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NASA TECHNICAL MEMORANDUM

NASA TM-78201

ARC TERMINATION CRACKS IN INCONEL 718 AND INCOLOY 903

By E. Bayless, J. McCaig, and R. Poorman
Materials and Processes Laboratory

October 1978

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

(NASA-TM-78201) ARC TERMINATION CRACKS IN INCONEL 718 AND INCOLOY 903 (NASA) 17 p HC A02/MF A01 CSCL 11F

N79-10184

Unclas
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ARC TERMINATION CRACKS IN INCONEL 718 AND INCOLOY 903

INTRODUCTION

Arc termination crater cracks were appearing in a majority of the arc terminations on the Shuttle main engine in Inconel 718 and Incoloy 903 materials. Some 3000 welds are involved in fabricating a main engine, with a majority of these being multiple pass welds. It is estimated that there are more than 30,000 arc terminations on one engine where manual GTA, automatic GTA, and Electron Beam Welding processes are employed.

Repair of crater cracks involves grinding the crack, etching the ground material to remove any smeared metal that might obscure detection of any remaining crack, then dye-penetrant inspection to assure complete removal. Considering the amount of time involved in making one repair, multiplied by 30 000 plus, a tremendous amount of time and money could be expended in arc termination crater crack repairs on a single engine.

APPROACH

The Materials and Processes Laboratory initiated a program to investigate the welding conditions that are conducive to crater cracks and to establish techniques for prevention. The program was divided into four phases:

Phase 1 — Investigation of several weld termination techniques to determine frequency and degree of crater cracks:

a) Weld termination without weld current decrease

b) Weld termination at 50 percent of normal welding current

c) Weld termination using current decay to 5 - 6 A.

Phase II — Investigation of techniques to eliminate crater cracks in arc terminations. One of these techniques consisted of a decay in welding current, a decay in wire feed while continuing the forward travel. The other technique involves stopping the travel and decaying current and wire feed rate. This results in a metal buildup at the termination. If a crack occurs, there is a high probability that it will be constrained within the buildup and will be removed during mechanical removal of the buildup.

Phase III — Investigation of the effects of:

a) Welding over a crater crack

b) Welding over a crater crack which has been dye penetrant inspected

c) Welding over an area that had the crater crack mechanically removed, the area chemically etched and dye penetrant inspected.

Phase IV — Investigation of crater cracks in Incoloy 903. The approaches used in Phases I and II were repeated for manual welding using Incoloy 903 in lieu of Inconel 718 to verify that techniques developed for Inconel 718 would work for Incoloy 903.

In Phases I, II, and III, weld terminations were made by manual and automatic welding. All of the tests (Fig. 1) were conducted on 1/4-in. thick Inconel 718 and Incoloy 903 alloy plate using filler wire of the respective alloys. The test panels were 2 by 6 in. with a prepared joint. Three or four weld terminations were made in each panel after producing welds approximately 1 in. in length. After completion of welding, each panel was visually, radiographically, and penetrant inspected to determine if crater cracks were present.

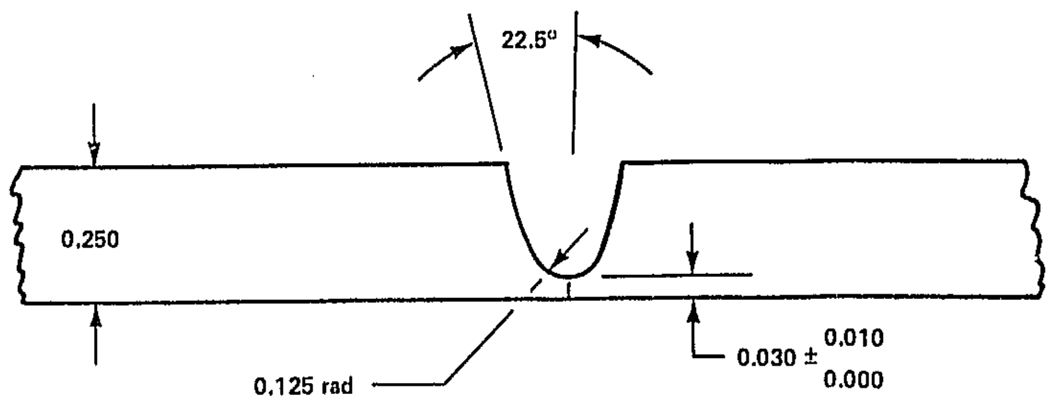


Figure 1. Joint design for 0.250 in. thick alloy 718 crater crack study.

