Effects of GTA Dressing on the Fatigue Properties of Aluminum Alloy Welded, Butt Jointed and Fillet Welded Plates

The GTA dressing of toe regions in critical welded butt joints and fillet welds appears to be a simple, permanent method to enhance fatigue behavior for a wide range of loading conditions

BY I. J. POLMEAR AND D. R. WILKINSON

ABSTRACT. A study of the fatigue behavior of 5083 aluminum alloy plates containing transverse welded butt joints and fillet welds has shown that GTA dressing on the toe regions of welds may increase average lives by factors ranging from two to seven times. This beneficial effect can be correlated directly to a reduction in the notch effect at weld toes due to the dressing operation.

Introduction

Welding of aluminum alloys usually causes softening of the heat-affected zones adjacent to welds, and the mechanical strength of components or structures may be substantially reduced. Fatigue properties are also decreased, and this effect is aggravated when the weld geometry leads to the concentration of stress, particularly at the toes of welds.

Earlier work in the present program involved a study of the effects of needle peening on the fatigue performance of fillet welds. This treatment induces compressive residual stresses and laboratory tests have shown peening to be beneficial under most loading conditions (Ref. 1). Similar results have been obtained in laboratory tests by Nordmark (Ref. 2) using shot and hammer peening on aluminum alloy welded butt joint specimens and by Montemarano and Wells (Ref. 3) in similar tests using the technique of brush shot peening of welded butt joints and fillet welds in aluminum alloy specimens.

There are, however, some limitations when applying peening as a means of reducing fatigue cracking in service applications. One is the fact that peening should be applied after the welded structure, e.g., a railway truck, has been loaded, otherwise the imposed stresses may modify the beneficial pattern of compressive stresses induced by the peening operation. The second limitation is that peening may be ineffective when welds have re-entrant angles or are relatively inaccessible.

Experience with field trials has shown that such welds may well be locations for the initiation of fatigue cracks. For these reasons, attention has now been directed at gas tungsten arc (GTA) dressing the toe regions of welds as an alternative procedure to improve fatigue behavior. This treatment involves remelting of the toe regions of welds with the aim of improving their profile so that the notch effect is reduced where the weld bead meets the base metal. Although GTA dressing has been successfully applied to steel welds (Ref. 4), comparatively little attention appears to have been paid to welded aluminum alloys and the results are conflicting (Ref. 5).

Experimental Details

Materials

The material used for the investigation was 5083 aluminum-magnesium alloy plate welded with 5456 filler metal. Plates 375 × 150 mm (14¾ × 5.9 in.) were prepared with either a welded butt joint or fillet weld in the longer dimension using the gas metal arc (GMA) process. One half of the length of all welds on each side of the plates were then GTA dressed, care being taken to concentrate the tungsten arc mainly on the weld bead so as to minimize possible undercutting of the base metal during melting.

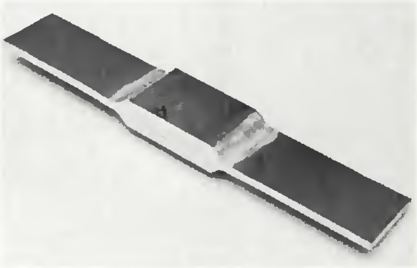
Fig. 1 — Configuration of the fillet welded specimen (GTA dressed)

Currents of 180 A and 230-250 A were used for the welded butt jointed and fillet welded plates, respectively. The rate of travel of the GTA torch was about 6 mm/s (14 ipm). Fatigue specimens were then cut transverse to the welds after the ends and mid-regions of the plates had been discarded to avoid weld starts and stops. The welded butt jointed specimens were prepared from 8.8 mm (0.35 in.) thick plate; each was 37.5 mm (1.48 in.) wide and 300 mm (11.8 in.) long.

The configuration of the fillet welded specimens was identical to that used for the peening studies — Fig. 1. They were prepared from 6.1 mm (0.24 in.) thick plate using 8.8 mm (0.35 mm) thick side straps, and each specimen was 50 mm (1.97 in.) wide and 300 mm (11.8 in.) long. A comparison of GTA dressed and undressed fillet welds is shown in Fig. 2.

