THE WELDING OF MONEL AND K-MONEL

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Abstract

In this paper the author describes the welding of Monel and the heat-treatable modification known as 'K' Monel. The alloys can be welded by all normal techniques, but the advantages and limitations of fusion, resistance and pressure welding for various types of fabrication are covered in detail. The cause and cure of various welding defects are described and the procedure for avoiding corrosion, particularly of the cavity type, in fabricated structures is outlined.

A number of specific examples of defective welds in Monel and 'K' Monel are given and the reason for each is detailed in technical terms.

MONEL and K-Monel are two associated alloys which are extensively used to resist corrosion, particularly by sea water, salts and other chlorides, and they find wide application in chemical plant. It is only by the use of welding, and in particular the fusion methods, metallic arc, argon arc, oxy-acetylene, atomic hydrogen and carbon arc, that structures and plant can be fabricated in these alloys, to take full advantage of their resistance to corrosion.

They are both alloys containing approximately one-third of copper and two-thirds of nickel, K-Monel containing in addition 2·0-4·0 per cent aluminium and 0·25-1·0 per cent titanium, by virtue of which the alloy can be hardened by heat treatment. Monel, on the other hand, does not respond to heat treatment and can only be hardened by cold-work. Monel is magnetic below about 60°C., whilst K-Monel is non-magnetic, and for certain marine applications the latter alloy is preferred because of this property.

The alloys can be welded by all the normal techniques. The fusion methods, by means of which the smooth, crevice-free joints, so essential in chemical plant and other applications involving corroding conditions, can be obtained, are the most frequently used. The resistance and pressure welding methods, on the other hand, are used mainly in the fabrication of the smaller, more intricate parts, and for those assemblies in which lap-joints will not lead to crevice corrosion.

Both alloys, in the wroguht condition, and it is not proposed here to discuss the cast form, have an equiaxed single-phase structure, as shown in Figs. 1 and 2. The Monel in Fig. 1 is in the annealed condition, and

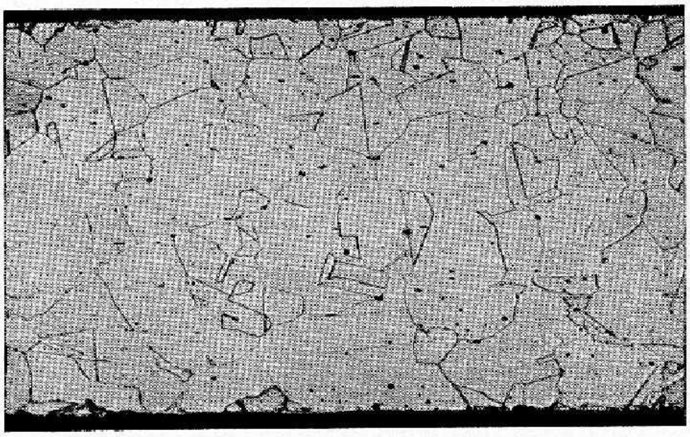

FIG. 1 — STRUCTURE OF MONEL (× 100)

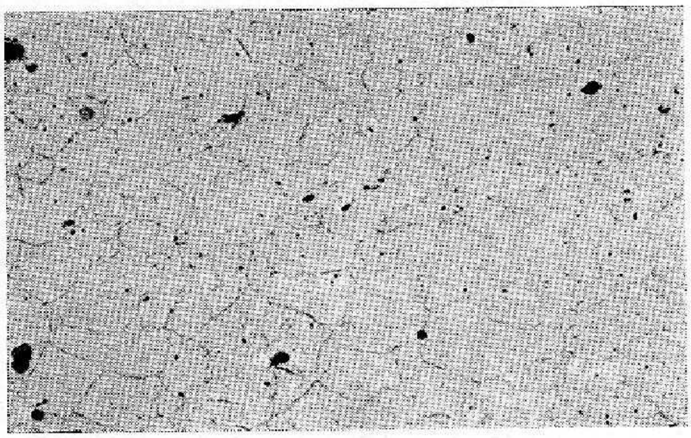

FIG. 2 — STRUCTURE OF K-MONEL AS SOLUTION TREATED AND AGED (× 300)

TABLE 1 — TENSILE PROPERTIES AND HARDNESS OF MONEL AND K-MONEL

Alloy	Condition	Proof stress 0·2%, tons/sq. in.	Maximum stress, tons/sq. in.	Elongation % on $4\sqrt{A}$	Hardness D.P.N.
Monel	Annealed	11-20	31-38	50-30	100-140
K-Monel	Solution-treated	18-26	40-49	45-35	155-195
K-Monel	Thermally hardened	40-49	58-67	30-20	260-280

the K-Monel in Fig. 2 has been heat-treated at 585°C., this heat treatment materially increasing the strength and hardness of the alloy. This has resulted in the precipitation of a finely dispersed second phase which is just visible on the photomicrograph. The mechanical properties of the alloys are given in Table 1, including those obtainable with K-Monel by heat treatment. Monel is, wherever possible, welded in the annealed condition, although with special precautions welding has sometimes been carried out on material in the hard condition. It is usual to weld K-Monel in the solution-treated condition and to apply the hardening heat treatment subsequently.

