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ATOMIC POWER
LABORATORY

MASTER

***Tempering Behavior
of Two
Pressure-Vessel Steels***

D.A. Ferrill

L.J. DiNuzzo

R.H. Oberdick

February 15, 1965

Operated for the
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TEMPERING BEHAVIOR OF TWO PRESSURE-VESSEL STEELS

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R. H. Oberdick

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J. E. Kilian
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Schenectady, New York
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CONTENTS

	<u>Page</u>
ABSTRACT	ix
INTRODUCTION	1
PROCEDURE	1
Material	1
Preparation and Treatment of Specimens	1
RESULTS	3
DISCUSSION	3
CONCLUSIONS	4

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ILLUSTRATIONS

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	Tempering Parameter for Mn-Mo Steel (KS-56043, Unclassified)	7
2	Tempering Parameters for Ni-Cr-Mo Alloy Steel (KS-56044, Unclassified)	8
3	Cooling Curves from 1720°F in Various Media (KS-56045, Unclassified)	8
4	Photomicrographs Showing the General Structure of the Two Alloy Steels When Subjected to Various Quench and Temper Conditions (KS-56046, Unclassified)	9

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ABSTRACT

Two pressure-vessel steels (MIL-S-871, Class 2 and MIL-S-22494, Comp. A) were tested to determine the variation in hardness as a function of tempering temperature and time. The data obtained will aid in predicting changes in the hardness of these steels and their weld heat-affected zones during tempering and stress-relief treatments.

TEMPERING BEHAVIOR OF TWO PRESSURE-VESSEL STEELS

D. A. Ferrill, L. J. DiNuzzo, R. H. Oberdick

INTRODUCTION

A study was made to determine the effect of tempering temperature and time on the hardness of manganese-molybdenum (Mn-Mo) alloy steel (MIL-S-871 b, Class 2) and nickel-chromium-molybdenum (Ni-Cr-Mo) alloy steel (MIL-S-22494, Composition A), two of the materials commonly used for nuclear pressure vessels. The investigation was undertaken after a literature survey disclosed no specific tempering data for these steels.

Variations in microstructures, attributable to differences in cooling rates, were obtained in as-cooled material. There was no significant metallographic difference between material fully quenched to martensite when tempered for 1 hr at 1200F or when tempered 8 hr at 1300F.

Frequently, while fabricating heavy vessel steel components for nuclear reactors it is desirable to predict the structure and properties following heat treatment or in weld heat-affected zones. To do so, one needs tempering data for the specific steels in question after they are cooled at rates encountered in production.

PROCEDURE

Material

The samples tested weighed between 21 and 33 gm and were taken from material whose compositions are listed in Table 1.

TABLE 1. MATERIAL COMPOSITION

Material	Source	Heat No.	Composition, %								Fe
			C	Mn	P	S	Si	Ni	Cr	Mo	
Mn-Mo	Lukens	A6623	0.20	1.40	0.01	0.017	0.20	-	-	0.47	*
Mn-Mo	Lukens	20926	0.19	1.29	0.019	0.055	0.22	-	-	0.46	*
Ni-Cr-Mo	Bethlehem Steel	124C482	0.23	0.63	0.013	0.013	0.26	0.70	0.34	0.58	*

*Balance.

Preparation and Treatment of Specimens

The specimens were surface-ground prior to heat treatment. To simulate the cooling rates at various depths of heavy sections during heat treatment, the specimens were cooled at different rates from the austen-

itizing temperature by water quench (WQ), oil quench (OQ), salt quench (SQ), and by air cooling (AC) or furnace cooling (FC). The details of the heat treatments are listed in Table 2.

TABLE 2. HEAT TREATMENT DETAILS

Material	Heat No.	Normalize	Austenitize	Cooling Rates	Tempering Treatment
Mn-Mo	A6623	-	1720F for 20 min	WQ, OQ, FC, and AC	600, 800, 1000, 1100, and 1200F for 1, 4, and 8 hr at each temperature
Mn-Mo	20926	1700F for 45 min	1525F for 1 hr	WQ	1100, 1150, 1200, 1250, 1300F for 1, 4, and 8 hr at each temperature
Ni-Cr-Mo	124C482	1600F for 2 hr	-	WQ	1100, 1150, 1200, 1250, 1300F for 1, 4, and 8 hr at each temperature

NOTE: All specimens were air cooled from the tempering temperature.

