joints by means of FEM. Although the real phenomena of fatigue failure for spot welded joints occur in 3 dimensions, in order to simplify the problems of stress analysis the computations were carried out in 2 dimensions. The computations were carried out by using the finite element analysis models that consider load applied to the nugget of spot welded joints. Such a model has also been used by Y. R. Kan (3).

The computed results for the single-spot welded joint are shown in Fig. 1. The vertical axis (α_s) of this figure is the ratio of the load at which the maximum stress of a single-spot welded joint with any plate width and lap length becomes a given stress (in this computation, yield stress was used) to that in the case of a 60 mm plate width and a 30 mm lap length. The horizontal axis is the non-dimensional plate width which is obtained by dividing the plate width by nugget diameter (5 mm). In the case of a 2-spot welded joint, the symmetrical property of the stress distribution of each spot weld is a little less, when compared with that of a single-spot welded joint. However, the applied load at which the stress of the element showing maximum stress achives the yield stress becomes about 2 times that in the case of a single-spot welded joint with the same plate width as the spot space, if the lap length of each spot welded joint is equal. Accordingly, it can be considered that the computed results for a 2-spot welded joint become the same as in Fig. 1. when the plate width is replaced by spot spaceing.

From the above results, if an applied load is known when either the maximum stress of a single-spot welded joint with given plate width and lap length or of a multi-spot welded joint with given spot space and lap length becomes a given stress value, it is possible to estimate by using Fig. 1, a similar load for a single-spot welded joint with any plate width and lap length or for a multi-spot welded joint with any spot space and lap length. If a relationship between the stress distribution and the fatigue strength of a spot welded joint is found, it is possible to estimate the fatigue strength of single-spot welded joints with various plate widths and lap lengths or of multi-spot welded joints with various spot spaces and lap lengths.

COMPARISON OF FATIGUE TESTING RESULTS WITH STRESS ANALYSIS RESULTS

In order to investigate the relationship between the fatigue strength and the stress distribution of spot welded joints, a comparison of the load ratio (α_f) of the fatigue strength and the load ratio (α_s) of the stress distribution was made. The load ratio (α_f) of the fatigue strength for a single-spot welded joint is the ratio of the fatigue strength of a single-spot welded joint with any plate width and lap length to that of a single-spot welded joint with 50 mm plate width and 25 mm lap length at 2×10^6 cycles. The load ratio (α_f) of the fatigue strength for the multi-spot welded joint is the ratio of the fatigue strength of a multi-spot welded joint with any spot space and lap length to 3 times that of a single-spot welded joint with 50 mm plate width and 25 mm lap length.

The results for single-spot and 3-spot welded joints are shown in Figs. 2 and 3, respectively. Plate width, spot space and lap length of spot welded specimens used in the experiments are different from those used in the stress analyses for experimental reasons. Accordingly, in these figures, the values in the case of stress analysis were modified to become the same values as those used in the experiment. It is evindent that in the case of a single-spot welded joint (Fig. 2) the load ratio curve of fatigue strength shows a good agreement with that obtained from stress analysis, while in the case of a 3-spot welded joint (Fig. 3) the agreement is not so good. It is thought that the main reason has to do with uneven load bearing produced during fatigue testing of the 3-spot welded joint. In the comparison at $1x10^5$ cycles, both the load ratio curves of the fatigue strength and the stress distribution did not almost agree, even in the case of a single-spot welded joint. It is considered that the main reason is the plastic deformation of the spot welded joint, which is caused by applied load.

GRAPHICAL ANALYSIS OF 2-DIMENSIONAL STRESS DISTRIBUTION OF SINGLE-SPOT AND MULTI-SPOT WELDED JOINTS

The influence of the plate width of single-spot welded joints and of the spot space of multi-spot welded joints on stress distribution was investigated by the graphical method. Generally, fatigue failure of spot welded joints of thin steel sheet with a conventional nugget diameter commences at the end of the weld in the interface and, after that, the crack propagates towards the outerface. In a previous section, it has been shown that the fatigue strength of spot welded joints corresponds to the stress analysis results well, even in the case of 2-dimensional stress analysis. Accordingly, in the analysis of stress distribution by means of the graphical method, the 2-dimensional stress distribution on the X-axis through the front of the weld nugget as shown in the following figures was used.

