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FOCAL POINT

"Local Control of Microstructure"

EFFECTS OF PEENING ON THE FATIGUE PERFORMANCE OF ALUMINIUM ALLOY FILLET WELDS*

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SYNOPSIS. An investigation has been made of the effects of surface peening on the fatigue characteristics of aluminium alloy specimens having load-carrying fillet welds to see if the improved performance reported for butt welded components was also observed.

Separate batches of specimens with transverse and longitudinal fillet welds were tested in the peened and unpeened conditions over wide stress ranges involving high tensile preload/low cyclic loads and low tensile preload/high cyclic loads. Peening of the welded regions with a needle gun was carried out either before or after the application of the preload. Tests have shown peening to be beneficial under most conditions, notably when peening was carried out after preloading. Field trials are currently in progress.

1. INTRODUCTION

It is now widely realized that peening to induce surface compressive stresses may improve the repeated-tension fatigue properties of steel and aluminium components, and a similar trend has been observed in results for specimens containing butt welds [1, 2]. Less information is available about fillet welds, although Gurney [3] and Knight [4] have reported that peening was beneficial for several welded steels.

So far as aluminium alloys are concerned, Gurney [5] has shown that the residual stresses induced by spot heating or local compression may increase the fatigue strength of both load-carrying and non-load-carrying fillet welds. Less attention seems to have been given to the effects of peening. Brine *et al.* [1] have reported that, except for relatively short-life high-stress conditions, peening caused negligible change in the fatigue strength of transverse, load-carrying fillet welds in an aged aluminium-zinc-magnesium alloy. On the other hand, Sanders [6] has reported that peening of certain aluminium-magnesium alloys consistently improved the fatigue strength of transverse, but not longitudinal fillet welds.

The Australian Welding Research Association considered that more information should be obtained concerning the effects of peening on the fatigue properties of aluminium alloys containing fillet welds, and this paper presents results of an investigation involving separate batches of specimens with transverse and longitudinal fillet welds. The work was reported, in part, at the International Institute of Welding 1976 Public Session in Sydney [7].

2. DESIGN OF SPECIMENS

(a) *Specimens with Transverse Fillet Welds*

(i) In order to examine the effects of peening, it was necessary to design a standard specimen in which fatigue cracks would initiate at the outer surface of the welded joint. Moreover, testing requirements dictated that the geometry of the specimen had to be such that minimal misalignment of the two ends occurred due to residual stresses generated as a result of welding. Three configurations were tried and the final design that was chosen is shown in Fig. 1.

The specimen may be described as a fillet welded, double-strap, butt-joint. The butted members were 50 × 6.3 mm in section, the straps were 50 × 9.5 mm in section and each specimen was 30 cm long. The specimens were prepared in batches of six from continuously MIG welded plates which were made from the aluminium-magnesium alloy B5083-H321 using a 5356 filler wire.

Static tensile tests were carried out on three specimens selected from

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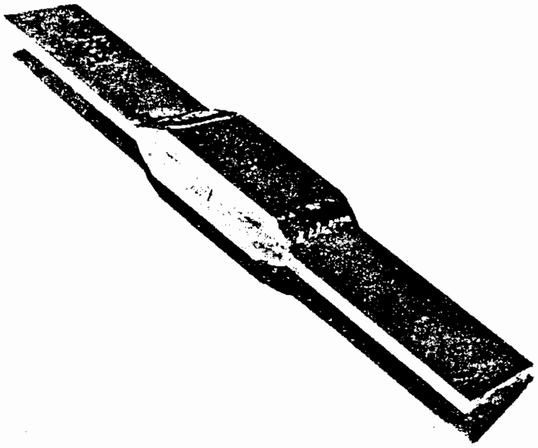

Fig. 1. *Transverse fillet welded, double-strap, butt-joint specimen*

Fig. 2 Cylindrical fillet welded specimen containing stop-start weld beads (e.g. A)

Fig. 3. Specimen containing longitudinal fillet welds

different plates and gave consistent tensile strength values of 322, 324, and 331 MPa, failure occurring in the heat-affected zone close to the welds.

(ii) Stop-start welds usually cause a discontinuity in a weld and provide a a likely place for the initiation of fatigue cracks. Thus there would be obvious economic advantages if it could be shown that confining peening solely to the region of stop-start welds led to improved fatigue performance. It was decided therefore to investigate this possibility in more detail using a cylindrical design of specimens (Fig. 2) to eliminate edge effects. The same alloys were used and static tests showed that tensile load* at failure averaged 48.5 kN.

