Some Considerations in the Welding of Chemical Equipment
In Aluminium-Magnesium Alloys

By A N SUBRAHMANYAN*

Chemical equipment is fabricated in aluminium and aluminium alloys in view of their following characteristics :—

(i) Good resistance to corrosion. The welded joints normally have approximately the same resistance to chemical action as the parent material.

(ii) Aluminium is generally non-contaminating.

(iii) Aluminium-Magnesium alloys are ductile even at sub-zero temperatures. They are therefore used for low-temperature applications, like the storage and transport of liquefied gases.

(iv) Light weight.

(v) Non-sparking properties.

(vi) Low resistance to heat flow.

Of the various wrought, and cast aluminium types varying from pure aluminium to non-heat treatable types and heat treatable alloys, this paper deals with our experience in welding of chemical equipment made with the indigenously manufactured Aluminium—2% Magnesium alloy (0.3% Manganese), which is classified as NP-4 for plates from 6.3 mm to 25.0 mm in thickness and NS-4 for sheets upto 6.3 mm in thickness, in the Indian Standard Specification IS 737 : 1965.

The purpose of the paper will have been served if it evokes discussions amongst welding engineers, who have had similar or different experiences with various aluminium alloys, so that the knowledge, the practical aspects of which are in the writer's opinion, presently very limited in India, can be shared by all to advantage.

Material

The typical principal properties of this wrought Al-Mg alloy are given in Table I.

Design Requirements (welding)

The chemical equipment were to be fabricated from annealed sheets and plates. They were designed and were to be manufactured to the requirements of the ASME Unfired Pressure Vessel Code Section VIII, with spot radiography of the welded seams (to meet certain other internal quality control requirements, 100% radiography of the longitudinal seams was carried out as explained later in the paper). The plate thicknesses involved in the jobs ranged from 6.3 mm to 20 mm and most of the main welded seams in the pressure vessels were accessible from both sides. In view of the non-availability of aluminium alloy pipe elbows (1″ to 2½″), the design provided for fabrication of the elbows in two pressed halves with a full penetration weld, welded from one side, since the undersides of the weld were not accessible for "back-chipping".

Welding Process

It was decided to use both the TIG and MIG welding processes for the fabrication of the vessels.

*Mr. Subrahmanyan is Welding Engineer, Larsen & Toubro Ltd. Bombay.

TABLE 1

Plate or Sheet and Condition	*Nominal Composition %*	*UTS Kg/mm²*	*Elongation on 50 mm %*	*Brinell. Hardness*	*Coeff. of Linear Expansion / °C (10—200°C)*
Sheet (NS4) (Flat and Coiled)					
Annealed	Mg 2% Mn O.3%	17.5-22.0	18.0	48.0	0.000025
¼ H		20.5	8.0	67.0	
½ H		23.5	5.0	75.0	
¾ H		24.4	3.0	80.0	
Plate (NP4)					
Annealed	Mg 2% Mg 0.3%	19.7	24.0	48.0	0.000025
As manufactured		21.3	20.0	60.0	

Later development work proved that the MIG process was unsuitable for obtaining consistently acceptable radiographic quality welds and as such the MIG welding process was used only for the fabrication of the non-pressure parts and attachments like the saddle supports of the vessel, etc. where the speed of this process and the higher deposition rates contributed largely to economy in welding costs.

Welding Equipment

The TIG welding equipment used for the fabrication of the vessels, comprised :

(i) Welding Transformer—300 Amps rating (continuous)

(ii) High Frequency Unit—300 Amps rating

(iii) (a) Water cooled welding torch—350 Amps rating with 8 metres long cable/hose assembly.

(b) Zirconiated Tungsten electrodes 1/8″ dia and 3/16″ dia.

(iv) Water Tank filled with clean potable water and fitted with a 1/4 HP pump.

(v) D.C. Suppressor Unit.

(vi) Argon/Water Economiser Unit.

(vii) Foot switch for initiating the HF Unit.

As explained later, a current contactor of 300 Amps rating was a desirable accessory but was unfortunately not available at the time when these jobs were in progress.

The MIG welding equipment was of the conventional type, comprising the power source, welding control/wire feed units, water cooled torch and water tank fitted with a 1/4 HP pump.

Filler Wire

The problem of cracking during the welding of aluminium-magnesium alloys has been studied extensively abroad, and it is known that in simple alloy systems, the degree of cracking will be at a maximum when the Magnesium content is 4%. It is also known that the severity of cracking may be modified by the presence of other alloying elements in commercial alloys, namely manganese, iron and silicon. It has generally been established in the U.K. that cracking problems are the greatest with the Al—2%Mg. alloy.

