CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 63-76

CAUSES OF LEAKAGE IN COMMODITY TANKS; RCAF D-38 REFUELLERS

by

M. J. NOLAN & W. A. POLLARD

PHYSICAL METALLURGY DIVISION

COPY NO. 16

JULY 31, 1963

Mines Branch Investigation Report IR 63-76

CAUSES OF LEAKAGE IN COMMODITY TANKS; RCAF D-38 REFUELLERS

by

M. J. Nolan * and W. A. Pollard **

SUMMARY OF RESULTS

The causes of leakage in D-38 refuellers have been investigated by inspection of leaking tanks in service and by detailed examination of sections cut from tanks. Almost all of the failures occurred through welded joints in two locations and appeared to be due to the use of single fillet welds in places where the loading conditions were unsuitable for this type of joint. Also, many of the welds were of poor quality and this probably contributed to the failures. Permanent repair of the tanks is not thought feasible but it is suggested that the findings of this investigation be considered in the design of future vehicles of this type.

* Technical Officer, Welding Section, and ** Senior Scientific Officer, Non-Ferrous Metals Section, Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

INTRODUCTION

In April, 1963, several officers of the Physical Metallurgy Division, Mines Branch, met with representatives of the Royal Canadian Air Force (RCAF) to discuss the causes of leakage in the commodity tanks of D-38 refuellers. Forty-six of these units had been procured in 1958 and minor leakage had been experienced immediately after delivery. The tanks were made from 54S aluminum, welded with 56S filler wire, and these initial leakages were corrected by re-welding. No further difficulty was encountered until the period of 1961-1962, when the incidence of leaks increased to a point where the RCAF considered a complete engineering and metallurgical analysis necessary.

A report prepared by the RCAF showed that leaks had been recorded and repaired in twenty-four of the forty-six units. A typical example of leakage was examined, by those concerned, at Uplands Airport.

It was decided that an officer of the Physical Metallurgy Division should accompany representatives of the Royal Canadian Navy and the RCAF on visits to Aluminum Laboratories Limited, Kingston, Ontario, and to Fruehauf Trailers Limited, New Toronto, Ontario. The purpose of the visit to Aluminum Laboratories Limited was to discuss with their technical personnel the possible causes of failure in aluminum tanks and the most recent developments in the fabrication of these vessels. A defective refueller from the Air Force base at Trenton, Ontario, had been sent to Fruehauf Trailers Limited for complete examination.

Three additional refuellers were inspected, two at Uplands Airport and one at Johnson Welding Company, Ottawa. Mr. Robert Johnson, whose company had repaired several of these units, was interviewed.

PROCEDURE

An analysis of the RCAF report on leakage indicated that 85% of the leaks had occurred in the area of #3 bolster immediately above the rear bogey suspension and 10% at the lower part of the front bulkhead. All of these leaks were associated with welds; those in the area of #3 bolster occurring in the fillet weld between the sump section and the tank sheet; those at the front end were in the weld joining the front bulkhead to the tank sheet. Unfortunately, no record of the exact location of the leaks in relation to the weld was kept; whether failure had occurred in the actual weld or in the heat affected zone of the weld. However, information supplied by Johnson Welding Company indicates that in all the units repaired by this company, the leaks had occurred through the throat of fillet welds at the locations mentioned in the report.

Inspection of the exterior of the unit at Fruehauf Trailers Limited revealed (1) that a poor quality metallic arc repair had been made on the starboard side in the region of #3 bolster, and (2) that damage to the paint indicated a leak on the port side of the tank in the same region. In the interior of the tank, the welds joining reinforcing collars at the bottom openings of the three baffles to the tank sheet were cracked, the extent of cracking being greater in the baffle above #3 bolster. There was no evidence of cracking in the tank sheet above the sump section nor in other visible welds. Arrangements were made to remove sections from this unit for more detailed examination. These were (1) the area of the suspected leak on the port side, which extended for six inches on each side of #3 bolster and included the joint between the sump and the tank sheet, the sump reinforcement, part of #3 bolster with the welds joining it to the sump and the tank sheet, and part of the interior baffle and baffle reinforcement with the weld joining the reinforcement to the tank sheet, (2) a similar section from the starboard side including part of the metallic arc repair, (3) a section of the joint between the sump and the tank sheet from the rear of #2 bolster on the starboard side. Unfortunately, through some misunderstanding, the section above #3 bolster on the port side was not removed as outlined and it is possible that the actual leak was missed because of this.

