

THE EFFECT OF POST-WELD TREATMENTS ON FATIGUE AT FILLET WELDED ATTACHMENTS

1. INTRODUCTION

This Item provides information on the effect of post-weld treatments on the as-welded fatigue strength of non-load-carrying longitudinal and transverse fillet welded attachments to steel plates subjected to axial fatigue loading. The attachments covered by this Item are transverse fillet welded attachments, longitudinal stiffener and flange type attachments and wing butt welds, as illustrated in Sketch 3.1.

The fatigue strengths at fillet welded attachments in the as-welded condition are given in Items Nos 75016 and 76007. Where the as-welded fatigue strength is unsatisfactory, redesign is the best solution, and post-weld treatment should be used only when redesign to give improved geometry and/or lower stresses is not practically or economically feasible.

2. NOTATION

K	elastic stress concentration factor based on stress in loaded plate (at weld toe for transverse attachments and at end of weld run for longitudinal attachments)		
P	load applied to plate (see Sketch 3.1)	N	lbf
R	stress ratio = $S_{min}/S_{max} = (S_m - S_a)/(S_m + S_a)$		
S_a	alternating stress (half range) in loaded plate	N/m ²	lbf/in ²
S_m	applied mean stress in loaded plate	N/m ²	lbf/in ²
S_{min}	minimum stress ($S_m - S_a$) in loaded plate	N/m ²	lbf/in ²
S_{max}	maximum stress ($S_m + S_a$) in loaded plate	N/m ²	lbf/in ²
S_y	yield stress	N/m ²	lbf/in ²

Both SI and British units are quoted.

3. GENERAL PRINCIPLES

As-welded joints contain a highly localised system of residual stresses resulting from internal constraints arising during cooling of the weld. Experience shows that these stresses in the critical regions at the weld toe and the ends of weld runs are often tensile. Residual stresses in the direction of welding are high, usually of the order of the material yield strength, whereas stresses at 90 degrees to the direction of welding are not necessarily of this magnitude but depend on plate thickness. In thin plate the temperature during cooling is reasonably uniform through the thickness of the plate and the resulting transverse and through thickness stresses are likely to be small although stresses along the weld may be high. In thicker plates the temperature differences are more pronounced and the larger is the section that remains relatively cool during welding

the higher are the residual stresses in the region of the weld. Therefore in very thick joints the transverse and through thickness stresses will be of the order of the material yield strength. Because of this the plate thicknesses are given on the figures.

Longitudinal fillet welded attachments are stressed along the line of the weld. Since the residual stress in this direction is of the order of yield, any applied loading will cause local yielding in the region of the stress concentration at the end of the weld run during the first few load cycles. This causes the actual stress experienced in the critical region to cycle between the yield stress and the yield stress less the local stress range, that is from S_y to $(S_y - 2KS_a)$.

In transverse fillet welded attachments the joint is loaded at 90 degrees to the welding direction. The maximum stress developed at the stress concentration at the weld toe is the sum of the residual stress and $K(S_m + S_a)$. If this sum exceeds the yield stress, S_y , local yielding will occur and, locally, subsequent cycles will range from S_y to $(S_y - 2KS_a)$. In thinner joints the residual stresses tend to be low and hence low applied stresses may not cause local stresses to exceed yield.

The condition where the residual and applied stresses are high enough to cause local yielding in critical regions is termed the yield limited condition. Where this condition applies the stress experienced at stress concentrations will cycle between the yield stress and the yield stress less the applied stress range irrespective of applied mean stress or the material yield strength. If however the residual stresses are low, as in the case of transverse fillet welded joints in thin plate, or can be brought to a low level by post-weld treatment, then the effects of mean stress may become evident. If the mean stress is such that, at the stress range applied, the maximum local stress is less than yield the fatigue life will be greater than that found if the same stress had caused the yield limited condition. If the yield limited condition does not apply then lowering the mean stress applied will give an increase in endurance; the effect of mean stress will be more noticeable at lower alternating stresses. The effect of the joint being out of the yield limited condition is to rotate the fatigue curve for as-welded joints anticlockwise, see Sketch 5.1. The point about which this rotation occurs is dependent upon the residual and applied stress but for cases where the applied stress cycle is fully tensile this rotation is about the material's yield stress, see Sketch 5.2.