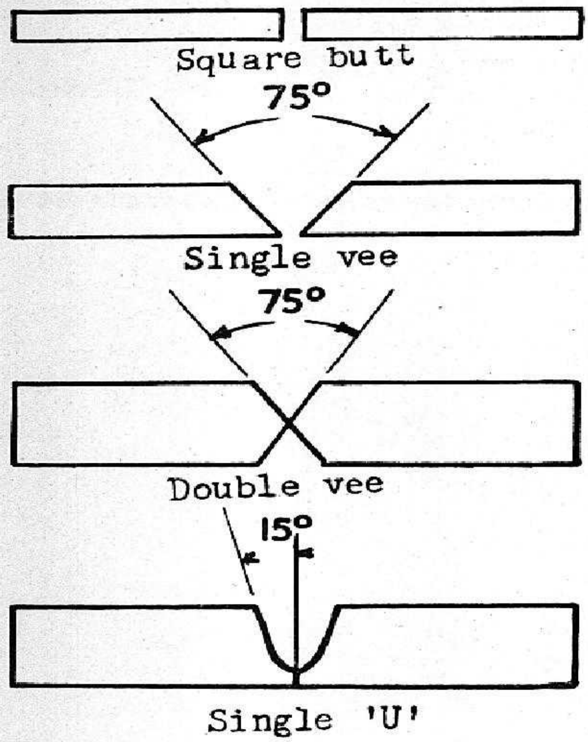

FIG. 3 — EDGE PREPARATION FOR VARIOUS THICKNESSES

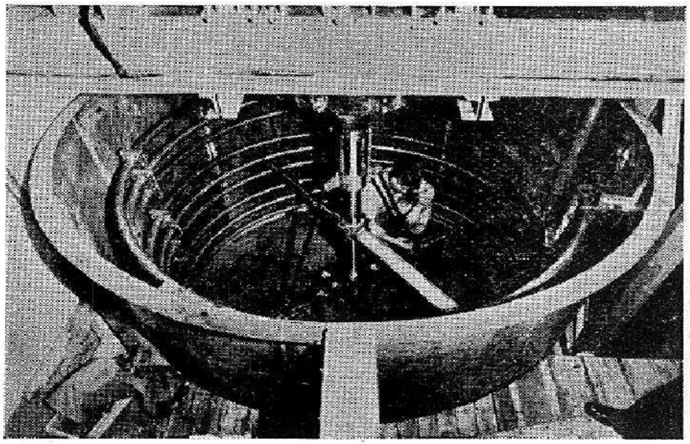

FIG. 4 — MONEL GRANULATING TANK FOR THE PRODUCTION OF POTASSIUM DICHROMATE (*By courtesy of Chrome Chemicals Pty. Ltd., Parrametta, N.S.W.*)

Equipment in material of $\frac{1}{10}$ in. thickness and over is most often fabricated by metallic arc welding, since this process results in more rapid welding and less distortion than is possible when the other fusion methods are used. For butt joints the edges of the sheets are left square in thicknesses up to $\frac{1}{8}$ in., and for sections between $\frac{1}{8}$ and $\frac{1}{2}$ in. the edges are prepared to a single vee with a 75° inclusive angle, as shown in Fig. 3. For plates over $\frac{1}{2}$ in. thick, a double-vee edge preparation or a U, as detailed in Fig. 3, is the normal preparation. An example of metallic arc welding is the vessel shown under construction in Fig. 4, a Monel granulating tank for use in the production of potassium dichromate. It measures 8 ft. 6 in. diameter, 6 ft. 2 in. high, and 0·104 in. thick sheets were used for the bottom and the sides. The agitators fitted to the $3\frac{1}{2}$ in. diameter Monel shaft were arc welded also.

TABLE 2 — CURRENT IN AMPS. USED WITH ARC WELDING ELECTRODES

Electrode diameter, in.	Current, amps.
0·075	25-40
$\frac{3}{32}$	45-60
$\frac{1}{8}$	60-95
$\frac{5}{32}$	80-150
$\frac{3}{16}$	140-190
$\frac{1}{4}$	170-260

The coated arc welding electrodes available for the welding of these two alloys have more satisfactory deposition characteristics when used on direct current than when used with alternating current. The fine gauge electrodes below 10 s.w.g. can, in fact, only be used with the former type of current. The currents used with the various electrodes are given in Table 2, and experience has shown that when these currents are exceeded, unsoundness, severe undercut and weld metal cracking usually result due to overheating of the weld metal and to the excessive loss of deoxidants in the arc. Single runs are used for thicknesses up to $\frac{1}{8}$ in., although it is often considered desirable to apply a backing run to these joints to ensure a smooth weld on the underside. Where multi-runs are deposited wide weaving is found to be disadvantageous, even with the finishing runs, as it leads to overheating and so to unsoundness and cracking. Because the electrodes do not have the smooth metal transfer characteristics of a modern mild steel electrode, the welding operator has to manipulate the electrode to ensure satisfactory base metal fusion and hence the preparation of butt joints is made wider than for mild steel. The electrodes are adversely affected by damp storage and have to be kept in warm dry storage. It is usual to dry them thoroughly immediately before use, a typical treatment being 2 hr. at 110°-120°C. This treatment does not embrittle the coating, but dries the electrodes to the extent necessary to give sound welds. If the electrodes have been in poor storage and are used in the undried condition, gross unsoundness will be present in the weld deposit, as shown in the radiograph of a butt joint in. Fig. 5.

