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OTTAWA    June 6th, 1944.

# REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1659.

Examination of Gas-Welded Engine Mounts for Anson V Aircraft.

(Copy No. 10.)

Bureau of Mines
Division of Metallic
Minerals
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Physical Metallurgy
Research Laboratories

CANADA

DEPARTMENT
OF
MINES AND RESOURCES

Mines and Geology Branch

OTTAWA June 6th, 1944.

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### Examination of Gas-Welded Engine Mounts for Anson V Aircraft.

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**Origin of Material:**

On April 1st, 1944, the Department of National Defence, Air Service, Ottawa, Ontario, submitted two cracked samples of gas-welded cluster welds of an Anson V engine mount for examination. These mounts were fabricated by the White Canadian Aircraft Company, Hamilton, Ontario.

The covering letter, dated March 31st, File 938DD-5-5(AMAE DAI), stated that these samples were representative of fairly recent production in which rejections amounted to 60 per cent of all mounts produced. A subsequent revision of the welding procedure brought about a considerable reduction in percentage rejections and it was stated the problem at the moment may be considered to be under control. No details of the revised welding procedures were available but the procedure productive of defective

(Origin of Material, cont'd) -

welds was outlined. The following is an abstract of this information:

> "Welding is done with a No. 24 tip. Due to the type of jigs used, all welding on one side of the clusters (rear mount, Part No. 50090) is welded completely and then transferred to a revised jig where welding is completed. The only means of relieving the tubing for expansion is by removing the locating pin from the joint being welded and replacing it by driving when the joint is at bright red heat (approximately 1600° F.). The final assembly is accomplished in the same manner and, in all, the cluster welds receive four successive applications of heat. The driving of the locating pins takes up approximately 50 to 60 thousandths of expansion and is sometimes sufficient to buckle the tubing."

Records of batch control tubing (by S numbers) give analyses of tubing used in the samples submitted. These analyses are quoted later in the present report.

A visit to the White Canadian Aircraft Company for further information as to welding technique revealed the following: Due to the difficulty of securing steel of X4130 analysis, a concession was granted to permit the use of off-specification material. All welders are required to pass qualification tests and these are checked again at six-month intervals. Subsequent to welding, the engine mounts are subjected to sandblasting and a visual examination. There is no magnaflux examination or post-welding heat treatment. The unsatisfactory nature of engine mount examination is revealed by service failures which are probably due to the spreading of undetected cracks.

A sample of the welding electrode used was secured for chemical analysis. It is stated to be DOC Oxweld No. 1, made by the Dominion Oxygen Company Limited.

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Procedure:

1. Both samples submitted were subjected to a close visual examination. The samples were numbered 1 and 2 and each tube lettered for the purpose of identification. The samples were then photographed in the "as received" condition (Figure 1).

2. Since there was insufficient material available for a chemical analysis, small samples were machined from each tube of each sample for spectrographic analysis. The following tables show the analyses given from the batch control, the analyses secured, and also list the specified composition of X4130 steel. It should be noted that the spectrographer who made the analyses stated that the values listed are only roughly approximate as his equipment was not fully set up. It is certain, however, that possible errors do not exceed 15 per cent of the percentages shown in the table.

BATCH CONTROL ANALYSIS

| | | Tube S9204 | Tube S8167 |
|---|---|---|---|
| | | - Per | Cent - |
| Carbon | - | 0.286 | 0.289 |
| Phosphorus | - | 0.020 | 0.020 |
| Sulphur | - | 0.022 | 0.018 |
| Manganese | - | 0.56 | 0.63 |
| Silicon | - | 0.22 | 0.33 |
| Chromium | - | 0.914 | 0.992 |
| Nickel | - | 0.26 | 0.40 |
| Molybdenum | - | 0.18 | 0.18 |
| Copper | - | - | - |
| Vanadium | - | - | - |

(Continued on next page)

