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WELDABILITY TESTING OF X52 STEEL SAMPLE

by

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SUMMARY OF RESULTS

C. T. S. weldability tests have been made on X52 steel from pipe available from a previous investigation of a pipeline failure. The weldability was found to be poor, and the results were in agreement with the observation that, though cracking could normally be avoided in the field butt welding of 3/8 in. wall pipe, trouble was apt to be encountered in fillet welds or whenever extra thicknesses of metal were incorporated in the joint.

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INTRODUCTION

In an earlier investigation of a pipeline failure[1], it appeared that heat-affected zone cracking could occur adjacent to welds made in X52 steel if the cooling rate was sufficiently severe, although this condition was apparently usually avoided in most field butt welds. In order to establish more exactly the relationship between cooling rate and heat-affected zone cracking for this steel, it was decided to undertake a series of Controlled Thermal Severity (C.T.S.) tests (see Appendix) covering a range of thermal severity.

MATERIALS

A supply of X52 steel plate of approximately 3/8 in. thickness was available from a previous investigation, this being a piece of pipe, taken from near the origin of brittle failure, which had been flattened by the force of the explosion. This steel had a carbon content of 0.30% and a manganese content of 1.23%, being designated Pipe II in the earlier report[1]. The composition complies with specification requirements which permit 0.32% carbon and 1.30% manganese by check analysis, and the steel is representative of compositions with carbon and manganese content at the high end of the permitted range.

The electrodes used were of the E7010 classification of the type often used for the hot pass and cover pass in field butt welding of pipelines. However, the results may be considered typical also for the E6010 electrodes often used for the root pass, since both classes have a high hydrogen potential.

PROCEDURE

The plate material was used to provide 3 in. x 3 in. top plates for standard C.T.S. tests. For this purpose, one surface should have a ground finish. To provide for a machining allowance, the finished thickness was fixed at 1/4 in. Bottom plates were provided from ordinary mild steel in finished thicknesses of 1/2 in., 3/4 in. and 1 in. in order to provide a range of cooling rates. The three test conditions therefore provided Thermal Severity Numbers (T.S.N.)* of 3, 4, 5, 7 and 9. A thermal severity of 5 would occur twice, once in the Bithermal (R) weld of the test using a 1 in. bottom plate, and once in the tri-thermal (S) weld of the test using 1/2 in. bottom plate.

Two tests were made for each of the above three configurations, once with an energy input of 20,000 joules/inch, and the other with an input of 30,000 joules/inch.

After testing, three sections were removed from each of the test welds for magnetic (Magnaglo) and microscopical examination. The extent of cracking was determined from the magnetic examination and subsequently confirmed by the microscopical examination. The extent of cracking was expressed as a percentage of the leg length. The sections were etched in 2% nital for the microscopical examination.

A few bead-on-plate tests have been made for comparisons of results with those of the C.T.S. test. In this case a single section was cut from the test weld.

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*The thermal severity number is given by the addition of the heat paths in units of 1/4 in. thickness available for heat conduction from the joint.

Hardness traverses were made on the heat-affected zones of all the sections examined, using a Tukon tester with a diamond pyramid indenter and a 500 g load. The D.P.H. values obtained were converted to the Rockwell C scale.

RESULTS

The results of the C.T.S. testing are given in Table 1. The amounts of cracking shown represent an average for the three sections examined. The peak hardness values obtained are also included in the table.

TABLE 1

Cracking and Peak Hardness in C.T.S. Tests

Thermal Severity Number (T.S.N.)	Bottom Plate Thickness (in.)	Weld Type	Input 20,000 Joules/in.		Input 30,000 Joules/in.	
			Cracking (%)	Peak Hardness (R_c)	Cracking (%)	Peak Hardness (R_c)
3	1/2	R	30	45	0	47
4	3/4	R	86	49	68	49.5
5	1	R	93	51.5	55	48.5
5	1/2	S	75	47	67	51.5
7	3/4	S	97	52.5	100	49
9	1	S	100	50	78	52.5

The results indicate that the X52 steel used here has poor weldability. The C.T.S. test is not very severe, and yet cracking was obtained in every case except with the higher heat input (30,000 joules/inch) with the lowest thermal severity (T.S.N. 3). There is evidently a trend towards increased amounts of cracking as the thermal severity is increased from T.S.N. 3 to T.S.N. 9, as would be expected. The amount of cracking for any given thermal severity level tends to be a little greater for the lower energy input, again as expected.

