REPORT

ON

INFLUENCE OF MOLYBDENUM ON THE CREEP-RUPTURE PROPERTIES OF A "COMPLETELY" MALLEABLIZED CAST IRON AT 1100°F

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Project 2135 March 10, 1955

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A study was carried out to establish the influence of addition molybdenum of 0.19 and 0.51 percent on the creep-rupture properties at 1100°F of a pearlitic malleable cast iron after the material had been heated for a prolonged time at 1200°F to essentially complete conversion of carbide to graphite. The object was to establish whether or not molybdenum would provide any benefit to strength in such materials where continued graphitization might be expected in service. More particularly the objective was to determine the effect of molybdenum on the creep-rupture properties at 1100°F of a structure consisting essentially of ferrite and malleablized graphite.

SUMMARY

Rupture tests were carried out to 2500 hours at 1100°F that gave the following results:

1. Molybdenum additions increased the rupture strength of pearlitic cast iron about 40 percent. There was no significant difference in strengths between 0.19 and 0.51 percent of molybdenum. There was likewise little difference in elongation and reduction of area values as the result of adding molybdenum. Somewhat better ductility characteristics for the 0.19 percent molybdenum than for the 0.51 percent material or the molybdenum-free iron may or may not be significant.

2. Total deformation data, obtained from the creep curves for the rupture tests, also show a substantial improvement for limited creep deformation from molybdenum additions. The higher molybdenum content was somewhat superior on this basis up to 1000 hours but not at 10,000 hours.

3. Care should be exercised to recognize that the data reported are for fully or nearly fully graphitized materials, and that the data might be considerably different over the same testing time periods at 1100°F for the usual condition in which such alloys are placed in service. The data are probably more representative of properties after the structural changes which might take place during prolonged service.

MATERIAL

Rough pearlitic malleable cast iron test bar blanks with varying amounts of molybdenum were submitted for testing at 1100°F. The analysis was reported as follows:

Set	C	Si	Mn	Mo
335	2.63	1.37	0.40	0.01
338	2.61	1.37	0.42	0.19
351	2.63	1.42	0.42	0.51

The material had received the regular "Arma" steel quench cycle: air quench cycle 27.6 hours. All bars had been poured from iron to which 0.0003% boron was added, but contained boron should be less due to oxidation losses.

The blanks had been tempered to 229 BHN as follows:

Set	Tempered	Hardness
335	8 hours at 1250°F	229
338	11-1/2 hours at 1250°F	229
351	10-1/2 hours at 1300°F	229

Before being submitted for testing, the blanks were heated for 1040 hours at 1200°F. The treatment at 1200°F converted essentially all the carbides to graphite in the molybdenum-free iron. The molybdenum irons, however, did retain a small amount of spherodized carbide.

The room-temperature and 1100°F short-time tensile properties were reported as follows:

Set	335	338	351
Mo(%)	0.01	0.19	0.51
	Room Temperature		
Tensile Strength, psi	92,000	91,300	89,800
0.2% Offset Y.S., psi	60,200	64,900	72,200
0.1% Offset Y. S., psi	56,900	62,600	69,600
Elongation in 2", %	4.0	4.0	3.5
Reduction of Area, %	4.2	4.8	4.2
	1100°F		
Tensile Strength, psi	13,840	19,610	23,320
0.2% Offset Y.S., psi	10,440	14,580	19,200
0.1% Offset Y.S., psi	10,040	13,820	17,690
Elongation in 2", %	26.5	18.0	13.0
Reduction of Area, %	27.9	23.9	18.5

PROCEDURE

The rough test bar blanks were machined to 0.505-inch diameter by 2-inch long gage length specimens. Tests were carried out in accordance with ASTM Recommended Practice E-85.

The testing program had as its objective the establishment for each material of the stress-rupture curve at 1100°F out to approximately 2500 hours. Tests were started at about the same fraction of the tensile strength as for carbon and carbon-molybdenum steels to obtain rupture in about 100 hours. Based on these initial tests, lower stresses were selected to establish the curves to 2500 hours.

RESULTS

The data obtained from the rupture tests at 1100°F are summarized in Table I. The stress-rupture time curves for all three materials are shown in Figure 1 and the desired rupture strengths are given in Table II.

Creep data were taken during the rupture tests. Table III includes derived values of time to reach total deformations of 0.2, 0.5, 2.0, and 5.0 percent. These data are presented in Figures 2, 3, and 4 as stress-time for total deformation curves. Stresses for total deformations of 0.1, 0.2, 2.0 and 5.0 percent in 100 and 1000 hours established by these curves are included in Table IV. The influence of molybdenum on the rupture and deformation strengths is summarized in Figures 5, 6, and 7.

The actual creep curves for the rupture tests are included as Figures 8, 9, 10, and 11. Minimum creep rates for these curves are included in Table III.

DISCUSSION

The rupture strengths of the molybdenum-free alloy were about 70 percent of those for the two molybdenum-bearing alloys. Stated another way, the molybdenum additions increased the rupture strengths by amounts ranging from 37 percent at 100 hours to 43 percent at 1000 hours and 45 percent at 10,000 hours.

There was no significant difference in strength between the 0.19 and 0.51 percent molybdenum alloys.

