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ELEVATED-TEMPERATURE PROPERTIES OF A CAST VALVE MATERIAL

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The present research extends an initial investigation (Ref. 1) of creep-rupture properties of the International Harvester Company's cast alloy Number 4. Two additional variables have been introduced. First, the manganese and nickel were slightly increased in one of the three new lots of material to produce a more-austenitic structure. Secondly, specimens from one of the new lots were cast in green sand molds and the other lot was CO_2 molded.

Tests were conducted in the as-cast condition and after a water quench from 2150°F. In addition the influence of 8 and 500 hour ages at 1400°F on creep-rupture properties was investigated. Short-time tensile tests were used to evaluate the compositional and molding differences for the as-cast condition. One specimen of the material from Reference 1 was subjected to a tensile test at room temperature after being heated 1000 hours at 1400°F.

The results reported herein were obtained on specimens shipped to the University of Michigan under Miscellaneous Shipping Orders X-101, X-334 and X-475. All data are indexed and summarized in Data Book No. 3216 on file under Project 2830 of the University of Michigan Research Institute.

CONCLUSIONS

The results indicate the following:

1. The short-time tensile properties at room temperature, 1400° or 1600°F exhibited relatively little difference between the three lots of material in the as-cast condition. Aging the material from Reference 1 at 1400°F for 1000 hours reduced the strength and ductility at room temperature.

2. Creep-rupture tests at 1500°F under 12,000 psi indicated one limiting factor to be the amount of creep the materials would undergo before

rupturing. Material "B" (apparently Number 4 alloy cast in green sand) came nearest to one-percent deformation in 500 hours without rupturing. There was little difference between the material as-cast and after quenching from 2150°F.

3. Material "C" (presumably normal composition, CO_2 molded) had high creep resistance but fractured when the total creep was about 0.5 percent or less. This limited the time for rupture.

4. Material "A" (somewhat higher Mn and Ni) was not quite as creep resistant as Material "B" and had no better ductility under the rupture test conditions.

5. Aging at 1400°F for 8 hours reduced the amount of creep before rupture for all materials. Increasing the aging time to 500 hours intensified this effect. The aging did reduce the amount of creep in a given time up to the point where rupture occurred.

6. Care should be exercised in applying these results. On the basis of tensile tests the variables investigated had little effect. With ductility being a limiting factor under creep conditions, Material "B" appeared best. However, if lower stresses and less creep were used so that rupture was not involved as a criterion of strength, Material "C" would probably have appeared strongest and aging at 1400°F would have reduced the amount of creep. These varied test performances should be carefully related to the factors which govern valve performance.

MATERIALS

Three sets of specimens were supplied by International Harvester Company Engineering Materials Research, designated by them as "A", "B" and "C". Chemical Analysis of the "A" material was reported by the

Company to be as follows:

	Percent
Carbon	1.01
Manganese	9.42
Silicon	0.81
Nickel	2.42
Chromium	20.51
Nitrogen	0.36

This material has slightly higher Mn and Ni than the material used for Reference 1. The difference in composition is also indicated by comparison with materials "B" or "C" in the following paragraph.

The only information supplied on the "B" and "C" lots was that they fall within the composition range:

Carbon	0.90-1.20
Manganese	5.00-8.00
Silicon	0.60-0.90
Nickel	1.00-2.00
Chromium	20.00-23.00
Nitrogen	0.20 min.
Sulphur	0.04 max.
Phosphorous	0.04 max.

The "B" specimens were made in green-sand molds while the "C" specimens were CO_2 molds.

In each case, specimens in the "as-cast" condition were furnished for short-time tensile tests. Duplicate specimens for creep-rupture evaluation were supplied with each of the following treatments:

Code Designation	Heat Treatment
4	As cast
5	2150°F, 30 min., W.Q.
6	2150°F, 30 min., W.Q. + 1400°F., 8 hrs.
7	2150°F, 30 min., W.Q. + 1400°F., 500 hrs.

Specimen diameter was 0.357-inch to approximate the diameter of valve stems except for the "C" specimens which had a diameter of 0.312-inch.

EXPERIMENTAL PROCEDURE

Modified Martens-type extensometers were employed in both short-time and creep tests. Attachment to the specimens was through a collar threaded onto each end of the specimen. Two sets of extension rods, on opposite sides of the specimen, permitted measurement of the differential movement between the upper and lower extremities of the specimen. Magnification through an optical beam provided a sensitivity of about 0.000010 inches per inch of strain. The two sets of readings for each specimen were averaged to compensate for any non-axiality of loading.

Tensile-test loads were applied by a conventional hydraulic machine. The creep specimens were stressed by dead weights acting through a simple lever.

Each specimen was provided with three chromel-alumel thermocouples, one attached at the center and the others at the ends of the gauge section. The instrumented specimen was placed into a preheated electric-resistance furnace and brought to the proper temperature level and distribution in the least practicable time prior to the start of the test.

