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DATE 29.3-79
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CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 58-206

EXAMINATION OF INDUCTION WELDED STEEL PIPE

by

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Copy No. 26

NOVEMBER 24, 1958

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SUMMARY OF RESULTS

An investigation involving mechanical testing, visual and metallographic examination was performed on induction welded joints in 2½ in. O.D., 7/32 in. wall steel pipe. Extreme variation in quality was observed. Inferior quality was due to the presence of excessive oxide at the joint interface, resulting in inadequate ductility shown by bend testing. It was concluded that satisfactory welds could be made by this process but that consistency of weld quality should be improved.

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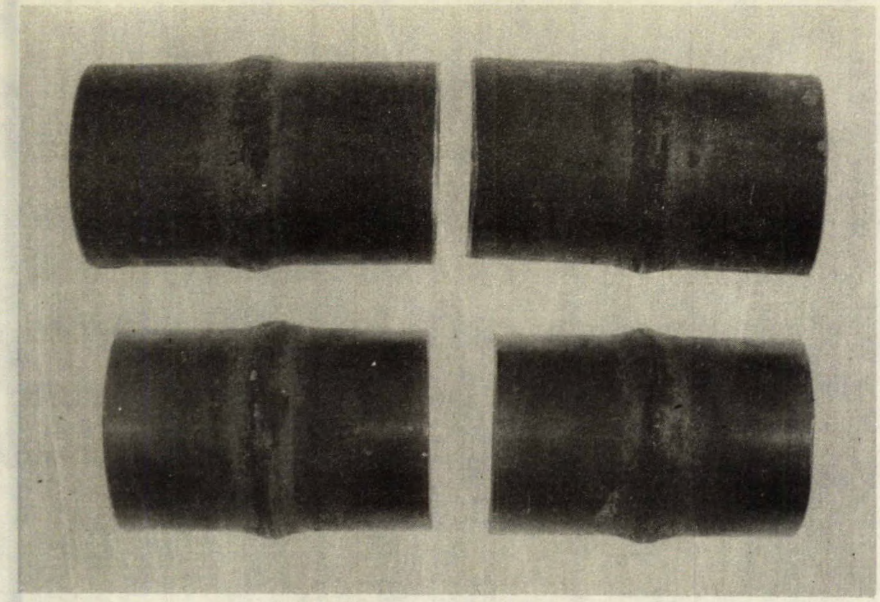
INTRODUCTION

In a letter dated September 26, 1958, Mr. M. S. Cotterell, Civilian Atomic Power Department, Canadian General Electric Company Ltd., Peterborough, Ontario, requested that an examination be conducted on six welded samples. These samples consisted of short lengths of 2½ in. O.D., 7/32 in. wall thickness piping, pressure welded together by the induction welding process. The welds were made by the Ohio Crankshaft Corporation, Cleveland, Ohio, using a Tocco 40 kw, 30 kc heating equipment and a heavy stationary press which was custom made for a Japanese firm of boiler makers. The piping was stated to be Japanese in origin and having a carbon content indicating that the steel is in the SAE 1015-1020 range.

Mr. Cotterell stated that he was particularly interested in microstructural changes occurring in the heated zone as a result of the welding and which might indicate that further treatment would be necessary.

PROCEDURE

(1) Four samples were cut in half longitudinally by sawing, and photographed to record the appearance of the internal and external surfaces. Figures 1 to 4 inclusive, are typical of all the samples.



(About 4/10 actual size)