DISCUSSION

Phase I

Eight root pass weld beads were made manually with the weld current terminated as rapidly as possible. This technique would simulate an unplanned termination such as loss of power or malfunction of equipment. Seven were similarly made by machine weld operations. All 15 weld terminations had crater cracks and most were very deep, some completely through the weld nugget. A typical termination is shown in Figure 2.

Approximately 16 terminations, eight manual and eight machine welded, were made by reducing the weld current to 50 percent of its normal value before cutoff. Investigation of this technique provided a better understanding of the crater crack causes, although it probably would not be used in production. Using this technique, the crack sizes at termination were smaller and in 50 percent of the cases were either too small to be detectable, or were nonexistent, as indicated by nondestructive testing. Termination cracks were detected in the other 50 percent of the terminations. Typical terminations are shown in Figure 2. Variation in cracks appeared to be related to travel speed and wire rate addition during the "tail out" modes.

Eight manual and eight automatic weld terminations were made by slowly reducing the weld current to the lowest value possible while maintaining an arc. This value was approximately 5 A in manual operations and 6 A for the automatic operations. Control of the arc during the current reduction, from welding current to the minimum value, is difficult, especially with the automatic operations.

The technique required the simultaneous adjustment of voltage and current slope controls. When the current is reduced, the arc length must be adjusted, by increasing the voltage, to maintain a stable arc. On the automatic control system, the current slope was used to reduce the current, and the voltage slope was used to simultaneously increase the voltage. The rates of increase/decrease were adjusted to maintain a stable arc of sufficient length to avoid contact between the tungsten electrode and the work piece. When this condition was reached, the automatic voltage control was shut off and the voltage control head was locked in position to maintain a constant arc length. Using this technique, detectable crater cracks were eliminated in the automatic

