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REPORT ON ELEVATED TEMPERATURE PROPERTIES OF CROSSWELD SPECIMENS FROM ASTM A212 AND A201, GRADE B CARBON STEEL PLATE

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REPORT ON ELEVATED TEMPERATURE PROPERTIES OF CROSSWELD SPECIMENS FROM ASTM A212 AND A201, GRADE B CARBON STEEL PLATE

Tensile and rupture tests were conducted on cross-weld specimens from A201 and A212 carbon steel plates made to coarse grain practice. The investigation was undertaken to obtain data which The Timken Roller Bearing Company contributed to a cooperative investigation of the high temperature properties of welds sponsored by the Chemical and Petroleum Panel of the ASTM-ASME Joint Committee on the Effect of Temperature on the Properties of Metals.

The results of the cooperative investigation were covered in a report entitled "Strength of Welded Joints in Carbon Steel at Elevated Temperatures" by W. B. Hoyt. The results of the tests carried out are correlated with the overall results in the Hoyt Report.

SUMMARY AND CONCLUSIONS

Tensile tests on cross-weld specimens from welded A201 plate agreed closely with results from other cooperative laboratories.

Rupture tests on cross-weld specimens from A201 plates also agreed closely with results from another laboratory. Similar tests at 1000°F on welded A212 specimens were higher than were obtained by another laboratory. The tests on A212 specimens at 800°F were the lowest reported for either type of plate while those at 1000°F were highest.

The conclusion of the Hoyt Report that strength and location of fracture is governed by the relative strength of base metal and weld deposit and that presumably weak heat-affected zones do not introduce a "metallurgical notch" was discussed. It was pointed out that non-uniform yielding or creep causes complex stressing during simple tension tensile or rupture tests. This could influence fracture location particularly as they could be influenced by the proportion of base metal, heat affected zones and weld deposit in the specimens and might result in different points of weakness under complex stresses.

The Hoyt Report showed that location of fracture in rupture tests cannot be reliably predicted from tensile tests. It also indicated that flaws can have different effects in tensile and rupture tests.

MATERIAL

Two varieties of carbon steel were used for base material.

1. Plates, 1-inch thick conforming to ASTM Specification A-201 Grade B, Firebox Quality, Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels.

The chemical composition of this plate was as follows:

Ladle Analysis						
C	Mn	P	S	Si	Al* (Acid Sol.)	Total Al*
0.19	0.57	0.023	0.034	0.19	N.D.**	0.0022

* Check Analysis
** None detected

This plate was stamped 34 U 225 (heat number) 68032 (plate number), USC-CG-1 and was made by the U.S. Steel Corporation by coarse grain practice. It is a portion of one of the steels used in the recent ASTM-ASME Joint Committee cooperative investigation of the high temperature strength of carbon steel(1). The plate was furnished in the hot rolled condition.

2. Plate, 1-inch thick, conforming to ASTM Specifications A-212, Grade B, Firebox Quality, High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels.

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(1) "Strength of Carbon Steels for Elevated Temperature Application", R. F. Miller, ASTM Proceedings, Vol. 54, 1954

The chemical composition of this plate was as follows:

C	Mn	P	S	Si	Cu
0.27	0.65	0.017	0.021	0.22	0.15

This plate was rolled at the Sparrows Point Plant of Bethlehem Steel Company from Heat No. 72D408 and furnished in the stress relieved condition. Other portions of this plate are being used in a high temperature test program under Project SP-4 for the Steam Power Panel of the Joint Committee.

Welded Joints

Five welded joints were prepared as described below, three in A-201 plate and two in A-212 plate.

Joint Designation

201-M-6: A-201, Gr. B., manual weld, E6010 electrodes
201-M-7: A-201, Gr. B., manual weld, E7016 electrodes
201-A : A-201, Gr. B., automatic weld, #36 wire*
212-M : A-212, Gr. B., manual weld, #7016 electrodes
212-A : A-212, Gr. B., automatic weld, #40A wire*

*Note: Designations for wire and flux used automatic submerged arc welding refer to Unionmelt (Union Carbide and Carbon Corp.) materials.

Welding grooves for the manual welds were double Vee, 60° included angle, 1/16" land, and 1.8" root gap. For automatic submerged arc welds the grooves were double Vee, 90° included angles, 5/16" land, and 0" root gap; No. 80 flux* was used.

