ALUMINIUM WELDMENTS

Second International Conference
Munich, May 24 to 26, 1982

– Proceedings –

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Düsseldorf

Aluminium Weldments

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Preface

Aluminium viewed in terms of a life-cycle-curve including product introduction, growth, maturity, and degeneration is a "young" metal, which will undergo further developments in the coming decades. A development which is to be realized in rather new environmental conditions and to be accomplished through new methods and intensified efforts in research, creativity and innovation on the part of the industry. An existing wealth in knowledge must yet be scientifically analyzed, understood and rationally put into use. The Second International Conference on Aluminium Weldments should be understood as a contribution towards this goal.

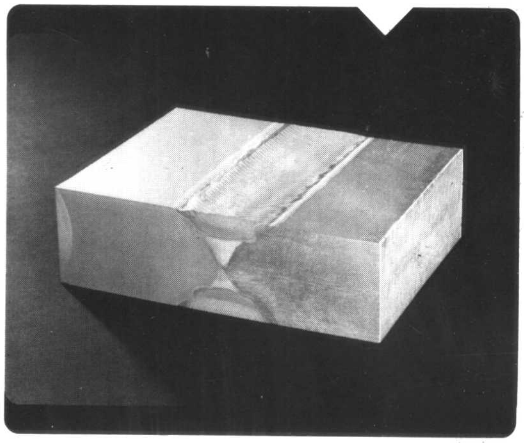
Welding is a key jointing method for aluminium structures all over the world. We are especially happy about the fact that a great number of distinguished researchers and colleagues representing most of the technologically advanced centres in development and design of aluminium constructions have contributed their papers. We hope that this Conference, along with the accompanying Proceedings, will serve as a forum for an exchange of acquired knowledge and a fruitful discussion about new concepts, by means of which some obstacles may be overcome, in reaching more appropriate design principles in terms of economics and safety. As a matter of fact we have been witnessing in the last years an intensive activity in developing new, harmonised design recommendations for various structural materials. And we feel that the "aluminium community" has pioneered a new procedure, namely, the co-operation of responsible people and specification writing bodies, actually on an international level, exchanging views at an early stage as to how a unified design approach as well as a world-wide use and exchange of data can be accomplished.

We wish to express our appreciation to the authors, session chairmen, and attendees for their contributions towards a successful Conference. The iniative and primary responsibility for this Conference has come from Mr. R.A. Kelsey,Alcoa, Chairman of the Aluminum Alloys Committee of the Welding Research Council and Dr. H. Nielsen, Head of the Aluminium-Zentrale, Düsseldorf, respectively; the Chair of Steel Structures and Prof. Dr.-Ing. D. Kosteas at the Technical University of Munich having initiated many of the international contacts, responded with pleasure to this call and contributed to the organisation of the Conference, too. Special appreciation is extended to the staff of Aluminium-Zentrale, especially to Mr. W. Hufnagel, and to the staff of the Chair of Steel Structures of the Technical University of Munich for their efforts in handling the arrangements for the Conference.

The financial support of the Second International Conference on Aluminium Weldments through the Deutsche Forschungsgemeinschaft, Bayerisches Staatsministerium für Wirtschaft und Verkehr as well as Aluminium-Zentrale is gratefully acknowledged.

Organizing Committee

The 3rd. International Conference will be held in conjunction with the American Welding Society Annual Meeting in Philadelphia, USA, April 24-29, 1983. Those wishing to present papers should submit a 200-word summary to R.A. Kelsey, Alcoa Laboratories, Alcoa Center, PA 15069, USA, by August 31, 1982. Manuscripts in photo-ready form for publication in the Proceedings of the Conference will be due by December 31, 1982.



60 mm plate AlMg5, X joint welded in 2 x 2 layers, 3.2 mm ø wire. Root passes: plasma 250A, MIG 440A, wire speed 7 m/min, welding speed 27 cm/min. Filler passes: plasma 220A, MIG 320A, wire speed 4.5 m/min, welding speed 10 cm/min. Torch oscillation ~ 1.5 Hz.

