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MASTER

WELD POOL MOTION IN GTA WELDING:
IMPORTANCE AND DESCRIPTION

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ABSTRACT

Studies of material and arc effects on penetration in GTA welding are summarized and the resulting conclusions given. Metal flow in the weld pool, the apparent control mechanism, is described as having two basically different patterns which lead to the observed fusion zone shapes. Experimental evidence for these patterns and their likely mode of interaction with the arc are also presented.

INTRODUCTION

In seeking the cause of problems encountered in making deep penetration GTA welds in high manganese stainless steel (21Cr-6Ni-9Mn), temperature profiles in the arc plasma immediately above the weld pool (Manganese vapor dominated) for identical arc parameters and different heats of steel were measured. These measured profiles were then simulated by a computer solution to the radiation equations using assumed radial temperature and vapor density distributions. The results of these measurements and calculations showed that the temperature distributions (current density distributions) were essentially the same even though the depth-to-width rations (D/W) of the fusion zones in the different heats of steel varied by a factor of 1.8. There were no definitive variations in heat flow within the arc which related consistently to the changes in D/W.

Looking at other influences on D/W, the effect of helium on welding arcs was considered. Typically, helium is added to argon shielding gas to obtain an increase in weld penetration without the increase in weld width usually obtained with an increase in weld current. This suggests some subtle effect of increased energy or a sharpening of the energy (current) density in the arc. Therefore, current density distribution measurements were made in arcs on a chilled copper block (no molten pool) and the results indicated that the current density distribution is slightly broader (less heat concentration) in a

50%He-50%Ar arc than in a 100% Ar arc. This is contradictory to the weld behavior and suggests that heat flow distribution in the arc does not have primary influence on D/W.

To get a broader base of information on GTA welding behavior, an extended series of welds was made on rotating stainless steel bars using a representative range of arc length, current and gas mixture values. From these welds, values of fusion zone width and area were determined for each set of parameters. Then, a computer was used to calculate the heat input and "arc width" required to duplicate the experimental fusion zone areas and widths. Compilation of these data revealed that the heat input widths determined from the calculations did not correlate with experimental values of current density full-width half-maximum (FWHM). More significantly, the larger values of D/W could not be accounted for by diffusive heat conduction alone. Further details and results of these investigations may be found elsewhere [1,2,3].

The conclusions drawn from all of the work discussed so far are that weld fusion zone shape (D/W) does not correlate with the energy distribution in the arc, the differences in heat flow which yield various D/W's must occur in the weld pool, and the arc has a secondary effect on D/W.

PENETRATION CONTROL MECHANISM

Having drawn the conclusions just mentioned, the following question became most pertinent: How does the arc (and other factors such as material properties) influence the flow of heat in the weld pool and what are the fundamental differences that result in high or low penetration welds? The mechanism which fit all of the welding results obtained to date was "inverted convection" driven by the flow of weld current through the liquid metal. Current flowing into the weld pool exerts a (Lorentz) force distribution on the liquid metal which is the analog of the force exerted by the acceleration of gravity acting on a thermally induced density gradient in a fluid (normal convection). Under proper conditions, this force on the weld pool will induce a circulation of metal downward at the center and radially inward at the surface with outward flow at the bottom completing a stable convection cell (Figure 1). The flow of metal enhances the flow of heat to the perimeter of the pool and produces a relatively broad, shallow weld.

With such a convection analogy in mind, the effects of the arc current density distribtuion could be understood. If the distribution was narrow (argon arc) rather than broad (helium-argon arc), convection was more likely; just as in heating a beaker of water with a constricted (Figure 2) rather than broad (Figure 3) heat source. In the case of a welding arc, another phenomenon enters which explains the exceptionally deep, narrow fusion zones. Instead of a strong transverse flow developing as above, a predominantly front-to-back flow can occur in which heat is carried down by the metal flow at the arc center but is held near the weld centerline as the metal flows backward and then to the surface at the rear of the weld pool (Figure 4). This flow develops if the convection flow is suppressed by a broad current density distribution or surface forces which restrain spreading of the liquid metal.