The weld metal from Monel and K-Monel arc welding electrodes, when examined microscopically, shows a fine acicular dendritic structure, as in Fig. 6. This section also shows the nature of the narrow zone of partial fusion between the base material and the weld metal, the partial fusion having occurred primarily at the grain boundaries. In the macro-structure of the weld, illustrated by Fig. 7, the individual runs can be readily distinguished, and the continuity of the dendrites across the adjacent runs is apparent. In this particular joint, the root face, as prepared for welding, $\frac{1}{8}$ in., was excessive and in consequence the welding operator did not achieve complete penetration

FIG. 5 — RADIOGRAPH OF UNSOUNDNESS IN MONEL ARC WELD RESULTING FROM USING DAMP ELECTRODES (× 1)

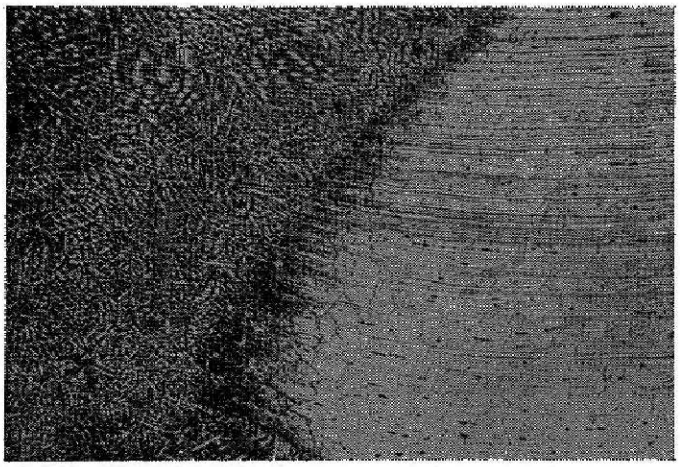

FIG. 6 (183) — WELD METAL AND ZONE OF PARTIAL FUSION IN METALLIC ARC WELD (× 50)

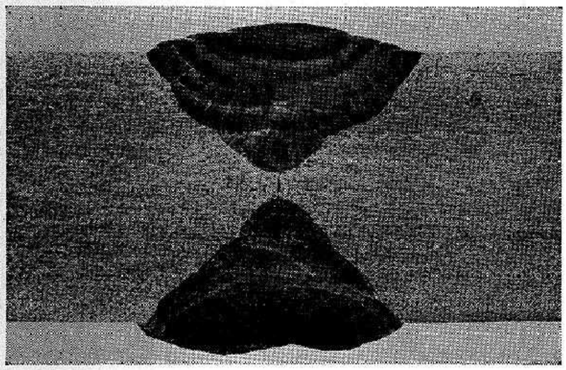

FIG. 7 (H. 2354) — MACRO-SECTION OF BUTT JOINT IN $\frac{3}{4}$ IN. THICK MONEL PLATE. DOUBLE-VEE PREPARATION. LACK OF ROOT PENETRATION AT CENTRE OF JOINT (× 3)

through the thickness of the joint. This section was taken from a trial test-piece made prior to the fabrication of a large Monel pressure vessel, and consequent on the findings from the examination of this sample, the root face was reduced to $\frac{1}{16}$ in. and the current for the root-runs increased. Radiographs of the joints in the welded vessel confirmed that the lack of root fusion apparent on the test sample had been avoided in the vessel itself.

The oxy-acetylene process is used extensively for the fabrication of equipment in the thinner material and the general techniques used are those for mild steel. The welding equipments used are those capable of giving a welding flame of constant size and characteristics. Whilst generated acetylene is occasionally used, the danger of incomplete purification is always present and in consequence the risk of the welds being contaminated with phosphorus and sulphur. Such welds will be very prone to cracking whilst welding is in progress, and even if crack-free welds are obtained, the finished joints will have poor cold ductility. To avoid these risks most fabricators now use acetylene as well as oxygen from cylinders with dual stage regulators on each cylinder. These regulators give uniform gas flows, which ensure that the welding flame does not vary in setting during the welding operation. For welding Monel the flame is set slightly on the reducing side of neutral, the excess of acetylene showing a faint fringe round the centre cone. A greater excess causes an increase in the carbon content of the weld metal, whilst an oxidizing flame leads to an unsound weld. It has been found necessary to have a somewhat larger excess of acetylene when welding K-Monel to avoid oxidation of the aluminium and titanium in this alloy. Both alloys are welded with a flux. Whilst such compounds as borax and boric acid are useful active fluxing agents, flux/metal reactions occur when they are used with Monel and K-Monel, and boron is introduced into the weld metal. Boron-contaminated weld metal is prone to hot-cracking, and so it has been found necessary to use fluxes free from boron compounds. The most successful flux for Monel is one based on fluorides of sodium, calcium and barium, with some chlorides added. The one for K-Monel contains lithium fluoride also, this being added to flux any alumina formed. Both are free from boron compounds. The filler wires used are of similar compositions as the base alloys. The main difference in welding technique compared with that used for steel is the absence of 'weaving' or 'puddling' when welding the two nickel alloys. The welding operator has to achieve complete fusion through the joint by careful control of the speed of welding and the addition of the filler metal, as the deoxidizers are easily burnt out of the molten metal if this is moved about appreciably by the welding flame.

The oxy-acetylene process is, to some extent, being superseded by the argon arc process for the welding of the sections below $\frac{1}{10}$ in. thick. Filler wires have been developed which facilitate the obtaining of sound ductile welds, which is not possible when using the base alloy for this purpose. Fig. 8 shows the unsoundness in a weld in Monel made with Monel as the filler wire, and Fig. 9 the surface of a joint made with the Inco '60' Monel filler wire as the

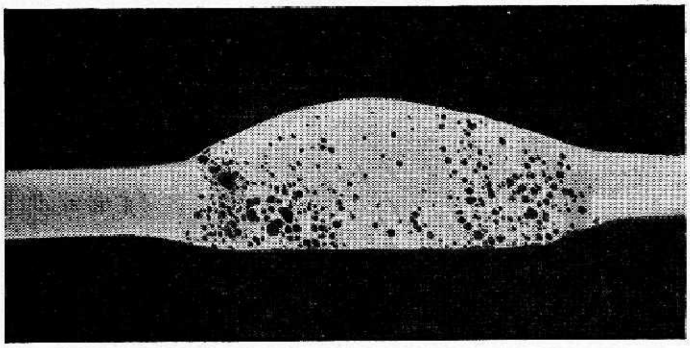

FIG. 8 (9534) — MACRO-SECTION OF ARGON ARC WELD IN MONEL, USING NORMAL MONEL AS FILLER WIRE (× 10)