Philips plasma-MIG welds thick aluminium plate with fewer passes; improved control promotes superior joint quality

Latest developments in Philips plasma-MIG welding improve productivity, mechanical performance and appearance of butt welds in aluminium plate from 6-60 mm, compared with conventional MIG.

The process, illustrated below, has many advantages; joint preparation is simpler, no preheating is required.

Weld quality improved. A special ignition control circuit enables the process to be started *without spatter*; the starting point of the weld can be *preheated* by the plasma arc, during welding this also *cleans* joint surfaces just ahead of the molten pool. Heat transfer to the workpiece can be *better regulated*, with metal droplet transfer controlled to ensure *satisfactory penetration*. Weld metal has finer crystal structure, with less porosity, so mechanical performance improved.

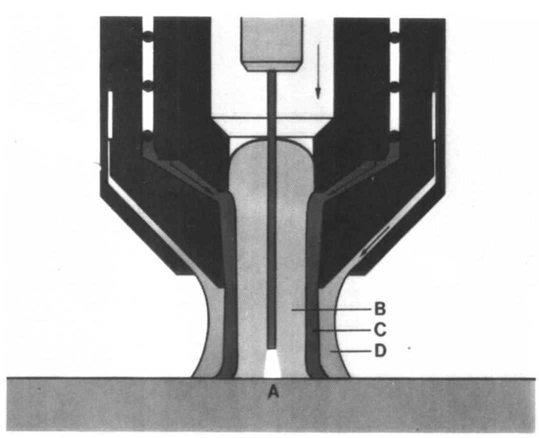
Lower droplet temperature means less burn-off of wire components, bringing improved control over weld composition; less vapour is produced. Weld metal is deposited in smaller droplets with very much reduced spatter.

Productivity increased. Higher welding currents enable 3.2 mm ø wire to be used. Deposition rates up to around 9 kg/h are attainable. Thick layers are achieved, bringing major gains in productivity; fewer passes reduce risk of faults; heat input is lower, so less deformation.

More versatility. Philips plasma-MIG process is used extensively for high quality fillet welds in aluminium, by mechanised welding; a complementary *hand torch* is also available. In terms of productivity and weld quality, plasma-MIG is proving superior to pulsed MIG or TIG/MIG procedures due to its greater control and adaptability.

Latest torch provides extra arc stability. *Improved focusing of the plasma arc around MIG arc "A" brings extra stability, so improved weld quality. This is due to plasma gas flow divided into main "B" and intermediate "C" streams, with self-regulation created by torch design allowing excess of "C" to diffuse into the shielding gas "D".*

Integrated plasma and MIG arc has greater diameter than MIG alone, for better cleaning.



Further information available
If you have any application for high quality aluminium welding, Philips plasma-MIG can probably provide a more productive procedure.

Contact:
Philips Schweißtechnik GmbH
Wieselweg 5
4300 Essen 11
Tel. (0201) 34996.

PHILIPS Welding

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INTRODUCTION

BACKGROUND

Since low structural weight is essential for high performance ships, high-strength, corrosion-resistant weldable aluminum alloys have been selected as the primary hull material. A previous investigation on the high-cycle fatigue behavior of 5086-H116 and 5456-H117 aluminum alloys and welds in air and in seawater[1] showed that the fatigue performance of these two alloys is essentially the same. Therefore, if fatigue is the limiting factor in marine hulls, the higher strength of the 5456 alloy offer no advantage over the 5086 alloy.

This earlier work also showed that the fatigue strength of 5456-H117 and 5086-H116 welds is considerably lower than that of base metal in both air and seawater. This fatigue strength data was generated using a rotating cantilever beam specimen configuration. It was concluded from this work that minute porosity, within allowable radiographic standards, significantly reduces the fatigue strength of aluminum alloy welds. This paper presents the findings of an investigation aimed at developing methods to improve the fatigue performance of 5086 aluminum welds. This work was initiated because of concern over the potential poor fatigue performance of aluminum welds,especially in surface effect ships(SES). During high speed operation of these ships, the hull is expected to experience high cyclic loading due to wave encounters.

