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THE CORROSION OF STAINLESS STEEL PIPE, WELDED BY VARIOUS METHODS, IN MOIST SAND

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Irvine I. Tingley and R. R. Rogers

Mineral Dressing and Process Metallurgy Division

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SUMMARY OF RESULTS

Specimens of stainless steel Type 304 pipe, welded by various methods, were tested in moist sand to determine their resistance to corrosion. All specimens on which flux-coated welding rods had been used corroded at the welds, while specimens welded by inert gas arc methods did not corrode. The corrosion was found to be initiated by the chemicals in the flux, and aggravated by crevice corrosion occasioned by porous layers of solidified flux.

* Scientific Officer, Mineral Dressing and Process Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

** Head, Chemical Metallurgy Section.

INTRODUCTION

While on a visit to Atomic Energy of Canada, Chalk River, Ontario, on August 6, 1957, Mr. I.I. Tingley discussed with Dr. F.H. Krenz the corrosion of welded stainless steel Type 304 pipe, which had been installed underground to convey radioactive waste solutions to a "burial ground". It had been found that corrosion had occurred at and near the welds of this piping and in several places the pipes had been perforated within three months after installation, even before any of the waste solutions had been run through it. It was agreed that experiments would be carried out at the Mines Branch Laboratories, to determine if possible the cause and nature of the corrosion of welded stainless steel pipe in an environment of moist sand.

APPARATUS

Sections of the same stainless steel Type 304 piping that had been used in the waste disposal lines were welded by methods similar to that used in the actual installation, and also by other methods for comparison. The resulting samples were tested for corrosion resistance in an environment which was believed to be fairly representative of that to which the waste disposal lines had been exposed. The pipes had been installed six feet underground in sand, and it was considered that burying the samples in moist sand in a vacuum desiccator under a slight nitrogen pressure would satisfactorily reproduce this environment.

PROCEDURE

Specimens of the 2" O.D. stainless steel piping were shop-welded at Chalk River and supplied for testing at the Mines Branch. The samples and their various treatments are listed in Table 1. Those welded using the argon-shielded tungsten arc method, have the letter "A" after the sample number, while those welded using unshielded metallic arc methods have the letter "M" after the number.

TABLE 1

Treatments Used in Preparing Welded Stainless Steel Type 304 Samples

Sample No.	Weld	Filler Wire	Treatment After Welding
1A	Argon shielded Tungsten Arc	Type 316 Stainless Steel	Wire brushed
2A	" " " "	" 316 "	None
3M	Metallic Arc, Unshielded	1/16" Type 347 AC/DC	Wire brushed
4M	" " "	3/32" " 316 "	" "
5M	" " "	1/16" " 316 DC	" "
6M	" " "	3/32" " 316 "	" "
7M	" " "	1/16" " 316 "	None

Each welded sample was cut to an overall length of 4 inches, 2 inches on each side of the weld. The samples were not degreased or pickled, but were tested in the "as received" condition. One ml of distilled water was pipetted into the interior of each welded sample, and both ends were closed with rubber stoppers which had been treated to prevent material from being leached from them during the test. The treatment consisted of boiling the stoppers in 5% NaOH for 30 minutes, boiling in distilled water for 15 minutes, and sealing them by dipping them in melted paraffin.

The prepared specimens were then buried in clean sand which was thoroughly moistened with distilled water until wet throughout its volume, in a vacuum desiccator. The air above the sand in the desiccator was displaced with nitrogen which resulted in a small positive pressure of nitrogen left over the moist sand surface. After 5 weeks the desiccator was opened, and specimens Nos. 1A, 4M, 5M, 6M and 7M were removed. Specimens Nos. 1A and 6M were sectioned and examined, and Nos. 4M, 5M and 7M were returned to their positions in the sand, covered over again, and put under nitrogen pressure again. At the end of another 9 weeks all of the specimens were removed for examination.

RESULTS

When the specimens were removed from the desiccators at the end of 5 weeks it was seen that those which had been welded with flux-coated rods, without inert gas shielding, had rusted in the region of the welds.