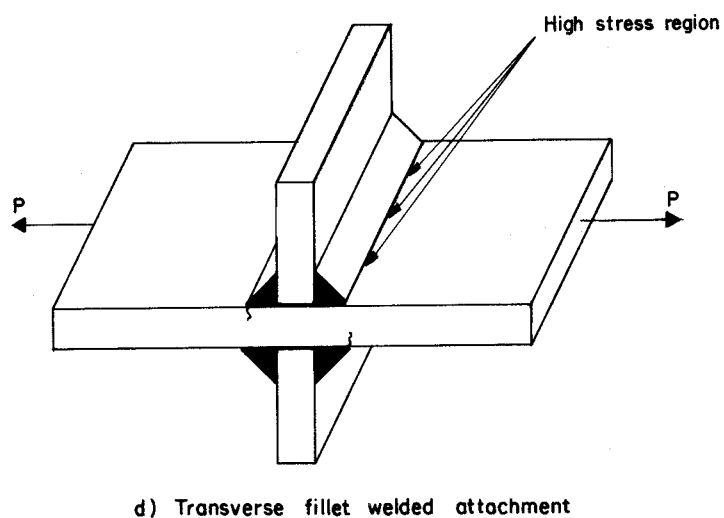
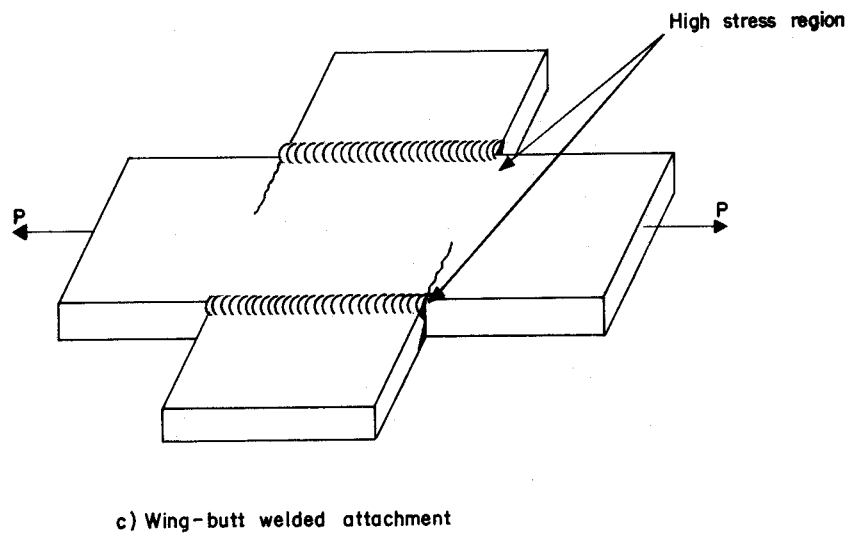
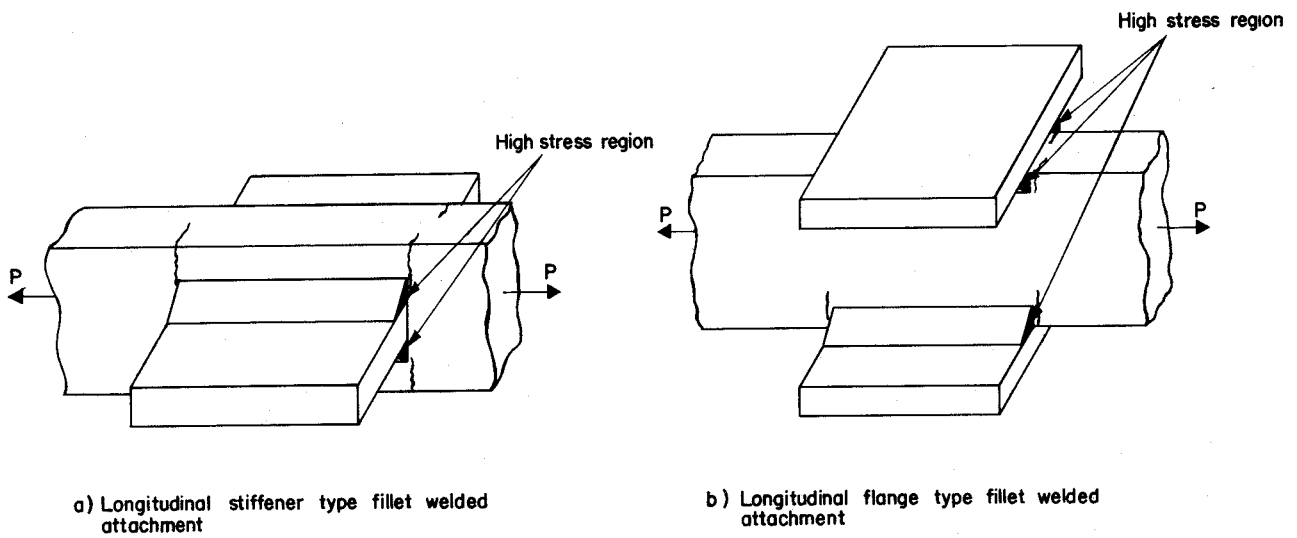
Improvements in fatigue strength can be brought about both by reducing the stress concentration factor, K , and/or reducing the residual stress. The fatigue strength can also be improved by removing defects at points of stress concentration from which fatigue cracks may grow to cause failure.