EXPERIMENTAL PROCEDURE

MATERIAL

The aluminum alloy selected for this work was 5086-H116, conforming to interim Federal specification QQ-A-00250/20. This alloy is nonheat-treatable, strengthened primarily by work hardening and has an exfoliation resistant temper.[2] The base plate thicknesses used were 1/4-, 5/8-, and 1-inch (6, 16, and 25 mm). Typical tensile properties for this material together with corresponding specification requirements, are shown in Table 1. Both butt and fillet gas metal-arc welding (GMAW) weldments and electron beam welding (EBW) butt weldments were investigated. Aluminum alloy 5356 filler wire was used in the fabrication of welds using the GMAW process.[3] The welding parameters used to fabricate these welds are given in Table 2.

SPECIMEN PREPARATION

The weldments were inspected by radiographic examination to determine the overall quality and aide in specimen selection. Test blanks were selected from areas meeting the requirements of the NAVSEA 0900-003-9000, class 3 specification (quality level for typical GMAW aluminum welds) as well as from areas with defects. These test blanks were machined in two specimen configurations, flat plate and rotating cantilever beam, shown in Figure 1. All specimens were prepared so that the welds were transverse to the long specimen axis. The test section of the flat plate specimens, after machining, was given a rotary wire brush finish. The test sections of the rotating beam specimens was circumferentially and longitudinally polished to ensure complete removal of machining marks and to provide a uniform, fine metallographic quality surface finish.[1] This is performed for uniformity of test conditions and elimination of the effect of surface condition.

FATIGUE TESTING

The fatigue properties were developed in bending using the rotating cantilever beam and flat plate testing techniques. The rotating cantilever beam fatigue test was conducted using a test configuration as shown in Figure 2a. A constant, deadweight load was applied at the bearing end, and the maximum nominal reversed stress, $S_r = \pm Mc/I$, is calculated from the applied load. The rotating cantilever beam specimens were tested at a cyclic frequency of 1400 cycles per minute. The flat plate fatigue test was conducted using a test configuration as shown in Figure 2b. The flat plate specimens were subjected to constant-moment, constant-amplitude loading at a rate of 1800 cycles per minute in a Sonntag Model SF-1U fatigue testing machine. All specimens were tested in air in completely reversed, bending fatigue (R=-1) with the failure criterion being complete fracture of the specimen, except when no failure occurred at 10^7 and 10^8 cycles at various stress levels.

SHOT PEENING

Shot peening studies were conducted using two types of commercially available peening brushes. The first type of brush consisted of cast steel shot uniformly distributed and bonded to nylon cloth flaps which are mounted on a rigid hub. These brushes were in either 8 or 12 inch (203 and 305 mm) diameter by 1 inch (25 mm) width and were mounted on conventional electric hand grinders as shown in Figure 3a. The other type of brush, described in Military Specification MIL-W-81840,[4] consists of tungsten carbide shot bonded in one or two rows along the outer edges of two small nylon reinforced polymeric flaps. The flap assembly is held in a mandrel mounted in a hand-held grinder or flexible shaft tool as shown in Figure 3b.

The degree of peening (Almen intensity) is determined by measuring the curvature, in terms of arc height, induced in an originally flat standard steel strip. The Almen intensity is dependent on the force with which the shot impacts the workpiece and the length of time of peening. The impact force is dependent on the type of shot, brush diameter and rotational speed.