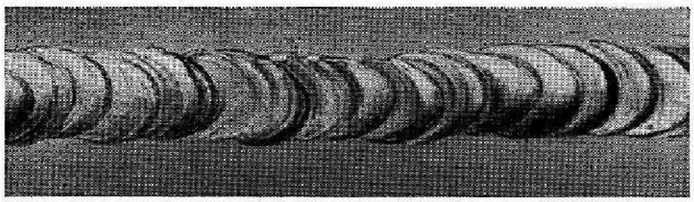

FIG. 9 — SURFACE OF ARGON ARC WELD IN MONEL USING INCO NO. 60 FILLER WIRE (× 2)

filler metal. The welding of K-Monel is also carried out with a modified alloy as filler metal to ensure sound weld metal.

Whilst the argon gas provides protection against oxidation of the top surface of a butt joint, the protection of the underside is incomplete and some oxidation occurs unless further precautions are taken to exclude the air. This is normally done by fitting grooved backing bars, or by applying a coating of flux to the underside of the joint. The flux used for oxy-acetylene welding has been found suitable and the moisture is completely dried off before welding is commenced, as residual moisture can cause porosity and piping.

The thoriated tungsten electrode is preferred to the plain tungsten electrode, particularly with low welding currents. Direct current, with the electrode negative, is preferred to alternating current, and the superimposition of a high-frequency current enables the arc to be started without contact between the electrode and the joint, so that electrode contamination is avoided.

Only in the United States is there a choice of protective gas, as nowhere else are there available supplies of helium at a cost comparable with that of argon. Helium enables sounder welds to be obtained more readily than does argon, and since the arc voltage, and hence the arc energy, is some 40 per cent higher with helium than with argon, faster welding is possible with the former gas. With thinner material, however, the lower arc energy is an advantage, and even in the United States argon is used for such welding. Although argon has these disadvantages, sound welds are, nevertheless, produced economically in both alloys using this gas as the protective cover. The gas consumption ranges from 8 cu. ft. per hour for thin material such as 20 s.w.g. (0·036 in.) to 20 cu. ft. per hour for $\frac{1}{8}$ in. thick sheets. The purity of gas now available is adequate for welding these nickel alloys.

The atomic hydrogen process has been applied to the welding of Monel, and the process is particularly applicable to the welding of long joints. Since no flux is required with this process, it is particularly suitable for automatic welding and it has been used successfully in the continuous production of tubing. Fig. 10 shows a macro-section of a Monel tube produced by atomic hydrogen welding, and subsequently cold-drawn and

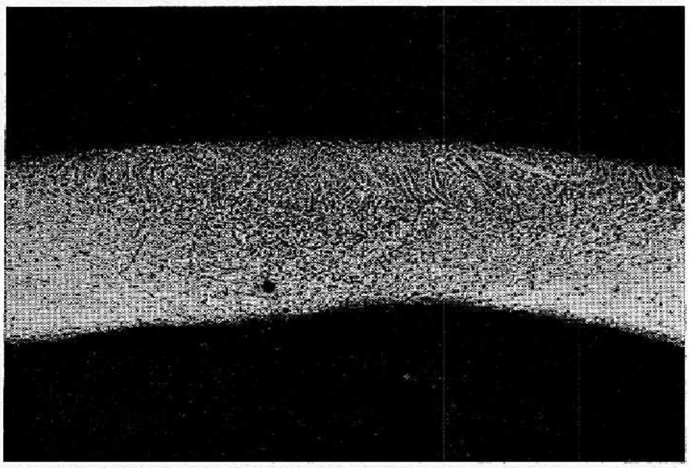

FIG. 10 (1198) — ATOMIC HYDROGEN WELD IN MONEL TUBE, COLD-DRAWN AND ANNEALED AFTER WELDING (× 30) annealed. Hydrogen is normally fed into the inside of the tube to provide protection of the underside of the joint, the one in Fig. 10 having been completed without the addition of a filler rod. This tube had been used successfully in the handling of beer.

The carbon arc welding of Monel is usually limited to the range of thicknesses 0·036-0·064 in. Specially coated filler wires are used and a flux is applied to the underside of the joint prior to welding. This flux and that on the filler wires are thoroughly dried prior to use to avoid unsoundness in the weld. Fig. 11 shows a cylindrical tank being carbon arc welded, and as can be seen from the illustration this is being successfully carried out in the vertical position.

The lining of steel vessels with Monel sheet is used extensively as an alternative to the use of Monel-clad steel in those applications where a continuous bond between the Monel surface and the mild steel backing is not necessary. The lining is usually fixed by metallic arc welding and the types of joint used are shown in Fig. 12. Overlap joints of Type A call for fillet welds on all the horizontal joints, and the vertical joints are staggered to avoid continuous

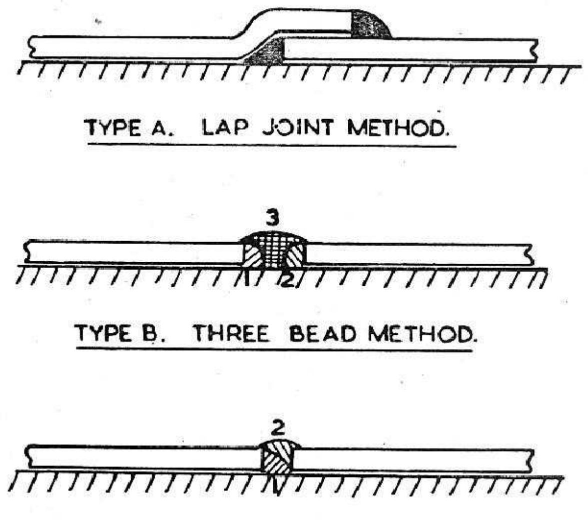

FIG. 12 — METHODS OF FIXING MONEL SHEET LININGS TO MILD STEEL VESSELS

seams. This method has the disadvantage that the lining is not flat over the joints.