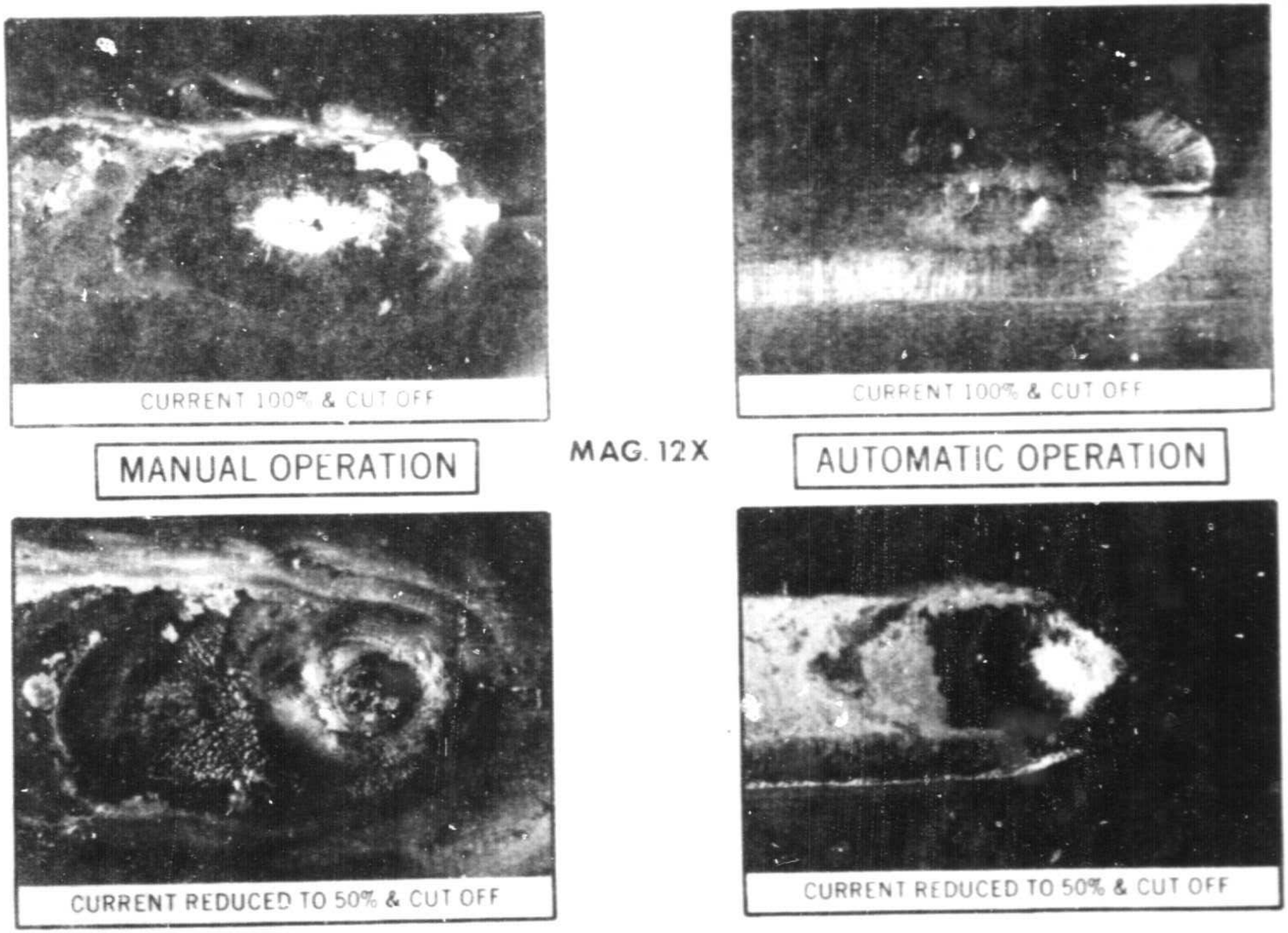


Figure 2. Weld termination in 0.250 in. Inconel 718.

process. Two of eight terminations resulted in crater cracks in the manual welds, probably a result of the lack of control as compared to an automatic weld.

All welds were examined visually, radiographically, and by dye penetrant. A typical termination zone produced by this reduced current technique is shown in Figure 3.

During this phase a comparison of visual inspection results and penetrant inspection was conducted to determine if visual examination was sufficient to detect crater cracks. Each specimen was visually inspected with the unaided eye, visually inspected using 10X magnification, and penetrant inspected using a high sensitivity flourescent penetrant. Where severe cracking occurred, unaided visual examination was sufficient. However, in 25 percent of the specimens 10X magnification was required to reveal the crater cracks. No additional crater cracks were found with penetrant over those found with 10X visual inspection. After inspection, each termination was ground until the crack was thought to be removed. Visual inspection at 10X and penetrant inspection revealed no cracks in the as ground surface. Each ground area was then etched and reinspected using penetrant. Two cracks were then noted, indicating that etching and penetrant inspection is required to assure removal of crater cracks.

Phase II

This phase was an investigation of weld termination buildup techniques. Eight terminations (weld buildups) were made manually and eight by machine welding. The buildup technique required a weld movement dwell and buildup by wire addition while the current was uniformly reduced to approximately 5 - 6 A. This requires precise control of current, wire feed rate, and arc voltage during weld termination. Wire is added and a low current arc continued to maintain a slow cooling weld puddle. As the current decreases, the wire addition is reduced proportionately and the buildup is created. All test weld terminations of this type were crack free. All buildups showed various degrees of surface crazing as shown in Figure 3. This technique normally requires mechanical removal of the buildup before subsequent weld passes are made.

A comparison of the cracking frequency for the various termination techniques is given in Table 1.