A standard Almen strip and Almen gage used for determining almen intensity are shown in Figure 4. The procedures used for determining Almen intensity are described in military specification MIL-R-81841.[5]

Manufacturers' literature (3M Company) concerning these brushes states that sufficient brush flap deflection must be obtained for optimum peening results.[7] Minimum and maximum brush deflections to be used for the small [9/16 x 1 inch (14 x 25 mm)] tungsten carbide shot brush and tungsten carbide brush - 1/4 inch (6 mm) [minimum] and 11/32 inch (9 mm) [maximum] and cast steel brush - 1/8 inch (3 mm) [minimum] and 5/8 inch (16 mm) [maximum]. Preliminary peening tests were run with the operator applying sufficient pressure to cause flap deflections equivalent to both the minimum and maximum limits of the range. These minimum and maximum limits will be referred to throughout this paper as light and heavy peening pressure, respectively. The rotational speed of the peening brushes was controlled through the use of a variable speed drive motor and a strobe light. With the use of a practice plate, the brush speed was set by an assistant adjusting the variable speed control while the operator maintained the proper peening pressure. The operator could then vary peening pressure, as necessary, to maintain a constant speed as indicated by the stationary image of an index mark on the brush when illuminated by the strobe light set at the desired speed of the drive motor. This technique controlled both the brush speed and peening pressure and was not diffiult to master.

RESULTS AND DISCUSSION

GAS METAL-ARC WELDING (GMAW) PROCESS

The results of Sonntag fatigue tests (flat plate specimen) performed on 5086-H116 base plate, transverse GMAW butt weldments with reinforcement removed, and transverse GMAW tee fillet weldments are presented in Figure 5. These results indicate that the fatigue strength of this alloy is seriously degraded by welding. The fatigue strength of transverse 5086-H116 butt welds was decreased 50% to 7.5 ksi (52 MPa) at 10^7 cycles with the fillet weld fatigue strength being further reduced to only 5 ksi (34 MPa) at 10^7 cycles compared to base metal fatigue strength of 15 ksi (103 MPa). In the butt-welded specimens, fatigue cracks initiated in and propagated through the weld metal. Cracks in the fillet-welded specimens initiated at the weld toes and propagated through the HAZ of the continuous member (flange).

Shot Peening Techniques

To improve fatigue performance of 5086-H116 aluminum alloy plate welded using the GMAW process, the effect of brush peening was investigated. This type of peening, rather than conventional shot or hammer peening, was investigated because of its potential for use as a portable, manual or automatic method of controlled peening. To determine initial peening intensities for use on the fatigue specimens, sections of 5/8 inch (16mm) thick 5086-H116 plate were brush peened using the 8 and 12 inch (203 and 305 mm) diameter brushes. The effect of different combinations of brush diameter, brush revolutions per minute (rpm), peening time and operator pressure on peening intensities is shown in Figure 6. During the preliminary peening tests, the maximum brush deflection (heavy peening pressure) was found to be the easiest for the operator to maintain. It is evident from Figure 6 that an increase in the magnitude of any one of the peening variables, while maintaining the others constant, will result in increases in the peening intensity. Photographs showing the typical surface appearance of peened aluminum plates with the peening parameters and peening intensities used are shown in Figure 7. Examination of the peened surfaces revealed two types of general surface appearance. Light peening pressure gave the appearance of overlapping circular spots. This spotted surface, Figures 7a and 7c, would normally be expected when using conventional shot peening in which the steel or carbide shot strikes normal to the surface of the workpiece. Heavy peening pressure produced a spot appearance, superimposed on a background of waves running in the direction of peening, Figures 7b, 7d, and 7e. The wave pattern is felt to be unique to rotary brush peening and is caused by lateral plastic flow of the surface in the direction of brush rotation.

Based on the amounts and types of surface deformations obtained during the preliminary studies, peening parameters were selected for fatigue testing. Almen (A) scale intensities from 0.0015 to 0.0065 inch (0.038 to 0.165 mm), and peening conditions which results in both spot- and wave-type surfce patterns were investigated.