Radiographic inspection of welds in critical areas of the tank was carried out by The Warnock-Hershey Company. The resultant films and the removed sections of the tank were sent to the Physical Metallurgy Division for detailed examination. Figure 1 shows the section from the port side above #3 bolster and identifies the various components of the tank.

The tank at Fruehauf Trailers Limited showed greater deterioration in the welds than any of the four units examined. In all of the others, the only cracks apparent were in the welds joining the baffle reinforcement to the tank sheet above #3 bolster. These were usually small cracks, originating in the crater of the weld and running along and across the weld. Leakage had occurred in all of these tanks in the fillet weld joining the tank sheet to the sump in the region above #3 bolster. In all cases, it was stated that the leak had occurred through the throat of the weld.

Examination of the radiographic films and the report submitted by The Warnock-Hershey Company revealed several defects associated with welding. All of the fourteen areas inspected contained linear porosity ranging from minor to heavy and, in two areas, small cracks were found. Five recommendations for repair were made but none of these concerned locations where leakage usually occurred.

Because the majority of leaks (85%) occurred in the fillet weld joining the sump to the tank sheet, this particular weld was examined in all sections taken from the unit at Fruehauf Trailers Limited by various nondestructive tests. These included fluorescent penetrant inspection and radiography of samples treated with X-ray absorbent fluids. When these tests failed to reveal a crack, cross-sections of the weld were taken in the suspect area and, after suitable preparation, were examined at various magnifications. Figures 2 to 5 are macrophotographs illustrating, at 6X magnification, different defects in the weld. In these Figures, the tank sheet is shown above the sump section.

Figures 2 and 3 are single-pass welds typical of those made in the production of the tanks. Figures 4 and 5 are multi-pass welds, indicating that repairs had been made in these areas either during production or after initial testing. It is evident in Figures 2 and 3 that greater fusion has been obtained in the tank sheet than in the sump section. The resultant fillets are poorly formed and suffer from lack of root fusion. The effective strength of the section is considerably reduced and severe notches are provided by the defects. In Figures 4 and 5, a greater cross-section is provided by the multi-pass welds but similar root defects exist and there is evidence of cracking originating at the roots of these welds.

In Figure 1, attention is drawn to a crack in the weld joining the sump reinforcement (C) to the sump wall (B). This crack is shown in greater detail in Figure 6 and a macrophotograph of a cross-section taken from this weld is shown in Figure 7. It will be noted that the crack, which had its origin in the crater of the weld, has extended and run into the parent metal at the toe of the fillet weld. Figure 7 also shows a crack in the weld extending from a root defect and a small crack in the sump section a short distance from the main crack. After this section had been photographed, it was broken and the surfaces of the metal in the crack were examined. The appearance of these surfaces and the lack of evidence of deformation before fracture indicated that the crack was caused by fatigue.

RESULTS AND DISCUSSION

The RCAF report of leakage shows that leaks had occurred in two principal locations, i.e., in the area of #3 bolster, which is located immediately above the rear bogey suspension and at the lower part of the joint between the front bulkhead and the tank sheet. These leaks did not occur until the units had been in service for some time.