The second method, Type B, involves more welding, as three beads are deposited and the weld metal is liable to be high in iron due to fusion of the underlying steel. It has the advantage that both sheets are welded separately to the steel base. In the third method, Type C, the Monel sheet is welded to the steel with a fillet weld, the second sheet being placed close up against the foot of the fillet weld after the slag has been removed. The joint is then completed by a second run which is made between the edge of the second strip and the first fillet weld. This method gives less iron contamination of the exposed weld metal. Recent tests using this method gave iron contents of 3·1, 2·5 and 2·8 per cent in the second run of joints in 16, 14 and 12 s.w.g. sheets. Whilst 16 s.w.g. linings have been used with all the methods, they call for very accurate fitting and considerable skill on the part of the welder, and 14 or even 12 s.w.g. linings are usually preferred.

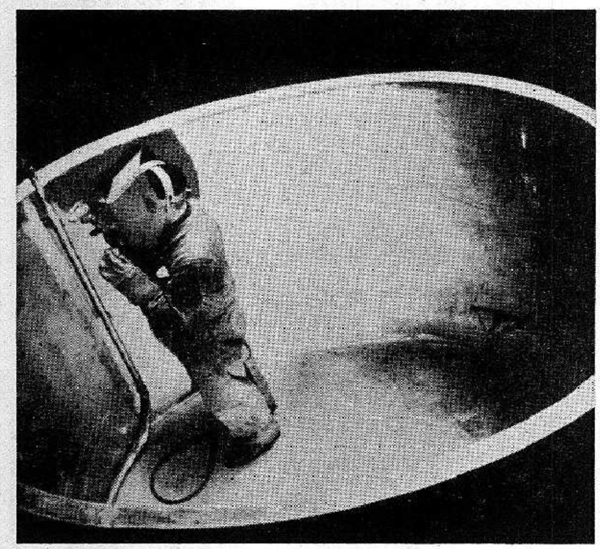

FIG. 11 — CARBON ARC WELDING OF MONEL TANK FOR USE IN INK MANUFACTURE (*By courtesy of Welders Ltd., Belgium*)

Fusion welds in Monel have tensile strengths and bend ductilities equal to those of the annealed plate or sheet material, and indeed because of the additions made to the electrodes and filler wires used, the yield strength and tensile strength of the weld metal itself will be superior. The welds in K-Monel are capable of being hardened by heat treatment, but as the weld metal is in a cast and not wrought condition, the tensile strength obtainable by ageing is a little lower than that obtainable in wrought material.

In all the resistance welding processes heat is generated in the parts to be welded by the passage of an electric current and the joint is completed by the application of pressure. The currents used are usually large and pass for relatively short periods of time. The condition of the surfaces meeting at the joint are of considerable importance, and for consistent results in the welding of Monel and K-Monel it has been found essential to remove all surface contamination, including oxide, grease, oil and also the deposit which can collect on the surfaces of sheets and sections when these are stored, even for short periods, in an industrial atmosphere. Both alloys are embrittled by sulphur and any surface contamination containing sulphur is liable to lead to brittle welds. Oxides, including those usually referred to as tarnishes, have a high electrical resistance and lead to excessive heating at the surfaces, and in consequence are always carefully removed before the welding is carried out. Pickling is probably the most common of the oxide removing processes, although mechanical grinding is used in some seam welding fabrication. Whilst the surface of bright annealed Monel requires no further cleaning prior to welding, K-Monel when annealed by this process takes on a slight surface tarnish due to the aluminium and titanium present, and this film has to be removed before welding is carried out.

Whilst magnetic or mechanical timers are widely used for the spot welding of steel assemblies, it has been found that high quality welds can only be obtained consistently in Monel and K-Monel, particularly in the thinner sections, when electronic timers are used. A detailed determination of the procedures for use with Monel was made some years ago by Hess and Muller[1] and detailed procedures based on their findings are given in Table 3. As an example of the data given by these investigators, for 0·031 in. thick Monel sheet a welding current of 10,500 amps. was needed on a 3/16 in. diameter electrode under a thrust of 700 lb. Whilst these investigators used domed electrodes, many operators prefer to use flat electrodes, in which case the nugget diameters are somewhat greater. The flat electrodes call for more accurate setting up than the domed ones, as any lack of parallelism is reflected in irregularities in the weld nugget. In the more modern spot welding machines the top electrode moves vertically on the end of its arm, so that when the electrode surfaces are adjusted parallel, they remain parallel

TABLE 3 — SPOT WELDING — MONEL

Thickness, in.	Electrode diam., in.	Electrode thrust, lb.	Firing time, cycles	Current, amps.	Sheet strength per spot, lb.
0·125	1/2	5000	30	30000	7300
0·093	3/8	2760	20	22600	4860
0·063	5/16	2700	12	15200	2584
0·031	3/16	700	12	10500	1056
0·021	3/16	300	12	6200	560
0·015	3/16	300	2	8600	310
0·010	5/32	270	2	7200	180
0·005	5/32	220	2	5000	70