The depressions left in the sand by specimens Nos. 5M, 6M and 7M are shown in Figure 1. The rust stains in the sand are apparent, especially in the case of the pipe which had no wire brushing (No. 7M). Similar depressions left by specimens Nos. 1A and 4M are shown in Figure 2. Specimens Nos. 2A and 3M can be seen still partly embedded in the sand. In this desiccator, the argon-shielded tungsten-arc-welded specimen (No. 1A) had left no stain, while the sand in proximity to the unshielded metallic-arc-welded specimen, No. 4M, had been rust-stained.

Specimens Nos. 1A and 6M were sectioned and examined closely. The observations are given in Table 2.

TABLE 2

Comparison of Specimens Welded by Two Different Methods

Specimen No. 1A (Argon Arc)	Specimen No. 6M (Unshielded Arc)
Exterior	**Exterior**
Weld nearly uniform grey with very few flakes of rust.	Weld rusted and lightly pitted.
Some porosity at folds in weld, but no corrosion products. Heat-affected zone lightly stained.	Heat-affected zone heavily discoloured. Evidence of pitting and local attack at base of welds.
Interior	**Interior**
Weld clean, partially covered with light temper film.	Weld rusted and pitted. Complete loss of passivity in some regions.

Observations on the depressions in the sand left by specimens Nos. 2A, 3M, 4M, 5M and 7M are given in Table 3.

TABLE 3

Observations on Depressions in Sand Left by Samples After 14 Weeks
(Specimens Listed in Order of Decreasing Resistance to Corrosion)

Specimen No.	Observations
2A	No band of rust
4M	No more rust than at the first examination (after 5 weeks)
5M	Same as after 5 weeks
3M	A heavy rust band
7M	A heavy rust band (worst of all the specimens)

These five specimens were examined under the Zeiss stereoscope at low power. The observations are given in Table 4.

TABLE 4

Observations on Specimens After 14 Weeks in Moist Sand

Specimen No.	Magnification Under Zeiss Stereoscope	Appearance of Exterior Surface	Appearance of Interior Surface
2A	20X	Weld bead not bright as when new, but coated with a loose light grey deposit which rubbed off easily, revealing a lightly-etched metal surface. Slabs of unidentified glossy material adhering to the weld. Heat-affected zone discoloured by thin, reddish-brown temper film.	Still wet, corroded very slightly.
4M	12X	Particles of flux still adhered with varying degrees of tenacity to the stainless steel weld metal and weld zone. The weld metal under the flux was bright and clean when the flux was pried up, but the metal in the heat-affected zone was rusted under the flux. A number of shallow, elongated pits in the heat-affected zone.	Badly corroded at the weld and in the weld zone.
5M	12X	Similar to specimen 4M. Coated in spots with scabs of flux and pitted at the edge of the flux layers.	Badly corroded at the weld and in the weld zone.

(Continued)

TABLE 4 (Concluded)

Specimen No.	Magnification Under Zeiss Stereoscope	Appearance of Exterior Surface	Appearance of Interior Surface
3M	12X	Heavily rusted, but less pitting than on 4M and 5M.	Very badly corroded in the weld zone. Some relatively deep pits in the junction line between the two pieces.
7M	12X	Much solidified flux adhering to folds and corners of the weld. Welded region heavily rusted. No pitting or local attack, however.	Very badly corroded in the weld zone, similar to 3M.

A pit on the interior side of the weld on specimen No. 3M is shown in Figure 3. Another section of the same weld, where the flux has not been scraped away, is shown in Figure 4. Some of the solidified flux adhering to the exterior weld surface can be seen in Figure 5.