The method of suspension used to attach the tanks to the chassis of the refueller unit causes greater loading at #3 bolster than at any other point in the tank. In this region, where 85% of the leaks occurred, the conditions of loading of the various components of the structure are complex. Most of the tank load is transmitted directly to the bolster through a load spreading strip but, as the bolster is welded to the sump wall, some load is presumably transmitted through the tank-sheet/sump-wall joint. The tank is a flexible structure and, except where stiffened by the bolster and the interior bulkheads, it appears (as shown by pronounced bulging) to deform considerably under load. The sump, owing to its box-like section is comparatively stiff and thus the tank-sheet/sump-wall joint is presumably subject to considerable dynamic strains in service. The type of joint used (single fillet) is inherently weak when subject to this type of loading, (a hinging action leading to extremely high stress concentrations at the root of the weld). Published information (1,2) shows that fillet welds in general are not suitable for use under dynamic loading conditions.

The leaks, in this region, usually occurred a few inches away from the bolster and this was presumably where maximum relative movement took place between the joint components.

Although examination of sections of the joint in question did not reveal any cracks that penetrated the joint completely, incipient cracks were observed (Figures 4 and 5) and, in most cases, welding defects such as uneven or insufficient penetration, porosity and insufficient throat section, would be expected to reduce the fatigue resistance of the joint even further.

From these considerations it seems most probable that the observed leaks near #3 bolster were due to fatigue failure of the tank-sheet/sump-wall welded joint.

With regard to the other location of leaks, that is, the front bulkhead/tank-sheet joint, again a single fillet weld was used and the loading conditions were such that high dynamic stresses would be produced at the root of the weld during acceleration and deceleration of the vehicle. By contrast, the joint between the tank sheet and the rear bulkhead (which is convex outwards), is subject to much less objectionable loading as there is less tendency to impose a tearing action on the joint.

The significance of the cracking of the sump wall at the joint with the sump reinforcement (Figures 6 and 7) is uncertain as no leaks have actually been observed in this region. However, in future designs the possibility of fatigue in this situation should be considered.

It had been suggested that a possible cause of failure might have been corrosion, as described in a recent paper dealing with the effect of fuel contamination on aluminum aircraft tanks (3). Examination of the interiors of four tanks failed to show any significant corrosion of this nature.

CONCLUSIONS

(1) Because the greater percentage of leaks occurred in two highly stressed areas of the tank after the unit had been in service for some time, the indicated cause of failure is fatigue.

(2) The location of single fillet welds in areas of high stress is not considered good design procedure and, in this instance, has resulted

in failures in the welds.

(3) The quality of welding is not good, as confirmed by the presence of linear porosity and cracking in the welds examined.

(4) The shape of the fillet welds in the sections examined was poor, with a small cross section at the throat and root defects that could act as notches in dynamic loading.

RECOMMENDATIONS

(1) There seems to be little possibility of repairing existing refueller units with any guarantee of satisfactory service life. Some consideration should be given to a design modification that would remove the loading from the fillet welds attaching the sump to the tank sheet and eliminate the bending movement on the weld joining the front bulkhead to the tank sheet.

(2) Since it is not possible to avoid single fillet welds in attaching the sump to the tank sheet in the present design, consideration should be given to eliminating this particular sump configuration in all future designs.

(3) Greater control should be exercised over the quality of welding - both in the repair of the present units and in any future construction.

MJN/WAP/gm

REFERENCES

1. Welding Handbook, Fourth Edition, Section 4, p. 69A26 - American Welding Society, New York, N.Y. (1961).

2. J. G. Sutherland (Aluminium Laboratories, Kingston, Ontario) - "Welded Aluminum Fatigue Behaviour" - Can. Metalworking 25, 33-40 (May 1962).

3. W. J. Digman (Douglas Aircraft Company) - "Effect of Fuel Contamination on Corrosion of Aircraft Fuel Systems" - Esso Air World 15 (4), (Jan/Feb. 1963).