First, the stress distribution of multi-spot welded joints with even spot spacing was investigated, for a sheet of infinite plate width, as shown in Fig. 4. In this figure, the stress distribution of the multi-spot welded joint (indicated by an unbroken line with maximum stress σ_0) can be regarded as a superposition of the stress distributions produced in each spot weld - these are shown by an unevenly broken line (alternate long and short sections) with a maximum stress of σ_1. The underlying assumption is that the total load has been divided by the number of spots in the weld. Based on this, it can be shown that when the spot space decreases, so does the load required to produce the given maximum stress of σ_0, because the interaction between stress distributions for each spot weld increases. Moreover, although the stress distribution of the multi-spot welded joint is a superposition of the stress distribution produced in each spot weld, if stand on a different viewpoint, it can be also considered to be the stress distribution which is produced by turning up and adding the stress distributions of an unevenly broken line on the center line (Y-axis in Fig. 4) between spot welds.

The next objective was to examine the influence of plate width on the stress distribution in a single-spot welded joint.

Fig. 5 shows the stress distribution of such a joint which has a finite plate width (W) equal to the spot space (p) of the multi-spot welded joint in Fig. 4. In Fig. 5, if the Y'-axes are approximated to the Y-axes in Fig. 4, it is possible to approximate the single-spot welded joint to an individual joint separated by the center lines (Y-axes) between spot welds in Fig. 4. As a result, the stress distribution of single-spot welded joint is possible to approximate the stress distribution of the single-spot welded joint (indicated by an unbroken line) with maximum stress $_0$ in Fig. 5 is possible to approximate the stress distribution which is produced by turning up and adding the stress distribution of the unevenly broken line in the Y'-axes. And, the respective influences of the plate width of single-spot welded joint and the spot space of multi-spot welded joint on the stress distribution of each spot welded joint can be considered to be approximately equivalent.

Here, although the stress distribution shown by the unevenly broken line in Fig. 5 was obtained by applying load to only a certain spot weld in a multi-spot welded joint having infinite plate width and even spot space, it is assumed that this distribution approximates to that which would result if the same load were applied to a single-spot welded joint of infinite plate width. It has been demonstrated by the results of FEM and fatigue tests that such an approximation is sufficiently valid for the estimation method the subject of this investigation.

On that basis, if the applied load (P_0) and the stress distribution on the X-axis such that maximum stress in a single-spot welded joint with infinite plate width becomes a given stress (σ_0) are known, it is possible to obtain the applied load (P_1) and the applied load ($n \times P_1$) respectively, such that the maximum stress of a single-spot welded joint with any plate width, and the maximum stress of a multi-spot welded joint with even spot spacing respectively become given stresses (σ_0). This can be accomplished by using the graphical method described above. The method is thought to be especially appropriate for estimating the fatigue strength of multi-spot welded joints with uneven spot spacing and uneven load bearing, where fatigue testing is rendered very difficult.

CONCLUSIONS

1) It was possible to assess the influence of the plate width and/or the lap length of single-spot welded joints and of the spot space and/or the lap length of multi-spot welded joints on fatigue strength.

2) It was also possible to show the influence of these basic factors concerning joint shapes on the stress distributions of single-spot and multi-spot welded joints.

3) It was found that the respective influences of the plate width of single-spot welded joints and of the spot spacing of multi-spot welded joints on the fatigue strength or on the stress distribution of each spot welded joint can be considered to be approximately equivalent.