In the selection of a suitable filler alloy, apart from the above knowledge, the degree of dilution in the weld due to melting of parent metal had also to be taken into consideration. With an assumed average dilution of 50 to 60% in the butt welds of thicknesses upto 20 mm, it was found that use of a 5% Mg alloy wire was preferable to a 3½% Mg alloy filler, so that a weld composition well above the critical concentration of 2% magnesium can be produced.

It was found that though IS 2680 : 1964 provides for a filler alloy of this composition for TIG welding process, such an alloy was not readily available indigenously to the requirements of the specifications. We had therefore to import 1/16″ dia and 1/8″ dia rods for TIG welding and 1/16″ dia spooled coils for MIG welding from the U.K. ; these filler wires/rods meet the requirements of BS 2901 Part I NG-6 for TIG welding and BS 2901 Part II NG-6 for MIG welding applications.

Development Work

The plate thicknesses involved in the vessels ranged from 6.3 mm to 20 mm in thickness. It was therefore necessary to qualify the welding procedure and the welders for this range of thicknesses, as per the ASME Unfired Pressure Vessel Code Section IX Welding Qualifications. The thickness selected for development work was 10 mm since qualification in this thickness will enable the welder to perform welding on plates from 5 mm to 20 mm in thickness. Since all the welds on the vessels could be made in the downhand position with suitable rotators/positioners, the welding development/training work was restricted to the downhand position of welding only in both the TIG and MIG processes.

Defects in Welds

In the initial stages of the development work, it was difficult, using the TIG welding process to obtain welds meeting the maximum permissible porosity levels, specified in the ASME Code Section VIII.

It was known that hydrogen is the main source of porosity in an aluminium weld. The solubility of hydrogen in molten aluminium is about 0.7 cc per 100 gm, whereas in the solid metal just below the solidus, it is only 0.036 cc per 100 gm. Therefore, any hydrogen in excess of this, absorbed during melting will be rejected from solution during freezing to form gas pockets. While welding under an argon shroud, direct reduction of the water vapour in the atmosphere would not be counted as a major source of hydrogen but vapour may be present in the oxide film on the surface of the parent metal or filler wire.

To eliminate any such possibility, it was decided, as a procedure, that the welding groove and not less than 40 mm of the parent metal on either side of the weld groove will be thoroughly degreased chemically (with acetone) and scratch-brushed with a power wire brush used exclusively for aluminium, immediately prior to welding, to remove all traces of oxide film from the surface. The filler rod was also cleaned with steel-wool immediately prior to use, in TIG welding.

Inspite of these elaborate precautions, it was found that the porosity levels were higher than permissible, though it was realised that isolated groups of porosity cannot be eliminated at "starts" and "stops", especially with the MIG process.

As anticipated, the problem of porosity was greater with the MIG process. This was attributed to the oxide scale in the filler wire in the spool, which was not possible to avoid in storage; nor was it possible to clean the wire efficiently/economically before it was fed into the welding gun.

In the search for the cause for the high porosity levels, our attention was then directed to the purity of the shielding gas. The typical analysis of the welding grade argon, was given by the supplier as under :

Argon	: Not less than 99.97%
Oxygen	: 10 vpm max.
Nitrogen	: 250 vpm max.
Hydrogen	: 5 vpm max.
CO_2 Carbonaceous matter	: Less than 5 vpm
Water Vapour	: 0.0056 gm/cu.m.

Mr. D Seferian, the eminent French Metallurgist has suggested that argon with not exceeding 0.3% nitrogen, 0.01% hydrogen and 0.01% oxygen is suitable for welding aluminium. The typical analysis of the argon available indigenously showed much less hydrogen, nitrogen and oxygen contents. It was then found that one manufacturer could supply "special argon" at substantially increased prices (about 36% costlier than welding grade argon), to the following nominal specifications :—

Argon	: Not less than 99.97%
Nitrogen	: 250 vpm max.
Oxygen	: 5 vpm max.
Hydrogen	: 5 vpm max.
CO_2 and carbonaceous matter	: Less than 5 vpm.
Water Vapour	: 0.0050 gm/cu. metre.

The typical analyses of two cylinders of "special argon" obtained from this firm for experiments were :

Cylinder A	: Oxygen—2 vpm Nitrogen—60 vpm
Cylinder B	: Oxygen—1.2 vpm Nitrogen—55 vpm

The hydrogen and water vapour contents were said to be to the specification values for both the cylinders.