Three hardness readings were taken and averaged for each tempered specimen, following removal of heat-treatment scale. The data were plotted using the Hollomon and Jaffe* temperability parameter:

$$M = T(C + \log t)$$

where

M = temperability parameter

T = absolute temperature, °R

t = time, hr

c = constant ≈ 19.5 for 0.20 to 0.40% carbon,

in order to make the resulting curve applicable to many combinations of time and temperature.

*Hollomon, J.H., and L.D. Jaffe. "Time-Temperature Relations in Tempering Steel." Am. Inst. Min. & Met. Engrs. Trans (Iron and Steel Div.) 162. 1945. Pp. 223-247.

Several of the heat-treated specimens were selected at random to check for decarburization by metallographic and hardness tests. No decarburization was detected.

Photomicrographs were taken of several of the specimens at different stages of heat treatment to show microstructures typical of the various cooling rates and tempering treatments.

RESULTS

Tables 3 through 10 show hardness data after tempering vs tempering temperature and time. Tempering results are plotted as curves in Figures 1 and 2. Data pertaining to materials having comparable composition and similar heat treatment are plotted in the same figure for comparison. Figure 3 shows cooling curves plotted for each of the four cooling rates evaluated. Photomicrographs E and F of Figure 4 show the microstructure of Ni-Cr-Mo alloy steel (heat 1240482) after tempering at 1200F for 1 hr and at 1300F for 8 hr, respectively, following water quench. Photomicrographs G and H show comparable structures for the same tempering treatment for salt-quenched samples.

Photomicrographs (A,B,C, and D of Figure 4) of Mn-Mo steel (heat A6623) samples show typical microstructures for four rates of cooling from the austenitizing temperature and represent structural variations likely to be encountered by traversing a heat-affected weld zone or penetrating beyond the as-cooled surface.

DISCUSSION

From the photomicrographs (Figures 7 and 8) one sees that both the water- and the oil-quenched samples of Mn-Mo alloy steel have no appreciable structural differences at 500X. The as-quenched hardness readings substantiate this observation. These results help to indicate the location of the nose of the T-T-T curve.

The minimum tempering temperature for both these steels is fixed at 1200F by specification. The results show that although hardness values will change significantly between fully quenched samples tempered at 1200 and at 1300F, the corresponding microstructures (E and F, G and H of Figure 4) in each case reveal no clearly discernible difference at magnifications up to 500X. Differences in microstructure are obvious in samples quenched at different cooling rates and in fully quenched samples tempered as low as 600F in contrast to fully quenched samples tempered above 1000F.

CONCLUSIONS

1. One may conclude from this study that cooling rates $>23\text{F/sec}$ will produce a fully hardened structure in Mn-Mo alloy steel of compositions similar to those tested.
2. Tempering curves are established for two pressure-vessel steels. These curves will enable prediction of the decrease in hardness of these steels, with tempering time and temperature for various quenching rates.
3. The differences in hardness obtained by tempering these steels at 1200 and 1300F are not reflected in the microstructure of a fully quenched material at magnifications up to 500X.

TABLE 3. HARDNESS (R_A) AFTER TEMPERING

Prior to tempering, material was cooled to room temperature by water quench after 20 min at 1720F. As-quenched hardness: 71 R_A

Tempering Time, hr	Tempering Temperatures ($^{\circ}\text{F}$) for Mn-Mo/ht A6623				
	600	800	1000	1100	1200
1	71	69	66	65	60
4	70	68	66	64	58
8	70	68	65	62	56

TABLE 4. HARDNESS (R_A) AFTER TEMPERING

Prior to tempering, material was cooled to room temperature by oil quench after 20 min at 1720F. As-quenched hardness: 70 R_A

Tempering Time, hr	Tempering Temperatures ($^{\circ}\text{F}$) for Mn-Mo/ht A6623				
	600	800	1000	1100	1200
1	68	68	66	64	60
4	68	66	66	63	58
8	68	67	65	61	56