All modifications had high elongation and reduction of area values in the rupture tests. The material containing 0.19 percent molybdenum apparently did not show as much decrease in ductility with increasing fracture time as the other molybdenum material or the unalloyed heat.

The deformation-time characteristics show that molybdenum also increased the stress required for limited amounts of deformation in the time periods covered by the investigation. This data can also be used to estimate the load carrying ability for limited deformation. It should be noted that up to

1000 hours, the addition of 0.51 percent molybdenum injured the limited deformation strengths but at 10,000 hours there was little difference between the 0.19 and 0.51 percent levels.

The initial treatment of the test material was unorthodox. Very prolonged malleablizing treatments were used in order to convert the structure to the practical end point of what might result from prolonged service and thus show the properties of the irons when such changes were complete. Thus two main points should be kept in mind in using the data:

1. With the usual commercial malleablizing treatments, considerably different data would probably be obtained from the 2500 hour tests at 1100°F. The indicated influence of molybdenum might or might not be the same order of magnitude.

2. If usual treatments had been used in preparing the samples, the structural changes at 1100°F under stress might not result in the same end point properties at the completion of the structural changes as those induced by the heating at 1200°F in the absence of stress.

In conducting the tests, fair success in selecting stresses were obtained by reference to data for carbon and 0.5 Mo steels. The same fraction of the tensile strength usually giving rupture in about 100 hours for steel was fairly successful for the initial tests. The slopes of the curves for steel were used as a guide in selecting second stresses, again with fair success.

TABLE I.

Rupture Data at 1100°F on Malleable Cast Iron with Varying Molybdenum Content after Heating 1040 Hours at 1200°F

Set No.	Mo (%)	Bar No.	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Reduction of Area (%)
335	0.01	2	6,500	95.2	31.0	25.0
		1	5,000	246.3	27.0	24.8
		3	4,500	647.4	28.5	13.0
		4	4,000	1397.4	15.5	21.9
338	0.19	1	9,500	35.6	36.2	26.8
		2	8,000	131.3	38.0	24.0
		3	7,000	311.4	32.5	23.4
		4	5,900	1190.0	24.0	22.5
		5	5,300	2227.9	25.0	22.4
351	0.51	1	10,000	37.5	18.5	18.4
		2	8,500	121.1	17.5	19.5
		3	6,000	966.0	19.5(a)	(a)
		4	5,200	2555.2	10.5	13.0

(a) Section Broken Out, Approximate Value.

TABLE II

Stress for Rupture in Indicated Periods at 1100°F for Malleable Cast Iron with Varying Molybdenum Content after Heating 1040 Hours at 1200°F

Set No.	Mo(%)	100 Hours	1000 Hours	10,000 Hours
335	0.01	6,000	4,200	3,000
338	0.19	8,400	6,000	4,400
351	0.51	8,700	6,000	4,200

TABLE III

Creep and Total Deformation Data at 1100°F on Malleable Cast Iron with Varying Molybdenum Content after

Heating 1040 Hours at 1200°F

Bar No.	Stress (psi)	Deform. on Loading (%)	Time to Reach Specified Total Deformation (hours) 0.2%	0.5%	1.0%	2.0%	5.0%	Min. Creep Rate (% per hour)
					Set 335 (0.01 Mo)			
2	6,500	0.06	0.5	1.7	3.5	5.2	14.0	--
1	5,000	0.036	0.7	1.9	6.5	18.0	60.0	0.034
3	4,500	0.028	3.0	10.0	29.0	100.0	260.0	0.15
4	4,000	0.021	13.0	17.0	63.0	210.0	655.0	0.00328
					Set 338 (0.19 Mo)			
1	9,500	0.108	>0.1	0.2	0.7	1.8	7.6	--
2	8,000	0.063	0.4	1.3	3.2	7.5	31.5	0.118
3	7,000	0.055	1.0	3.5	8.5	27.0	82.0	0.0372
4	5,900	0.042	2.0	13.5	33.0	87.0	322.0	0.0114
5	5,300	0.039	12.0	32.0	80.0	216.0	740.0	0.00205
					Set 351 (0.51 Mo)			
1	10,000	0.080	1.0	3.4	8.1	-	-	--
2	8,500	0.059	2.7	10.0	27.0	51.0	-	0.0285
3	6,000	0.042	10.0	39.0	104.0	275.0	634.0	0.0063
4	5,200	0.038	-	78.0	224.0	550.0	1344.0	0.00315

TABLE IV

Stress for Total Deformations of 0.1, 0.2, 2.0 and 5.0 Percent in 100 and 1000 Hours at 1100°F for Malleable Cast Iron with Varying Molybdenum Content after Heating 1040 Hours at 1200°F

Set No.	Mo (%)	Stress for Indicated Total Deformation at Indicated Times (psi)				
		5%	2%	1%	0.5%	0.2%
			100 Hours			
335	0.01	5,000	4,400	3,800	--	--
338	0.19	6,900	5,800	5,100	4,600	(3,900)
351	0.51	8,300	7,400	6,000	5,000	(3,900)
			1000 Hours			
335	0.01	3,800	3,350	2,800	--	--
338	0.19	5,100	4,400	3,800	(3,400)	(2,900)
351	0.51	5,500	4,600	3,900	(3,100)	(2,450)

(-) Extrapolated value

FOR FIGURES 1—11 REFER to FILE Copy