DISCUSSION

All the welds made with flux-coated welding rods rusted, and some had shallow pits in the heat-affected zone; however, none was as severely corroded as the actual pipe which failed at Chalk River. In none of the specimens did a perforation of the pipe occur. This indicates that the corrosive conditions in the desiccators were not as severe as those which existed in the soil at Chalk River. The pipe on the soil may have been more effectively aerated than was at first thought, and this partial aeration may have enhanced the crevice corrosion of the stainless steel initially attacked by the weld flux. This possibility is supported by the fact that the specimens were more severely attacked from the inside, where there were both air and moisture, than from the outside, and examination of specimen No. 3M in section (Figure 3) shows a large pit under the deposit of solidified flux, which in time might have penetrated the wall of the pipe. The flux deposit on this section of the pipe had a honeycomb structure (Figure 5) ideally suited to crevice corrosion.

CONCLUSIONS

It is concluded that the corrosion at and near metallic-arc welds on stainless steel Type 304 pipe was started by chemicals in the flux which coated the welding rods used, and that the severe corrosion proceeded by a crevice corrosion mechanism in crevices caused by adherence of solidified flux to the metal surfaces. Specimens welded by argon shielded tungsten arc method (without flux) did not undergo the same severe corrosion in moist sand.

It has been suggested by Mr. G.E. Rowan of Atlas Steels Limited that low-carbon stainless steels, such as Type 304L, welded with Type 308L rod, and Type 316L, welded with Type 317L rod, might exhibit better corrosion resistance in the moist sand environment. Further experiments will be carried out using these materials if they can be obtained.

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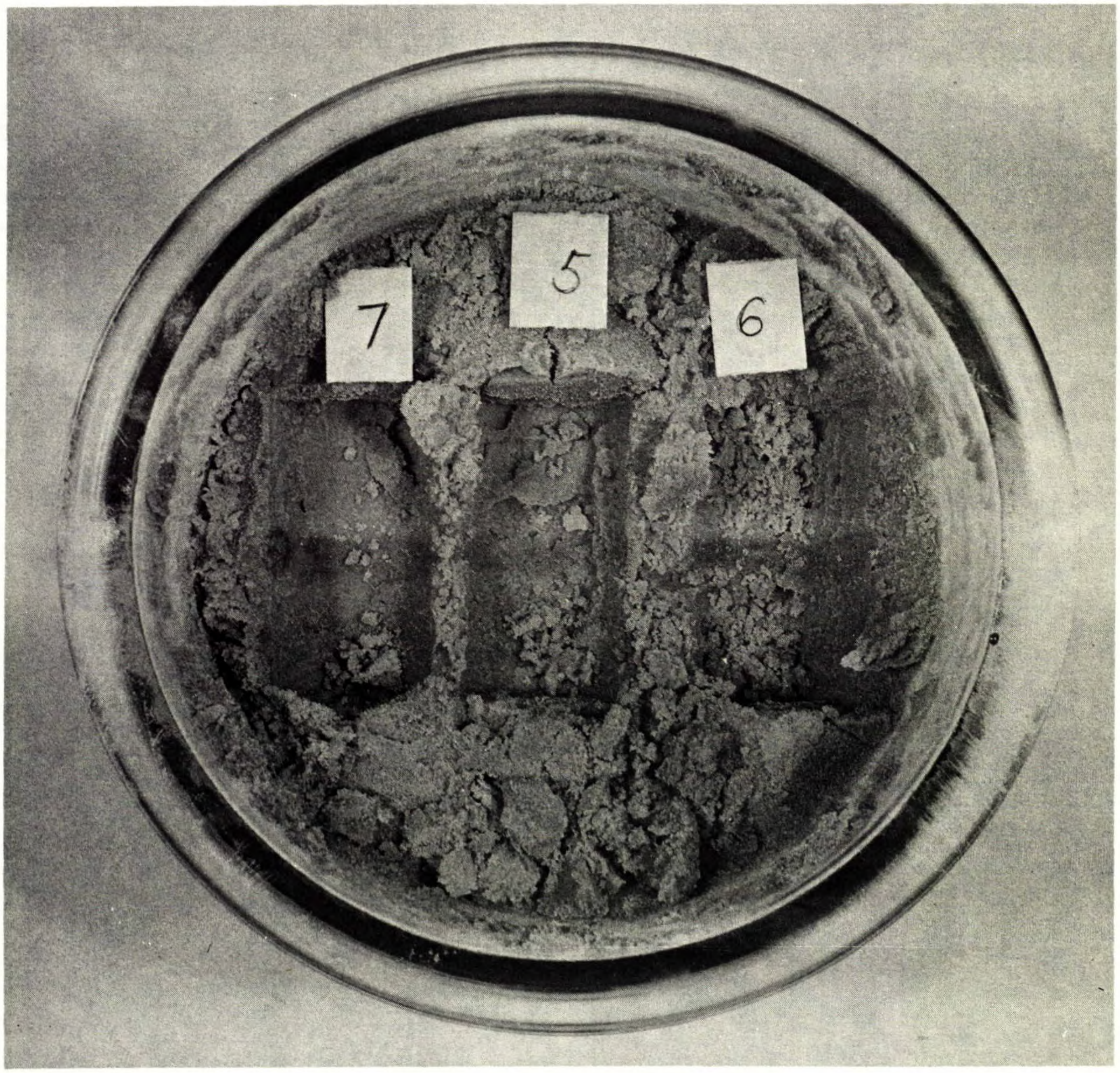