Figure 1 - Outer Surface

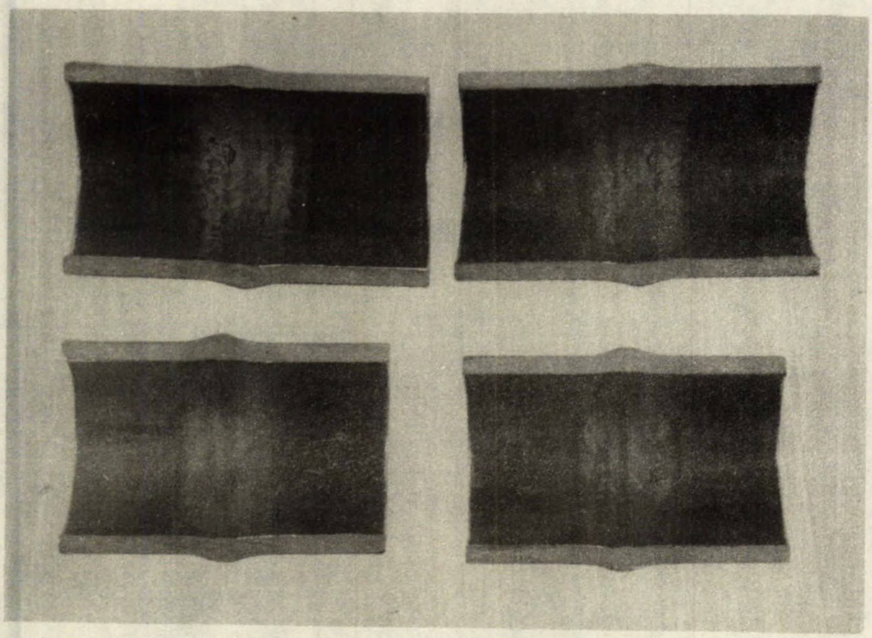


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Figure 2 - Inner surface of samples shown in Figure 1

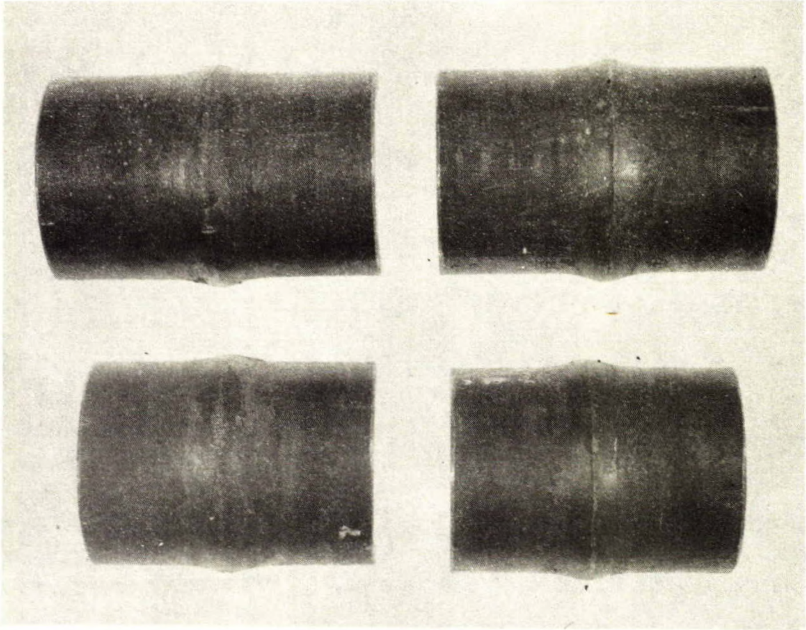

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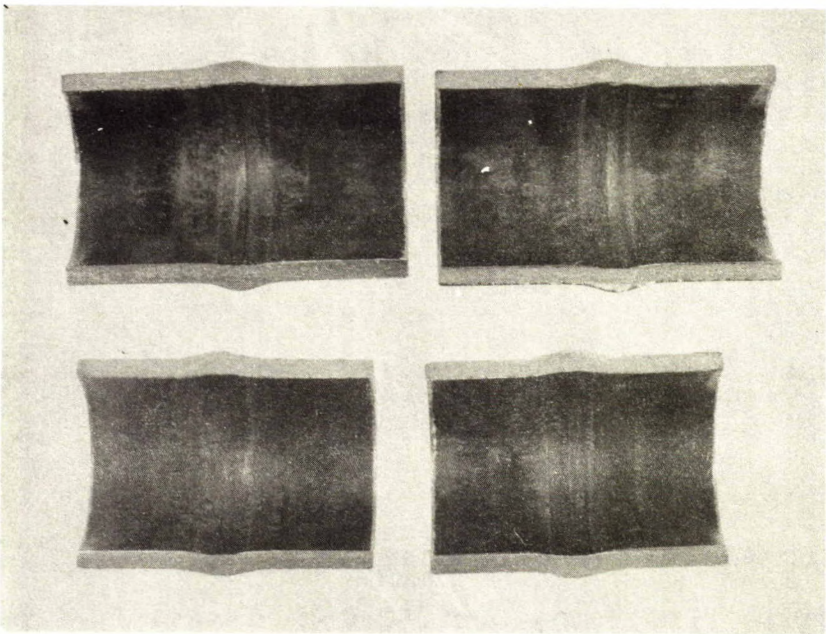
Figure 3 - Outer Surface