Butt Weld Peening

With weld reinforcements removed, butt-welded 5/8 inch (16 mm) thick fatigue specimens were peened using the 8 and 12 inch (203 and 305 mm) diameter peening brushes to Almen (A) scale intensities of 0.0015, 0.0025, 0.0035, and 0.0065 inch (0.038, 0.064, 0.089, and 0.165 mm). Peening was performed on both plate surfaces only in the weld area. To assure that peening intensities achieved were precise, an almen strip was peened along with each fatigue specimen.

After peening the specimens were fatigue tested. The results of these tests compared to the results of unpeened butt welds are presented in Figure 8. These results showed that brush shot peening improved the fatigue strength of 5086-H116 GMAW butt welds from 7.5 to 15 ksi (52 to 103 MPa) at 10^7 cycles. Brush shot peening improved the fatigue performance of the weld to be equivalent to that of the base metal. Also some peened specimens exhibited surface discontinuities from previous handling, such as dents and machining marks. These surface discontinuities however did not affect the fatigue life since fracture occurred away from these defect locations.

A comparison of fatigue results for unpeened and peened specimens taken from the same weldments (S5-2, S5-4) is shown in Table 3. From weldment S5-2, the effect of peening on fatigue performance was evident. The improvement in fatigue life of peened versus unpeened specimens tested at the same stress level, 15 ksi (103 MPa), was by greater than an order of magnitude (1.25×10^7 versus 0.37×10^6 cycles). In weldment S5-4, where radiographic examination revealed extensive lack of fusion defects in the specimens used for test, peened specimens lasted significantly longer when tested at a higher stress level [15 ksi (103 MPa) at 1.06×10^7 cycles versus 10 ksi (69 MPa) at 1.52×10^6 cycles] and did not fracture through the defect area.

Analysis of these data did not reveal any deleterious effects due to the type of peened surface (either wave or spot) on fatigue performance. Additional butt-welded specimens were peened to generate a full S-N curve. Tests were also conducted to determine if overpeening [almen (A) scale intensity of 0.0080 inch (0.203 mm)] causes a degradation of fatigue performance. Figure 9 shows that peening in the range of 0.0035 to 0.0080 inch (0.064 to 0.203 mm) [the maximum peening intensity that could be obtained using the 8 or 12 inch (203 or 305 mm) diameter brushes] significantly improves the fatigue strength of butt-welded 5086-H116. At the high-cycle to failure (10^6 to 10^7 cycles) end of the curve, the peened specimen fatigue performance is equal to or possibly higher than the base metal performance [stress levels = 15 and 17.5 ksi (103 and 121 MPa)]. In the low-cycle(10^5 to 10^6 cycles), high stress [20 and 22.5 ksi (138 and 155 MPa)] region, peened specimens, while performing better than unpeened welds, are only slightly lower in fatigue strength than the base metal. It is also significant that the maximum intensity which could be obtained with the 8 or 12 inch (203 or 305 mm) brushes did not result in any deleterious effects caused by overpeening. This observation, along with the overall wide range of peening intensities that improve fatigue performance, 0.0035 to 0.0080 inch (0.069 to 0.203 mm) almen (A), indicates that the brush shot peening process is relatively insensitive to operator error.

Fillet Weld Peening

The effects of postweld peening on fillet-weld fatigue performance were screened using the optimum peening intensities determined for butt welds. Peening was performed using the 12 inch (305 mm) diameter brush rotating parallel to the stiffener length direction. Areas further than 3/8 inch (9.5 mm) away from the toe of the weld were masked, using glass cloth adhesive tape to limit peening in these areas. Fillet specimens were fatigue tested with the toe of the weld peened and where both the weld toe and the plate surface opposite the stiffener (underside) was peened.