(Procedure, cont'd) -

SPECTROGRAPHIC ANALYSIS
(Per Cent)

| | Sample No. 1 | | | | | Sample No. 2 | | | | Specification |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1A | 1B | 1C | 1D | 1E | 2A | 2B | 2C | 2D | SAE X4130 |
| Molybdenum | 0.44 | 0.57 | 0.57 | 0.48 | 0.45 | 0.52 | 0.49 | 0.49 | 0.52 | 0.40/0.60 |
| Silicon | 0.25 | 0.23 | 0.24 | 0.25 | 0.24 | 0.22 | 0.23 | 0.22 | 0.24 | 0.15/0.30 |
| Chromium | 0.95 | 0.97 | 0.95 | 0.95 | 0.99 | 0.84 | 0.87 | 0.98 | 0.93 | 0.8/1.10 |
| Nickel | 0.27 | 0.26 | 0.22 | 0.21 | 0.28 | 0.16 | 0.18 | 0.18 | 0.28 | None |
| Molybdenum | 0.19 | 0.24 | 0.24 | 0.31 | 0.31 | 0.19 | 0.26 | 0.31 | 0.39 | 0.15/0.25 |
| Copper | Tr. | Tr. | Tr. | Tr. | Tr. | Tr. | Tr. | Tr. | Tr. | None |
| Vanadium | None | None | None | None | None | None | None | None | None | None |

Tr. = Trace.

3. The chemical analysis of the welding electrode secured from the White Canadian Aircraft Company plant is shown below, together with the chemical analysis supplied by the manufacturer of the electrode.

| | | Analysis Obtained | Manufacturer's Analysis (Average) |
|---|---|---|---|
| | | - Per Cent - | |
| Carbon | - | 0.16 | 0.15 |
| Phosphorus | - | 0.021 | |
| Sulphur | - | 0.032 | |
| Manganese | - | 1.04 | 1.10 |
| Silicon | - | 0.25 | 0.25 |
| Chromium | - | 0.02 | |
| Nickel | - | Trace | |
| Molybdenum | - | Trace | |

4. Micro samples were machined from the ends of the tubing remote from the welds and also through cracks adjacent to the weld. Figure 2 shows the structure of the tubing remote from welds. None of these structures is of the usual normalized type, showing that the heat applied during welding has been sufficient to affect the structure four or five inches away from the weld.

Figures 3 and 4 show two common types of structure adjacent to welds and in the areas in which cracks have occurred. Figure 3 shows a coarse martensitic structure, which is hard and

(Procedure, cont'd) -

brittle. Figure 4 reveals a very coarse-grained structure with ferrite in the grain boundaries. This area would have low fatigue strength. Figure 5 reveals an area of lack of fusion between tubing and weld metal. Figures 6 to 11 show the character of cracks in the tubing adjacent to welds. Figure 12 shows a series of cavities and Figure 13 the same area after repolishing. These last two figures indicate that the cracks are extensive and are associated with porosity.

5. Hardness readings, using a Vickers machine and a 10-kilogram load, were made on several cracked samples. The following table shows the ranges of the hardnesses obtained:

| Area Tested | | Vickers Hardness No. |
|---|---|---|
| Tubing remote from weld | - | 212-376 |
| Coarse heat-affected zone | - | 245 |
| Hard heat-affected zone | - | 285-350 |
| Weld metal | - | 140-160 |

Discussion:

A visual examination of the samples in the "as received" condition revealed that all welds contain a greater volume of weld metal than is usual; that is, the welds are uniformly oversize.

Both batch control and spectrographic analyses show that the materials used do not fit into either the X4130 or its common alternative NE 8630 specification. If X4130 steel is specified no nickel should be present, whereas the amounts of nickel detected are too high to be regarded as residuals. On the other hand, if NE 8630 is specified the manganese content is low, the chromium content high, and the nickel content low. In the majority of tubes the molybdenum content is higher than either specification. In summary, it may be stated that the analyses are such as to confer high hardenability, and the material therefore should be handled with considerable care in welding. It is

(Discussion, cont'd) -

recognized that supply difficulties are sometimes acute, necessitating the use of off-specification materials to maintain production. Where this is the case welders should be instructed to take particular care with these materials.

The chemical analysis of the electrode being used checks closely with the manufacturer's stated analysis. This electrode, properly used, should be satisfactory.