TABLE 4 — SEAM WELDING — MONEL (2)

THICKNESS, in.	WIDTH OF ELECTRODE, in.	ELECTRODE FORCE, lb.	TIMING, CYCLES On	TIMING, CYCLES Off	WHEEL SPEED, in./min.	CURRENT, amps.
0·062	$\frac{3}{8}$	2500	8	12	20	19000
0·031	$\frac{3}{16}$	700	4	12	19	10000
0·021	$\frac{3}{16}$	600	3	12	22	9500
0·015	$\frac{3}{16}$	300	1	3	75	7600
0·010	$\frac{5}{32}$	200	1	3	75	5300

throughout the welding cycle, and the setting is unaffected by variations in the thickness of the sheets. The electrodes used are usually copper alloys containing either chromium or cadmium. Sticking of the electrodes to the surfaces of the sheets is not common, but one fabricator who had some trouble with this overcame it by coating the electrode tips with a thin electrodeposit of silver.

Detailed procedures have not been worked out for K-Monel, but it has been found that the use of slightly lower currents, because of the higher electrical resistance, and high pressures, to compensate for the higher strength, than those recommended for Monel give sound welds. In the as-welded condition, welds in K-Monel have a somewhat higher strength than welds in the same thickness of Monel sheet. Heat treatment increases the shear strength of the welds in K-Monel by about 50 per cent.

It has been found that K-Monel is more prone to cracking in the weld nugget and this tendency is usually overcome by the use of higher pressures. The modern type of spot welding machine, incorporating a low inertia head holding the upper electrode and fitted with slope control of the welding current, is particularly suitable for this alloy.

Stitch and seam welding of the two alloys are carried out on conventional machines, provided they are capable of exerting the necessary thrust. Procedures have not been worked out for the full range of thickness as with spot welding, but those available for Monel are given in Table 4. It is usual to have the 'off' period at least twice the 'on' period, otherwise the major portion of the previous spot will be remelted because of current shunting, and this metal will subsequently solidify whilst not under pressure. In consequence cracking will occur.

Spot and seam welds made under the conditions given in Tables 3 and 4 always tear through the metal and not the weld interface when tested in shear or by the chisel test.

The joining of sections by flash butt welding is successfully carried out on the machines in which the current cut-off can be accurately positioned relative to the application of the upset thrust. It has been found essential to continue the welding current, preferably at a lower level, for a short period of the order of a 1/25 of a second after the upset has been applied. If the current is stopped before the upset starts, the flashing faces have sufficient time to oxidize, and there is a layer of oxide at the weld line, which seriously reduces the weld strength. Table 5 gives procedures for two thicknesses of each alloy. To enable a satisfactory build up and distribution of temperature to be achieved it is usual to point the ends of the sections to be joined. The currents used in flash welding are considerable, and, particularly on compact sections, it is a usual practice to feed the current in through both the top and the bottom jaws of the clamps. Current through only half of the clamps can give excessively high current densities into the work, and local melting of the work-piece at the edge of the dies often results.

TABLE 5 — FLASH WELDING CONDITIONS FOR MONEL AND K-MONEL RODS (3)

ALLOY	ROD DIAM., in.	FLASHING DISTANCE, in.	FLASHING TIME, sec.	CURRENT DURATION DURING UPSET CYCLES	UPSET DISTANCE, in.	STRENGTH, tons/sq. in.	
						Weld*	Rod
Monel	$\frac{1}{4}$	0·442	2·4	$1\frac{1}{2}$	0·125	30·5	31·4
	$\frac{3}{8}$	0·442	2·5	$2\frac{1}{2}$	0·145	35·9	37·8
K-Monel	$\frac{1}{4}$	0·442	2·5	$1\frac{1}{2}$	0·125	41·9	44·6
	$\frac{3}{8}$	0·442	2·5	$2\frac{1}{2}$	0·145	44·1	44·2

*In the as-welded condition.

Resistance butt welding, in which a high current is passed through the contacting ends of the sections to be joined, pressure being applied when the metal becomes plastic, is considered by some to be an unsuitable process for these two alloys, because of the difficulty of breaking up and extruding the tenacious oxide formed at the interface during the heating up period. On smaller sections it has, however, been used successfully, a large upset being employed to remove the oxide. Fig. 13 shows the joint in a $\frac{3}{16}$ in. diameter K-Monel rod made by this method. In the as-welded condition these joints had a tensile strength of only 2 tons/sq. in. lower than that of the rod, and after thermal hardening the deficiency was less than 3 tons/sq. in.

Monel and K-Monel are produced under conditions which exclude any possibility of contamination, but there have been instances of defective welds resulting from surface deposits accumulated during storage or fabrication. In the case of the repair or modification of equipment, there is the additional danger of harmful deposits which may have accumulated on the surface. Both alloys are embrittled by sulphur, phosphorus and lead, and these can be introduced through grease, oil, paints, traces of solder, and even the dust which accumulates with time in an industrial atmosphere. Fig. 14 shows a Monel arc weld applied to an ice cream unit, in which the joints had originally been soft soldered. During the modification of the unit, it had been decided to arc weld certain of the joints, but no thought had been given to the need to remove a thin layer of soft solder which was on part of the surface. In consequence severe cracking had occurred when the welds were made due to lead pick-up by the weld metal.