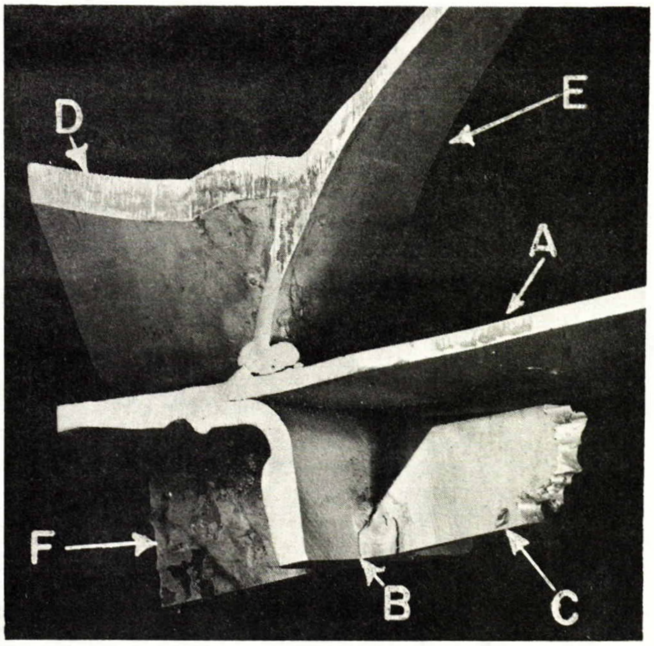

Figure 1. Section from port side above #3 bolster showing: A - tank sheet, B - sump wall, C - sump reinforcement, D - baffle, E - baffle reinforcement, F - bolster.

Note: (1) crack in weld joining B to C
(2) crack in weld joining E to A

(X1/2 approx.)

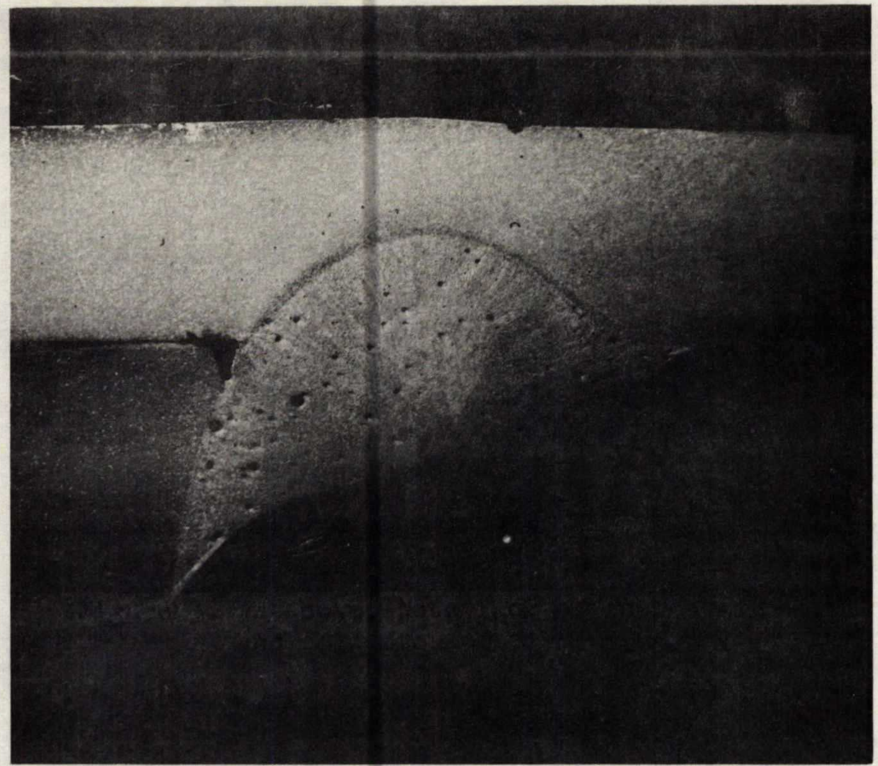

Figure 2. Single pass weld joining tank sheet (above) and sump section (below). Note: poor fillet weld contour and lack of root fusion. (Keller's etch; X6)