Figure 1 - Depressions left in moist sand by specimens Nos. 5M, 6M and 7M.

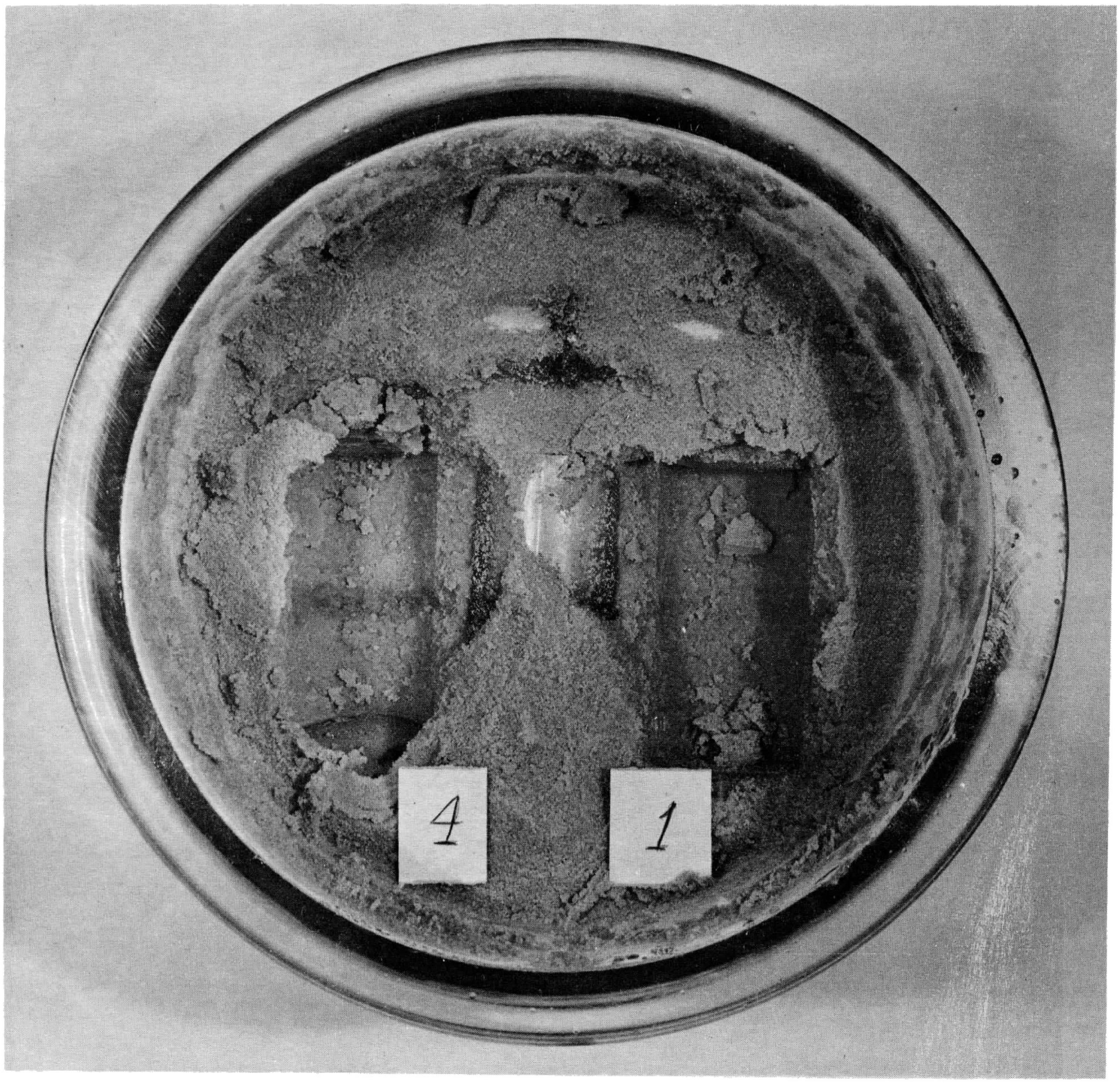

Figure 2 - Depressions left in moist sand by specimens Nos. 1A and 4M. Tops of specimens 2A and 3M also visible.