Experiments then proved that in TIG welding, with the shielding argon of the special grade, porosity levels were within the permissible limits, including at the "stop" and "start" areas. Depending on the skill of the welder, porosity levels within the permissible limits could be otained with the MIG process, using the "special argon". Consistency of results with the MIG process could not, however, be achieved, though the mechanical properties of the welds were not inferior even with the higher porosity levels. It was therefore decided, that the MIG process would be used only for the attachment welds of non-pressure parts and for the fabrication of the non-pressure parts, viz. the cradle supports, lugs, etc. The TIG process was chosen for all butt welds and nozzle attachment weld.

Oxide Inclusions

The tenacious refractory oxide skin on the metal surface that develops during heating and a similar film that tends to build up at the junction between the weld metal and the parent metal at the side of the weld, were problems we had to contend with.

With the special argon from Cylinder B—oxygen content 1.2 vpm—remarkable improvements in the quality of weld metal were noticeable and it was therefore decided to use for the manufacture of the chemical equipment, special argon gas of similar composition as the gas in Cylinder B. The gas company was also agreeable to selective supply of special argon with oxygen content not exceeding 1.5 vpm.

Tungsten Inclusions

In the TIG welding process, prolonged use of high currents was found to cause melting/collapse of the Zirconiated tungsten electrode, which formed an inclusion in the weld. Similarly, tungsten inclusions were found to occur at the start of the weld and invariaably a conglomeration or colony of inclusions was seen to occur at every "restart".

Apart from the fact that such inclusions tend to form hard spots in the weld, they also may affect the corrosion resistance of the weld. The ASME code is silent on the permissible limits of such inclusions in the weld and for our own quality control we set the standard of acceptability, using the Imperial Chemical Industries (UK) specification for welding Aluminium pressure vessels. The relevant clauses of the specifications read as under :

a) Isolated inclusions upto 1/16″ in diameter or 10% of the plate thickness, whichever is less, are not cause for rejection, provided that no two such particles are less than 1″ apart and there are not more than two in any one foot (30 cm) length of weld.

b) Colonies of tungsten inclusions are not cause for rejection provided that :

i) the particle size does not exceed 1/32″ in dia.
ii) area bounded by the inclusions does not exceed 1/2″ dia.
iii) the number of particles does not exceed 5.
iv) no two colonies are less than 2″ apart.
v) there are not more than two colonies in any two feet (60 cm) length of weld.

Cracking

It was invariably seen that cracks tended to appear at the craters of tack welds used for alignment of the weld seams. Cracks also appeared at the "stops" of weld, when the welding torch was removed to cut off the current thus providing no shielding for the cooling metal, at the "crater" or the "stop", even when the crater is filled as a procedure before breaking the arc.

Ideally a welding contactor is required in the circuit, which will cut off the HF and the welding current when the foot pedal is released, without the necessity of having to remove the torch away from the surface to break the welding arc. Such a contactor was not available with us nor was it available indigenously for use in conjunction with the TIG welding equipment in the shops. It was therefore necessary to eliminate these cooling cracks by the welding procedure and operator training. The welders had to be trained to cut off the welding current by lifting the torch from the surface and removing the foot from the foot pedal to cut off the HF operation and then to bring back the torch to the crater to allow the weld to cool under argon shielding. This process should not take more than 2 seconds and our welders could make consistently sound welds without cracks, after repeated trial and training exercises.

The tack welds were filed and the cracks removed by chipping. As a procedure, tack-welds were made on the side of the plate opposite that in which welding was to commence. Since the backside was chipped to sound metal before the sealing weld was made, the tack welds were always removed in chipping. In the initial stages, liquid penetrant examination of the filed tack-welds was carried out to establish that cracks, if any, had been completely removed.

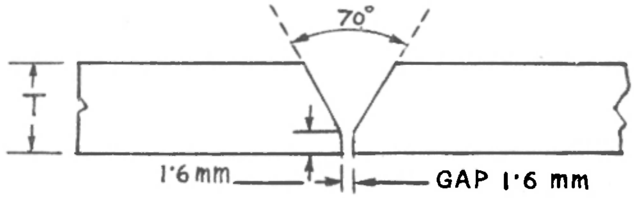
Incomplete penetration/lack of fusion

It was seen early in the development work that "chip back" had to be very deep to reach sound metal, if the root run on the first side of the groove was made with filler wire addition, resulting in areas of lack of penetration.