A microscopic examination of the tubing four or five inches away from the welding area indicates that the normalizing operation has involved a fairly rapid cooling rate. This is shown by the absence of lamellar pearlite. In thin-walled tubing of this kind the material should not be cooled in air but, rather, should be furnace-cooled. The range of hardness (212-376 Vickers) indicates spotty normalizing practice or, more probably, is due to the heat effects of welding. It is known that the effect of prior structure on cracking tendency is pronounced and is at a minimum when the material has been normalized and then spheroidized.

A microscopic examination of the areas in which cracking has occurred reveals a wide range of structures. These may vary from a normalized structure to martensite. This is not difficult to understand, in view of the fact that the weld areas are heated and cooled a number of times before the engine mount is completed. The martensitic and coarse-grained areas, which are the most dangerous, are probably the result of the last heating-and-cooling cycle. Since there is no post-welding heat treatment of any kind, structures of these types would be fertile sources of cracking when subjected to the vibrational stresses of service because of their low fatigue strength. In particular, the high notch-sensitivity of the martensitic structure would render the material sensitive to shocks such as rough or emergency landings.

(Continued on next page)

(Discussion, cont'd) -

The cracked samples, when examined under the microscope, show a variety of conditions. Only one crack (Figure 11) shows evidence of being of mechanical origin and contains no oxides. This crack must have occurred after welding and is probably due to contraction stresses. Other cracked samples are either partially or nearly completely filled with oxides, indicating that the cracking has occurred during welding. This may be the result of too rigid jigging or to pin driving when the material is red hot. As is common with all steels, SAE X4130 has low strength at high temperatures, and such treatment may easily rupture the tubing. In addition, X4130 has a distinct tendency to hot shortness, which further aggravates the susceptibility to cracking during pin driving.

There is also evidence that the cracks, in a number of cases, are associated with large voids in the steel. The material remote from the welds shows no evidence of such voids. It would seem that the material has been overheated during welding; that is, the steel at the area of welding has been heated above the solidus point for too long a period of time. Some molten material has melted but not escaped and remains enclosed in a heavily decarburized area. Figures 12 and 13 show the same areas, as first examined and after repolishing. These two photomicrographs show the relationship between voids and cracks. In a one-cycle welding sequence, confirmatory evidence would be found in the microstructures around the welds. In this case, however, this has been marked by subsequent heating-and-cooling cycles.

The hardness readings obtained indicate hard areas adjacent to and remote from welds. This type of hardness pattern is the end result of repeated heating-and-cooling cycles with varying cooling rates and it is not uncommon with oxy-acetylene

(Discussion, cont'd) -

welding.

It would appear that the report that a No. 24 welding tip is used is erroneous. If it were correct it would indicate that a far larger tip is being used than is either necessary or desirable. It is recognized that various manufacturers of welding equipment use different numbering systems for welding tips, but all are roughly comparable. A welding tip having an orifice 0.035 inch in diameter would be approximately of the right size.

Since field failures are occurring, a change from the present method of visual inspection after sandblasting is desirable. From the samples submitted it is apparent that the small cracks may easily escape a visual inspection. Cracked mounts in service would soon fail, due to crack propagation under vibrational stresses.

In the visit to the White Canadian Aircraft plant it was noticed that the area in which the final assembly is welded is so situated as to be exposed to strong air draughts. It should be recognized that cold draughts playing on hot thin-walled tubing can produce a quenching effect. This may be at least a partial explanation of the range of hardnesses found in these samples.

At the moment cracking is no longer a problem, and it is probable that the recent revision of welding procedure contributed to this improvement. Welding sequence in cluster welds is of the utmost importance and is entirely a matter of experiment beyond the principle that welding should proceed away from the open edges. Improper welding sequence can result in high stress concentrations within the cluster which, even though not producing cracks immediately after welding, will result in cracking failure on application of a slight load. This is due to the fact that high stress concentrations prevent plastic

(Discussion, cont'd) -

deformations when service loads are applied and the consequent absorption of these new stresses.

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CONCLUSIONS:

1. Cracking of the tubing cannot be definitely attributed to any one cause but is probably due to one or more of the following:

(a) The use of off-specification material, which would require considerable care in welding.

(b) The use of too high welding heat, as indicated by (1) oversize welds; (2) types of coarse structures found; (3) cracks filled with oxides; (4) voids in the tubing in cracked areas, apparently due to melting out low-solidus point constituents in the steel; and (5) the possible use of too large a welding tip.