No preheat was used; however, the welded plates of A-212 Gr. B steel were stress-relieved at 1100-1150°F. All welds were inspected by the magnetic powder method and by X-ray. Boiler Code standards of X-ray quality were met.

Chemical analysis of weld metal are as follows:

Weld	C	Mn	P	S	Si	Mo
201M6	0.07	0.41	0.024	0.025	0.04	----
201M7	0.08	0.55	0.035	0.021	0.37	---
201A	0.12	0.96	0.025	0.034	0.14	----
212M	0.11	0.53	0.031	0.021	0.31	----
212A	0.12	0.69	0.029	0.023	0.23	0.34

The welding procedures and electrodes are considered characteristic of practices in common use among fabricators of Code pressure vessels. The use of E7016 electrodes would not be usual when welding on carbon steel plates of 60,000 psi minimum tensile strength but this was done to observe the effects of weld deposits of a higher tensile strength than the base metal.

RESULTS

Tensile Tests

Tensile tests were conducted at 600°, 800°, 900°, and 1000°F on the A201-M-7 specimens with the results in Table I. Figure 1 shows the stress-strain curves. All fractures occurred in base metal. The tensile properties agreed quite closely with other values in the Hoyt report for A-201 specimens fracturing in the base metal. In fact, the agreement seemed remarkable for specimens with two different weld deposits tested at two different laboratories.

Rupture Test Properties

Rupture tests were conducted at 1000°F on the A201-M-6 and A201-A specimens, at 800°F on the A212-A specimens, and at 1000°F on the A212M and A212A specimens with the results given in Table II. The stress-rupture time curves are shown in Figure 2 and compared with those in the Hoyt Report from other cooperators in Figure 3.

The following comments apply to the data:

1. There was very little difference between the A201-M-6 and A201-A specimens, even though the two longer time tests on A201-M-6 fractured in the weld deposit and the other specimens fractured in the base metal. The Hoyt report showed a good agreement with tests on A201-M-7 specimens, except for a long time test (4067 hours) which appeared to have fractured in the heat-affected zone somewhat short of the time obtained by extrapolation of the other data. The Hoyt report indicated that this latter specimen had cracks in the weld deposit

which influenced the rupture time and fracture location.

2. The two tests at 800°F on A212-A specimens fractured in the base metal. The weld deposit of the A212-A specimens would be expected to be much stronger than the base metal due to the 0.34-percent molybdenum in the deposit. The rupture times and particularly the ductilities were less than those obtained by another laboratory on A212-M specimens for the Hoyt report.

3. The tests at 1000°F on A212-M and A212-A specimens agreed closely for the two shorter time tests even though the A212-M specimens fractured in the weld and the A212-A specimens in the base metal. The 9500 psi test on A212-M fractured at an abnormally short time with somewhat low ductility. The Hoyt Report showed that all of the A212-M specimens exhibited evidence of porosity. The higher strength of the weld deposit in A212-A specimens causing fracture in the base metal was to be expected due to the molybdenum present in the deposit.

4. Another laboratory tested A212-A specimens with significantly shorter rupture times than were obtained for the tests at The University of Michigan. No adequate explanation of this is available. Each laboratory machined its own specimens. The proportions of weld deposit and base metal could therefore be involved. The Hoyt Report photographs suggest that the gage length of the specimens tested at Michigan were appreciably longer.

Creep Characteristics During Rupture Tests

Creep curves for the rupture tests are shown in Figure 4 through Figure 8. All of the tests at 1000°F showed practically no first-stage and very little second-stage creep. The tests at 800°F showed some primary and secondary creep as well as pronounced third-stage creep.

The second-stage creep rates were either too rapid or so brief in duration that they were considered unreliable for indicating "creep strength". The creep curves include the effects of the weld deposit and heat affected zones. There were therefore variations in creep resistance along the gage lengths. For this reason, the creep curves were to some extent dependent on the proportions of weld deposit and heat-affected zones to unaltered base metal in the particular specimen used.

Microstructures

The microstructural examination was limited to the base materials. All specimens were forwarded to Mr. Hoyt after testing.

Both grades of plate had a pearlite and ferrite structure with an ASTM grain size of 4-5 as shown by Plates 1 and 2. The A212 material had more pearlite with a slight tendency towards a Widmanstatten form in accordance with its higher carbon content. The pearlite was also somewhat slightly granular, possibly as a result of the two stress relief heat treatments.