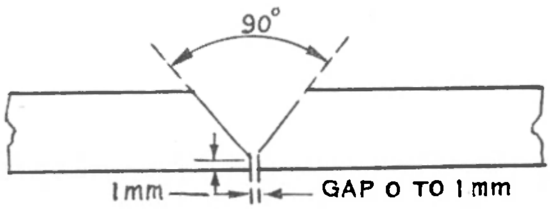
The joint preparation initially decided on was a 70° groove with a 1/16″ (1.5 mm) land or root face and a gap of 1/16″ (1.5 mm), both for the TIG and MIG processes. Development work showed that for effective fusion of the weld passes, the included angle for the TIG process had to be increased to 90° for thicknesses upto 1/2″ and the 70° included angle was suitable for the MIG process.

To avoid a deep chipback and to obtain uniform penetration, and root fusion, the best solution was found to be fusion of the root with the TIG process, without filler wire addition. For the MIG process the joint design had to be amended. The final edge preparation decided on as well as the initial preparations are detailed in Fig. 1.

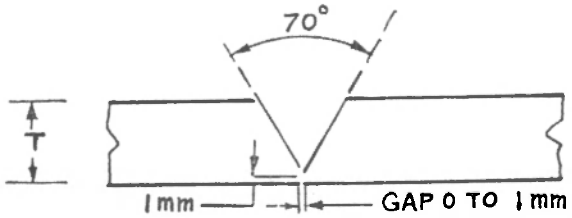
Fig. 1. Typical Edge



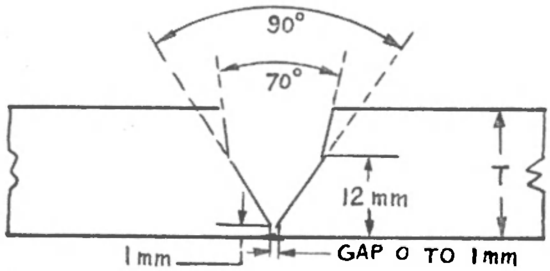
Typical Edge Preparation originally specified for TIG and MIG Welding-Thickness T from 5 mm to 20 mm



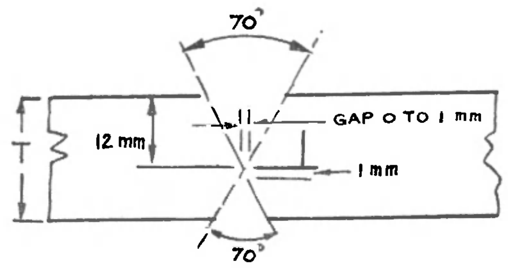
Modified Edge Preparation for TIG Welding-Thickness T upto 12 mm



Modified Edge Preparation for MIG Welding-Thickness T upto 12 mm



Modified Edge Preparation for TIG Welding-Thickness T from 12 mm to 20 mm



Modified Edge Preparation for MIG Welding-Thickness T from 12 mm to 20 mm

Inspite of the fact that full penetration was achieved by welding from one side, using the above procedure, to obtain welds of radiographic quality free from oxide inclusions drawn in from the root side during welding, it was decided to "chipback" the root to sound metal. The chipback did not have to be more than 1/16" to 3/32" (1.5 to 2 mm) depth from the plate surface. Freedom from defects in the chipped groove was ensured by a liquid penetrant examination.

For welds accessible from one side only—as for instance in fabricated pipe elbows—the joint configuration was the same as for plate but the underside of the groove was purged with special argon to eliminate oxide inclusions during welding. The volume of air under the groove was "purged" by atleast 6 times by volume of the special argon gas before weld commenced (to eliminate all traces of air). The purging gas was so vented as to prevent "blow-through" of the weld metal. The purging gas quantity had to be regulated for each application, since a higher rate of flow of the purging gas could cause a "suckback" and a lower rate might cause uneven penetration and an unacceptable weld.

The root pass in making such joints was always made with the TIG process without any filler wire addition.

Qualification of Welding Procedure

After we were satisfied that consistently good welds for the applications decided on could be made by our welders, the welding procedures by the TIG and MIG processes were offered to the Inspecting Authority for qualification tests to the requirements of the ASME Code Section IX. The welder's performance qualification tests were also conducted by the Inspecting Authority. The typical results obtained on 10 mm plate by the TIG and MIG processes are tabulated in Tables 2 and 3.