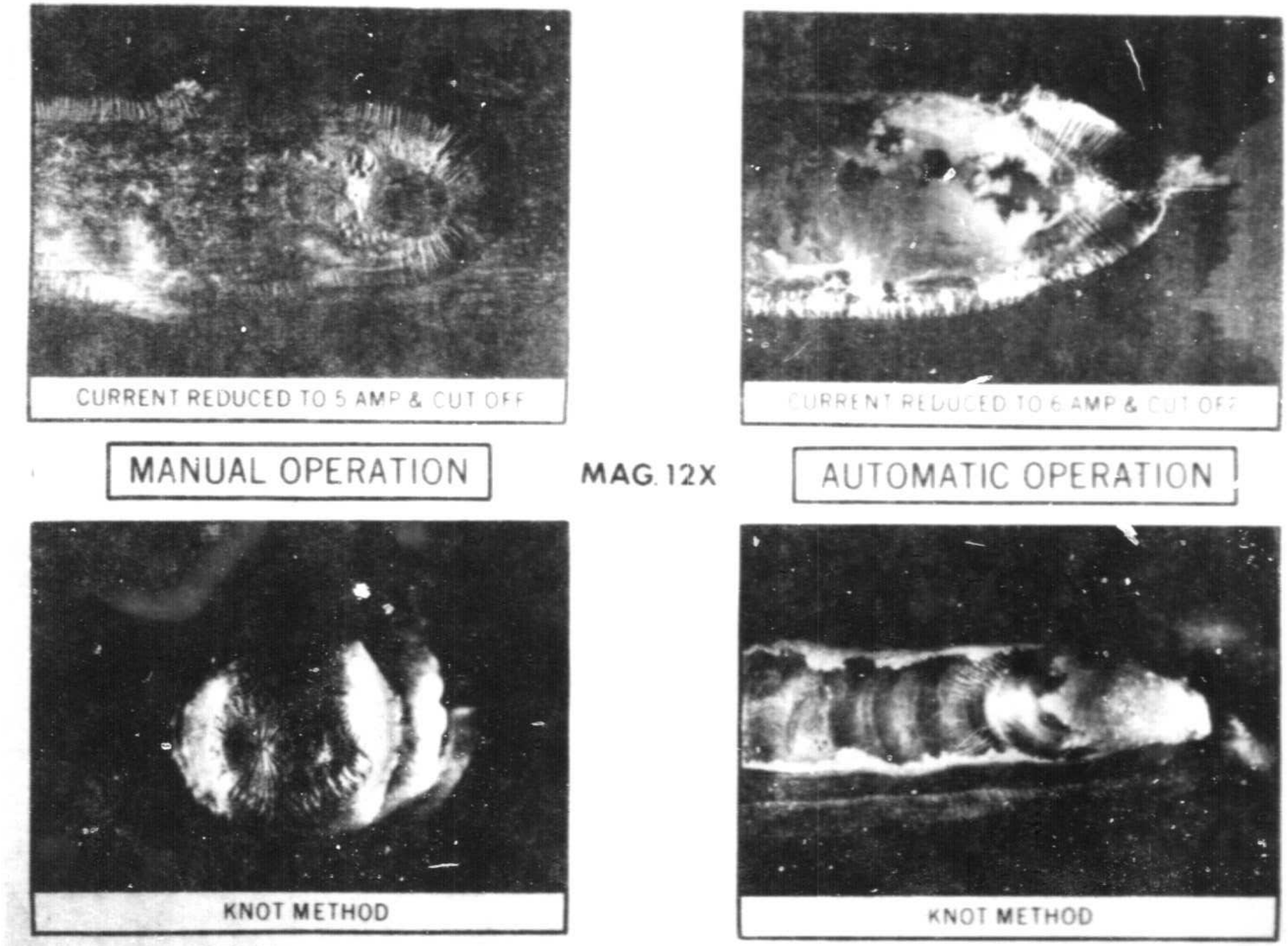


Figure 3. Weld termination in 0.250 in. Inconel 718.