(About 4/10 actual size)

Figure 4 - Inner surface of samples shown in Figure 3

(2) Four reduced section tensile specimens were removed from one pipe sample. Two of these were left in the as received state on the inner and outer surface of the joint, thus permitting the testing of the total weld cross section. The other specimens were machined to a rectangular cross section in the test portion. The following results were obtained on tensile testing.

Specimens having full weld cross section	Broke in pipe metal at 6000 and 6200 lb load about 3/4 in. away from joint.		
Specimens machined to rectangular cross section	UTS, psi	56,600	56,600
	Yield psi (by dividers)	44,400	42,200
	% Elongation in 1 in.	25.0*	29.0
	Both specimens broke in pipe metal about 1/2 in. away from joint.		

*Broke on punch mark.

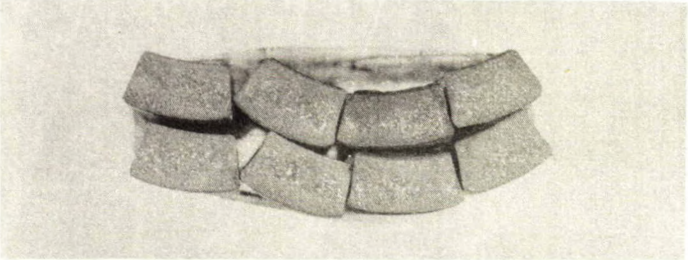
(3) Root (inner fibres in tension) and face (outer fibres in tension) bend specimens were obtained from each of three additional samples. One sample had been stamped 22, and the other two samples had been stamped only with three dots. These were designated (A...) and (C...). One root and one face bend specimen each 3/8 in. in width were removed at 90 deg. intervals from each pipe. No grinding of the joint area was done on the internal and external pipe surfaces. These specimens were bent around a former having a diameter 4 times the pipe wall thickness using a jig as recommended by ASME

in Section IX, Welding Qualifications, 1956 edition.

All specimens from pipe number 22 withstood a full 180 deg. bend. Slight traces of opening along the interface were found on two of the face bend specimens.

Similarly, all eight bend specimens from pipe number (C...) withstood the full 180 deg. bend. Two of the four face bend specimens contained openings about 1/32 in. deep across the entire sample width at the joint interface.

All eight bend specimens from pipe number (A...) failed in a brittle fashion after bending usually only a few degrees and at the most 45 degrees. The fractured surfaces had areas of distinctly different appearance as shown in Figure 5.



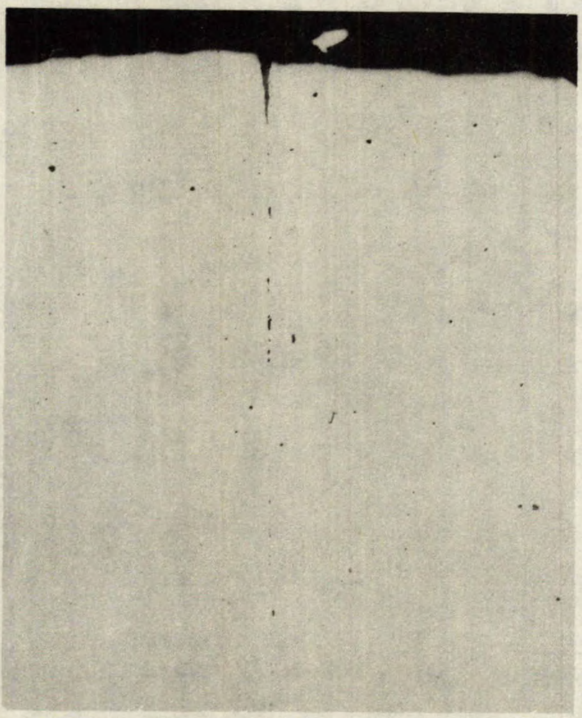
(slightly larger than actual)

Figure 5 - Typical fractured bend test specimens from sample (A...)