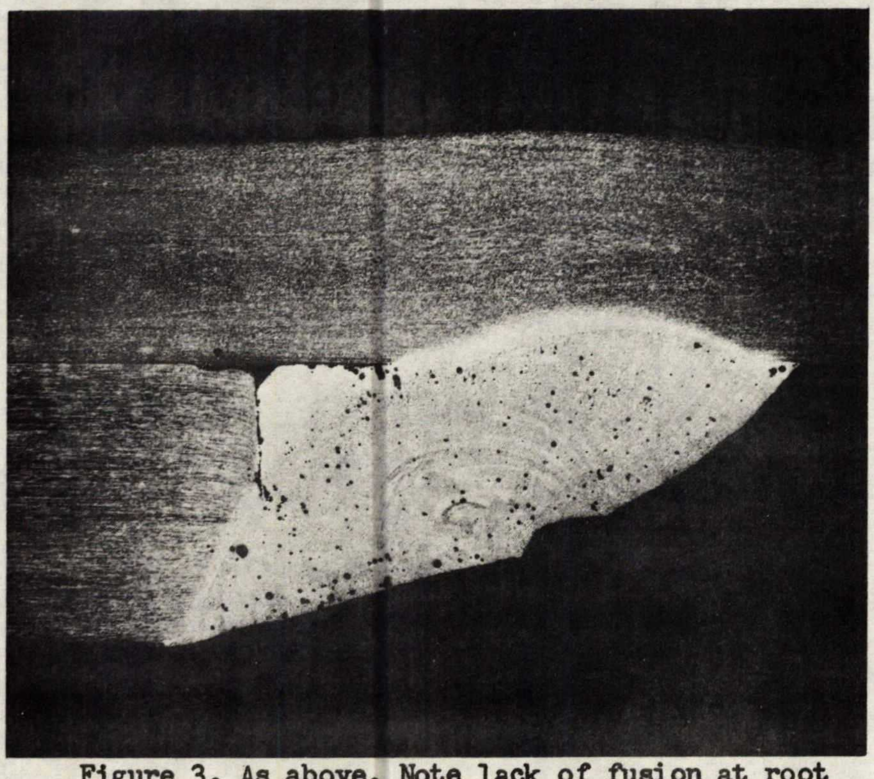

Figure 3. As above. Note lack of fusion at root and cold flow of filler metal. (Keller's etch; X6)