(c) The driving of locating pins while weld clusters are still at high temperatures.

(d) The possibility of draughts through the welding area, causing a quenching action on the thin-walled tubing at high temperatures.

2. The welding rod used should prove satisfactory.

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Recommendations:

1. In the event that the use of off-specification material is necessary, the welders should be warned that special care in welding is required.

2. The welders should be warned against using too high welding heats and the use of oversize welds. Welding equipment should be checked to make certain that oversize tips are not being used.

3. Driving locating pins at pick-up points when the point is at high temperature should be avoided.

4. An attempt should be made to shield the welding

(Recommendations, cont'd) -

areas from draughts.

5. The cracking tendency of the material may be reduced by using tubing which has been normalized and spheroidized.

6. Inspection procedure should include a magnaflux examination, to ensure that no cracked mounts get into service.

7. Welding sequence should be checked to establish a sequence resulting in a minimum of locked-up stresses.

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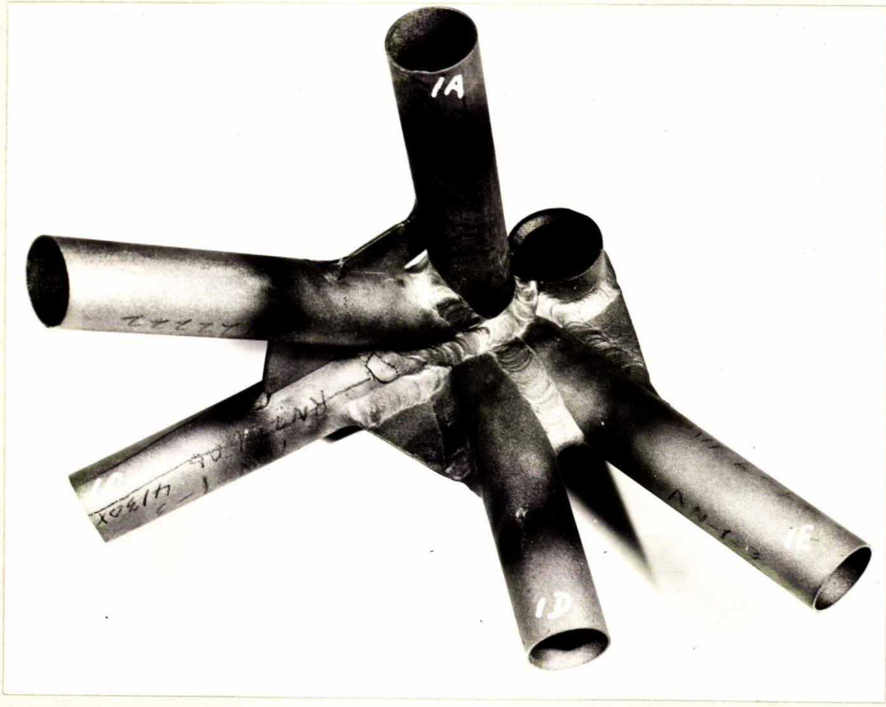
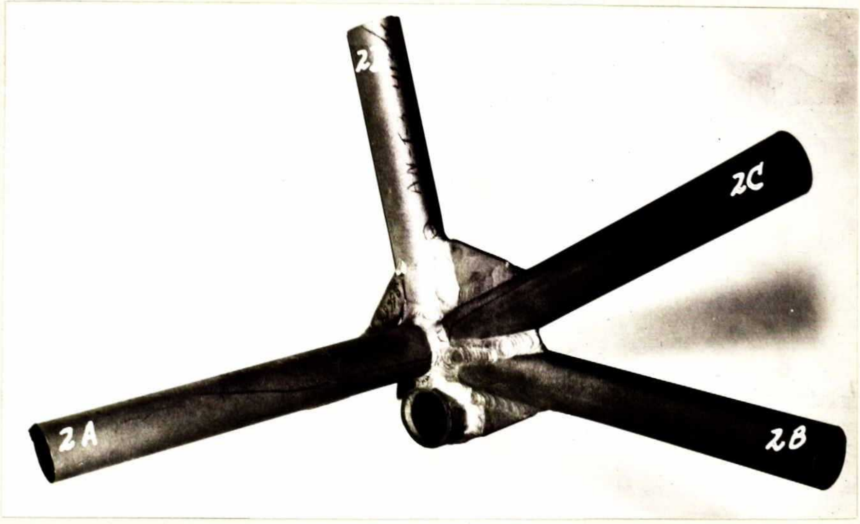
Figure 1.