Tensile Properties

Tensile tests were conducted on several dressed and undressed specimens of each type of weld and the results fell into

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the following ranges*: welded butt joint specimens — 300-335 MPa (loads 90-100 kN); fillet welded specimens — 310-325 MPa (loads 92-96 kN).

Fatigue Testing

The fatigue tests were conducted in an Amsler Vibraphore machine operating at 110-130 Hz. They were conducted under two types of loading conditions that are experienced in service:

1. High preload (maintained during the fatigue test)/low cyclic load (constant stress ratio of 0.54).
2. Low preload/high cyclic load (ratio 1:4).

In addition, stress/number of cycles (S/N) curves were determined for dressed and undressed fillet welds for which the specimens were all given the same small preload of +4 kN.

Weld Bead Profiles

After testing, polished sections were prepared from a number of welds so that measurements could be made of the following:

1. The reinforcement angle between the weld bead and base metal — Fig. 3.
2. The radius of curvature of the weld toe — Fig. 3.

An example of the effect of GTA dressing in reducing the notch effect at the weld toes is shown in Fig. 4 in which the profiles of sections of (A) undressed and (B) dressed fillet welds can be compared.

Metallography

Grain sizes in the region of welded butt joints were compared by polishing and electroetching sections which were then examined under polarized light. In addition, comparisons were made of the appearance of cracks (Fig. 3) in polished and etched specimens.

Microhardness Tests

Microhardness tests were made on polished sections of welded butt joints, traverses being taken across the weld bead/base metal interfaces as follows:

1. Close to the specimen surface.
2. Along the center of the plates.

Fatigue Test Results

Fatigue test results are tabulated in Tables 1-3. It will be noted that some individual results showed considerable scatter. These effects may be attributed to variations in the profiles at the weld toes and to minor undercutting of the base metal that sometimes occurred during GTA dressing.

Fig. 2 — Appearance of GTA dressed and undressed (GMA welded) fillet welds

Because of experimental scatter and occasional overlap in results for the dressed and undressed specimens, statistical analysis was used to determine whether or not the average fatigue lives were, in fact, significantly different. In this regard, consideration must be given to the possibility that the average of the fatigue lives of the dressed and undressed specimens both lay within the scatter band of results for either specimen.

Standard deviations are included with each set of results. The application of the t-test (Ref. 6) for comparative average values showed that the hypothesis that GTA dressing did cause a significant increase in fatigue lives led to a possible error of less than 10% for most results and less than 5% for some.

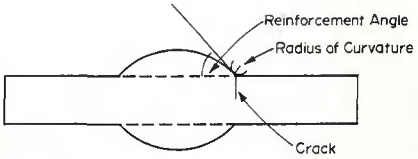

Fig. 3 — Terminology used in describing the geometry of the weld toe of a welded butt joint specimen

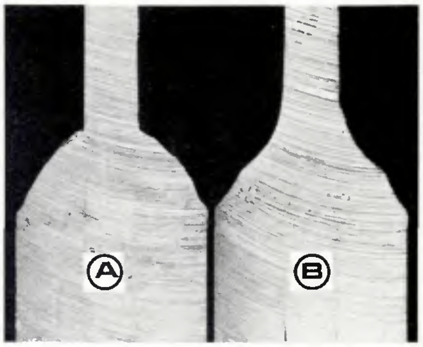

Fig. 4 — Weld bead profiles of (A) undressed and (B) dressed fillet welds

S/N Curves for Fillet Welded Specimens

S/N curves were determined for specimens of dressed and undressed fillet-welds that were fatigue tested after applying a small prestress of +13.5 MPa after GTA dressing. The results are shown in Fig. 5.