The peening initially produced inconsistent results on fillet-weld fatigue performance, as shown in Figure 10. Some specimens, peened at 0.0035, 0.0065, or 0.0080 inch (0.064, 0.165, or 0.203 mm) almen (A) scale intensity, showed a 50% improvement [5 to 7.5 ksi (34 to 52 MPa)] compared to the as-welded fatigue strength at 10^7 cycles, whereas other peened specimens exhibited fatigue life equivalent to unpeened welds. Examination of the fractured surface of these specimens revealed the presence of rolled lips that formed on the specimen edges during peening. It was determined that peening parallel to the stiffener into a free edge of the specimen, rolled lips were formed and sometimes acted as crack initiation sites. Crack initiation sites were also located in regions where local weld irregularities had masked the weld toe from the 12 inch (305 mm) peening brush. It was also observed that peening only the weld toe forced fatigue initiation to the back or unwelded side of the flange.

Further peening tests showed that the small tungsten carbide peening brushes, which were designed for peening in restricted areas, were the most effective method for obtaining 100% peening coverage, while avoiding excessive specimen edge deformation. The 9/16 x 1 inch (14 x 25 mm) flap brush could easily be manipulated to allow for peening irregularities at the weld toe while peening parallel or perpendicular to the stiffener.

Fillet-welded, 1/4 inch (6 mm) thick specimens were then peened on the weld toe and on the unwelded side of the flange to almen (A) scale intensities of 0.0040 and 0.0070 inch (0.102 and 0.178 mm), using the 9/16 x 1 inch (14 x 25 mm) flap brush and fatigue tested. Results of these tests (Figure 11) confirms that peening with this type of brush improves the fatigue strength of 5086 fillet welds from an as-welded strength of 5 to 10 ksi (34 to 69 MPa) at 10^7 cycles (100% improvement), while at 10^6 cycles a 50% improvement is seen, from 8 to 12 ksi (55 to 83 MPa).

ELECTRON BEAM WELDING

Because the fatigue strength of 5086-H116 is seriously degraded by GMAW, the effect of electron beam welding (EBW) on 5086-H116 in fatigue was investigated. The rotating cantilever beam fatigue test results of the electron beam (EB) butt welds are shown in Figure 12. These fatigue test results, when compared to the previous base metal and GMAW butt weld fatigue data[1], indicates that the fatigue performance of EB welds is similiar to 5086-H116 base metal [10^6 cycles at 22.5 ksi (155 MPa) and greater than 10^7 cycles at stress levels from 20 to 12.5 ksi (138 to 56 MPa)]. The enhanced fatigue performance of these EB welds versus GMAW welds is similiar to the previously reported improvement in fatigue life of GMAW welds due to brush shot peening.

To correlate the improvement in fatigue performance of 5086-H116 welds due to EBW and brush shot peening, flat specimens (Figure 1a) were taken from EB butt welds and fatigue tested as shown in Figure 2b. The fatigue test results for these EB welds are shown in Figure 13. These fatigue test results of EB welds, when compared to the flat plate base metal and GMAW fatigue data, indicate that their fatigue life is similar to as-welded GMAW condition. Both the EB and unpeened GMAW butt welds had a fatigue life at 12.5 ksi (86 MPa) of 10^6 cycles, while the EB welds versus GMAW welds fatigue strength was slightly better at 10^7 cycles, 10 ksi (69 MPa) versus 7.5 ksi (52 MPa).

These fatigue test results of EB welds using the rotating cantilever beam and flat plate specimens are incongruous, one showing improved fatigue performance, the other no improvement over unpeened GMAW butt welds. The fracture surfaces of ruptured specimens were examined in an attempt to explain these results. Visual examination of the fracture surfaces of the rotating cantilever beam specimens showed typical fatigue fractures with no apparent weld defects. However, visual examination of fracture surfaces of the flat plate fatigue specimens revealed indications of microporosity near the specimen edges. This incidence of porosity in the EB weld is suspected to be attributed to improper cleaning procedures during weld joint preparation. This porosity served in many instances as sites for crack initiation. Porosity is known[7-10] to be responsible for the lower tensile and fatigue property values of aluminum welds for