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OTTAWA March 19, 1945.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1814.

Examination of Compressed Air Cylinder.

(Copy No. 10.)

Bureau of Mines
Division of Metallic
Minerals
-
Physical Metallurgy
Research Laboratories

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
Mines and Geology Branch

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Introduction:

On February 21, 1945, a broken compressed air cylinder for Lancaster aircraft was submitted by A/C A. L. Johnson, for Chief of the Air Staff, Department of National Defence for Air, Ottawa, Ontario, for examination. A previous report on these cylinders (Report of Investigation No. 1734, November 8, 1944), issued by these Laboratories, is abstracted below:

> The sheet material of these cylinders conforms to the British Standard Specification 3S-3. Welding is done with a No. 7 D.O.C. (Dominion Oxygen Company) gas welding electrode containing approximately 0.05 per cent carbon. Hardness variations in the "as received" material were found to be due to slight variations in carbon content. It was shown that post welding stress relief at 1000° F. enabled the welded cylinders to withstand up to 950 pounds internal pressure before bulging began. This is well in excess of the 400 pounds working pressure and superior to the results obtained after normalizing. As a result, stress relief at 1000° F. was recommended rather than normalizing.

In the covering letter (File 938 BY-2-6 (AMSO DAI)) the following information was given:

> The cylinder blew apart when being filled. The cylinder was manufactured by Campbell Steel and Iron Works Limited, Ottawa, and successfully withstood a 900 pound internal pressure after completion. Due to an error in connecting the charging lines, the cylinder was subjected to a pressure estimated to be about 1,100 pounds or higher which resulted in failure.

Object of Investigation:

1. To determine the cause of failure of the cylinder.
2. To determine the quality of the welding used to fabricate the cylinder.
3. To offer recommendations designed to prevent future failures of cylinders.

Procedure:

(1) The material as received was subjected to a thorough visual examination. Figure 1 shows the material on arrival. Figure 2 shows the oblong sheet, flattened out, which forms the barrel of the cylinder. Note that the fracture is entirely confined to the weld. Figure 3 shows the fractured edge of one of the disc ends of the cylinder. Note that here also the fracture is through the centre of the weld. Figure 4 shows the fracture of one of the discs. This picture is typical of all fractured welds. Note the non-uniform penetration.

(2) A chemical analysis was removed from the centre of the oblong sheet and analyzed. The following table lists the results secured and also the analysis specified for the purpose of comparison.

		Material	Specification BSS 3S-3
Carbon	-	0.22	0.20-0.25
Phosphorus	-	0.025	0.05 max.
Sulphur	-	0.040	0.05 max.
Manganese	-	0.58	0.6 max.
Silicon	-	0.01	0.3 max.
Chromium) Nickel)	-	None.	0.3 max. (if present)
Molybdenum		Trace.	

(3) Samples were removed around the periphery of the welds where penetration had apparently varied and also from the centre of the large sheet. These samples were mounted, polished and subjected to microscopic examination. Figure 5 shows transverse section of a fractured weld where 100 per cent penetration

(Procedure, cont'd) -

has been secured. Figure 6 shows a similar section where penetration has been less than 50 per cent with a reinforcement of approximately 24 per cent of sheet thickness. These are typical of large areas of welds.

Figure 7 shows the typical structure of the heat-affected zones of the welds and Figure 8 the structure of the sheet material remote from the welds. No evidence was found of segregation of inclusions.

(4) Hardness tests were made on the weld areas as noted below, using a Vickers machine with a 10-kilogram load. The table below lists the results secured--the averages of five readings:

Area tested		Vickers Hardness Numbers
Normal sheet material	-	160
Heat-affected zone	-	185

(5) Two transverse sections of the sheet were deep etched in 50 per cent HCl at 180° F. No evidence was found of the normal rimmed pattern.

Discussion:

A visual examination of the material as received reveals that a total of approximately 68 inches of weld failed by fracture through the centre of the weld. A 100 per cent weld failure is extremely rare and indicates weld strengths well below that ordinarly obtained in butt welds. It was also noted that failure is entirely confined to the centre of the weld and that the penetration secured was non-uniform.

A microscopic examination of areas of complete and incomplete penetration confirms the visual examination. In some areas complete penetration to the root of the weld has been secured (see Figure 5). In other areas penetration may

(Discussion, cont'd) -

range as low as 35 per cent of the sheet thickness and this is accompanied by a reinforcement of approximately 24 per cent of the sheet thickness (see Figure 6). The microstructures of the weld indicate the use of a low carbon welding rod. The microstructure of the heat-affected zones of the welds indicates a normal response of the sheet material to the thermal cycle of welding. This normality is reflected in the hardness readings obtained. The microstructure of the sheet material remote from the welds is normal and no evidence was found of segregation of inclusions.

