

FATIGUE STRENGTH OF TRANSVERSE BUTT WELDS IN STEEL PLATE UNDER AXIAL LOADING

1. NOTATION

N endurance

R stress ratio = $\frac{S_m - S_a}{S_m + S_a} = S_{min}/S_{max}$

S_a alternating stress (half range) in loaded plate N/m^2 lbf/in²

S_m mean stress in loaded plate N/m^2 lbf/in²

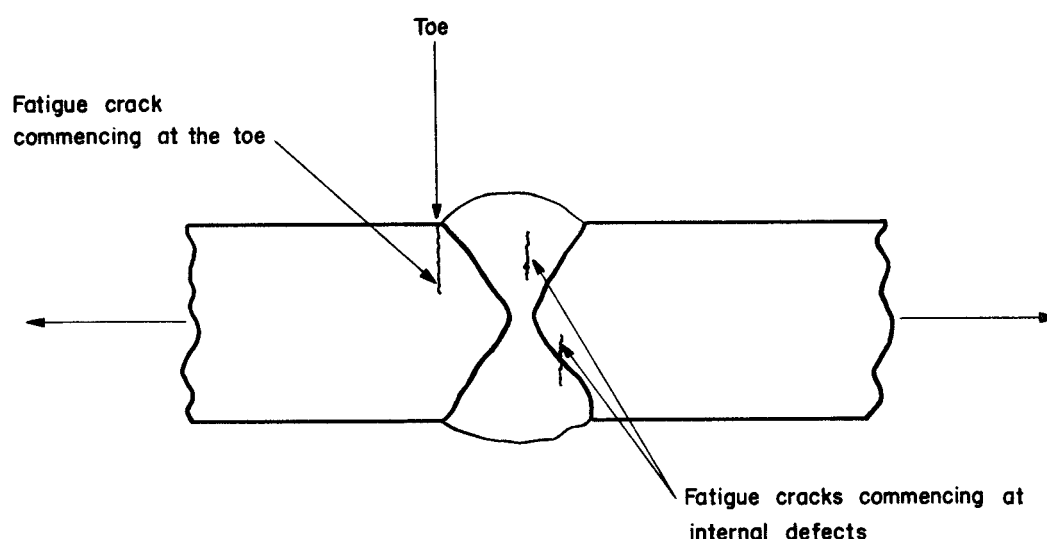
S_{min} minimum stress in loaded plate N/m^2 lbf/in²

S_{max} maximum stress in loaded plate N/m^2 lbf/in²

Both SI and British units are quoted.

2. NOTES

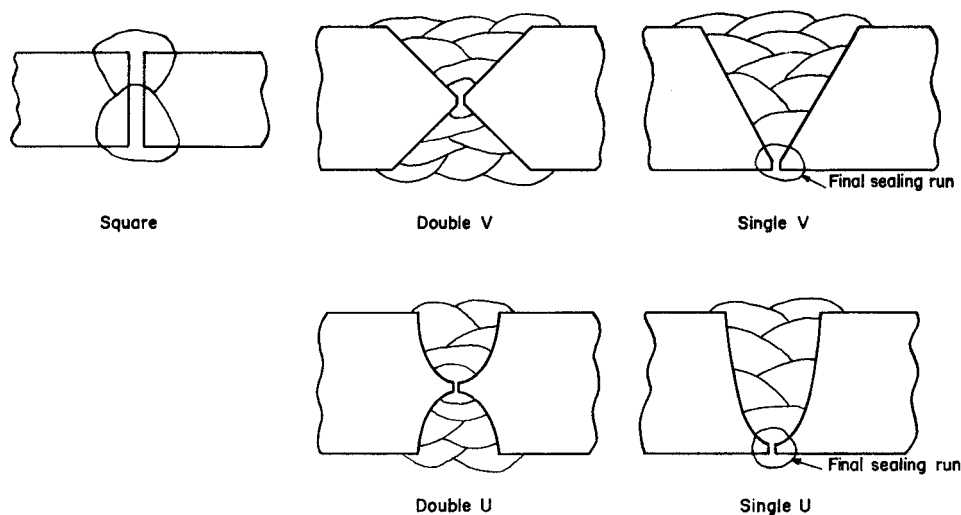
This Item provides data on the as-welded fatigue strength of transverse butt welds in steel plate under axial loading. The type of joint for which data are presented is illustrated in Sketch 2.1.



Sketch 2.1 Transverse butt weld showing types of failure

The joints were manufactured from plates between 6 mm and 50 mm thick prepared prior to welding with either square, single or double V or U weld preparation, as illustrated in Sketch 2.2, and welded from both sides. (Sealing runs were used in the case of single V or U weld preparation.) The welding methods

employed were either submerged arc welding or arc welding with flux covered electrodes. Root runs were backchipped except where backchipping was purposely incomplete to produce specific defect types and sizes that may arise from poor welding techniques that can occur in ordinary production. There was insufficient information to assess the effects of backchipping.



Sketch 2.2 Showing the types of weld preparation used for transverse butt joints

Failure may occur by the initiation and propagation of fatigue cracks from either the transition region at the toe of the weld bead or from weld defects arising from the welding process. Data for toe failures relate to specimens in the as-welded condition with the weld reinforcement intact and data for weld defect failures relate to specimens in the as-welded condition with the weld reinforcement either intact or machined flush to the plate surface.