WELD CLUSTERS IN THE "AS RECEIVED" CONDITION.

Figure 2.

X1000, etched in 4 per cent picral.
STRUCTURE OF TUBING REMOTE FROM WELDS.
Pearlite in a matrix of ferrite.

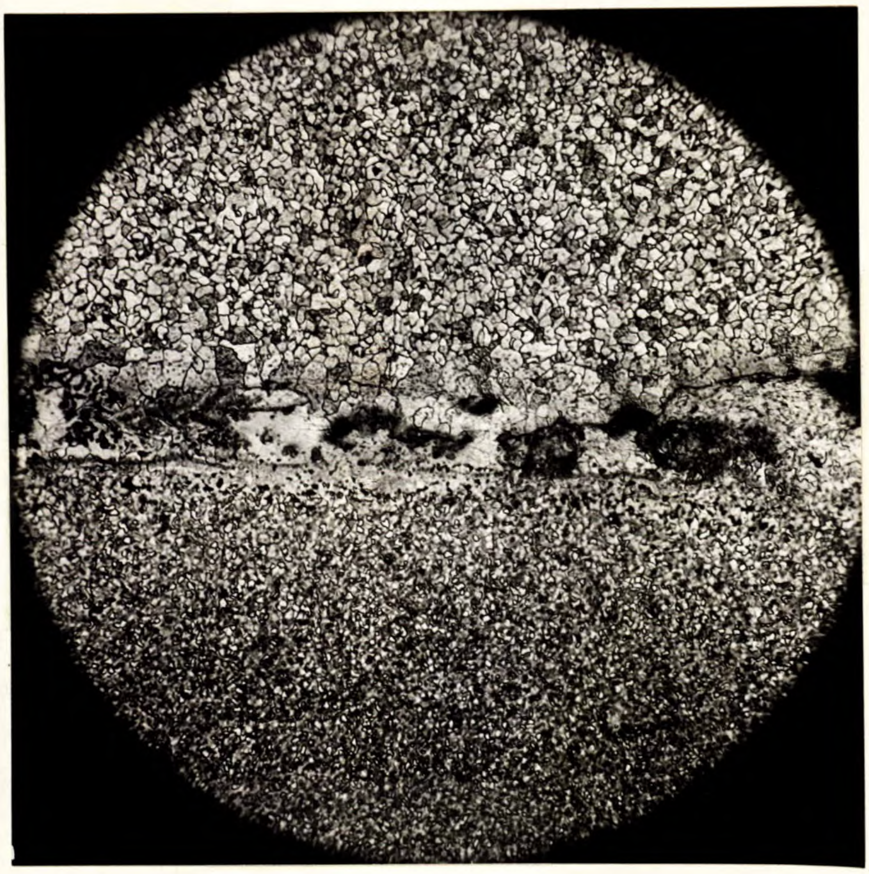
Figure 3.

X500, etched in 4 per cent picral.
MARTENSITIC STRUCTURE ADJACENT TO A WELD.

Figure 4.

X100, etched in 4 per cent picral.
COARSE STRUCTURE ADJACENT TO A WELD.
Note ferrite in grain boundaries.

