CONF-710342-6

HEAVY SECTION STEEL TECHNOLOGY PROGRAM

5th

ANNUAL INFORMATION MEETING

MARCH 25-26, 1971

Paper No. 6

U.S. ATOMIC ENERGY COMM.
ADVISORY COMMITTEE ON
REACTOR SAFEGUARDS

1971 MAY 19 PM 2 52

RECEIVED

MASTER

THE METALLURGICAL ASSESSMENT OF RETEMPER TEMPERATURE ON THE INTERMEDIATE VESSEL TEST COURSES

D. A. Canonico
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Sponsoring Program or Organization

HEAVY SECTION STEEL TECHNOLOGY PROGRAM

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

THE METALLURGICAL ASSESSMENT OF RETEMPER TEMPERATURE
ON THE INTERMEDIATE VESSEL TEST COURSES

D. A. Canonico

Introduction

The design and test parameters for the cylindrical body forging that are to be used in the fabrication of the Intermediate Test Vessels (ITV) were based on the mechanical properties typical for ASTM A508 class 2 steel. This specification requires that the minimum yield strength and ultimate tensile strengths be 50,000 psi and 80,000 psi, respectively. Further, a toughness requirement of an average of 30 ft-lb at +10°F was also imposed on the material. The cylindrical body forgings supplied for the vessels had yield and ultimate tensile strengths in excess of 82,000 psi and 102,750 psi. Moreover, the nil-ductility temperature of the steel as determined by the drop-weight test was below -20°F. The properties of the steel are acceptable as far as the ASTM A508 class 2 specification is concerned. However, the high tensile values are cause for concern when one anticipates that the ultimate tensile strength of typical submerged-arc welds may be equal to or below the yield strength of the cylindrical body forging.

A review of the ITV study program resulted in the conclusion that the cylindrical body forgings should possess mechanical properties within the following ranges which became the guidelines for the acceptance of the forgings.

Ultimate tensile strength	80,000 to 95,000 psi
0.2% offset yield strength	50,000 to 75,000 psi
Elongation in 2 in. (min %)	18%
Reduction in area (min %)	38%
Charpy impact energy (at 40°F)	
Average of set of 3 specimens	30 ft-lb
Minimum value of 1 specimen	25 ft-lb

The mission of this study was to determine what reheat treatment methods could be applied that would provide the cylindrical body forgings with mechanical properties that fall within the values set above. The

two previous papers, Nos. 4 and 5 by Messrs. Childress and Steltzman, discuss, respectively, the fabrication and heat treatments for the intermediate test vessels.

Experimental Procedure

The first investigation undertaken was to assure ourselves that the reported tensile properties were correct. This was done and our results showed yield and ultimate tensile strengths of about 91,000 psi and 109,000 psi, respectively. Moreover, we reheated tensile specimens at 1280°F and, indeed, saw no change in the tensile properties. Chemical analyses of the steel conducted by the Oak Ridge National Laboratory and a large steel company were in agreement with the analysis reported by the vendor for all elements except carbon. The ORNL analysis indicated a carbon range of from 0.29 to 0.30%. The carbon analysis reported by the steel company was 0.27%. This value agrees with the vendor's carbon analysis and is within the allowable range of the ASTM specification.

A sulfur print of the steel showed it to be acceptable. (The cylindrical shape was machined from the original forge material and, hence, the "centerline" stock was removed. This resulted in a uniform sulfur distribution across the 6 7/8-in. wall thickness.)