Two additional specimens from sample (A...) withstood a full 180 deg. face bend without any cracking, after the external portion of the joint had been ground flush with the outer surface of the pipe. Two other face bend samples on which the external portion had been reduced about 1/32 in. by grinding, failed in a brittle fashion after only a very few degrees of bending.

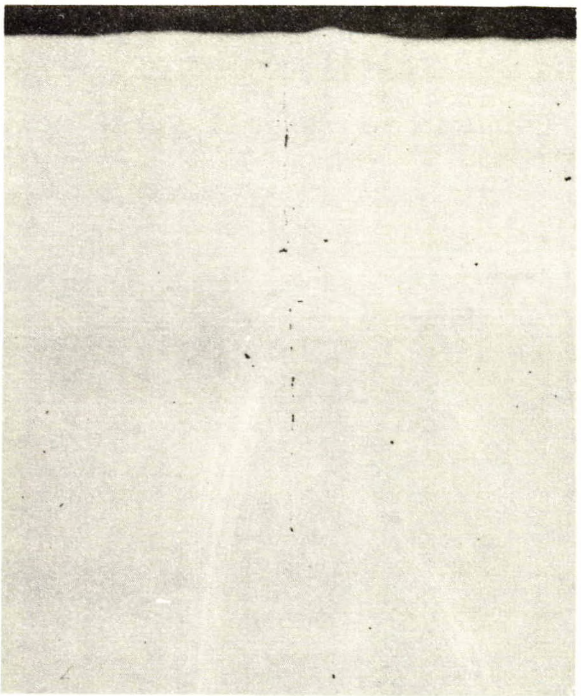
(4) Two sections, 180 deg. apart, were taken from each of the pipe samples 21 and 22 and three sections approximately 120 deg. apart were taken from sample (A...). One section remote from the joint was removed from each of samples 22 and (A...) respectively.

In the unetched condition the appearance of the sections from samples 21 and 22 is illustrated by Figures 6 and 7.



(X100, Unetched)

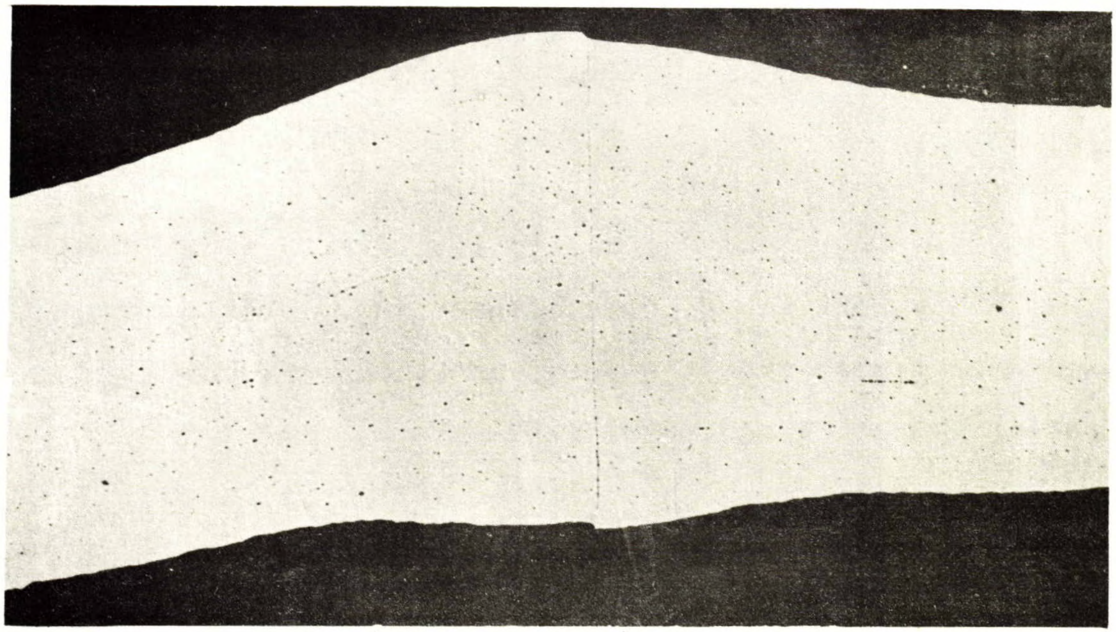
Figure 6 - Oxide at joint interface extending inward from outer surface