It is apparent that all welds are made in a single pass and without backing up. Poor or non-uniform penetration may be due to too close butting up of the edges to be welded, too high a welding speed or too low welding temperature. Ordinarily, welds of this type without back-up should be produced with 90 per cent penetration without difficulty. It is also quite noticeable that the normal reinforcing has not been allowed on these welds. By reinforcing is meant that amount of weld metal that projects above the surface of the sheet material. It cannot be over-emphasized that unfused roots of welds in an application such as this act as severe stress raisers and as such can easily cause service failures. Should the weld metal be of low strength the tearing action through the weld is made just that much easier.

In the case of this particular cylinder it would appear that failure has been due to drastic overstressing by loading to a high pressure. The fact that the cylinder successfully withstood a 900-pound internal pressure test certainly appears to indicate that the vessel would be quite satisfactory when subjected to the service pressure. It is felt that sweeping

(Discussion, cont'd) -

conclusions as to the unserviceability of similar cylinders on the basis of the performance of this particular one are completely unwarranted. In this case failure has been the result of overloading.

It is possible that some cylinders with incomplete penetration and low strength weld metal, although withstanding a pressure test successfully, may be damaged or weakened by handling or abuse such that they may then be marginal with respect to the operating pressure. Should this be the case, accidents may happen with cylinders which are considered satisfactory. This condition may be rectified by reviewing the welding procedure and using a higher strength weld filler rod. The use of the higher strength rod would not in any way alter the welding picture since its deposition characteristics are similar to the rod now used. In addition, these rods are readily available and would not present a supply problem.

The chemical analysis of the material shows that it is well within the specified ranges. The molybdenum content is residual and would have no bearing on the failure. The low silicon content indicates that this is a rimmed steel which is unusual for this high a carbon content. The absence of a rimmed pattern after deep etching points to the steel being killed by aluminium additions.

Conclusions:

1. Failure of the cylinder has been due to drastic overloading by accident. This failure has been facilitated by the notch effect at the unfused roots of welds due to irregular and incomplete penetration. However, the welding process is not primarily responsible for the failure.

2. The chemical analysis of the material is within the

(Conclusions, cont'd) -

specified range.

3. The microstructure of the weld heat-affected zone and the parent material indicate a normal response of the material to the thermal cycle of welding. This normality is reflected in the hardness figures obtained.

4. The quality of welding is not the best possible and should be reviewed with a view to obtaining greater and more uniform penetration.

5. The welding has been accomplished by too low a strength filler rod.

Recommendations:

1. All welds should be made with a higher strength filler rod such as an Oxweld No. 1 High Test (Dominion Oxygen Company) and normal weld reinforcement permitted.

2. The longitudinal barrel weld should be made by a pass inside and out.

3. On all welds tight butting up of edges to be welded should be avoided. Complete penetration is more easily secured with a 1/16-inch gap between edges.

4. Welding technique should be checked to ensure complete penetration. This investigation has shown widespread incomplete penetration which may result from any one of the following: too high welding speed, too low heat input or too tightly butting edges.

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Figure 1.

MATERIAL AS RECEIVED.

Oblong plate forms the barrel of the cylinder.

Figure 2.

SHEET FORMING BARREL OF CYLINDER, FLATTENED OUT.

Note that fracture is confined 100 per cent to the weld.