(b) *Specimens with Longitudinal Fillet Welds*

Longitudinal fillet welds also present a situation in which peening, if effective in improving fatigue behaviour, may need be confined only to certain locations such as the ends of weld runs. Accordingly a specimen of the same alloys was designed having longitudinal fillet welds (Fig. 3) and fatigue tests were made on batches with and without the ends of the weld runs peened.

3. TESTING DETAILS

(a) *Peening*

Some thought was given to using a method of peening that could readily be applied in practice and that would give an acceptable surface appearance. A Jason needle gun (Fig. 4) was finally selected for this purpose which gave the surface finish shown for each type of weld in Fig. 5. Attention was also given to the possibility of peening by another method and experiments were carried out with a riveting gun fitted with hammers of differing end contour. In general it was necessary to indent the specimen quite deeply in order to peen the groove at the toe regions of welds unless a relatively sharp tool was

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* Results are quoted as loads rather than stresses, as the latter values could not readily be estimated because of the shape of the specimens.

used. Such peening was hard to control and surface damage proved to be unacceptable.

For the transversely welded, double-strap butt-joint, the toe regions of all four welds on each specimen were peened in the manner shown in Fig 5 (a), the time taken for each 5 mm length of weld being approximately 10 s.

In the case of the cylindrical specimens, peening was confined to regions containing a stop-start weld bead. Similarly, the specimens with the longitudinal fillet welds were peened only at the ends of the weld runs as mentioned above (Fig. 5 (b)).

Fig. 4. Jason needle gun used for peening welded regions

(b) *Fatigue Testing*

Most tests were carried out under pulsating axial loading conditions using an Amsler Vibrophore machine operating at 100 Hz. The exception was the series of specimens containing the longitudinal fillet welds which were tested at 10 Hz in a servo-hydraulic machine.

Two series of tests were conducted for the double-strap butt-joint specimens:

(i) Specimens were tested with a small preload and high cyclic stress. The preload was +13.8 MPa and the cyclic stress range was ±27.4 to ±69 MPa. Thus the actual stress range was +41.4 MPa and −13.8 MPa to +82.8 MPa and −55.2 MPa. Tests were continued to failure or until some 3–5 × 10^7 cycles had elapsed.

A problem was encountered with several peened specimens in this series in that crack initiation was transferred from the normal location at the toe of the weld (A in Fig. 5(a)) to an internal surface at the root of the weld (B in Fig. 5(a)). This behaviour indicates a deficiency in specimen design and must be attributed to the effect of peening in improving the resistance to fatigue cracking at the toe of the weld. Accordingly, specimens that had failed in this way have been shown as being unbroken for the number of cycles recorded.

(ii) Specimens were tested with a high preload and low cyclic stress which represents a more practical situation. A cyclic stress amplitude of 30% of the preload was selected which corresponds to a constant stress ratio of 0.54, on a Goodman-type diagram [8]. The testing range was +82.8 MPa ±24.6 MPa to +138 MPa ±41 MPa.

In the first tests in both series, the as-welded specimens were compared with those that had been peened prior to loading in the fatigue machine. Subsequently it was decided to determine the fatigue properties of specimens in a third condition, namely peened after the preload had been applied.

The cylindrical specimens were also tested under conditions of low preload–high cyclic load and high preload–low cyclic load. The specimens were tested in the unpeened condition, and with stop-start weld beads peened either before or after the application of the preload.

So far as the specimens with the longitudinal fillet welds are concerned, tests were made in the unpeened condition and with specimens peened at the ends of the weld runs before and after preloading. Both types of testing conditions were again used.