TABLE 1. MATRIX OF INCONEL 718 ARC TERMINATIONS

Mode of Arc Termination	Cracks (percent)	
	Manual (percent)	Automatic (percent)
Termination at weld current	100	100
Termination at 5 percent weld current	50	50
Termination using current decay	25	0
Termination using current and wire feed decay but continuing travel	20	10
Termination by stopping travel, decaying current and wire feed	0	0

Phase III

In this phase, multipass welds were made over known crater cracks, crater cracks that had been revealed by dye pentrant inspection, and crater cracks that were mechanically ground, chemically etched, and examined with dye penetrant. Three welds were made by each technique, manual and machine welded. In all cases, there were no detectable cracks in the completed welds; however, porosity and oxide inclusions were noted.

Figure 4 shows a cross section of a weld over a crater crack in panels 14M and 15M. The crater cracks were in the penetration pass. Panel 15M shows defects that were found to be a combination of gas porosity and oxide contamination. Figure 5 shows the defects in panel 15M at 50X. The defect near the penetration side of the weld possibly is a result of welding over entrapped dye penetrant.

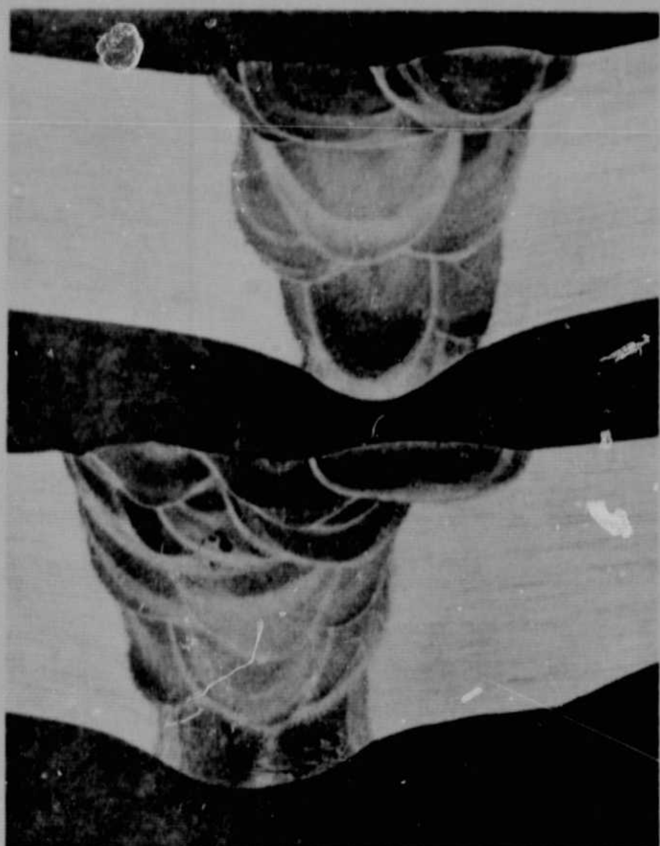
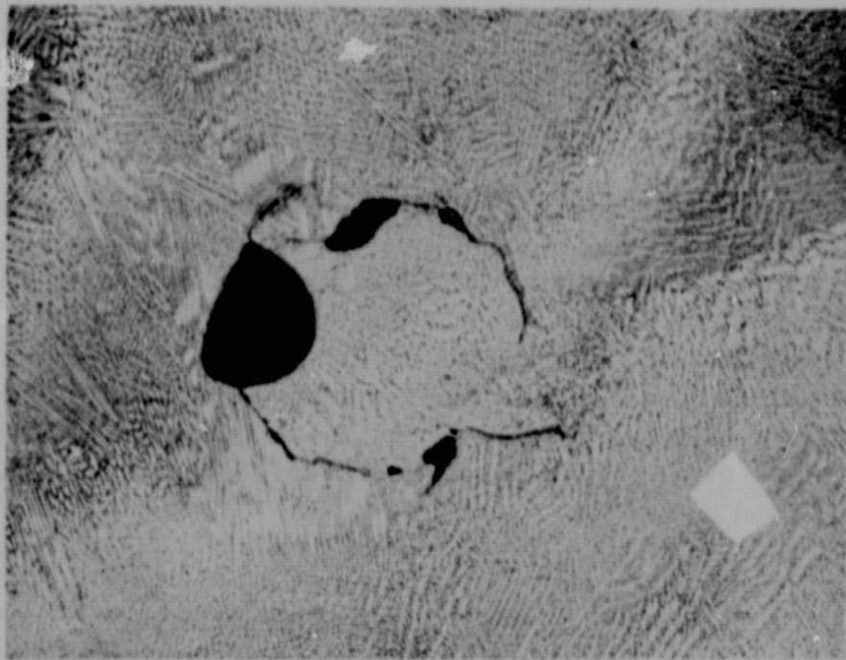
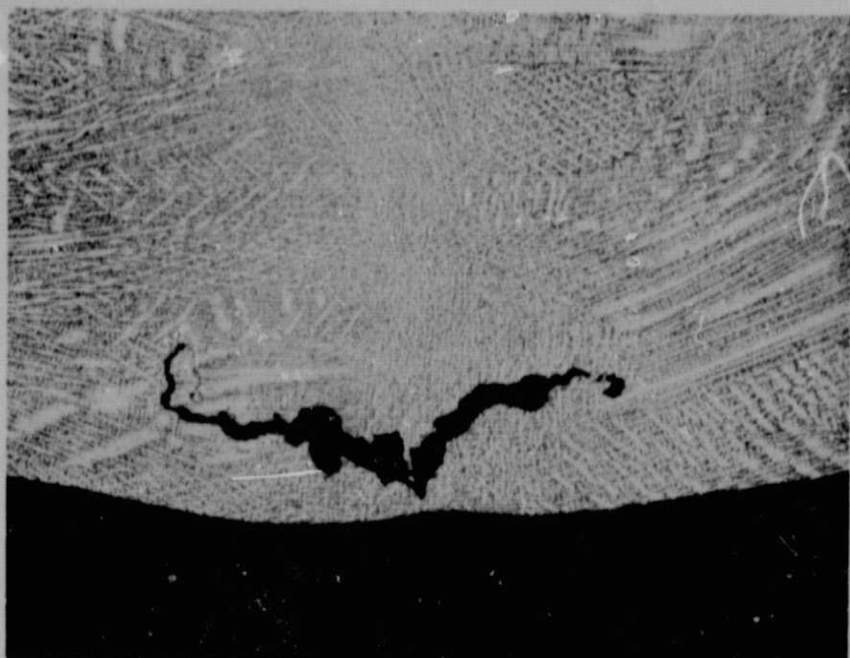