(X100, Unetched)

Figure 7 - As Fig. 6, but of a different section

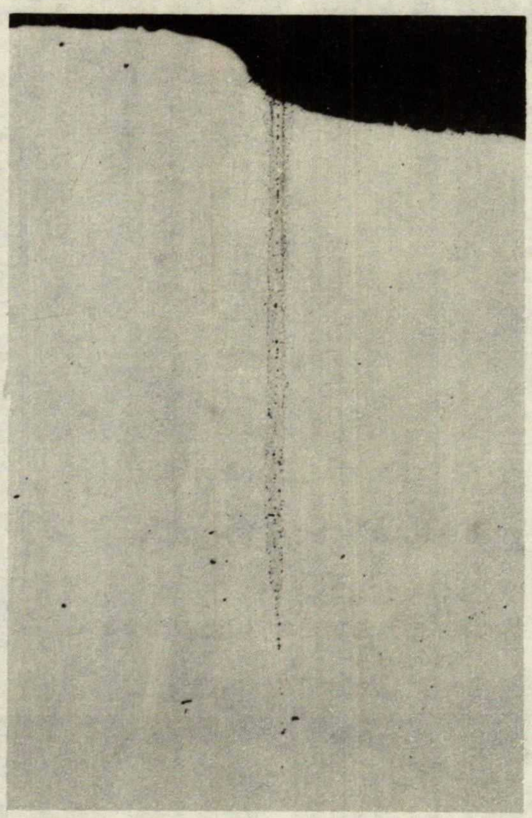
Figure 8 is a photomacrograph of one of the three sections removed from sample (A...).



(X8, Unetched)

Figure 8 - Oxide outlining joint interface

Figure 9 is typical of the appearance at the joint adjacent to the OD surface of all three sections from sample (A...).



(X100, Unetched)

Figure 9 - Oxide at joint interface

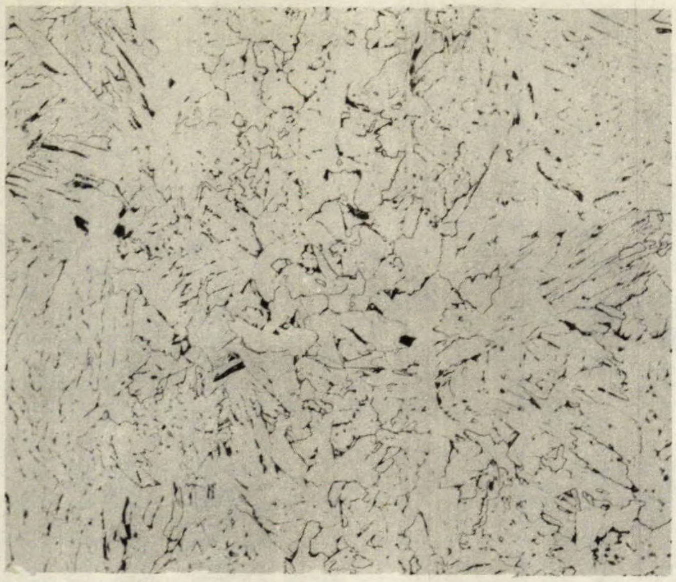
The next two figures compare the microstructure of the metal remote from the joint of samples 21 and 22 with that of sample (A...).