A reheat treatment study was undertaken in an effort to determine what avenues were available to reduce the mechanical properties to within those ranges previously stated. The heat treatment of the forgings was as follows:

Normalize	6 hr	1700°F
Austenitize	7 hr	1580°F
Quench in water		
Temper	8 hr	1270°F

The quench-and-temper heat treatment was witnessed by C. E. Childress. Further, thermocouples were imbedded in the cylindrical shell forgings; consequently, excellent cooling rate records were available. The cooling rate to half-temperature at the quarter-thickness location was about 2.5°F/sec. Our initial response was to reduce this rate by retempering the steel in a media whose H value (a measure of the severity of quench) was lower. This approach was cursorily investigated by placing a 3/4-in.

square by 6-in. long piece of steel in a furnace and heating it to 1600°F. It was held at temperature for 1 hr and the furnace was shut down. The piece cooled in the furnace at a rate of 0.07°F/sec which is 36 times slower than the rate for the forgings. The hardness value of the slowly cooled steel was 16 R_C versus 20 R_C for the quenched-and-tempered forging. The change in cooling rate did not appear to provide an easy means for reducing the strength. Further, the microstructure of an extremely slowly cooled (approx 0.006°F/sec) steel is even more atypical of ASTM A508 class 2 than the higher tensile properties of the forgings.

We then sought to lower the strength by retempering. A heat-treatment study was undertaken and change-in-hardness values were used as the measure of its effectiveness. A through-the-thickness hardness survey was made on the as-received steel. These R_C values ranged from 23 on the surface to 19 at a depth of 4 3/8 in. in from the outer surface. The hardness values for the various depth locations are given in Table 1. We then took a number of samples from the steel and subjected them to various retemper temperatures. Following the heating cycle, the specimens were cooled in air. The results of this study are also given in Table 1.

We retempered at 1220°F and saw no apparent change in hardness. A retemper at 1280°F resulted in a similar observation. At 1300°F, there was a small drop, about 2 R_C hardness values, within the steel, but the surfaces were essentially unchanged. Retempering at 1325°F resulted in a hardness increase. It is assumed that the steel began to transform to austenite and, upon air cooling, the 3/4-in. by 3/4-in. section hardened.

Concurrent with the hardness study, we had an electrical resistivity study made in an effort to determine the eutectoid temperature (the temperature at which we begin to undergo an allotropic transformation from body-centered cubic to a face-centered cubic crystal structure). The resistivity measurements indicated that the transformation occurred between 1315°F and 1346°F (713°C and 730°C). This value is in good agreement with the change in hardness observed after the 1325°F retemper treatment.

We also conducted a study of the hardenability of the body forging steel using the Jominy End Quench Test (JEQT). This test allows us to assess the effect of cooling rate on the hardness of a steel. The results

Table 1

EFFECT OF HEAT TREATMENT ON THE HARDNESS OF INTERMEDIATE

Through the Thickness Location ^a 1/16 in.	Hardness, Rockwell C					Through the Thickness Location ^a 1/16 in.	Hardness, Rockwell C				
	As Received ^b	Retemper, ^c °F					As Received ^b	Retemper, ^c °F			
		1220	1280	1300	1325			1220	1280	1300	1325
1	23					47	21.5		20.5		30
2	22		23.5			51	21.5			17	
6			24			66			21	17	
8	22	24	22.5			70	19		19.5		
10	21			17		72					25
13	21		22.5		26	76	20.5		21		
17			21	21	28	78					25
20		22				80			19.5		
24			20			82	20.5			20	
26	22			17		86			20	21.5	25
28			21			88	19.5				
30	20			19		90			21		
34	20		20.5			92	20.5				
36					23.5	95			23		
38	21		21		31	98			24		
42		21	21.5			104	23		25		
43	20.5					106				22	

Note: Specimen retempered at 1325°F was reheated to 1280°F. Hardness ranged from 12 to 18 R_c.

^aInner wall - 0 in.

^b1580 austenitize - water quench - 1280°F temper.

^cSpecimen quenched after retemper.

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

of the JEQT are shown in Fig. 1. A study of austenitizing temperature was conducted and the results show no effect over the 200°F temperature range employed. The JEQT results are typical for this steel with a carbon level of about 0.25 to 0.30%.