Dressing was found to improve average fatigue lives by factors ranging from

Table 1—Fatigue Test Results for Plates with Welded Butt Joints

Cycles to failure in high preload/low cyclic load tests:

Loading condition +36 kN ± 10.8 kN		Loading condition +30 kN ± 9 kN	
Undressed	Dressed	Undressed	Dressed
163,000	115,000	380,000	1,040,000
426,000	917,000	537,000	914,000
330,000	554,000	453,000	1,291,000
121,000	1,135,000	711,000	465,000
	553,000	422,000	
Averages:			
260,000	655,000	501,000	928,000
Standard deviations:			
143,000	391,000	131,000	346,000

Cycles to failure in low preload/high cyclic load tests:

Loading condition +6 kN ± 24 kN		Loading condition +5 kN ± 20 kN	
Undressed	Dressed	Undressed	Dressed
82,000	466,000	159,000	933,000
200,000	895,000	402,000	220,000
99,000	284,000	302,000	514,000
72,000	88,000	168,000	276,000
118,000	167,000	121,000	1,032,000
Averages:			
114,000	380,000	230,000	595,000
Standard deviations:			
51,000	321,000	118,000	372,000

**Conversions as follows: ksi = MPa ÷ 6.89; pound-force (lbf) = N × 0.2248. (Note that kN = 1000 N.).*

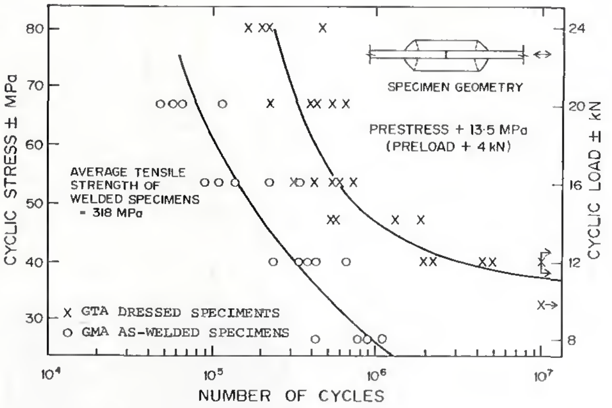

Fig. 5 — Stress/number of cycles (S/N) curves for dressed and undressed fillet welded specimens

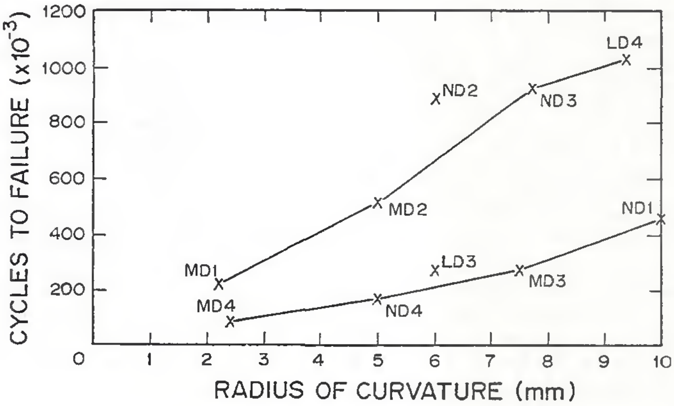

Fig. 6 — Variations in fatigue lives with the radius of curvature at the weld toe (see Fig. 3) for individual GTA dressed specimens tested at two stress levels

Table 2—Fatigue Test Results for Fillet Welded Plates

Cycles to failure in high preload/low cyclic load tests:

Loading condition +36 kN ±10.8 kN		Loading condition +24 kN ±7.2 kN	
Undressed	Dressed	Undressed	Dressed
75,000	994,000	740,000	1,551,000
117,000	315,000	427,000	1,027,000
81,000	364,000	804,000	1,172,000
96,000	842,000	512,000	7,548,000[a]
148,000	214,000	943,000	2,204,000
Averages:			
103,000	546,000	685,000	1,480,000[b]
Standard deviations:			
30,000	348,000	189,860	455,240

Cycles to failure in low preload/high cyclic load tests:

Loading condition +6 kN ±24 kN		Loading condition +4 kN ± 16 kN	
Undressed	Dressed	Undressed	Dressed
38,000	305,000	223,000	708,000
47,000	115,000	112,000	317,000
24,000	72,000	333,000	419,000
95,000	195,000	91,000	557,000
74,000	132,000	140,000	549,000
Averages:			
55,000	164,000	180,000	510,000
Standard deviations:			
28,000	90,000	88,773	133,014

(a) Specimen unbroken.
(b) Average of failed specimens only.