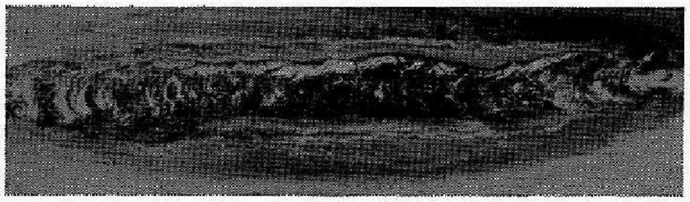

FIG. 14 — CRACKS IN METALLIC ARC WELD DUE TO LEAD (MONEL) (× 1)

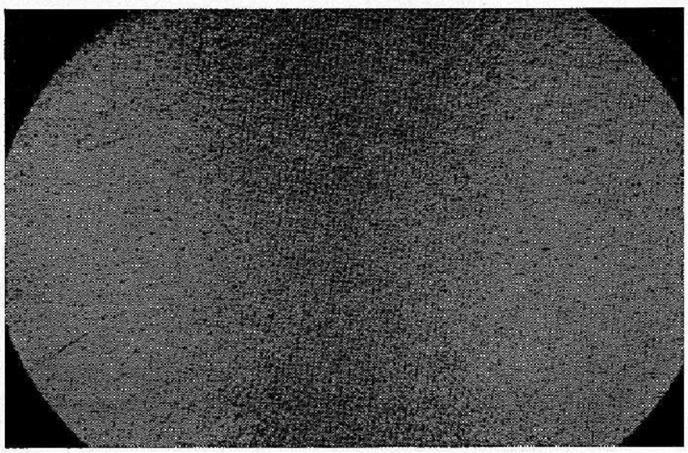

FIG. 13 (1203) — ELECTRICAL RESISTANCE BUTT WELD IN $\frac{3}{16}$ IN. K-MONEL ROD. AS-WELDED (× 50)

The severe cracking which can result from sulphur contamination in the weld metal is shown in Fig. 15. This oxy-acetylene

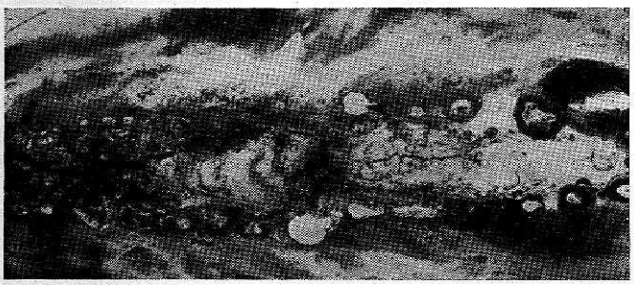

FIG. 15 — CRACKS IN OXY-ACETYLENE DUE TO SULPHUR (MONEL) (× 1)

weld had been made in Monel sheet which formed part of a vessel handling a high-sulphur compound. The weld was made without removal of deposits on the surface of the Monel sheet, and very severe cracking had resulted, as shown.

Whilst these are rather extreme examples of the effects of contamination present on the surface of Monel prior to welding, there are numerous examples of defective welds due to the presence on the surface of either a deposit or the product from the superficial corrosion of the Monel. The removal of the deposit from the surface would have enabled sound welds to be obtained, since the effect prior to welding was superficial.

The inspection of welds in these two alloys is not always carried out with the full appreciation that it is necessary for the welds to be of such a quality that they will resist the corroding conditions they are to meet as well as have the required strength. It is rarely that a rough or irregular surface will not lead to accelerated local corrosion, and an instance of this is shown in Fig. 16. This is a section from a Monel pickling chain link made by resistance butt welding using a machine which normally made steel chain. After a relatively short period of service in equipment pickling steel sheets, the chain was found to be badly corroded at the welds, whilst the remainder of the links were but little attacked. In the welding operation, the current was fed into the link through copper contacts which had not been in sufficiently close contact with the Monel to prevent arcing, with the result that some surface melting and deformation of the Monel rod section had occurred. In addition, as a finishing operation to the welding, the extruded flash from the weld had been hot formed over the joint instead of being removed. In consequence the link was put into service with a number of surface crevices which initiated crevice corrosion of the Monel and led to premature failure. The Monel chain had been proof tested before acceptance, but no inspection had been made of the surfaces of the links after welding. Whilst the process is used for the making of Monel chains, oxy-acetylene welding is often preferred, as this method enables the smooth surface so necessary for such application to be more readily obtained. A welded Monel frame used under the same conditions as the chain also failed prematurely because fillet welds, which were incompletely fused to the two component sections, had been passed as satisfactory. Accelerated cavity corrosion occurred in use and the weld metal eventually fell out, whilst the remainder of the structure was little attacked.

Even more rapid failures occurred in two oxy-acetylene welded Monel tanks holding zinc chloride solution for the dip fluxing of copper components prior to soft soldering. One-quarter inch thick Monel plate had been

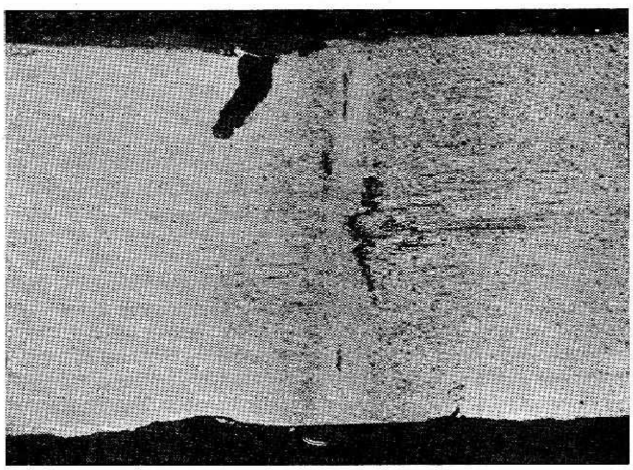

FIG. 16 — DEFECTS IN RESISTANCE BUTT WELDED MONEL PICKLING CHAIN SHOWING PIT (× 6)