(X100, Nital Etch)

Figure 10 - Microstructure remote from joint typical of samples 21 and 22

(X100, Nital Etch)

Figure 11 - Microstructure remote from joint of sample (A...)



(X100, Nital Etch)

Figure 12 - Microstructure at weld interface typical of samples 21 and 22

DISCUSSION

Figures 1 and 3, typical of the appearance of the external surfaces of the samples, show that the joint surface is clearly outlined by a sharp line, usually at the centre of the upset portion. At some locations, closer examination particularly with a magnifying lens, suggests that some lack of adhesion may be present. However, no definite conclusions as to the overall joint quality were possible on the basis of visual examination.

Some outward flaring of the pipe occurred during the upsetting as illustrated by Figures 2 and 4. Good flow conditions should result from this type of internal configuration. No evidence of joint deficiency was noted on examination of the "as welded" surface at the interior of the pipe. Oxidation of this surface and also the external surface suggests that no gas protection was used during welding.

The fact that this welding process is capable of producing joints having tensile properties at least equal to the pipe itself is shown by the results of tensile tests on one of the samples. It is pointed out that in the tests on the full thickness joints, the unit stress at the interface was less than that on the pipe metal at the point of fracture. In the tests on the fully machined specimens, any points of weakness close to the inner and outer joint surfaces would not be included in the test section.

Bending of strips from three samples was found to be a revealing test of weld quality. In two of the samples thus tested, a tendency for separation at the joint interface on the external surface was noted. This was associated with oxidation at the interface such as shown in Figures 6 and 7. As judged by the requirements of ASME Section IX, Para. Q 8(e), one of the samples would be considered to have failed the bend test. Heavier and more continuous oxidation across the interface such as illustrated by Figures 8 and 9 is considered to be the chief reason for the extremely poor performance in root and face bend tests on the third sample. The small crystalline appearing areas noted on the fractured surface of bend test specimens (see Figure 5) are considered to be the only areas where any appreciable degree of bonding was obtained. Removal by grinding of the more severely oxidized portion of the joint near the external surface appears to lessen the tendency for brittle behaviour. This grinding may reduce the cross section of the joint to less than that of the pipe wall. Also, if heavy intermittent oxidation is present across the remainder of the joint, it is very likely that inadequate ductility will still result. It should be noted that there was more continuous oxidation across the joint interface in one of the three sections (See Figure 8) compared with the other two sections from sample (A...), thus indicating variation around the weld periphery. Thus grinding away of the heavily oxidized outer portion of the joint should not be considered as a suitable substitute to reducing the oxidation at the interface during welding.

The microstructure remote from the joint in two of the three samples examined metallographically, is shown in Figure 10 to consist of ferrite and pearlite. This is a typical low carbon steel microstructure. In the third sample, the comparison specimen has a microstructure as shown in Figure 11, consisting of much finer grain ferrite with spheroidal carbides. This difference in microstructure is not believed to have influenced the weld quality, but it is pointed out to illustrate that the steels used in preparing the welded samples were not identical. The original microstructure of the pipe influences the microstructure in the joint area. For example, the microstructure in the joint area in samples 21 and 22 consists of ferrite and pearlite (Figure 12), while the microstructure (not shown) at a corresponding location in sample (A...) consists of much finer grain ferrite and spheroidal carbides.

CONCLUSIONS

(1) Satisfactory joint configuration is shown by the submitted samples.

(2) Tensile properties of induction welded joints can be equal to those of the unwelded pipe.

(3) Extreme variation in weld quality is illustrated by the fact that bend tests from one pipe sample were all satisfactory while those from another sample failed in a drastic fashion.

(4) This variation in weld quality is due chiefly to variation in the degree of oxidation at the weld interface during the welding operation.

(5) Heat treatment of the joint area is not believed to be an important factor in improving the weld quality.

(6) This examination suggests that the application of induction welding to critical pipe work construction should be deferred until this extreme variability in quality is corrected.

WPC/KW