Figure 4. Sections of weld panels 14M (top) and 15M (5X).



Weld 15M.



Root pass of weld 15M.

Figure 5. Defects in 15M (50X).

Phase IV

This phase involved a determination of the crater cracking sensitivity of Incoloy 903 as compared to Inconel 718. Arc terminations were made by arc shutoff at welding current. These also resulted in crater cracks in 100 percent of the terminations. Utilizing the weld buildup technique used on Inconel 718 eliminated the crater cracks in Incoloy 903. Figure 6 shows the defects resulting when the arc is terminated at welding current, and Figure 7 shows the defect free weld buildup technique. The limited amount of investigation on Incoloy 903 did not give us a relative comparison of the crater crack sensitivity of Incoloy 903 and Inconel 718.

CONCLUSIONS

Inconel 718 and Incoloy 903 are susceptible to crater cracks in the arc termination area. With proper arc termination techniques, crater cracks can be eliminated. One such technique is to develop a metal buildup by adding filler wire while sloping current to minimum values. The sluggishness of the alloys necessitates increased skill for wire addition, especially during the termination while the weld current is decreased and the puddle solidifies. Temperature control of the cooling puddle appears to be the primary requirement for obtaining crack-free terminations. It is desirable to have the lowest possible temperature difference throughout the puddle when the arc is terminated. Long dwell times at constant current tend to produce undesirable effects. Crazing and erosion on the welded surface were increased as dwell time increased at constant current.