Data for welds failing from the weld toe are given in Figures 1 and 2 and relate to tests carried out with fully tensile loading cycles and zero mean stress respectively. Figure 3 gives data for fatigue failures that started at weld defects. The distribution of the data in Figure 1 about the mean strength line was found to be sensibly Normal and statistical analysis has led to the confidence limits shown on the figure. The inner limits give bounds within which there is 95 per cent confidence that 95 per cent of the population will fall and the outer limits give bounds within which there is 99 per cent confidence that 99 per cent of the population will fall. These lines are also shown in Figures 2 and 3 for the purpose of comparison. The data in Figure 3 were not analysed statistically as, due to the large number of factors affecting fatigue strength, the distribution of data follows no acceptable form for analysis but it can be seen that the scatter is within the same range as the data in Figure 1. Figure 4 shows the reduction in fatigue strength with reduction in cross-sectional area due to various types of weld defect.

3. FACTORS AFFECTING THE FATIGUE STRENGTH

This section discusses the effects of residual stress, mean stress, joint size, weld bead shape and weld defects on the fatigue performance of the type of joint for which data are provided.

3.1 Residual Stress, Mean Stress and Size

As-welded joints contain a highly localised system of residual stresses which result from the constraints applied during cooling of the weld. In thin plates, say less than 10 mm thick, the temperature in the plate may be reasonably uniform through the plate thickness and the resulting residual stresses in the direction of loading are likely to be small (although in a wide plate the stress along the weld may be high). In thicker plates the temperature differences through the thickness will be more pronounced leading to higher residual stresses in the region of the weld. (A similar effect occurs if the plate is wide, that is, if the length of the weld is long, as a result of lateral strain setting up a complementary strain across the joint.) These stresses will be tensile in the toe region of the plate surface and compressive in the centre of the plate.

If the residual stresses are such that the applied stresses cause yielding at the weld toe then the actual stress experienced by the material at the toe of the weld bead will vary from the yield stress to the yield stress less the stress range. Thus, application of high alternating and/or mean stress, magnified by the stress concentration at the toe of the weld bead and any residual stress, will give a yield limited condition. However, if the mean stress and stress range are low this yield limited condition may not apply. These two conditions are illustrated by the differences between Figures 1 and 2 at lower values of S_a where for cases where $R = -1$ (Figure 2) the mean stress is zero and the yield limited condition does not apply leading to increased endurance. In the absence of positive assurance that the residual stresses in the direction of loading are insufficient to cause yielding it ought to be assumed that this yield limited condition prevails. This implies that the fatigue resistance will be low, that is, the fatigue strength will fall towards the lower boundary of the scatter band in Figure 1.

The fatigue strength of these joints is independent of the properties of plate and weld materials except in the low cycle region, where the applied stress approaches the tensile strength, or for compressive mean stresses.

3.2 Weld Bead shape

In the absence of severe weld defects, see Section 3.3, fatigue failure will start at the plate surface in the transition region between the plate and weld materials. Fatigue cracks start at small defects, typically up to 0.5 mm in depth, and subsequently propagate transverse to the loading direction to cause failure. The weld bead produces a stress concentration at the weld toe, the magnitude of which is determined by the local geometry of the bead. In general the smoother the transition from the plate surface to the weld bead and the smaller the weld bead the lower the stress concentration and, consequently, the higher the endurance. Submerged arc welding tends to give a poor weld bead profile and can produce a lower fatigue strength than that of a manually welded joint.

3.3 Weld Defects

Defects can be sufficiently severe to cause fatigue cracks to form and subsequently propagate from their extremities. Defects such as porosity, voiding, slag inclusion, lack of fusion, lack of penetration or any combination of these, may arise from the welding process. The severity of these defects is determined by their size, location and distribution in the weld. The data in Figure 3 are for specimens that failed at a defect. The data cover specimens, with or without the weld bead reinforcement, tested at stress ratios of both $R = 0$ and $R = -1$. As the figure shows, the fatigue strength can vary from that of the parent plate to a strength lower than that for the toe failures shown in Figures 1 and 2.

The parameter commonly used to describe defect severity is the percentage reduction in gross cross-sectional area brought about by weld defects. Figure 4 shows the relationship between the reduction in area due to weld defects and the corresponding reduction of fatigue strength below that of a defect-free weld, which, for the majority of cases, was coincident with the top of the scatter band on Figure 3. However,

reduction in area is not the only parameter that can be used to describe weld defects and may not be the correct parameter for all defect types. Figure 4 indicates the trends and uncertainty in such an analysis. In general, the larger the defect causing failure the lower the endurance, although the largest defect present does not necessarily contribute to the failure process. Where the defect breaks the surface of the weld, the larger the defect the lower will be the fatigue strength; however, if defects are fully enclosed within the bulk of the material, the fatigue strength is dependent upon their location and shape. Consequently the largest defect may not lead to the lowest fatigue strength and the scatter in the fatigue strength is large. If a defect is centrally located in the joint thickness it will initially be in a state of residual compressive stress but failures can nevertheless occur. If a defect is not centrally located the fatigue strength is likely to be lower owing to lower compressive or to tensile residual stress. Where low hydrogen (basic) electrodes are used the fatigue strength can be up to 40 per cent greater than that found in a joint welded with rutile electrodes, provided the defects are fully enclosed. No improvement due to the use of low hydrogen electrodes is found if the defect breaks the weld surface. A defect that breaks the weld surface is, in general, more severe than an internal defect of the same dimensions.

4. DERIVATION

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