EXPERIMENTAL CORROBORATION

Flow patterns such as these have been suggested, simulated and (in the second case) observed by other [4-8], but a clear direct observation of the vertical convection cell in a weld pool seems usually to be masked by single or double swirling flows in the horizontal plane. During the course of this present research, indirect evidence of vertical convection flow, possibly superimposed on the swirling flow, and the front-to-back flow was obtained in the case of the high manganese stainless steels dealt with earlier. The surfaces of weld pools were observed with a video camera (and recorder) through a narrow band optical filter which singled out manganese characteristic emission light whose intensity depended on plasma temperature and manganese vapor density. The physical set up of camera, torch and rotating bar is shown in Figure 5. For welds of intermediate to poor D/W, a ring of light concentric with the arc center appeared (Figure 6). For welds of high D/W, a plume of light was emitted behind the arc center and there was no ring (Figure 7). These areas of enhanced light emission resulted from local increases in manganese vapor density[1,2] caused by the surfacing of manganese-rich metal. The ring of light suggested strong convective flow which spread heat transversely and gave a weld of low D/W; the plume behind the arc center corresponded to the front-to-back flow that increased the D/W over that expected on the basis of thermal diffusion alone. While these varied distributions of manganese vapor immediately above the weld pool gave an indication of increased surface temperatures and rising manganese-rich liquid metal, in agreement with the proposed flow patterns, direct indication of the liquid metal flow would be more satisfying.

Conceptually, the flow could be revealed by a series of welds which were terminated at varying intervals after a dopant had been introduced to the weld pool. Various dopants, such as gold and tungsten powder which could be located by radiography plus a palladium-colbalt alloy which could be located by sectioning and chemical etching, were tried. The latter proved to be most satisfactory but a basic fault in the scheme developed as shown in Figure 8. The dark streaks in this longitudinal section of a 150 amp weld in 304 stainless steel depict the progress of the dopant during the approximately 0.2 second interval between introduction of the Pd/Co dopant and freezing of the weld pool. As the dopant prevaded almost the enitre weld pool during the shortest interval possible, the technique was clearly not satisfactory. The rapid mixing was evidently due to the swirling motion mentioned earlier and clearly shown in Figure 9.

The speed of mixing in the weld pool was shown even more emphatically by a real-time video recording of the mixing of gold dopant in a similar weld. An x-ray image intensifier system, made available by the Los Alamos Scientific Laboratory, was used to look through the weld pool as the gold was introduced. Counting video frames of the recording made indicated that the mixing took place approximately 0.1 second.

CONCLUSIONS

The seemingly anomalous variations in fusion zone shape (D/W) relative to the current density distributions in welding arcs are explained by the liquid metal flow patterns in the weld pools. Two distinct patterns proposed account for the extremes in D/W observed and qualitative experimental data support the existence of these two flow patterns in welds having the corresponding D/W's. A mode of interaction analogous to thermal convection explains how the welding arc influences metal flow and therefore has a second-order effect on D/W. Better knowledge of liquid metal fluid properties and flow patterns would help to explain the effects of subtle material property changes on weld penetration and is likely necessary for understanding the details of solidification phenomena.

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FIGURE CAPTIONS

Figure 1 - Schematic of the current flow (solid lines) and liquid metal flow (dashed lines) as seen in a transverse (perpendicular to the welding direction)

Figure 2 - Illustration of the convection flow which results from a constricted heat input to a beaker of water and the analogous welding situation. Note that the ink rises above the heat source in a well defined column and sinks outside the diameter of the copper heat conductor.

Figure 3 - Illustration of the absence of convection in the case of a broad heat source and the analogous welding situation. Note that there is only random stirring of the ink and no overall circulation.

Figure 4 - Schematic of the current flow (solid lines) and liquid metal flow (dashed lines) as seen in a longitudianl section of a weld pool exhibiting front-to-back flow. Enhances weld penetration.

Figure 5 - Schematic of the video camera and weld setup used to make the manganese characteristic emission light images shown in Figures 8 and 9.