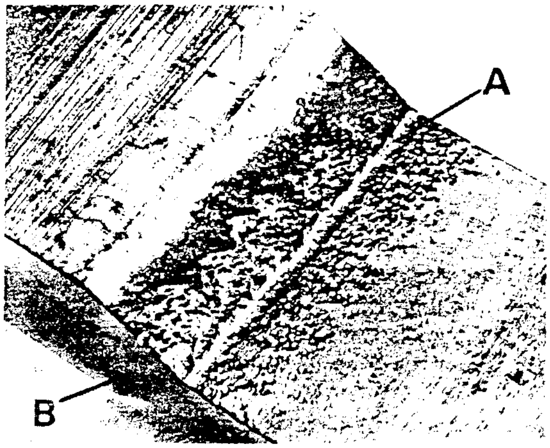

Fig. 5 (a). Peened region of specimen containing transverse fillet weld

4. EXPERIMENTAL RESULTS

(a) *Double-strap Butt-joint Specimens with Transverse Fillet Welds*

(i) Continuously Welded Specimens Tested with Low Preload and High Cyclic Stress

Test results are shown as standard S/N curves in Fig. 6. Although more individual tests would have been desirable in order to establish the precise positions of the three curves, the general shape of each seems clear. The lives of specimens peened before preloading were increased by a factor of four times for specimens that failed between 10^5 and $2–3 \times 10^6$ cycles. Alternatively it can be said that, for equal lives up to approximately 10^6 cycles, the peened specimens could accommodate approximately 40% higher stress levels. On the other hand, for stress levels giving lives in excess of 10^7 cycles, it is probable that the endurance limits for each type of specimen were relatively close although more tests are needed to confirm this. The general effects of peening were similar to those recorded by Brine *et al.* [1] for an

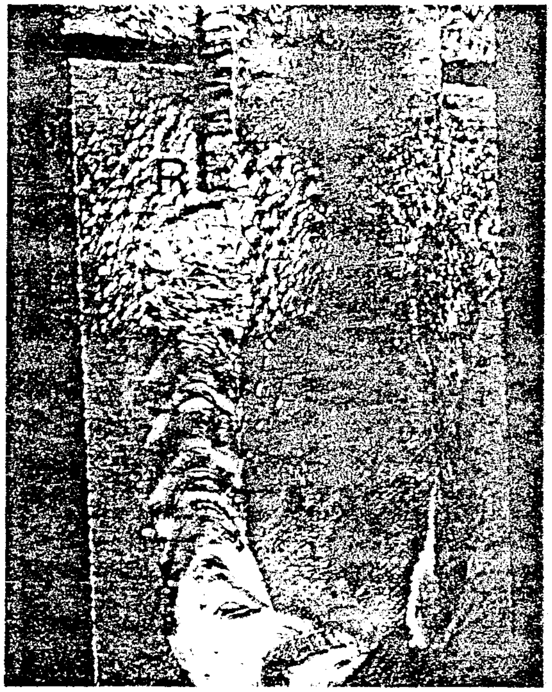

Fig. 5 (b). Peened ends of weld runs in specimen containing longitudinal fillet welds. Note small re-entrant region at R.

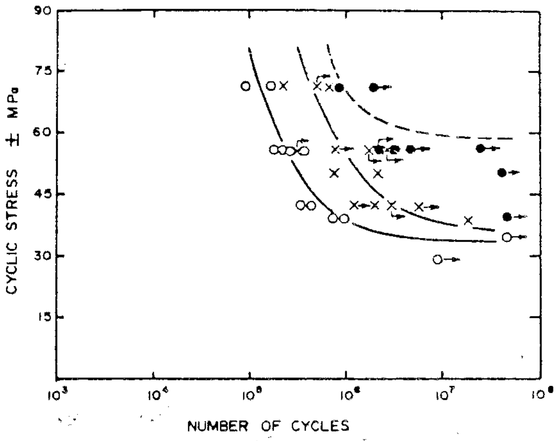

Fig. 6. S/N curves for specimens containing transverse fillet welds which were tested under conditions of low preload, high cyclic load. All specimens preloaded to a stress of + 13.8 MPa.

○ — ○ *As welded specimens*
× — × *Specimens peened before preloading*
● — ● *Specimens peened after preloading*

aluminium-zinc-magnesium alloy of rather similar specimen configuration, but which were not preloaded. However, the improvement in fatigue strength persisted for longer lives in the present work (to approximately 2–3 × 10^6 cycles compared with 2–3 × 10^5 cycles).

The S/N curve for specimens that were peened after preloading is shown dotted because of the small number of specimens that were available to test, and the fact that most were either unbroken after some 5 × 10^7 cycles, or had failed at the internal surface at the root of the weld. It is clear that fatigue lives have been increased at all levels of cyclic stress, the factor being as much as ten times. Alternatively, the specimens peened after preloading could accommodate stress levels that may be as much as 60% higher than allowable for unpeened specimens.