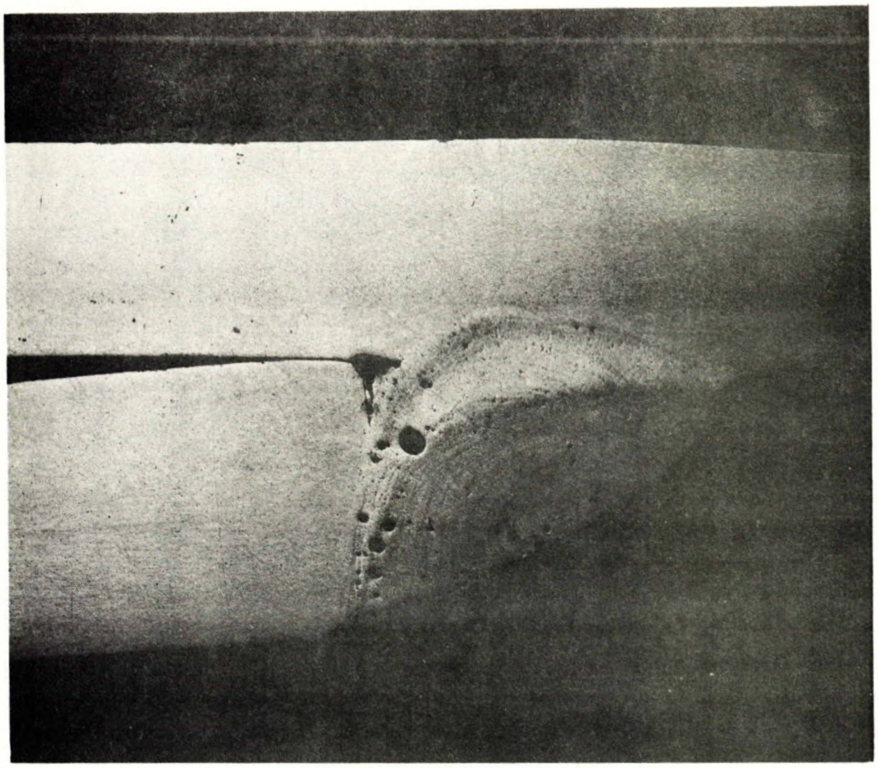

Figure 4. Multi-pass weld with incipient cracking in root defect. (Keller's etch; X6)

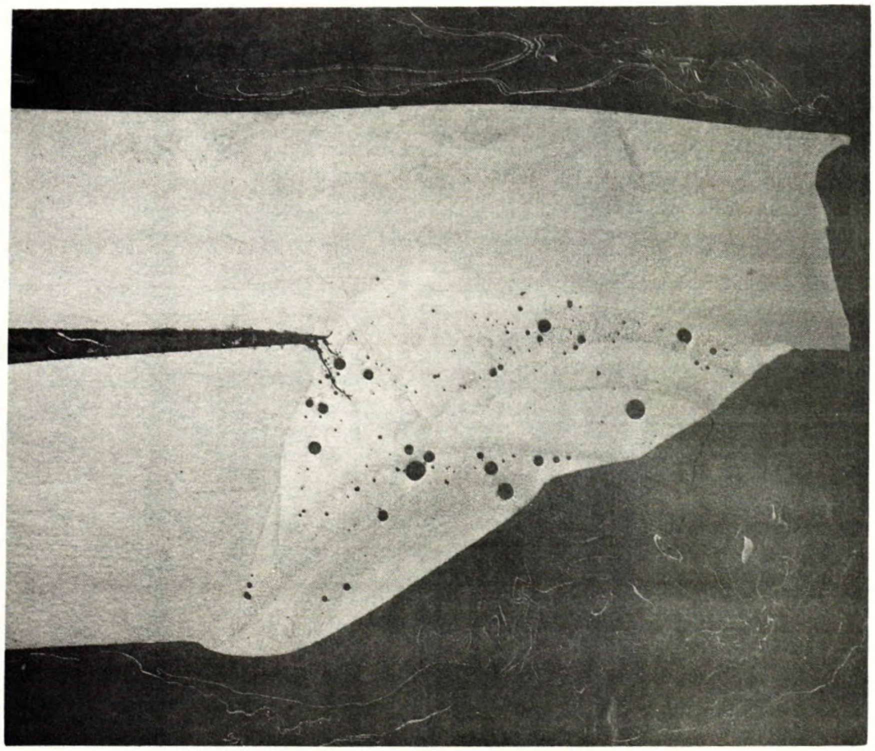

Figure 5. As in Figure 4. (Keller's etch; X6)