Figure 3 - View of interior weld after cleaning (6X).

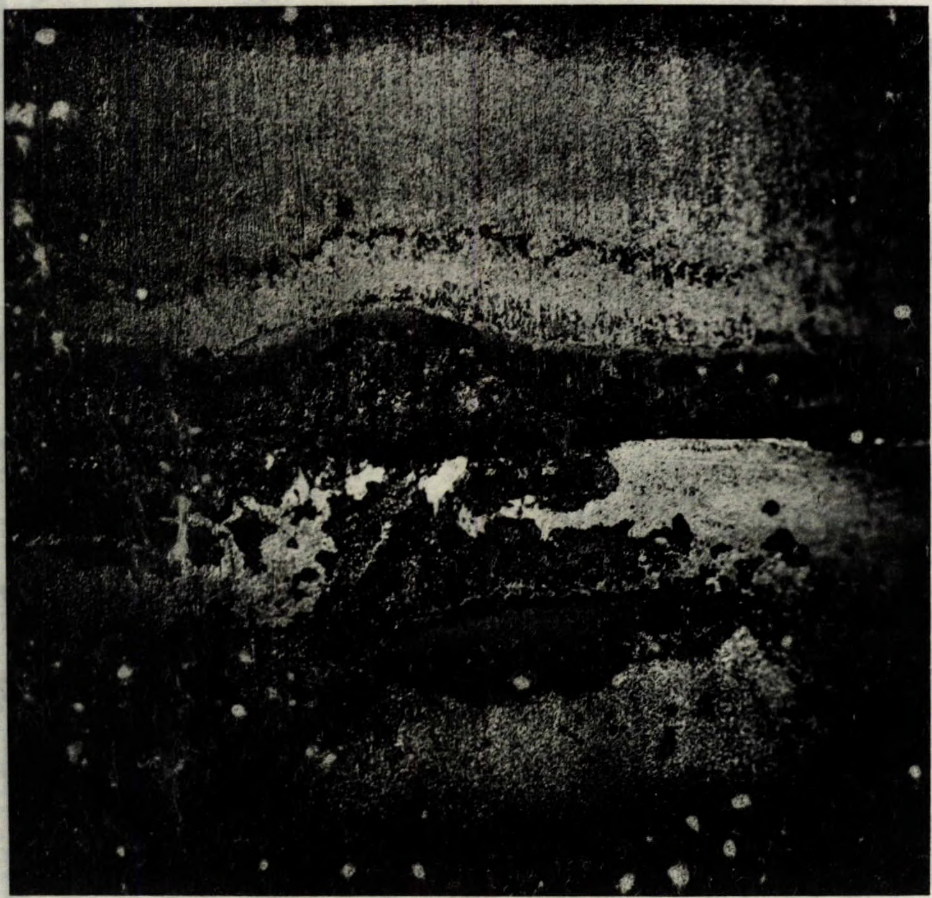

Figure 4 - Another region of same interior weld shown in Figure 3. Solidified flux and corrosion product not removed (6X).