The practice of welding over cracks is not recommended because of the possibility of not refusing the crack and the likelihood of having porosity and oxide inclusions. When a crack is detected the best practice is to remove the crack mechanically, etch the area, and dye penetrant examine for assurance of removal.

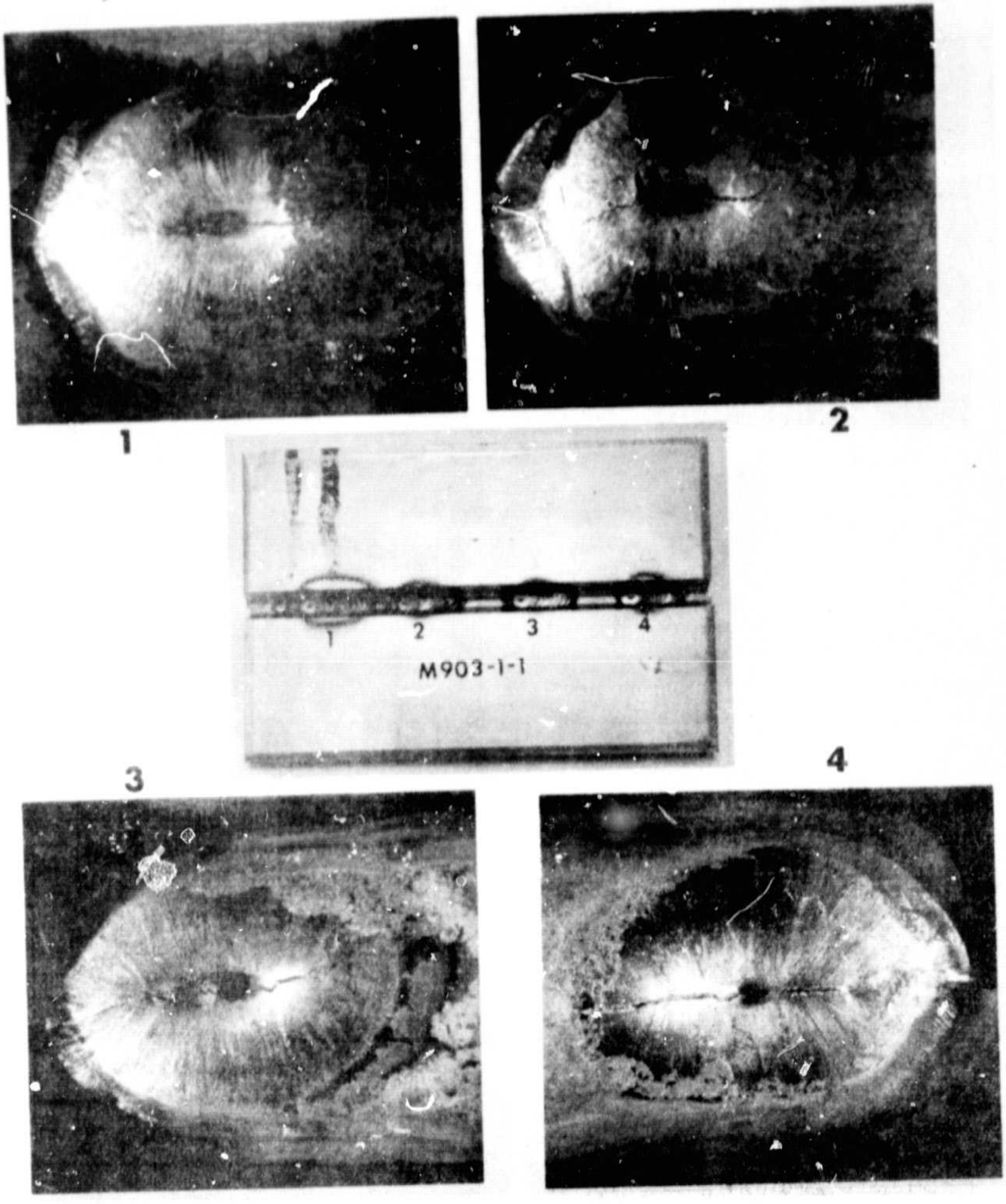


Figure 6. Panel M903-1-1 (welding A 70 and termination A 70).