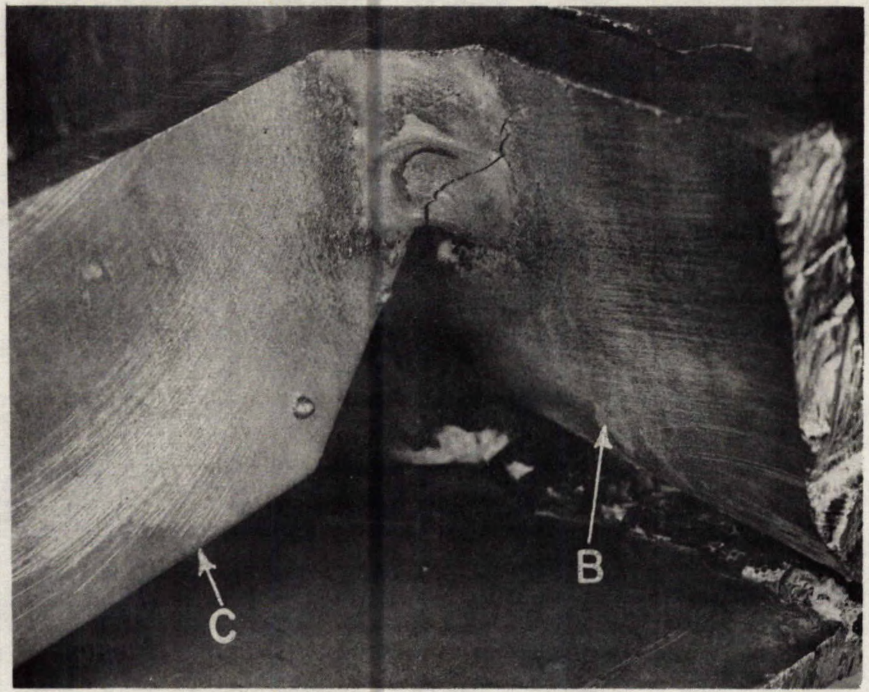

Figure 6. Showing crack in weld joining sump reinforcement to sump wall. C - sump reinforcement, B - sump wall. (X2).

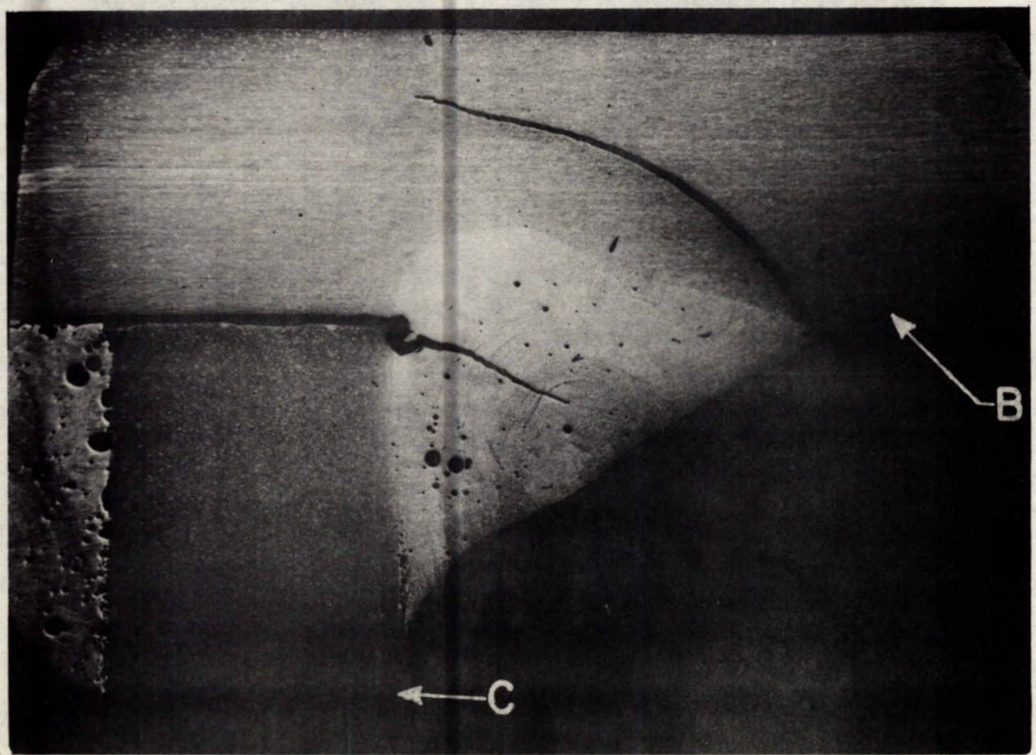

Figure 7. Macrophotograph of cross section of weld shown in Figure 6. (Keller's etch; X6).