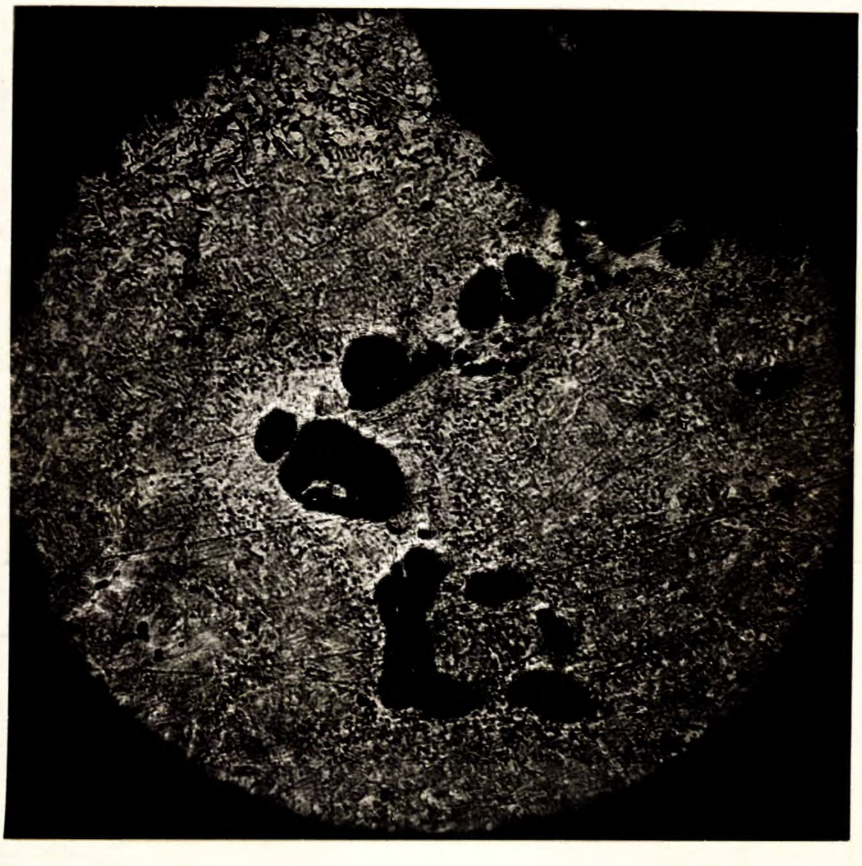
Figure 5.



X40, etched in 4 per cent picral.

AREA OF LACK OF FUSION BETWEEN A WELD AND TUBING.

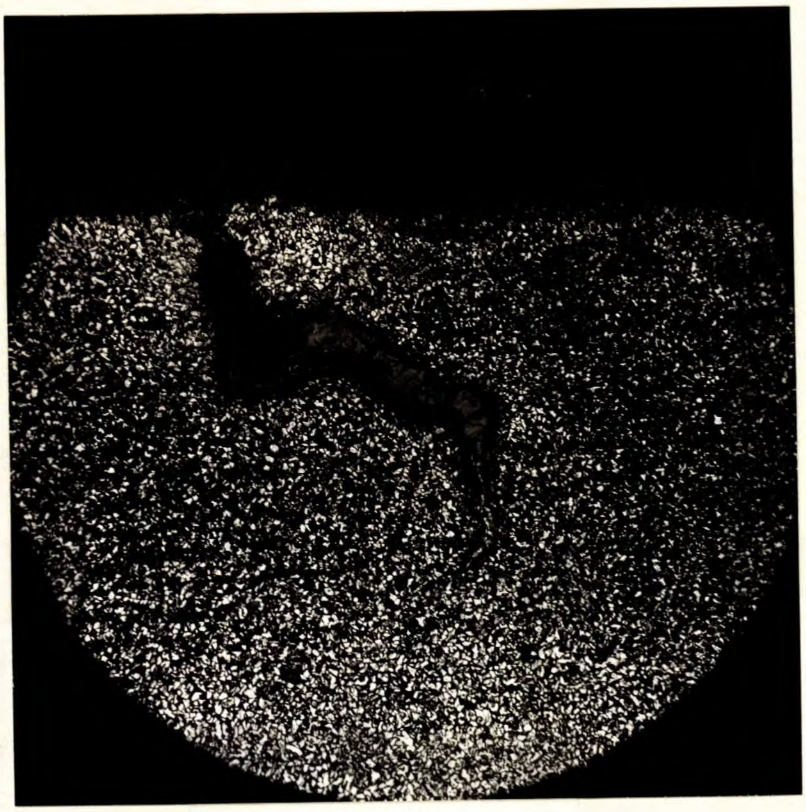
Figure 6.



X40, etched in 4 per cent picral.