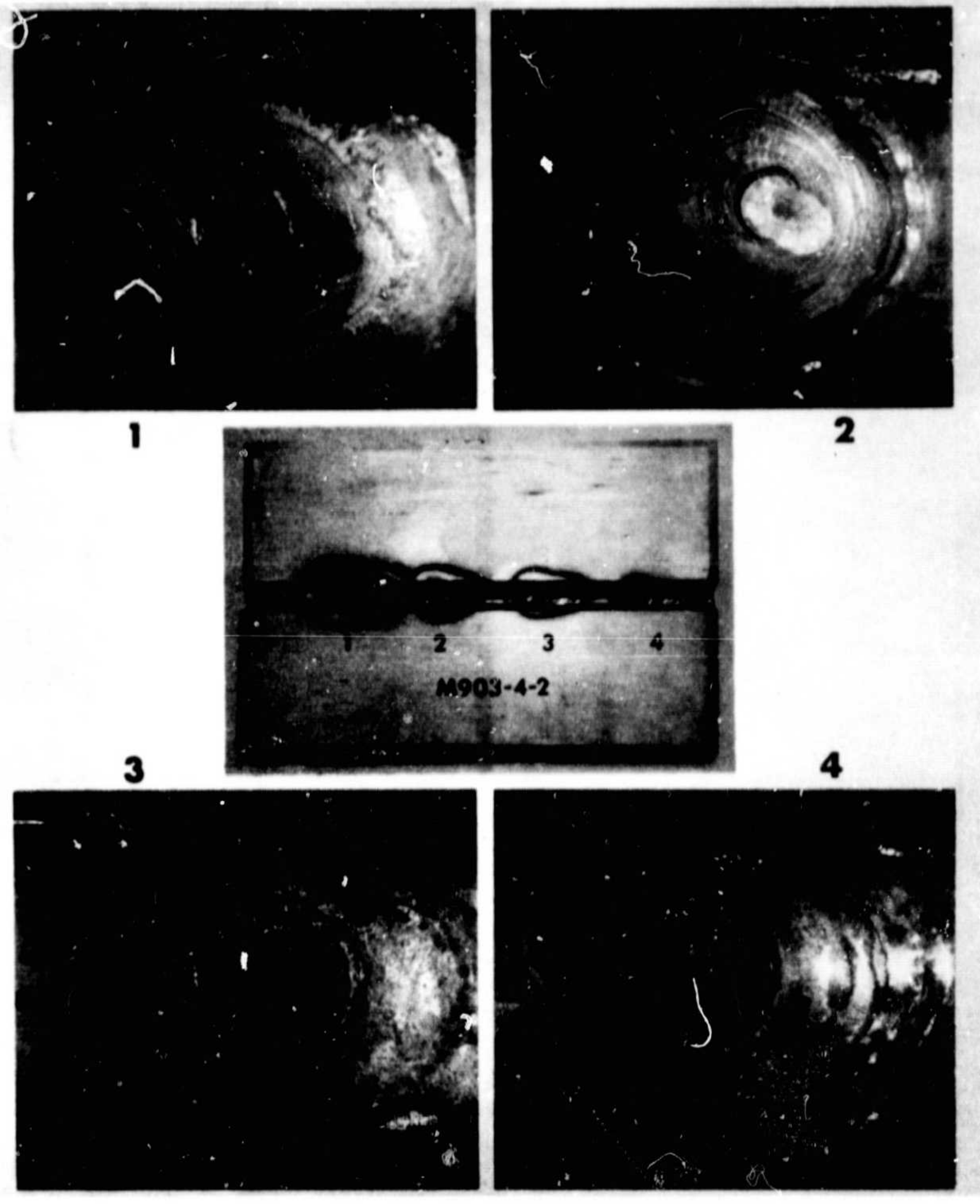


Figure 7. Panel M903-4-2 with wire added during termination (welding A 70 and termination A 06).