Post-weld treatments fall into three categories:

1. shape changing methods, for example weld profile grinding,
2. mechanical methods, for example peening or prior overloading, and
3. thermal methods such as stress relieving.

The following sections deal with the above three categories in turn. Treatments for which insufficient data are available or in which application methods are ill-defined are dealt with separately in Section 7. Summaries of these processes and their effects are given in Table 9.1. Improvement in fatigue strength may not always be the main reason for applying these processes.

Combinations of processes can be used as long as care is taken to apply them in the correct order. Shape changing processes are always beneficial as they reduce K and hence the local stress range. The effects of processes that alter the state of residual stress are not always so. This is because applied stresses can be such that even after treatment the yield limited condition applies or because subsequent treatment can remove material containing a beneficial stress system.



Sketch 3.1 Attachments covered by this Item

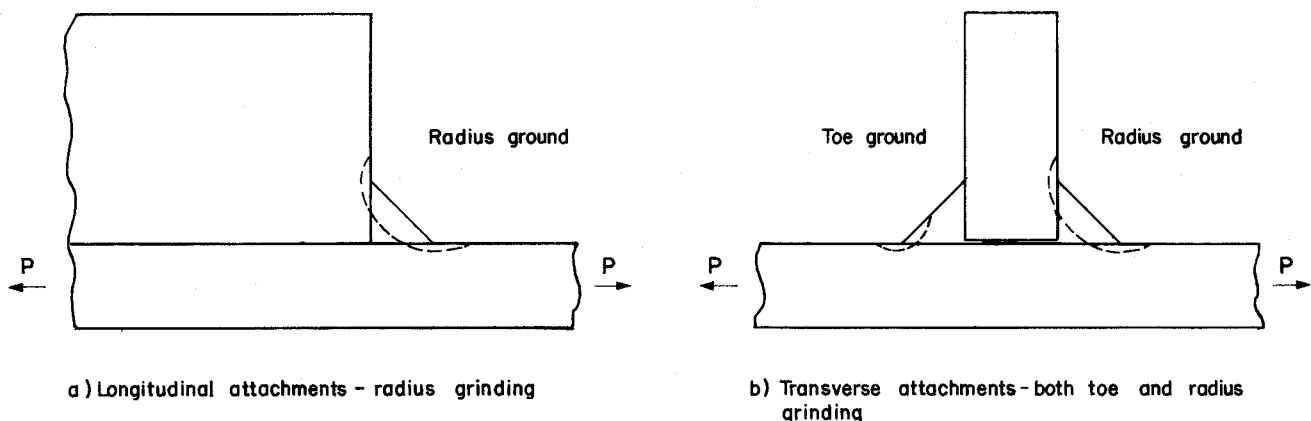
The improvements produced are determined by the method used, process variables and, to a great extent, by the skill and efficiency of the operator. **Care must be taken when applying these methods in practice as application of the wrong method (or the correct method applied in the wrong position or the wrong order) can reduce the fatigue strength.**

4. SHAPE CHANGING METHODS

The purpose of a shape changing process, either grinding or tungsten-inert-gas welding, is to increase the plate-to-weld transition radius, so reducing the stress concentration and hence increasing fatigue strength, and also to remove surface defects likely to be sites for initiation of fatigue cracks at critical regions of the joint.

4.1 Grinding of the Weld Profile

This process can be applied to both transverse and longitudinal welds. Grinding can be either light, involving grinding of only the transition region between the plate and weld materials, or full, involving radius grinding at the end of the weld run in longitudinal joints and along the toe of the weld in transverse joints (see Sketch 4.1).



Sketch 4.1 Illustrating the application of grinding to fillet welded attachments (exaggerated for clarity)

Since grinding alters the stress concentration in critical regions, improvements are produced at all applied stress levels so, in effect, the fatigue curve is lifted, without rotation. Improvements of 50 per cent in fatigue strength can reasonably be achieved by correct application of this method, see Figures 1 and 2, but even greater improvements are possible.