A bead-on-plate test carried out by the recommended procedures with an E6010 electrode gave severe cracking. The cooling rate is quite high, so that this result is in line with what might be expected from the C.T.S. testing. It is suspected that this test has been used incorrectly by some pipeline companies, in that the water cooling, which is an essential feature, may have been omitted. A test was done in this way, using air cooling, and no cracks were found under these conditions. Another test was made using low-hydrogen (E6016) electrodes, under standard conditions using water cooling. No cracking was found.

DISCUSSION

To examine the implications of these weldability results, it is necessary to consider the welding procedures used in pipeline construction.

From information previously supplied[2], typical conditions for circumferential butt field welding are: root pass 20 in./min with 175 amp at 28 volts; hot pass 8-20 in./min. with 190 amp. at 30 volts; cover pass 8 in./min. with 200 amp. at 32 volts. The approximate energy input corresponding to these conditions would be root pass 14,700 joules/in., hot pass 17,100 to 42,750 joules/in. and cover pass 48,000 joules/in.

For circumferential butt field welds in 3/8 in. wall pipe, there are two 3/8 in. paths for heat flow so that the thermal severity number is 3. The C.T.S. test results show that for joints of this severity, slight cracking (30%) would be expected with an energy input of 20,000 joules/inch, but no cracking with an energy input of 30,000 joules/inch or higher. Considering the component passes of the field weld in isolation, no cracking would be expected in the cover pass (48,000 joules/inch), though slight to severe cracking would be expected adjacent to the root pass (14,700 joules/inch). No cracking, slight cracking or moderate cracking might be obtained adjacent to the hot pass depending upon the energy input level used (17,100-42,750 joules/inch).

The above analysis illustrates the necessity of applying the hot pass as soon as possible after completion of the root pass, in order to avoid the rapid cooling that would otherwise occur, and so to prevent the onset of cracking adjacent to the first two welds, and particularly the root pass. Work at the Battelle Memorial Institute[3] has shown that as the delay period between the first two welds is increased from 2 minutes to 1 hour, the amount of cracking adjacent to the root bead increased from the range 0-4% to the range 16-20%, and that as much as 63% cracking could occur if the hot pass was eliminated. These findings are in line with the weldability test results reported here.

In practice, since heat-affected zone cracking is not usually found adjacent to field welds, it must be concluded that the normal procedure of applying the first two welds in rapid succession is providing effective protection against cracking.

A worse situation occurs where sleeves, patches, branches, etc., are joined to the pipe wall. To take the simple example of a 1/2 in. thick encirclement sleeve, the fillet weld attaching the sleeve to the pipe wall would have a Thermal Severity Number of 5. The same would apply to a fillet welded patch or to a branch line provided with a sleeve or shoulder fabricated from 1/2 in. wall steel and attached directly to the pipe wall. At this severity, the weldability results show that severe cracking may be anticipated under some circumstances. This is in line with the fact that investigation showed a significant amount of heat-affected zone cracking to be present adjacent to the fillet weld of a field-welded patch attached to the wall of a 30 in. diam. 3/8 in. wall X52 pipe(1). A similar investigation later showed that slight cracking was present in a fillet welded full encirclement sleeve. The extent of such cracking would depend upon the heat input and the welding conditions.

It would be expected that preheating or low-hydrogen electrodes might be required in some cases to prevent cracking when making attachments to the pipe wall. It is, however, possible that cracking could also be prevented by using sufficiently large beads and a controlled welding sequence; it would be interesting to check these possibilities on simulated joints.

Finally a word may be said about the hardness results. There is no clear relationship between peak hardness and thermal severity, and between peak hardness and amount of cracking. It may be noted that a peak hardness value of 47 Rc was obtained when no cracking was present, and that considerable amounts of cracking were associated with hardness values in the range 47-52.5 Rc. Peak hardness is therefore not a very sensitive criterion of the liability of the heat-affected zone to crack.