4) By using Fig. 1, it is possible to estimate the applied load, that is, the fatigue strength such that the maximum stress of a single-spot welded joint with any plate width and lap length or a multi-spot welded joint with any spot space and lap length achieves a given value, if the fatigue strength of a single-spot welded joint with a given plate width and lap length or of a multi-spot welded joint with a given spot spacing and lap length is known.

SYMBOLS USED

W = Plate width of single-spot welded joint (mm)

p = Spot space of multi-spot welded joint (mm)

L = Lap lengths of single-spot and multi-spot welded joints (mm)

d = Nugget diameter (mm)

n = Number of spot welds

α_f = Load ratio for fatigue strength

α_s = Load ratio for stress distribution

P_0, P_1 and P_2 = Applied loads (kN)

σ_0, σ_1 and σ_2 = Maximum values of stress distribution (MPa)

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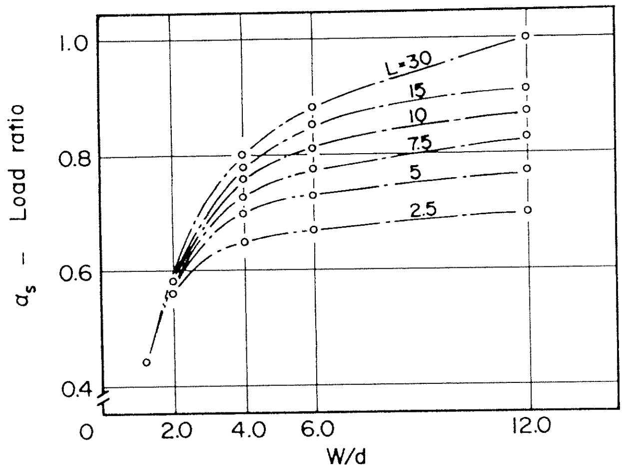

Fig. 1 Load ratio vs. plate width and lap length
W =Plate width, L =Lap length and d =Nugget diameter

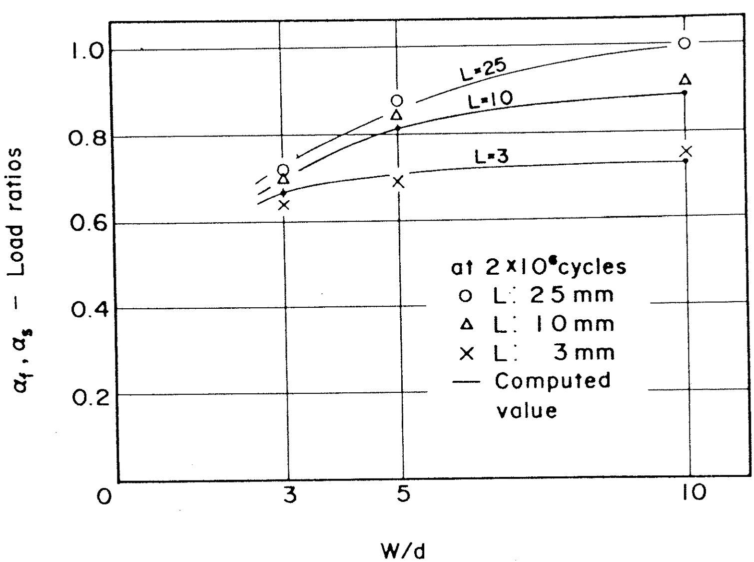

Fig. 2 Comparison of fatigue test results and computed results
W =Plate width, L =Lap length and d =Nugget diameter