Figure 6 - Photograph of a single video frame from a recording of manganese characteristic light emission above the weld pool of a 100 amp arc on low D/W stainless steel. The electrode tip is visible at the top and the leading edge of the weld pool is visible at the bottom. The black dot is a reference mark on the vidicon face used in obtaining quantitative data.

Figure 7 - Photographs of two video frames from a recording of manganese characteristic light emission above the weld pool of a 100 amp arc on high D/W stainless steel. The two views indicate the extent of random osciallation from side to side of the plume as it trails out horizontally over the back of the weld pool.

Figure 8 - Transverse section of a 150 ampere weld in 304 stainless steel. Dark streaks in the weld pool show the extent of mixing of the Pd/Co dopant in approximately 0.2 second. Magnification is 10x.

Figure 9 - Planar section of a 150 ampere weld in 304 stainless steel. Chemically stained Pd/Co dopant clearly reveals rotational motion in the horizontal plane. Magnification is 10x.

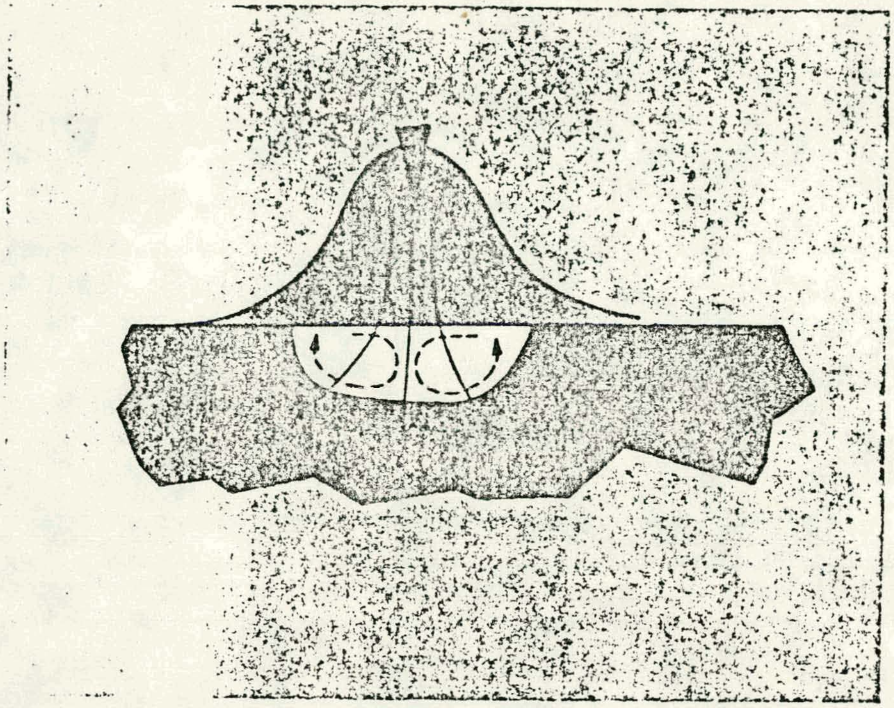


Fig 1

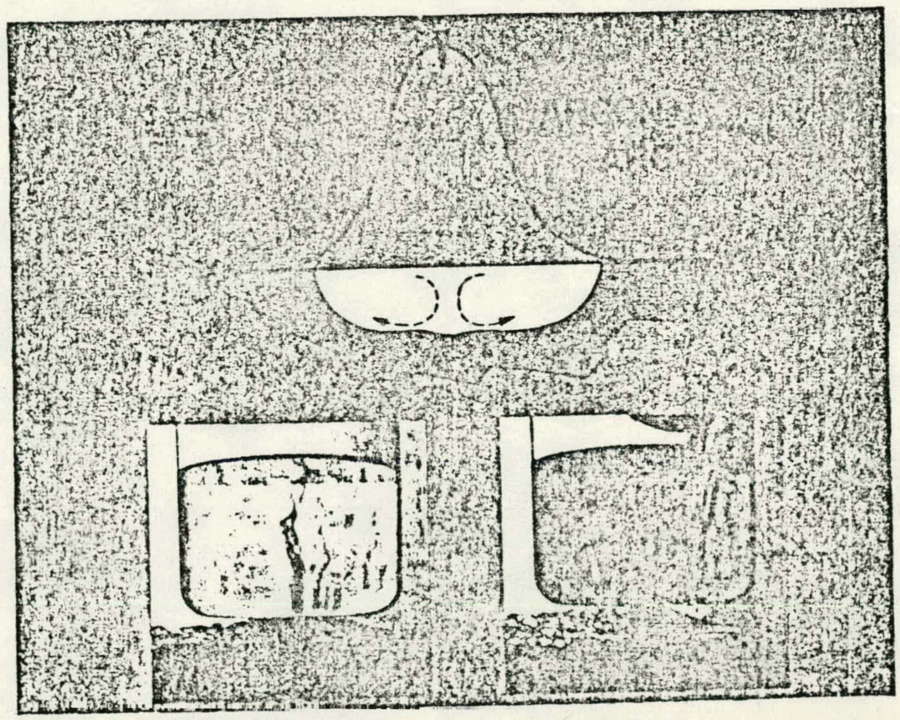


Fig 2

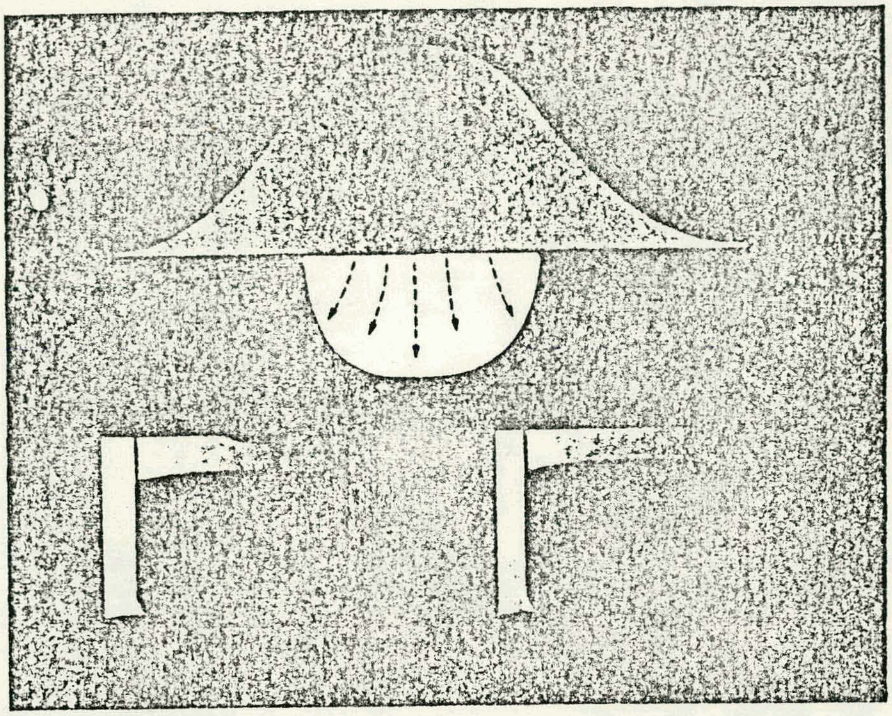


Fig. 5

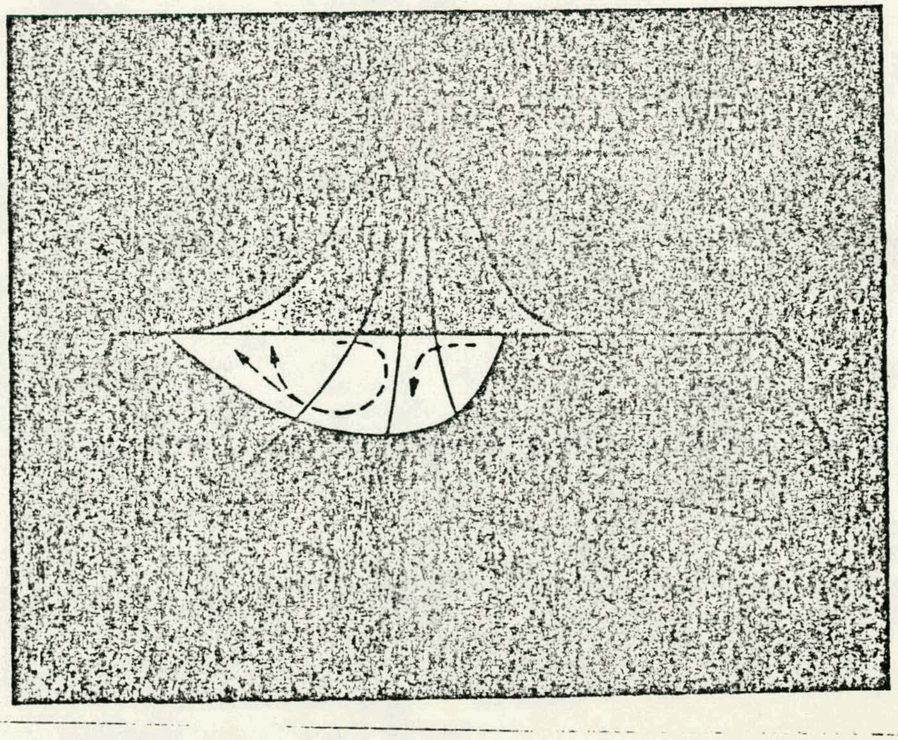


Fig. 4