DISCUSSION

In presenting the report on the overall cooperative program, Mr. Hoyt commented on several features of the results:

1. There was no evidence of failure in heat-affected zones in either tensile or rupture tests with one exception. This was interpreted to show that simple tension tests indicate no evidence of a "metallurgical notch" from the heat-affected zone. The fracture in the heat-affected zone for one specimen (the 4067 hour test on A201-M-7 at 6500 psi and 1000°F) was apparently caused by cracks in the weld deposit.

This conclusion by Mr. Hoyt should be treated cautiously. It is agreed that the presumably weak heat-affected zones do not normally induce fracture in cross-weld specimens under simple tension. This, however, could be due to the interaction of the complex stresses introduced by the non-uniform yielding or creep between base metal, heat-affected zones and weld deposit. If so, then the results are a function of the properties of base metal, heat affected zones and weld deposit in the specimens, as well as of the type of stress applied.

2. Care was exercised in the Hoyt Report to avoid quantitative comparisons between welds or between types of steel. This appears wise inasmuch as the results are probably dependent on the proportions of base metal, heat-affected zone and weld deposit in the particular specimens and their particular properties. It is, however, interesting to note that A212 specimens gave higher tensile strengths and higher rupture strengths at 1000°F. Their rupture strengths were, however, lower at 800°F and the results were mixed at 900°F.

3. The Hoyt report showed that in all cases and A201 specimens had equal or higher rupture strengths at 1000°F (Fig. 3) than the base metal properties presented in the Miller report. The one possible exception, the longest test on A201-M-7 specimens was considered to be influenced by a flaw in the weld. It should be noted that the plate material for the weld specimens was in the as-rolled condition and not stress relieved. The plate materials were stress relieved for 2 hours at 1150°F before testing for the Miller report. The stress relieved plate material did have lower tensile strengths and higher ductility than the weld specimens.

4. The Hoyt report showed that tensile strengths are not a reliable indicator of rupture strength. All but two of the A201-M-6 specimens fractured in the base metal during rupture tests even though tensile tests showed the weld deposit to be weakest. The relative strengths of weld deposit and base metal under tensile and creep conditions was considered to be the controlling factor.

5. The Hoyt report commented that the average rupture strengths of the A201 plates made to fine and coarse grain practices for the Miller report was intermediate to the welded specimens from A201 and A212 plates (See Fig. 3).

TABLE I

ELEVATED TEMPERATURE TENSILE DATA FOR CROSSWELD SPECIMENS

FROM JOINT A201-M-7 IN A201 GRADE B CARBON STEEL PLATE

Temp (°F)	Tensile Strength (psi)	Offset Yield Strength(psi) 0.1%	Offset Yield Strength(psi) 0.2%	Elongation (% in 2 inches)	Reduction of Area (%)
600	72,800	30,900	34,300	21.0	46.5
800	54,800	29,700	32,600	27.5	61.5
900	43,400	28,300	30,300	28.5	69.0
1000	31,100	21,400	22,900	39.0	73.0

All fractures were in base metal.

TABLE II

STRESS-RUPTURE DATA AT 800° AND 1000°F FOR CROSSWELD SPECIMENS FROM CARBON STEEL PLATE

Joint Designation	Type Steel	Type Weld	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 inches)	Reduction of Area(%)	Location of Fracture
			Rupture Tests at 800°F				
A212-A	A212, Grade B	Automatic	35,000	722	10.0	42.0	Base Metal
			30,000	2701	14.0	47.5	Base Metal
			Rupture Tests at 1000°F				
A201-M-6	A201, Grade B	Manual	14,000	73	39.0	82.0	Base Metal
			10,000	592	32.5	61.0	Weld Metal
			7,500	2876	25.0	50.0	Weld Metal
A201-A	A201, Grade B	Automatic	13,000	172	40.5	85.0	Base Metal
			10,000	697	40.5	82.5	Base Metal
			7,500	2738	35.0	67.5	Base Metal
A212-M	A212, Grade B	Manual	16,000	149	23.5	60.5	Weld Metal
			13,000	551	23.0	61.0	Weld Metal
			9,500	1457	10.0	31.5	Weld Metal
A212-A	A212, Grade B	Automatic	16,000	136	17.5	48.5	Base Metal
			13,000	646	18.5	53.0	Base Metal
			9,500	2658	13.0	44.0	Base Metal