Precautions in Fabrication

Certain important properties of aluminium alloys and basic precautions to be taken during fabrication of chemical equipment with these materials were known. These were scrupulously followed and it is needless to

TABLE 2

PROCEDURE QUALIFICATION RESULTS—10 mm Al. 2% Mg Plate, Filler Wire Al. 5% Mg Alloy, *TIG* Welding Process—Specimen made to the requirements of ASME Code Section IX—Flat Position

Specimen No. and Size (mm)	*Ultimate Tensile Stress Kg/mm²*	*Character of Failure and Location*	*Face Bend Transverse (on former of dia=4T)*	*Root Bend Transverse (on former of dia=4T)*
1 (38.0x9.6)	20.1	Clean fracture, broken outside the weld	—	—
2 (38.0x9.5)	20.3	-do-	—	—
3 (38.0x10.0)	—	—	Satisfactory	—
4 (38.0x10.0)	—	—	—	Satisfactory
5 (38.0x10.0)	—	—	—	—
6 (38.0x10.0)	—	—	—	—

TABLE 3

PROCEDURE QUALIFICATION RESULTS—10 mm Al. 5% Mg plate, Filler wire Al 5% Mg alloy, *MIG* Welding Process—Specimens made to the requirements of ASME Code Section IX—Flat Position

Specimen No. and Size (mm)	*Ultimate Tensile Stress Kg/mm²*	*Character of Failure and Location*	*Transverse Face Bend (on former of dia=4T)*	*Transverse Face Bend (on former of dia=4T)*
1 (32.2×9.5)	19.85	Clean fracture broken outside the weld	—	—
2 (38.1×9.6)	19.40	-do-	—	—
3	—	—	Satisfactory	—
4	—	—	-do-	—
5	—	—	—	Satisfactory
6	—	—	—	-do-

mention that they paid dividends, by way of improved productivity, less rectification work, etc.

(i) Aluminium is sensitive to contamination from grinding particles, dust from other materials, powder and dirt from the atmosphere. It was therefore necessary that strict attention to cleanliness was given in the fabrication of aluminium.

As far as was practicable, grinding of weld preparations was avoided. All weld preparations were made either by machining or chipping. The vessel penetrations, nozzle openings, etc. were made by cutting with a special electrode—with a sufficient allowance for further chipping to remove the affected zone and to make the required weld preparations.

(ii) Aluminium is also sensitive to contamination from rust from mild steel. Traces of rust on aluminium will cause chemical attack due to galvanic action. It was found that segregation of aluminium from other mild steel jobs on the shop floor was absolutely necessary, if good results are to be obtained. All steel stiffeners/bracings employed to reduce distortion were scrupulously positioned so that they did not come in contact with the aluminium vessel but were attached to "poison plates" tacked on to the jobs—these poison plates being of the same material as the alloy of the vessel.

The steel wire brushes and the wire wheels used for cleaning the weld preparations and the weld passes were exclusively used for aluminium only to avoid any contamination.

(iii) Aluminium alloys are sensitive to notches and to avoid even scratches on the plates, they were handled with great care. The welding positioners/rotators had rubberised rollers.

(iv) The quality of the welds was likely to be affected, should there be any disturbance of the argon welding shield. The assembly and welding of the vessels were done in relatively draught free but well ventilated areas of the shop floor and in some instances, it was necessary to provide protective screens around the job, to reduce the draught.

(v) The ultra violet radiation from the welding arc is intense, and it was therefore necessary for the welders to use welding glasses of EW12 or EW13 shade. These glasses are not indigenously available and are presently being imported.

Distortion :

The thermal coefficient of expansion of aluminium is nearly twice that of steel. It was therefore to be anticipated that distortion in the fabrication of aluminium would be severe and that effective steps to reduce distortion should be taken.

The shell course plates for the chemical equipment were initially "pre-bent" and then rolled to the required diameter. Welding of the longitudinal seam was done, with adequate supports inside the shell to prevent distortion. The weld passes also were, in some cases, alternatively made to equalise the stresses. Inspite of all these precautions, it was found that "peaking" resulted in the longitudinal seam which would make alignment with the next shell course difficult. Since the distortion had to be rectified to make the shell round, it was thought advisable to radiograph fully the longitudinal seams, after rectification of distortion, to ensure that the welds had not cracked. The distortion increased with the number of weld passes and before three or four shell courses had been welded, the effective steps necessary to reduce distortion to acceptable limits without the necessity of rectification or rerolling of the shell had been fully understood.

TO ALL MEMBERS OF
THE INDIAN INSTITUTE OF WELDING

We would like to ensure that your copy of INDIAN WELDING JOURNAL reaches you in time. If you are changing your address, please remember to inform us.

EDITOR