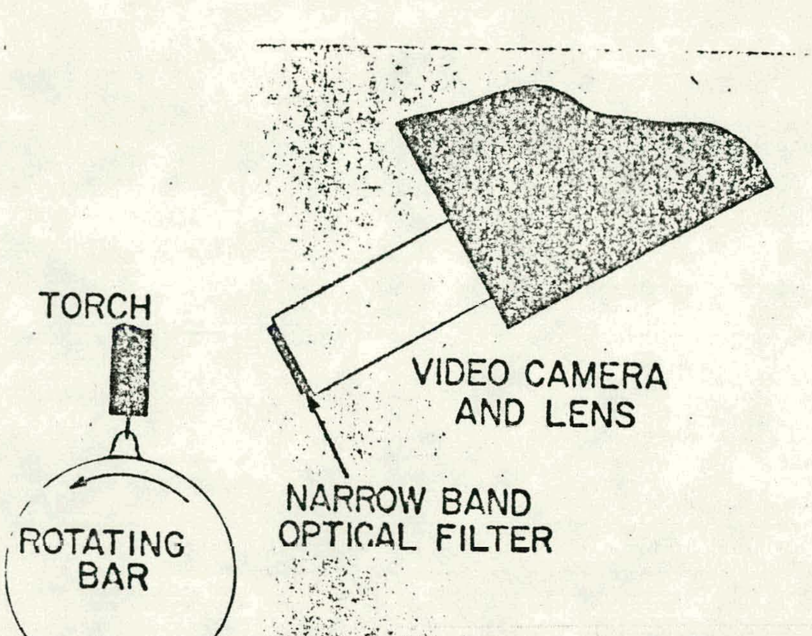

TORCH
VIDEO CAMERA
AND LENS
NARROW BAND
OPTICAL FILTER
ROTATING
BAR

Fig 5

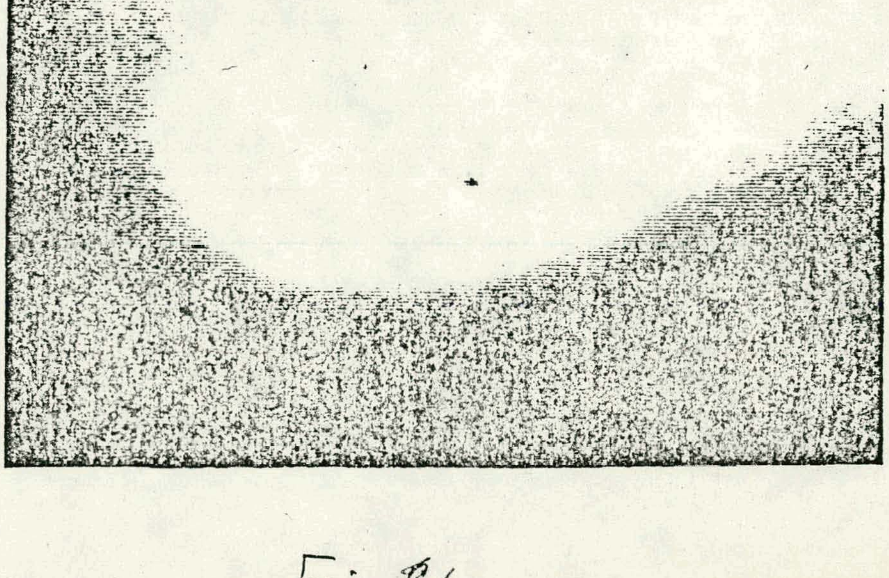


Fig 6

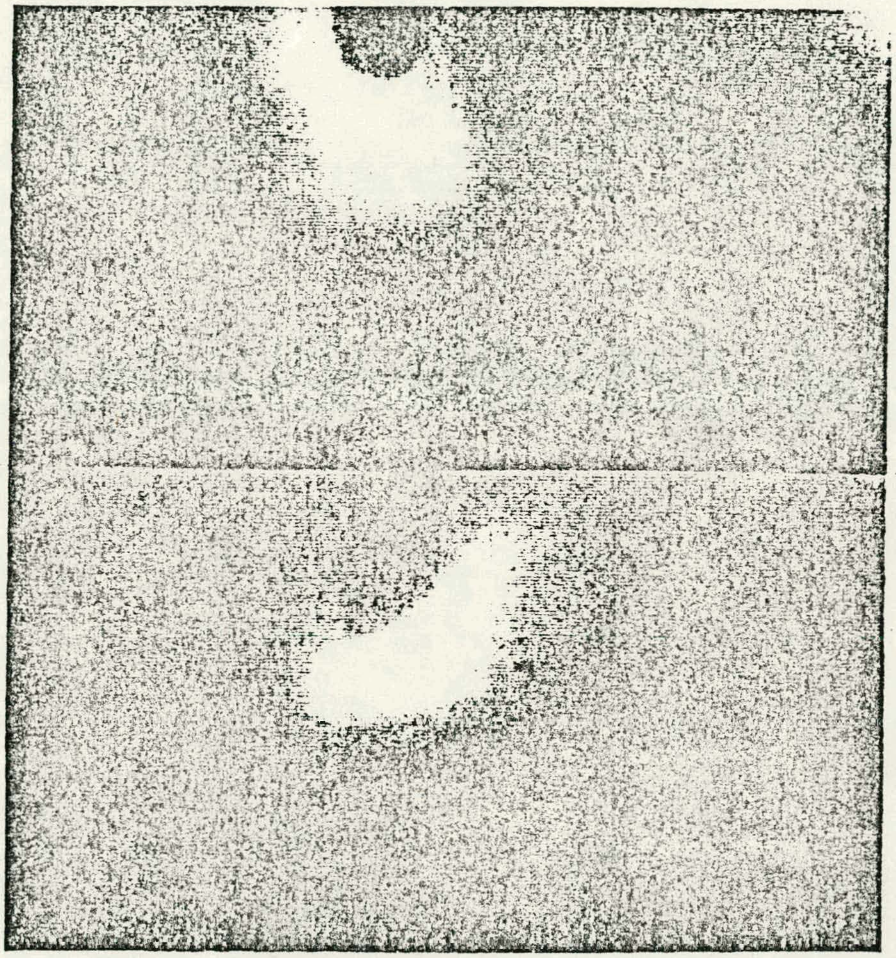
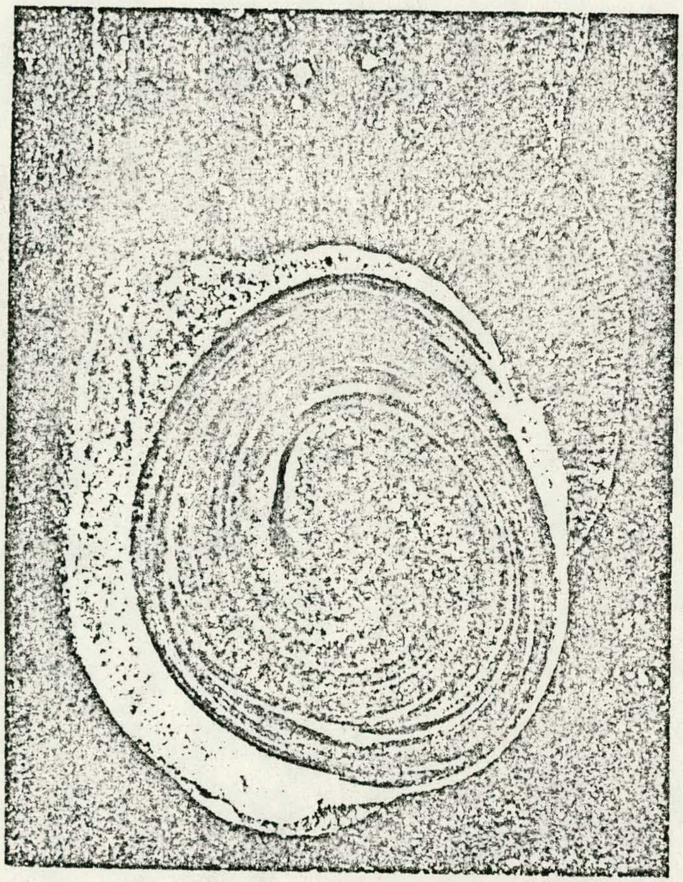
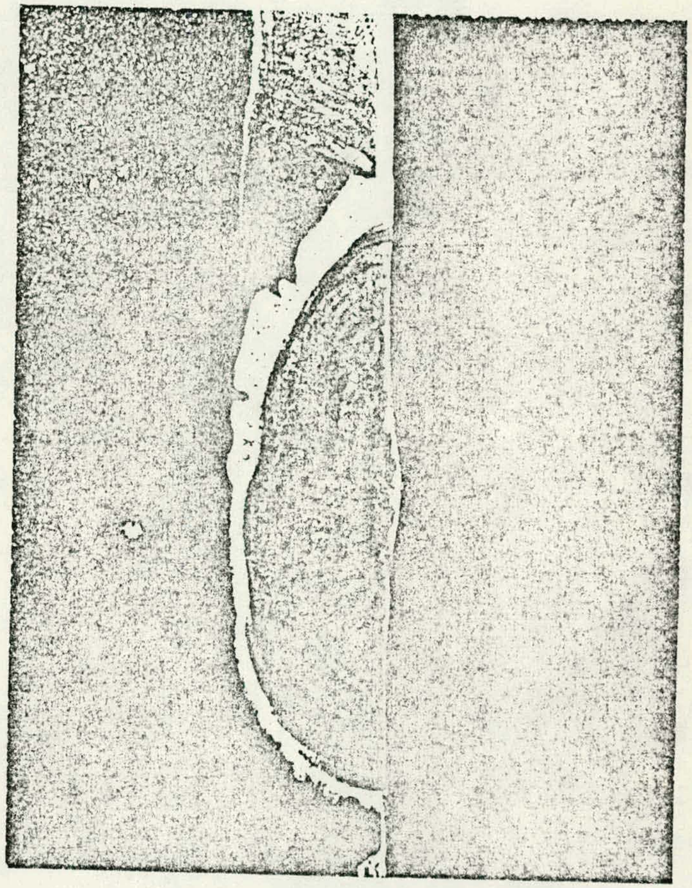


Fig 7





150A, 0.10, 5ipm, 20cfh Ar, 304