SHORT-TIME TENSILE PROPERTIES

For each lot of specimens ("A", "B" and "C") in the as-cast condition, short-time tensile tests including stress-strain curves were conducted at room temperature, 1400°F and 1600°F. Duplicate tests were run except for the "A" material at room temperature. Original stress-strain data for each lot of material are shown on Figures 1, 2 and 3. Pertinent properties are listed as follows:

Short-Time Tensile Test Properties of As-Cast Valve Alloys

Spec. Code	Test Temp., °F	0.2% Offset Yield Strength(psi)	Tensile Str. (psi)	Elongation (% in 2 in.)	Reduction of Area(%)
A1	Room	82,500	105,500	5.	6.
B1	Room	80,200	102,000	3.	4.
B1	Room	82,260	97,000	1.5	3.
C1	Room	81,750	107,200	3.	4.5
C1	Room	80,850	108,700	4.	4.5

Spec. Code	Test Temp., °F	0.2% Offset Yield Strength(psi)	Tensile Strength(psi)	Elongation (% in 2 in.)	Reduction of Area (%)
A2	1400	35,000	49,000	6.5	8.5
A2	1400	33,750	47,500	4.	8.5
B2	1400	34,250	50,000	4.5	9.5
B2	1400	33,000	50,250	5.5	11.
C2	1400	33,700	49,800	5.	7.5
C2	1400	37,100	50,500	4.5	7.5
A3	1600	27,000	33,600	5.	7.5
A3	1600	27,000	33,400	6.	9.
B3	1600	26,500	35,100	6.5	12.
B3	1600	23,250	31,400	4.5	14.5
C3	1600	25,500	30,250	5.5	9.
C3	1600	23,600	28,300	4.5	10.

No pronounced difference in short-time properties was evident among the three materials, in that differences between pairs of duplicate tests were of the same order as differences from one lot of material to another.

A single specimen (Code No. 4) with a 40-minute treatment at 2150°F followed by 1000 hours at 1400°F was supplied from the earlier lot of material covered in Reference 1. That specimen had the following room-temperature properties (See Fig. 4):

0.2% Offset Yield Strength	77,500 psi
Tensile Strength	93,000 psi
Elongation at Fracture	1% in 2 inches
Reduction of Area	1%

These strengths are somewhat below those for the as-cast materials covered in the present studies. Presumably the prolonged aging resulted in lower ductility than for any of the as-cast specimens in the present study.

CREEP-RUPTURE AT 1500°F

The original request asked for the determination of the stress to cause one per cent of creep strain in 500 hours at 1500°F. From the data on International Harvester Alloy No. 4 (Ref. 1) this stress was estimated to be of the order of 12,500 psi, wherefore that stress was used for an initial test each on "A" material as-cast and after the 2150°F treatment. Elapsed times of 205 and 360 hours, respectively, for one-percent of creep deformation for these heat treatments indicated that a stress of 12,000 psi should come closer to the desired objective. After discussion with the sponsor, the 12,000 psi stress was adopted for all further tests.

A separate graph has been allotted to each pair of duplicate tests, showing creep strain as a function of time. (See Figures 5 - 16.) All graphs are to the same scale for ease of comparison. The times required for stated amounts of creep deformation are tabulated below, together with the rupture time and rupture ductilities. In this listing specimens with similar prior treatments are placed together for the three lots of alloy.

Summary of Creep-Rupture Data at 1500°F for Three Lots of Valve Alloy after Various Heat Treatments

Spec. Code	Stress (psi)	Time(hrs.) for Creep Deformation of				Rupture Time(hrs)	Elongation (% in 2 in.)	R.A. (%)
		0.1%	0.2%	0.5%	1%			
				As-Cast Material				
A4	12,500	1.9	5.	29.5	(205)	212.4	1.	1.
A4	12,000	2.	5.	26.5	233	249.6	0.5	1.
B4	12,000	2.	6.	43.5	390	407.9	3.5	2.
B4	12,000	2.5	7.	38.5	476	510.6	2.5	1.5
C4	12,000	2.	7.	86.		284.6	0.5	1.
C4	12,000	3.	9.	104.		229.6	2.	1.5
				2150°F., 30 min., Water Quenched				
A5	12,500	1.5	5.	53.	(360)	357.3	1.	1.
A5	12,000	2.	8.	78.	416	460.2	1.5	1.5
B5	12,000	1.	4.5	51.5	374	445.6	1.5	1.5
B5	12,000	3.5	8.	60.5	403	485.3	3.5	2.
C5	12,000	8.5	22.	194.		330.0	1.	0.5
C5	12,000	5.	20.	237.		362.9	1.	2.
				2150°F., 30 min., W.Q. + 1400°F., 8 hours				
A6	12,000	3.	13.	(158.)	Broke in threads at 181.9 hours.			
A6	12,000	3.	15.	(186.)		193.1	1.	1.5
B6	12,000	1.5	8.	90.		214.2	0.5	1.
B6	12,000	2.	6.	115.		246.7	1.5	1.
C6	12,000	5.	27.5			224.6	1.5	1.
C6	12,000	5.	45.			259.0	1.	1.5