Grinding is of particular benefit in transverse fillet joints where even light grinding gives marked improvement in fatigue strength. Figure 1 gives data for transverse joints that have been ground and compares these with data for as-welded joints (from Item No. 75016). Light grinding has little effect at the ends of longitudinal weld runs as a severe stress concentration remains, associated with the change in stiffness, irrespective of the state of the ends of the weld run. Thus in longitudinal joints the stress concentration, coupled with the high residual stress is enough to give the yield limited condition even after light grinding, and reduction of applied mean stress has little effect on fatigue strength. Figure 2 gives data for longitudinal joints that have been radius ground such that the end of the attachment is contoured along with the ends of the weld run, and compares this with data for as-welded joints (from Item No. 76007).

4.2 Tungsten-Inert-Gas (TIG) Weld Run at the Weld Toe

This method consists of an additional run over the weld toe with a non-consumable tungsten electrode shielded with an inert gas which, although depositing no new weld material, remelts the surface material in the region of the weld toe. On solidification a smooth, larger, transition radius is formed which is relatively free of defects. This method is particularly useful for transverse welds. Data for joints treated using this process are given in Figure 1. The degree of improvement is the same as that produced by grinding.

5. MECHANICAL METHODS

Mechanical methods involve changing the residual stress state at the critical regions of welds. Two processes of this kind are peening and heavy shot blasting of the critical regions which causes plastic yielding and leaves the surface of the weld in a state of residual compressive stress. These processes may also lead to a beneficial increase in the radius of transition, some defects are removed and some work hardening of the weld material occurs thus giving an increase in fatigue strength. Another process is prior overloading which gives static tensile stressing in the direction of the intended fatigue loading such that yield is exceeded locally. On relaxation the local stresses are reduced and may become compressive.

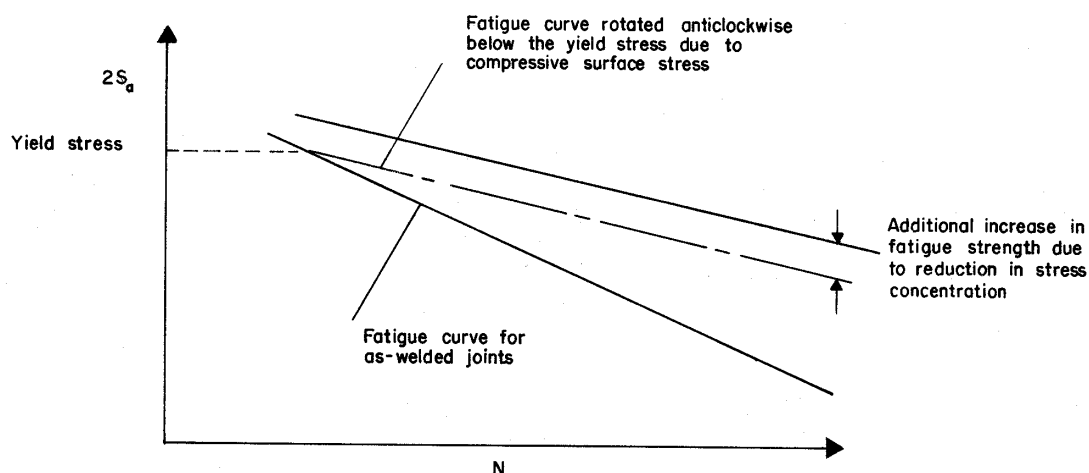
Methods which at present are unsatisfactorily defined are vibrational stress relief, causing reduction of peak residual stresses, and spot pressing, involving application of concentrated compressive load adjacent to points of stress concentration in longitudinal joints. These methods are discussed briefly in Section 7.

5.1 Peening

Peening is useful for both longitudinal and transverse welds. Improvements in performance depend upon the magnitude of the compressive stress introduced into the surface layer of the welds by the peening tool. The harder the joint is peened the greater the improvement found. A solid tool produces greater improvement than a multi-point tool. The effect of peening using a solid tool on transverse welds is given in Figure 3 and for longitudinal welds in Figure 4.

In transverse welds the compressive stress induced is sufficient to take the joint out of the yield limited condition, see Section 3. In longitudinal welds the fatigue curve was found to rotate. No difference in fatigue strength for attachments welded around the ends and those not welded around the ends was found.

Peening applied after grinding gives added improvement but grinding after peening simply removes the beneficial effects of the peening process.



Sketch 5.1 Expected effect of peening on the fatigue behaviour of fillet welded attachments