Table 3—Summary of Improvement Factors Attributed to GTA Dressing

Welded butt joints		Fillet welds	
Loading condition	Average improvement factor	Loading condition	Average improvement factor
+36 kN ± 10.8 kN	2.5	+36 kN ± 10.8 kN	5.1[a]
+30 kN ± 9 kN	1.9	+24 kN ± 7.2 kN	>2.1[a]
+ 6 kN ± 24 kN	3.3	+ 6 kN ± 24 kN	3.0
+ 5 kN ± 20 kN	2.6	+ 4 kN ± 16 kN	2.8

(a) >4 if result for an unbroken specimen is included.

about four times at higher levels of cyclic stress to more than seven times at lower stresses. For equal fatigue lives, the cyclic stresses that dressed specimens could sustain were found to be a minimum of 65% higher than those for undressed specimens.

Other Observations

Metallographic observations and microhardness traverses did not reveal any significant differences that could explain the effects of GTA dressing on fatigue lives. On the other hand, a definite correlation was found between the weld bead profiles and individual fatigue results. This is illustrated by comparing lives of specimens for similar loading conditions with the radii of curvature at the weld toes, longer lives being obtained with both dressed and undressed specimens having larger radii — Fig. 6.

The same correlation was found to exist if reinforcement angles were measured, longer lives being recorded with specimens having shallower angles. In each case, the reinforcement angles were the largest, or the radii of curvature were the smallest, of all those measured for the weld toes of the specimen concerned, (i.e., where the weld bead had the greatest notch effect). The particular weld toe where this occurred was also the one at which fatigue cracking initiated in most specimens.

Conclusions

1. GTA dressing has been found to improve the average fatigue lives by factors ranging from 1.9 to 3.3 times for welded butt joint specimens and from 3.0 to 5.1 for equivalent tests on fillet welded specimens. S/N curves were determined for the latter specimens and, for the ranges of experimental conditions where comparison could be made, GTA

dressing was found to cause the following improvements:

(a) For equal levels of cyclic stress, average fatigue lives were increased from four times (at ±50 MPa) to more than seven times (at < ±40 MPa).

(b) For equal fatigue lives, the average cyclic stresses that could be sustained were 70% to 100% higher.

2. The beneficial effects of GTA dressing can be correlated directly with the improvement in the profile at the toe of the welds that usually results from such a treatment. More particularly, lives increased the more GTA dressing reduced the notch effect of the weld bead. No other effects of GTA dressing were found to be significant.

3. The tests suggest that GTA dressing the toe regions of welded butt joints and fillet welds that are judged to be critical in aluminum alloy structures appears to be a simple and permanent method of giving enhanced fatigue behavior for a wide range of loading conditions. In this regard, the method is considered to be more effective than peening the welding regions. This follows because the beneficial effects of GTA dressing are associated solely with changes to the profiles of the weld toes which are unaffected by subsequent service conditions. On the other hand, the compressive residual stresses induced by peening can be modified by service stresses. Moreover, peening may be ineffective where welds have re-entrant angles.

Acknowledgment

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Weldability and Fracture Toughness of Quenched and Tempered 9% Nickel Steel: Part I—Weld Simulation Testing
by A. Dhooge, W. Provost and A. Vinckier

An investigation on the weldability of a quenched and tempered 9% Ni steel using weld simulation and artificial aging to estimate the heat-affected zone ductility at cryogenic temperatures is reported in Part I. Charpy-V bars were subjected to various weld simulation cycles and subsequent heat treatments and, after notching, broken at a range of cryogenic temperatures.

Weldability and Fracture Toughness of Quenched and Tempered 9% Nickel Steel: Part II—Wide Plate Testing
by A. Dhooge, W. Provost and A. Vinckier

In addition to standard impact and tensile tests, a large number of wide plate specimens welded with various consumables and welding processes were tested to evaluate the toughness and defect acceptability of 9% Ni steel in plate thicknesses greater than 25 mm.

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