CONCLUSIONS

1. The X52 steel used in this investigation has poor weldability with E7010 electrodes as indicated by the C.T.S. test. The amount of cracking tended to increase with increasing thermal severity of the joint or

decreasing energy input.

2. Analysis of thermal severity shows that cracking may be expected in the field butt welds of X52 steel pipelines of 3/8 in. wall adjacent to the root bead, and sometimes also adjacent to the hot pass, unless these two welds are laid in rapid succession.

3. Severe cracking may be expected, unless preheating or other precautions are applied, when added metal is welded to the pipe wall i.e., sleeves, patches, branches, etc., in X52 steel pipelines of 3/8 in. wall.

4. There was no clear relationship between the extent of cracking and the peak hardness in the heat affected zone.

REFERENCES

1. K. Winterton. "Investigation of Pipeline Failure", Mines Branch Investigation Report IR 61-149, March 1962 (Technically equivalent to Investigation Report IR 61-58, but with names and locations removed.)

2. A. G. Barkow "Gas and Oil Pipeline Welding Practices" Interpretive Report No. 76 Welding Research Council, April 1962.

3. H. B. Thompson and G. E. Faulkner. "The Effects of Welding Procedures on Base-metal Cracking Adjacent to Girth Welds and Welded Connections in Natural Gas Pipelines", Phase Report of the Supervising Committee for Pipeline Research Project NG-10, American Gas Association, Oct. 1955.

APPENDIX

PROCEDURE FOR THE C.T.S. TEST

The dimensions of the test plates and the method of assembly are shown in Figure 1. One face of each plate is surface ground, the assembly being bolted together with the two surface-ground faces in contact.

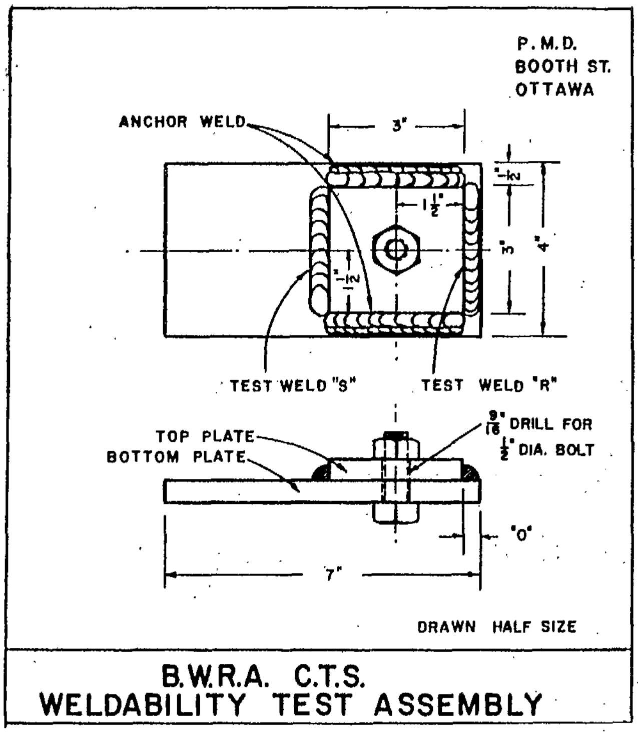

Fig. 1 - Plate dimensions and assembly method for C.T.S. test

Anchor welds are made on two opposite sides of the top plate, as shown in Fig. 1, and the assembly is allowed to cool to room temperature before making the test welds. The bithermal (R) weld is made first, and the assembly is allowed to cool to room temperature before making the trithermal (S) weld. The test welds are made downhand. The assembly is allowed to stand for 48 hours before sections are removed from the test welds for examination.

In the main series, top and bottom plates are of the same thickness and may vary from 1/4 in. to 2 in. thickness, giving a range of thermal severities from 2 to 24. In the supplementary series, similar results may be achieved using 1/4 in. thick top plates and varying the thickness of the bottom plates.