(ii) Continuously Welded Specimens with High Preload and Low Cyclic Stress

Tests were again carried out on specimens that were in the as-welded, peened-before-preloading and peened-after-preloading conditions, and the individual results are contained in Table 1. In this case, peening before preloading had little effect at high stress levels but gave some increase in lives when stress levels were lower. As in the other series of tests, peening after preloading appeared to give significant increases in lives over the entire stress range that was investigated.

TABLE 1. Fatigue Tests on Continuously Transverse Welded Specimens with Constant Stress Ratio of 0.54

	Cycles to Failure × 10^5			
Preload Cyclic stress	+138 MPa ± 41 MPa	+111 MPa ±32.8 MPa	+89.5 MPa ±26.7 MPa	+82.8 MPa ±24.6 MPa
Unpeened specimens	2.1 2.0	8.0 7.5 2.9 3.5	7.5 7.2 7.6 22.3 42.0	110 14.8 260 *U*
Peened before preloading	1.5 1.4 2.1	8.9 2.7 6.8	10.9 33.9 198 *U* 12.2 19.0	160 *U*
Specimens peened after preloading	6.6 6.0 4.9	8.4 12.4 340 *U* 7.6 17.0	17.6 198 *U* 190 *U* 22.4 26.0	245 *U*

Note: Where failures occurred, cracking always took place at the toe of the welds.
U = Unbroken.

(b) *Cylindrical Specimens with Transverse Fillet Welds Containing Stop-start Weld Beads*

Results of fatigue tests are shown in Table 2. As a generalization, it can be said that the arithmetic average fatigue lives of specimens for which the stop-start welds were peened were about double those of unpeened specimens. The actual scatter of individual results was such that peening could be ineffective or improve lives by as much as four times. Thus, confining peening to the regions of stop-start welds is marginally beneficial, and overall is less effective in improving fatigue properties than was shown to be the case for specimens

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with fillet welds that were completely peened.

Another observation was that, although comparatively few tests were made with specimens peened before the application of the preload, it did seem that the timing of peening with regard to pre-loading was less critical than was clearly shown to be the case with continuously welded and peened specimens.

(c) *Specimens Containing Longitudinal Fillet Welds*

It seems clear that the results for the longitudinal fillet welds follow a similar pattern to that recorded for the specimens with transverse welds (Table 3). Peening after the application of a preload caused a marked increase in fatigue lives in all but the very highly stressed conditions. Average lives were increased progressively as the levels of preload and cyclic load were reduced and factors of three and five times respectively were recorded for the two types of tests. Peening prior to the application of a tensile preload was still found to be beneficial when preloads were low, but was ineffective for high levels of preload.

Peening the ends of longitudinal fillet welds is an inexpensive procedure and offers good prospects for increasing service lives under fatigue conditions. It should be noted, however, that there may be re-entrant regions at the ends of such welds which makes peening difficult (e.g. R in Fig. 5 (b)). Thus, it would seem inadvisable to permit an increase in design stresses in peened components or structures which contain such welds.

TABLE 2. Fatigue Tests on Cylindrical Specimens (Peening Confined to Region of Stop-start Welds)

(a) Tests with High Preload and Low Cyclic Load (Constant Stress Ratio of 0.54)

Loading Conditions	Unpeened Specimens (Lives × 10^5)	Peened After Preloading (Lives × 10^5)	Peened Before Preloading (Lives × 10^5)
+22 kN ±6.53 kN	4.5	4.3	6.3
	7.3	9.7	5.4
	3.1	10.3	13.2
Average	4.9	8.1	8.3
+18 kN ±5.37 kN	11.4	44.7	not done
	19.0	36.3	
	18.0	31.1	
		26.3	
Average	16.1	34.6	

(b) Tests with Low Preload and High Cyclic Load

Loading Conditions	Unpeened Specimens (Lives)	Peened After Preloading (Lives)
+3 kN ±12 kN	8.4	20.2
	10.8	11.2
	6.0	6.1
Average	8.4	12.5

5. CONCLUSIONS

(a) Several conclusions can be drawn from the investigation that would seem to apply generally with regard to the effects of needle peening the toe regions of continuous transverse, load-carrying fillet welds in aluminium alloys:

(i) Peening after the application of a preload may cause a notable increase in fatigue resistance over a wide range of preloads and levels of cyclic stress. For low preloads and high values of cyclic stress, fatigue lives were increased by approximately ten times, whereas for equal lives, the level of cyclic stress that could be accommodated was some 60 per cent higher for the peened specimens. Rather similar behaviour was recorded for the specimens tested in the more practical situation of high preloads and low values of cyclic stress.