The effect of tempering temperature was investigated by conducting a conventional JEQT on steel that had been austenitized at 1600°F and then tempering the steel at various temperatures. Three temperatures, 1280, 1310, and 1340°F, were studied. These results are also shown in Fig. 1. The 1340°F temper resulted in a hardness level of about R_c 20. This value is higher than what can be expected in the 7/8-in. thick forging because the slowest cooling rate in the JEQT is faster than that of the 1/4 T location in the 6 7/8-in. forging. This study does indicate, however, that heating the steel above the eutectoid temperature did not result in a dramatic change in hardness properties.

These data served as the basis for a more extensive Data-Trak reheat temperature study. This work is reported by Steltzman and Berggren in the previous paper (No. 5). Their data show a limiting lower value of ultimate tensile strength of about 90,000 psi. (This is based on a cooling rate of 20°F/hr, 0.006°F/sec.) Their study included Charpy V notch (C_v) as well as tensile properties. Figure 2 contains photomicrographs of specimens that were retempered in the Data-Trak at the indicated temperatures. Following the temper cycle, the specimens were cooled at 200°F/hr, a rate which simulates an air cool. The microstructures of the as-received specimen and the specimens retempered in the Data-Trak at 1298, 1311, and 1318°F are quite similar. The retemper at 1343°F resulted in a structure in which the amount of carbide appears to be reduced. The difference, however, is nowhere near the magnitude exhibited by the surface and 1/4 T locations. These microstructures are dramatically different and yet represent a hardness variation of only about three R_c numbers.

This similarity in microstructure combined with the results of the reheat treatment studies, resulted in our suggestion that the desired mechanical properties could be obtained by retempering the forgings at about 1320°F. The vendor felt that his furnaces were controllable within $\pm 15^\circ\text{F}$ in the temperature range of interest. Our data indicated that a retemper at $1320^\circ\text{F} \pm 25^\circ\text{F}$ would provide acceptable mechanical properties.

Fig. 1. Effect of Cooling Rate and Tempering Temperature on Hardness of ASTM A508 Class 2 Steel.

Austenitized at 1580°F – Quenched in Water

As Received

Tempered at 1270°F

Retemper Study

1298°F

1311°F

1318°F

1343°F

Fig. 2. Results of Data-Trak Retemper Study of ASTM A 508 C1 2 Steel. Retemper temperatures are given below photomicrographs. 1500X.

One cylindrical shell forging was reheated at 1320°F. The heat treatment was monitored by a number of thermocouples and was observed by C. E. Childress. The results of heat treatment on the microstructure of the forging is shown in Fig. 3. The microstructure from the original 1280°F temper is included for comparison. There is very little difference in the two microstructures.

Conclusion

Retempering the ASTM A508 class 2 forgings (NF heat Nos. 3V924, 1V3828, 3V913, and 1V3809) at 1320°F ± 25°F should provide a steel that is within the range of mechanical properties that have been set for the cylindrical shells that are to be used in the fabrication of the ITV. It appears that the carbon content of the forgings (about 0.27%) sets the minimum tensile values that are possible for this steel. The fastest cooling rate that is possible in these thick sections is rather slow and results in what, for these steels, can be compared to an austemper heat treatment. The slow rate permits the carbides to agglomerate and, hence, tempering, in the classical sense, is not too effective. The small effect is shown in the tempered JEQT specimens wherein a 60°F difference (1280 to 1340°F) resulted in a hardness change of only three R_C numbers. Retempering at a temper above the eutectoid results in the transformation of areas of the steel to austenite. Upon cooling, these areas retransform. The cooling rate, however, which is in the range of 200°F/hr, results in a microstructure not too much different from that observed in the center of the thick plate. This conclusion is supported by our Data-Trak studies at 1343°F.

Austenitized at 1580°F

250×

1000×

Tempered at 1270°F

Tempered at 1320°F

Fig. 3. Comparison of Microstructures from ASTM A 508 C1 2 Steel (National Forge Heat Nos. 3V-924 and 1V-3828) Tempered at 1270 and 1320°F.