Spec. Code	Stress (psi)	Time(hrs.) for Creep Deformation of				Rupture Time (hrs)	Elongation (% in 2 in.)	R.A. (%)
		0.1%	0.2%	0.5%	1%			
		2150°F., 30 min., W.Q. + 1400°F., 500 hours						
A7	12,000	5	24	(74)		74.0	1.	0.5
A7	12,000	8	30	(83)		90.3	0.5	0.5
B7	12,000	30	160			324.4	0.5	0.5
B7	12,000	43		Discontinued at 114.7 hrs. (Control failure.)				
C7	12,000	22	83			96.0	2.5	1.5
C7	12,000	17				65.1	0.5	1.5

The more important features of these data are:

1. All materials and treatments ruptured in less than 500 hours with low ductility.

2. The elongation values reported were measured by fitting the two halves of the ruptured specimens together at room temperature. Due to the uneven nature of the fractures such elongation values are not reliable to more than 0.5-percent at best.

3. Aging all three materials at 1400°F prior to testing was detrimental to ductility. These treatments did increase the resistance to creep but the specimens fractured before the accumulated creep attained one-percent or even 0.5-percent in some cases. Heating at 1400°F for 500 hours caused rupture at lower ductility than did 8 hours at 1400°F.

4. The time required to attain a given amount of creep was improved over the as-cast condition by water quenching from 2150°F. Ductility may have been somewhat reduced by this treatment.

5. The comparison between materials is somewhat complicated. Material "C" was the most resistant to creep of all three materials up to the time rupture occurred. In no case, however, was one-percent creep attained for this material before rupture occurred. In the as-cast condition Material "B" had the highest creep resistance combined with the ability to creep one-percent before rupture. There was little difference between materials "A" and "B" after quenching from 2150°F. The "B" material was somewhat better

than "A" material after aging at 1400°F.

6. In all cases, the duplicate creep-rupture tests for each condition exhibited good agreement until the point of rupture was approached.

DISCUSSION

The stated objective of the program was to compare the materials on the basis of the time for one-percent creep. Several of the variables involved resulted in the specimens rupture before the creep attained one-percent. As is discussed later, care should be exercised in interpreting the results to differentiate between limitation of deformation on rupture life and the rate at which creep was accumulated. In general, those materials which ruptured with less than one-percent creep accumulated creep at a slower rate than did those which could creep one-percent before rupture.

The evaluation of properties of alloys is difficult, particularly if the results from limited tests are not truly representative of the material. Secondly, the significance of the test results in terms of the expected service conditions must be known. In valve application the latter problem is often important. There is, moreover, always the problem of translating the results from experimental lots of material to production conditions which all too often have pronounced effects on properties.

In so far as can be ascertained the test results seem to indicate that CO_2 molding was detrimental to ductility under creep conditions, although it did improve creep resistance up to the time rupture occurred. This observation assumes the composition of the "C" material was not greatly different from that of the "B" lot.

The implications of the CO_2 molding effect on properties is not clear from the available information. Probably it indicates that the properties of the alloy can be expected to be somewhat sensitive to production condition variables. Normally, the difference in specimen size would not be expected to influence the results. Specimen size in itself usually has little effect except when a very small number of grains in the cross section results; or the alloy is subjected to marked corrosion; or marked orientation effects in the microstructure exist.

Material "A" represented changes in composition which would tend to make the austenite more stable in the alloy. The data seem to indicate that these compositional changes had a minor effect.

The data seems very clear that prior exposure to 1400°F was detrimental to ductility. In general, this would be expected for alloys of the type considered. It might be possible to improve ductility by over-aging at higher temperatures. If this were successful it would, however, reduce creep resistance. The authors have not had sufficient experience with high-carbon alloys of the type of these valve steels to be certain of the results of prior over-aging treatments.

It is difficult to be sure of the comparison of the results of the present investigation in terms of the results reported in Reference 1. The test conditions were so different that direct comparison is impossible. The general impression is that materials "A" and "B" may have been slightly weaker. However, the prolonged heating at 1500°F for the tests in Reference 1 may have been responsible for the possible differences.

It should be noted that the tensile tests, including the material from Reference 1, indicated little difference between heats in the as-cast condition. Therefore, the variables studied apparently have more effect on creep-rupture properties than on short-time properties. In fact, the results from Reference 1 and those from the present investigation suggest that if the stresses were kept below those causing rupture the comparative ranking of the materials would be quite different again. Material "C" from the present study would probably show the highest creep strengths if lower stresses were used. The low stress would automatically limit creep to low amounts in 500 to 1000 hours. The higher creep resistance of material "C" would then become the predominant factor. The tendency to rupture with relatively little deformation would not have been apparent to make material "C" compare unfavorably with the others. This brings up the important question of how well the test conditions reflect the expected service and points out the care necessary in interpreting test results.

REFERENCES

1. H. R. Voorhees, and J. W. Freeman, "Influence of Heat Treatment on the Creep-Rupture Properties of International Harvester Company Cast Alloy Number 4.", Univ. of Mich. Research Institute report No. 2830-2-P, December 15, 1958.