(ii) Peening before the application of a preload also increased fatigue resistance at most stress levels although the effects were less than those recorded if preloading was carried out before peening. This result is to be expected as high preloads would cause a significant redistribution of stresses and thereby tend to nullify the desirable compressive surface stresses introduced by peening. For the low preload, high-cyclic stress specimens, fatigue lives were increased some four times for specimens that failed between 10^5 and 2–3 × 10^6 cycles. On the other hand,

TABLE 3 Fatigue Tests on Specimens with Longitudinal Fillet Welds
(Tests Conducted at 10 Hz. Lives in Number of Cycles × 10^5)

(a) Tests with High Preload and Low Cyclic Load (Constant Stress Ratio of 0.54)

Loading Conditions	Unpeened	Peened Before Preloading	Peened After Preloading
+44 kN ±13.06 kN	3.2 2.3	not done	2.7 3.3
Average	2.7		3.0
+36 kN ±10.07 kN	7.3 6.3 9.2 12.6 8.6 7.8	not done	14.4 16.0 11.2 9.7 26.6
Average	8.6		15.6
+ 30 kN ±8.33 kN	15.8 26.1 12.9 12.3	12.8 22.7 17.4 18.1	63.8 30.1 45.9 51.6
Average	16.8	17.7	47.9

(b) Tests with Low Preload and High Cyclic Load

Loading Conditions	Unpeened	Peened Before Preloading	Peened After Preloading
+6 kN ±24 kN	6.5 10.8 6.7 9.7	not done	25.8 17.2 25.9 16.4
Average	8.4		21.3
+4.5 kN ±18 kN	10.8	not done	33.3
+4 kN ±16 kN	19.0 14.0 16.4 15.7	40.0 49.3 40.9	121 55.7 99.5 79.2
Average	16.2	43.4	88.7

whereas peening had little effect on the high-preload, low-cyclic stress specimens tested at high stress levels, notable increases in fatigue lives were recorded for most low-stress, long-life specimens.

(iii) Confining peening solely to the region of stop-start welds gave marginal improvements in fatigue properties for most test conditions. In such cases the timing of the peening operation with respect to the applications of the pre-load seemed less critical than was the case with continuously welded and peened specimens.

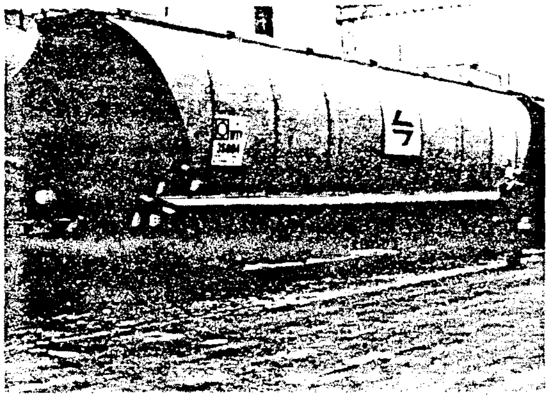

Fig. 7 (a). Welded aluminium alloy railway wagon

Fig. 7 (b). Peened end of one fillet weld

(b) A similar pattern of results was obtained for specimens with load-carrying longitudinal fillet welds which were peened at the ends of weld runs. Increases in fatigue lives of three and five times were recorded for specimens peened after the application of preloads and tested with high preloads–low cyclic loads and low preloads–high cyclic loads respectively.

(c) So far as the method of peening is concerned, needle peening proved to be a simple and satisfactory method of applying compressive stresses at the surface regions of a weld. An alternative technique of using a riveting gun caused unacceptable surface damage.

6. FIELD TRIALS

Three separate field trials are in progress in which the fillet welds on one side of an aluminium alloy truck tipper body and on one side of a number of aluminium alloy coal and wheat carrying railway wagons have been peened. For the truck tipper body and one set of railway wagons, peening had to be carried out prior to the application of the normal service preload. A second set of railway wagons were peened after they had been loaded with wheat, i.e. after the application of a preload, which is the more desirable practice. Fig. 7 shows one of these wagons and a view of the peened end of one of the longitudinal fillet welds. No results are yet available from any of these trials.

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