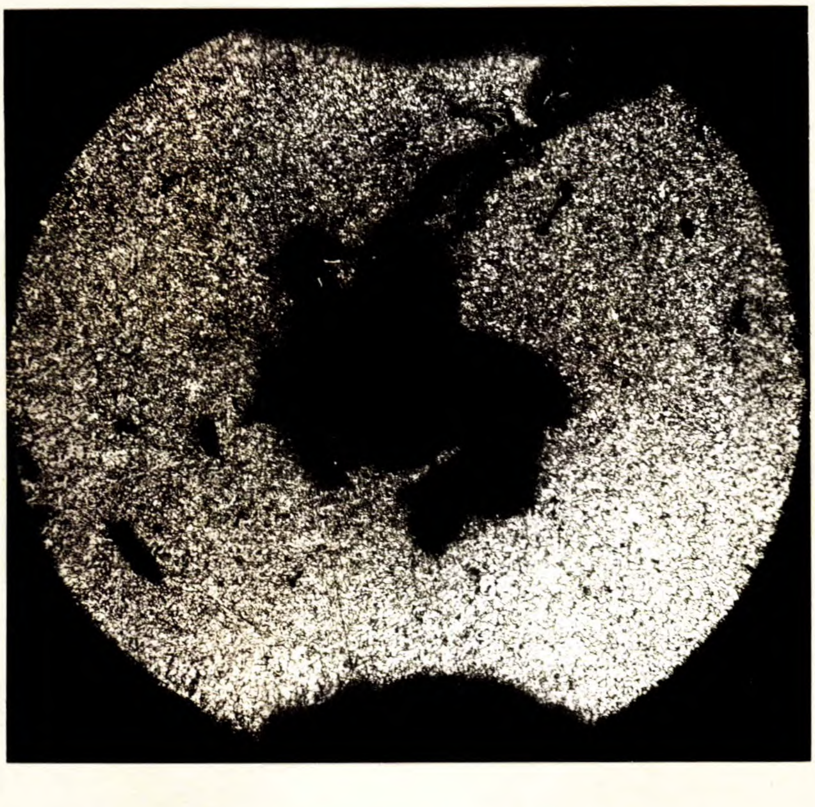
POROSITY IN AN AREA OF CRACKING.

Figure 7.



X40, etched in 4 per cent picral.
CRACK PARTIALLY FILLED WITH OXIDE.
This crack in tubing adjacent to a weld.

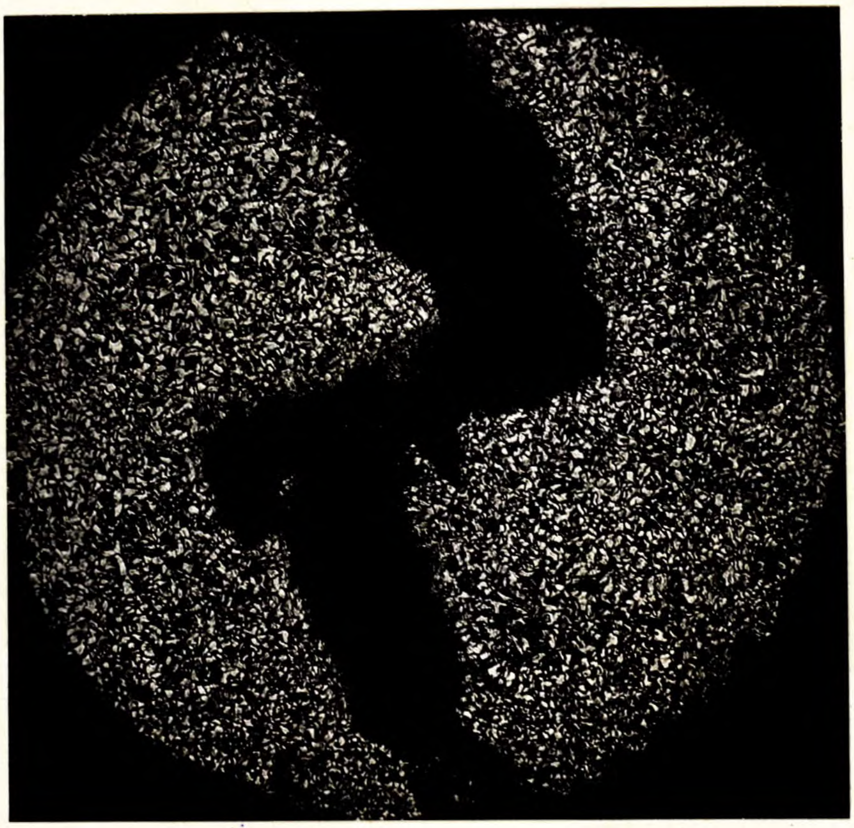
Figure 8.