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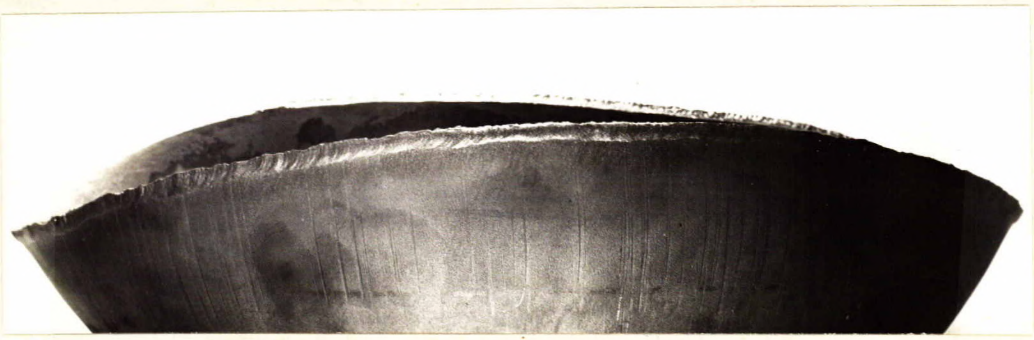
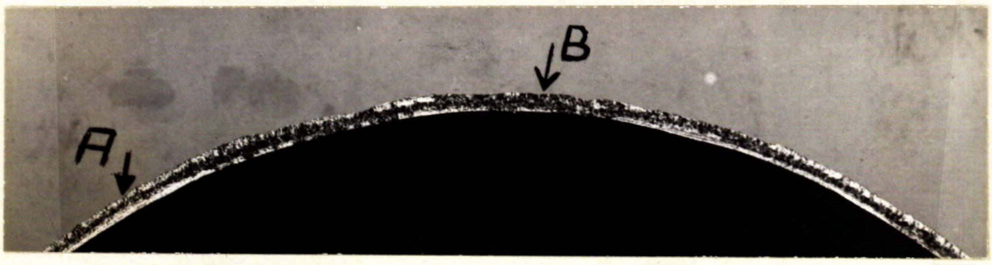
Figure 3.



CLOSE-UP OF EDGE OF DISHED END OF CYLINDER.

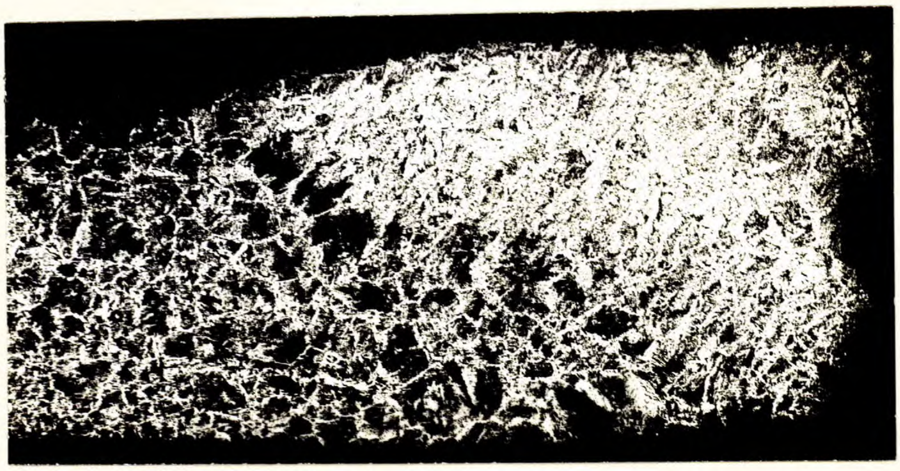
Figure 4.



PHOTOGRAPH OF FRACTURED EDGE OF DISHED END OF CYLINDER.

This is typical of all fractured edges. Note incomplete penetration (A) and complete penetration (at B).

Figure 5.



X25, etched in 2 per cent nital.

TRANSVERSE SECTION OF WELD AT AREA OF COMPLETE PENETRATION.

Note that weld metal penetrated the full thickness of the sheet.

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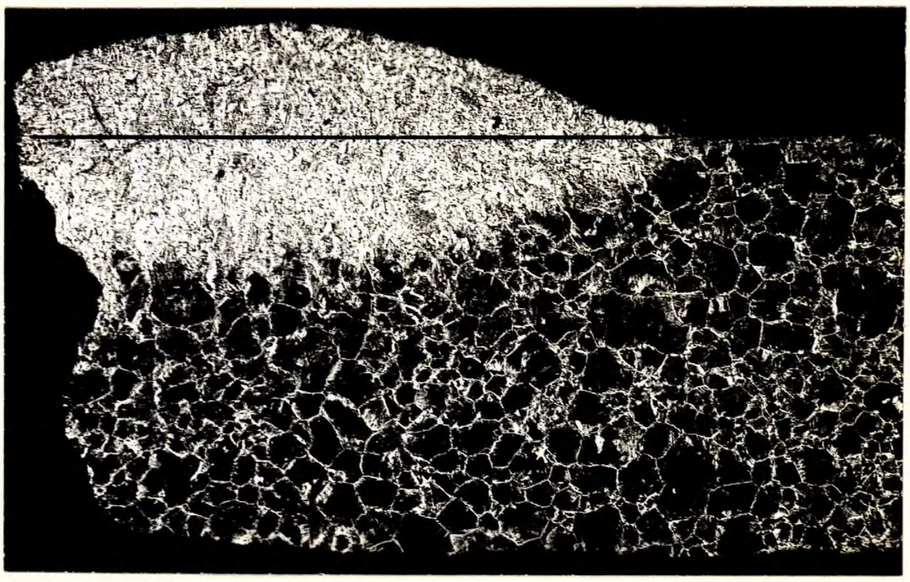
Figure 6.