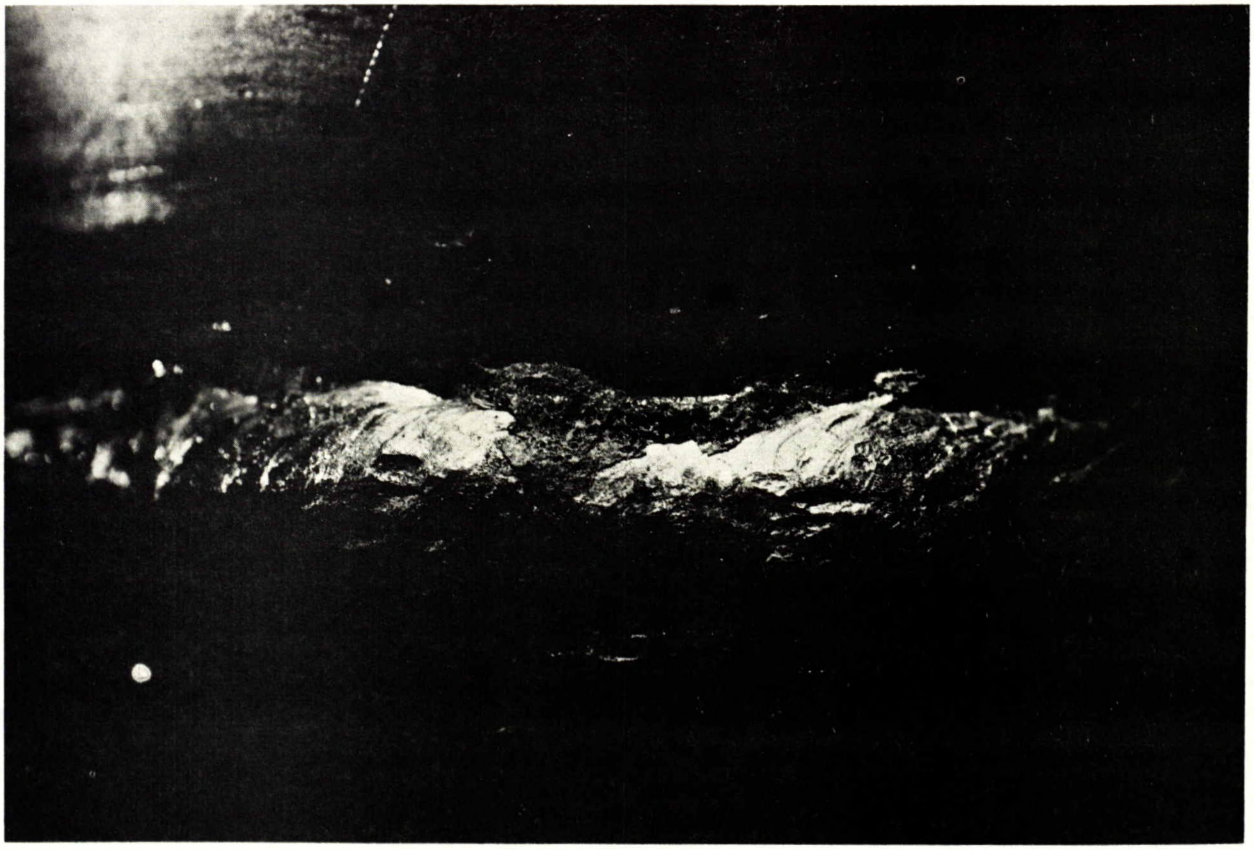

Figure 5 - View of exterior weld showing porous structure of solidified flux (6X).