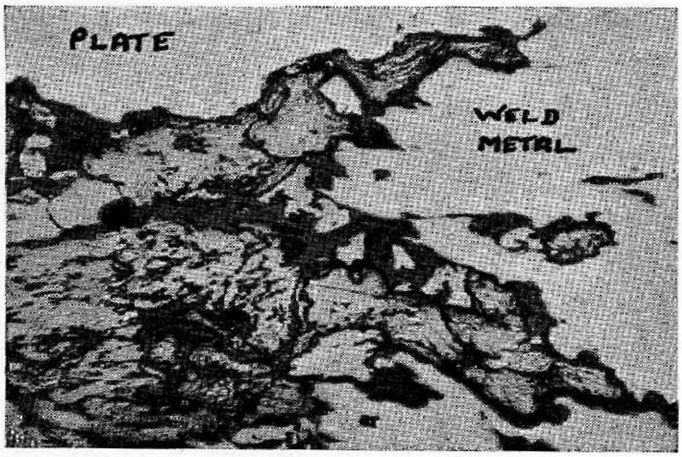

FIG. 17 — COPPER DEPOSITED DURING CORROSION OF MONEL WELD (× 100)

used in their construction, and in none of the joints had complete penetration been obtained. The tanks were put into service in this condition and after a short period the welds at the base of both tanks were found to be leaking. The welds had been severely attacked, and in places completely replaced by spongy copper, whilst the plates forming the bottom and walls of the tank were only slightly attacked. Subsequent examination showed that the conditions in cavities at the root of each weld were such that electrochemical deposition of copper from the flux had occurred with the simultaneous solution of the Monel. Fig. 17 shows the copper in the weld metal. The unsound welds were removed completely and replaced by metallic arc welds, a smooth sealing run being applied, on the inside of the tank, to the root of each. This re-welded assembly proved to be satisfactory in service.

An oxy-acetylene welded Monel tank, fabricated in 0·08 in. thick sheet and used for holding vinegar, was found to be leaking through perforations in the weld after about nine months in service. The welds were found to be slightly unsound, and the unsoundness had given rise to local accelerated corrosion which had eventually resulted in perforation of the weld at several places. Fig. 18 shows the unsoundness in the weld and a pit initiated by this unsoundness.

A steam heater coil fitted to a sulphate bath was built up from formed lengths of Monel tubing, $\frac{1}{16}$ in. wall thickness, by oxy-acetylene welding. After a short period in service, the coil developed leaks through the welds. These were found to be unsound as shown in Fig. 19 and pitting, initiated by the unsoundness, had penetrated through the thickness of the weld. It is apparent from the photograph that where the welds were sound, the welds were as lightly corroded as the tubing itself. Welding had been made difficult by the inaccurate fitting of the tubes at the joints, and it was necessary to cut out the unsound welds, carefully align the tubes, using internal ferrules, and to re-weld, to obtain satisfactory joints.

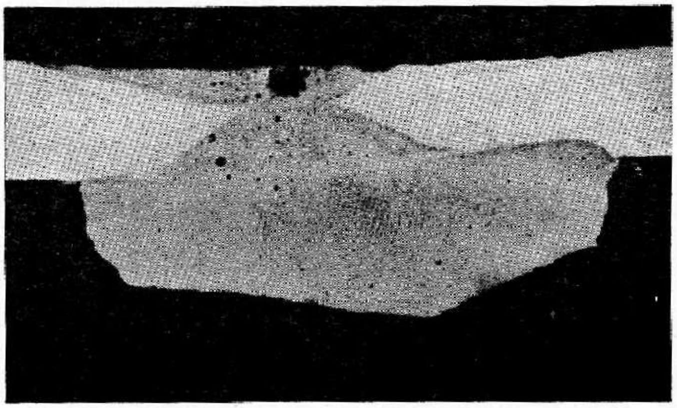

FIG. 18 (8907) — UNSOUNDNESS, WITH RESULTANT PITTING, IN MONEL WELD METAL (× 10)

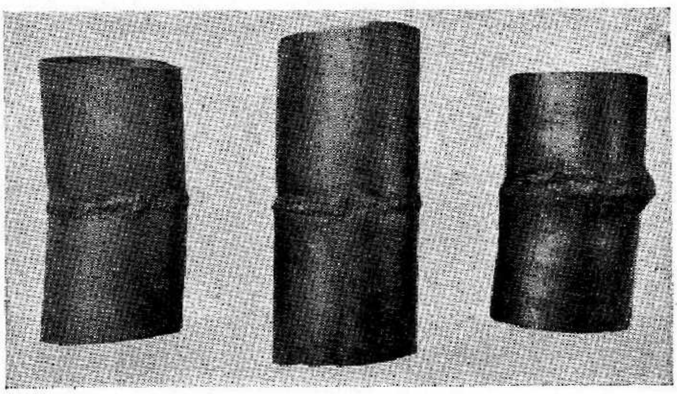

FIG. 19 — UNSOUND OXY-ACETYLENE WELDS IN MONEL TUBING, WHICH LED TO PITTING CORROSION (× $\frac{3}{4}$)

These examples have illustrated how structures having defects in the welds, resulting from insufficient care in the welding operation, have been allowed to go into service and have failed prematurely through accelerated corrosion initiated by the defects. The corrosion resistance of Monel and K-Monel is not adversely affected by the welding operation, as, for example, occurs with unstabilized stainless steels, and providing the weld joints are sound, they will resist corrosion as well as the parent material.

Acknowledgement

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