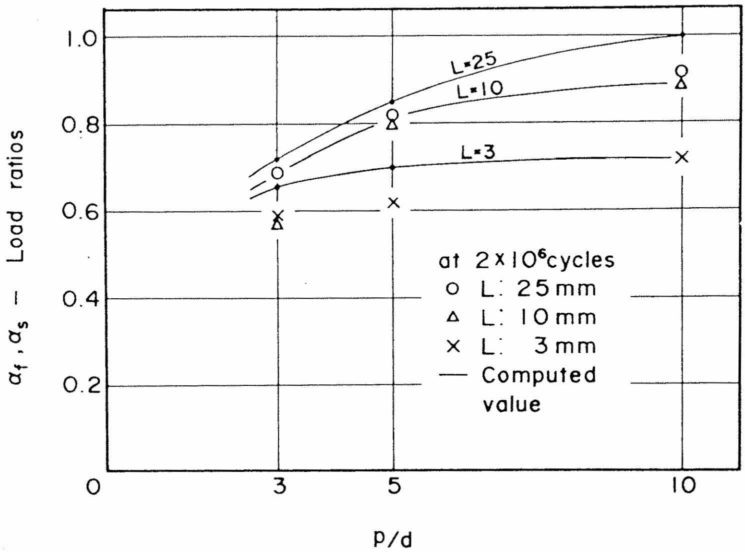

Fig. 3 Comparison of fatigue test results and computed results
p =Spot space, L =Lap length and d =Nugget diameter

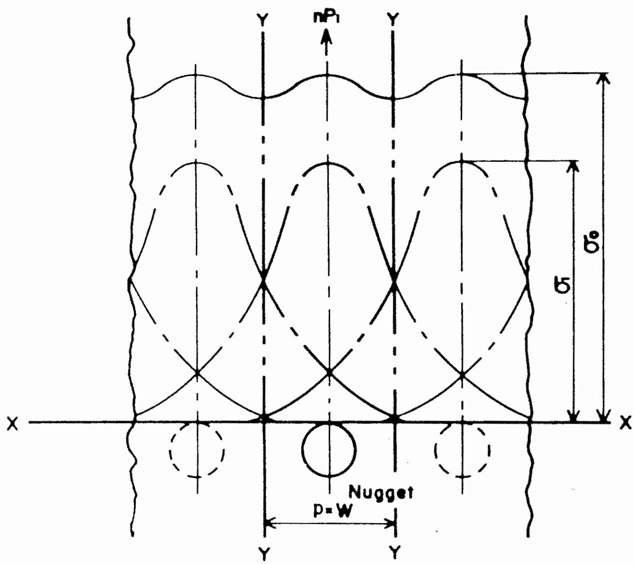

Fig. 4 Model of stress distribution for multi-spot welded joint

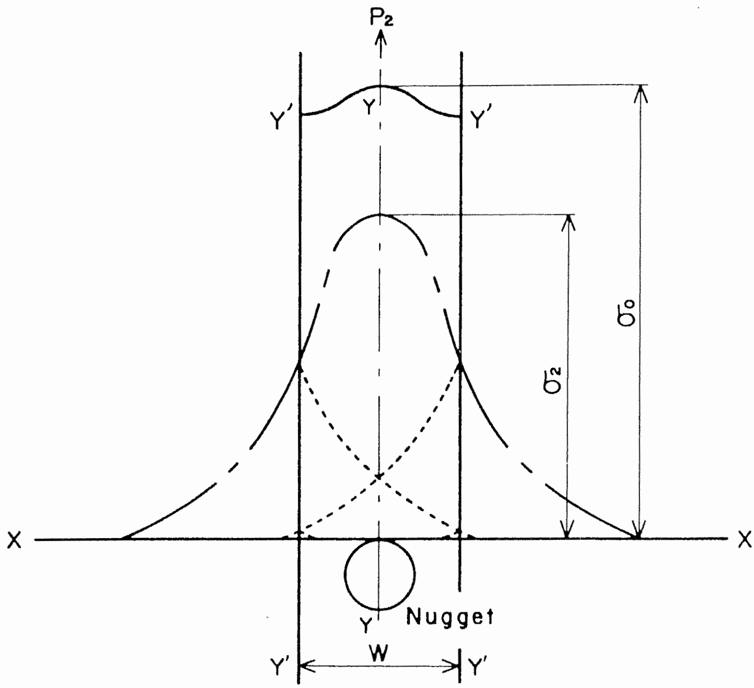

Fig. 5 Model of stress distribution for single-spot welded joint