TABLE 5. HARDNESS (R_A) AFTER TEMPERING

Prior to tempering, material was cooled to room temperature in still air after 20 min at 1720F. As-cooled hardness: 60 R_A

Tempering Time, hr	Tempering Temperatures ($^{\circ}$ F) for Mn-Mo/ht A6623				
	600	800	1000	1100	1200
1	60	60	60	59	56
4	60	60	59	59	54
8	60	59	59	57	54

TABLE 6. HARDNESS (R_A) AFTER TEMPERING

Prior to tempering, material was cooled to room temperature by furnace cooling after 20 min at 1720F. As-cooled hardness: 52 R_A

Tempering Time, hr	Tempering Temperatures ($^{\circ}$ F) for Mn-Mo/ht A6623				
	600	800	1000	1100	1200
1	52	52	52	52	51
4	51	51	52	51	49
8	51	51	52	51	50

TABLE 7. HARDNESS (R_A) AFTER TEMPERING

Prior to tempering, material was normalized at 1700F for 45 min followed by austenitizing at 1525F for 1 hr and water quenched to room temperature. As-quenched hardness: 71.5 R_A

Tempering Time, hr	Tempering Temperatures ($^{\circ}$ F) for Mn-Mo/ht 20926				
	600	800	1000	1100	1200
1	65	64	62	61	59
4	54.5	52.5	60	58.5	56
8	63	61	59.5	58	55.5

TABLE 8. HARDNESS (R_A) AFTER TEMPERING

Prior to tempering, material was normalized at 1700F for 45 min followed by austenitizing at 1525F for 10 min, quenched in salt bath at 325F for 1 min, and water quenched to room temperature. As-quenched hardness: 68 R_A

Tempering Time, hr	Tempering Temperatures (°F) for Mn-Mo/ht 20926				
	1100	1150	1200	1250	1300
1	58.7	57.6	56.2	54.7	54.2
4	57.2	55.4	55.2	51.8	52.7
8	57.2	55.0	53.6	52.3	52.3

TABLE 9. HARDNESS (R_A) AFTER TEMPERING

Prior to tempering, material was normalized at 1600F for 2 hr followed by austenitizing at 1525F for 1 hr and water-quenched to room temperature. As-quenched hardness: 75 R_A

Tempering Time, hr	Tempering Temperatures (°F) for Ni-Cr-Mo/ht 124C482				
	1100	1150	1200	1250	1300
1	68.2	67.4	64.8	65.7	60.5
4	67.9	66.7	64.1	62.6	52.6
8	67.4	65.1	62.2	59.7	45.1

TABLE 10. HARDNESS (R_A) AFTER TEMPERING

Prior to tempering, material was normalized at 1600F for 2 hr followed by austenitizing at 1525F for 10 min, quenched in salt bath at 325F for 1 min, and water quenched to room temperature. As-quenched hardness: 71 R_A

Tempering Time, hr	Tempering Temperatures (°F) for Ni-Cr-Mo/ht 124C482				
	1100	1150	1200	1250	1300
1	66.8	67.7	66.3	64.4	63.4
4	67.1	65.0	63.6	61.3	61.0
8	66.2	64.5	62.8	55.2	58.0

FIGURE 1. Tempering Parameter for Mn-Mo Steel.
 KS-56043

Unclassified

FIGURE 2. Tempering Parameter for Ni-Cr-Mo Alloy Steel.
KS-56044

Unclassified

FIGURE 3. Cooling Curves from 1720°F
in Various Media.

KS-56046

Unclassified

A. Water Quenched

4-1072C-6;500X

B. Oil Quenched

4-1072C-5;500X

C. Air Cooled

4-1072C-7;500X

D. Furnace Cooled

4-1072C-4;500X

E. Water Quenched and Tempered
1 hr at 1200F

4-4132C-2;500X

F. Water Quenched and Tempered
8 hr at 1300F

4-4132C-3;500X

G. Salt Quenched and Tempered
1 hr at 1200F

4-4132C-4;500X

H. Salt Quenched and Tempered
8 hr at 1300F

4-4132C-5;500X

FIGURE 4. Photomicrographs Showing the General Structure of the Two Alloy Steels When Subjected to Various Quench and Temper Conditions. (All specimens etched with 4% Picral).
KS-56046