X25, etched in 2 per cent nital.

TRANSVERSE SECTION OF WELD AT AREA OF INCOMPLETE PENETRATION.

Note that fracture follows line of least thickness of metal - through unfused root. Penetration - 35 per cent; reinforcement - approximately 24 per cent.

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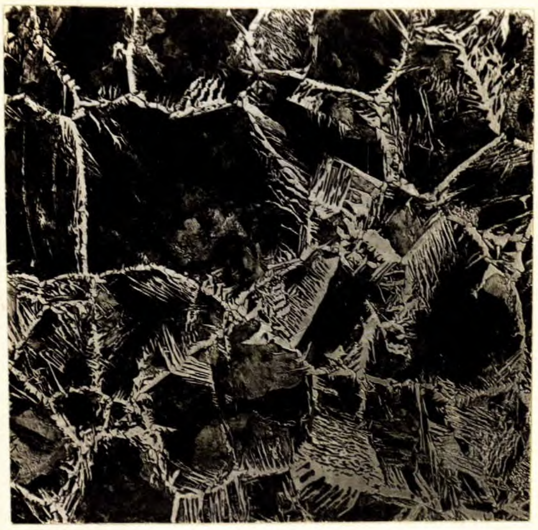
Figure 7.



X100, etched in 2 per cent nital.

TYPICAL STRUCTURE OF HEAT-AFFECTED ZONES.

Note tendency towards Widermanstätten type of structure.

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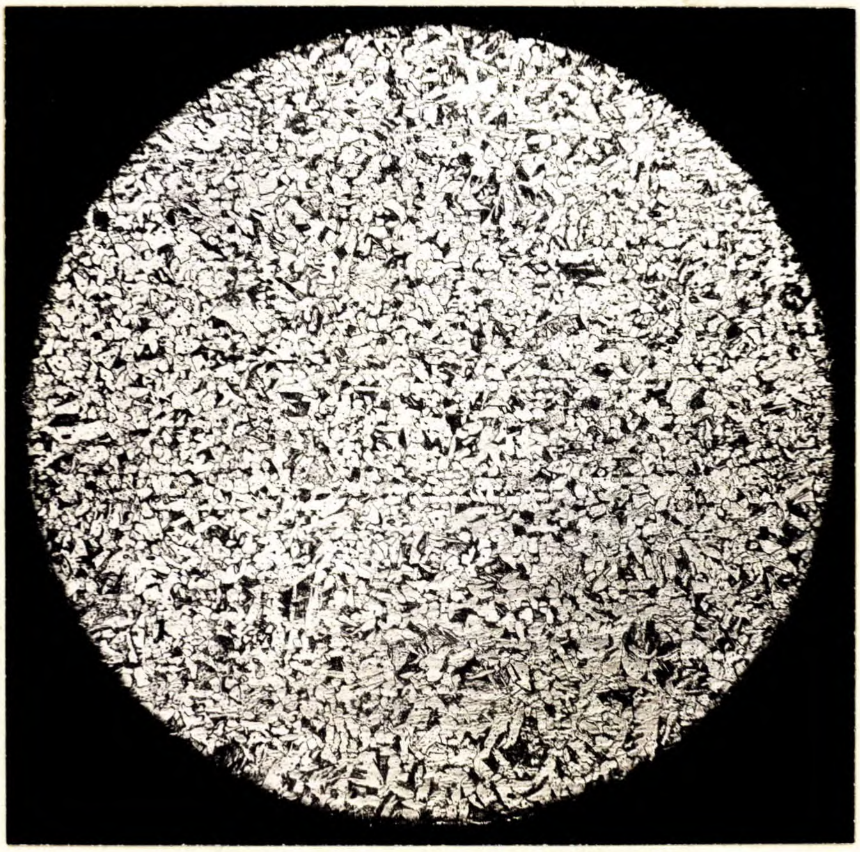
Figure 8.



X100, etched in 2 per cent nital.

NORMAL STRUCTURE OF SHEET MATERIAL.

Normalized after rolling to final size.

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