X40, etched in 4 per cent picral.
POROUS AREA ADJACENT TO WELD, EXTENDING TO SURFACE OF TUBING.

Figure 9.





X70, etched in 4 per cent picral.
CRACK IN TUBING ADJACENT TO WELD.
Note oxide adhering to side of crack.

Figure 10.

X30, etched in 4 per cent picral.
SLAG IN A CRACK--PROBABLY LOW MELTING POINT CONSTITUENTS.
Note decarburization around crack.

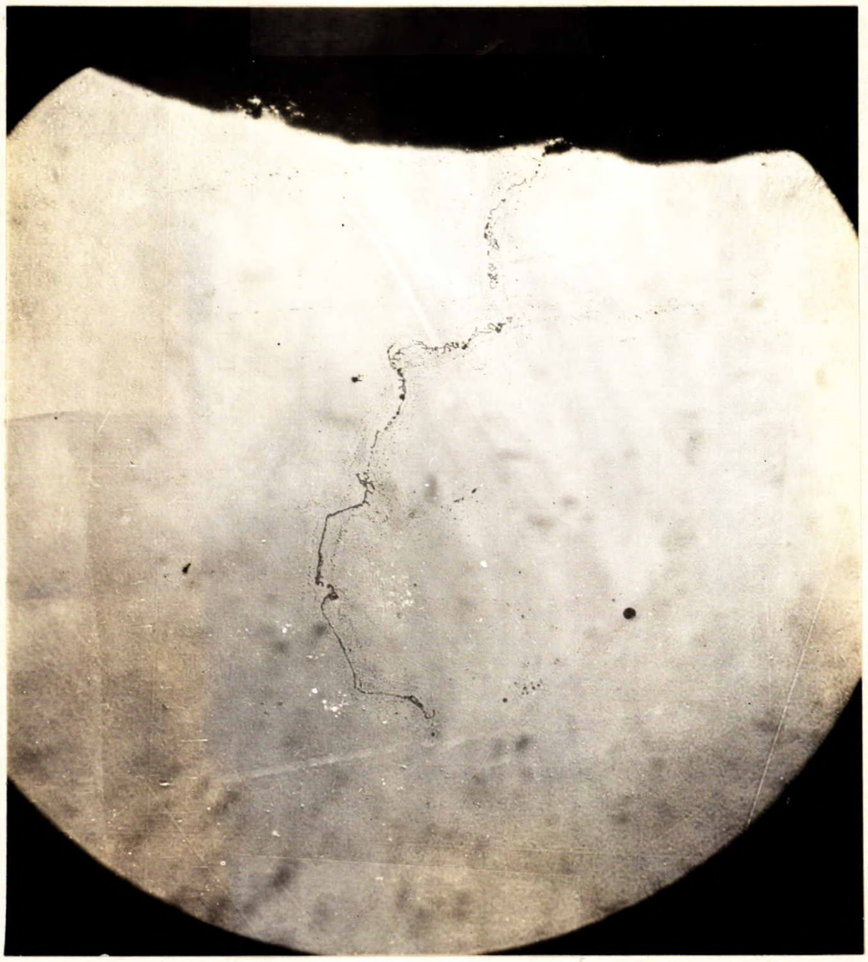
Figure 11.

X70, etched in 4 per cent picral.
CRACK IN TUBING ADJACENT TO WELD--
PROBABLY OF MECHANICAL ORIGIN.
Note absence of oxides.

Figure 12.

X40, etched in 4 per cent picral.
POROUS AREA ADJACENT TO WELD.
Note slag globule.

Figure 13.



X40, unetched.

SAME AREA AS FIGURE 12, AFTER REPOLISHING.

Note slag in crack.

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