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1100°F CREEP-RUPTURE PROPERTIES OF SICROMO 9M BARSTOCK AND TUBING

by

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INTRODUCTION

Two aspects of the properties of Sicromo 9M alloy at 1100°F have been investigated. The abnormally low creep strength, established in previous investigations, in relation to the rupture properties and to published data from other sources was checked for two other lots of bar stock. As part of the general program establishing the relative properties of production tubes to bar stock, an investigation of a 2-inch O.D. by 0.321-inch wall tube was carried out. Creep tests were continued to as long as 7975 hours and the rupture tests for the tube were extended to 5271 hours. The influence of testing time on properties was therefore investigated.

SUMMARY AND CONCLUSIONS

The data obtained for this investigation of Sicromo 9M steel can be summarized as follows:

1. Creep data, based on creep rates at the end of 1000 hours, indicated considerably higher creep strengths at 1100°F than was determined for Report 83.

Variations in the observed creep strengths at 1100°F appeared to be associated with heat treatment. The creep resistance of the Sicromo 9M steel increased with the following order of heat treatment.

(a) 6 hours at 1500°F.

(b) Cold drawn and tempered.

(c) Cooled 100°F per hour to 1350°F and 25°F per hour to 800°F.

(d) Annealed 40° per hour.

Creep strengths, based on creep rates at the end of tests run to as long as 7975 hours, were 1100 to 1300 psi higher than creep strengths based on creep rates taken at the end of 1000 hours.

2. The rupture strengths at 1100°F of the material tested for this investigation were considerably lower than was obtained for Report 83 as is shown in the following tabulation.

Material	Heat No.	Stress (psi) for Rupture in 100 hr	1000 hr	10,000 hr	100,000 hr
Cold drawn and tempered tube	18479	15,500	11,200	8,300	6,000
Annealed barstock	11832	16,600	12,700	9,800	7,500
Data from Report 83	15304	21,900	17,900	14,500	11,800

Cold drawing and tempering a tube appears to result in lower strength for Sicromo 9M steel than a full anneal.

3. The results indicate that Sicromo 9M steel has good ductility and a high degree of structural stability at 1100°F.

MATERIALS INVESTIGATED

Three different sources of specimens were used for the investigation.

1. Specimens supplied for Report No. 167. These were standard 0.505-inch diameter specimens remaining in the files from the investigation covered by Report 167. The specimens were forwarded during July, 1944 in order to provide sufficient specimens to complete the investigation. The supply of specimens remaining from Report 83 had been exhausted. The heat number and chemical composition was not furnished although it was indicated that the bar stock had been annealed from 1650°F by cooling at 40°F per hour.
2. Standard 0.505-inch diameter specimens machined from 1-inch bar stock from Heat 11832. These specimens were supplied under a letter dated June 12, 1957. The bar stock was reported to have been heat treated by heating to 1625°F, cooling at 100°F per hour to 1350°F and then cooling at 25°F per hour to 800°F. The resulting Brinell hardness was reported to be 149.
3. Specimens with a diameter of 0.250-inch and a gage length of 1-inch machined from a 2-inch O.D. by 0.231-inch wall production tube from Heat 18479. These were furnished under a letter dated June 6, 1957. The tube was reported to have been annealed, cold drawn and tempered to a Rockwell B hardness of 83 (153BHN).

The reported chemical compositions of Heats 11832 and 18479 were as follows:

Heat	Form	C	Mn	Si	Cr	Mo	Ni	Cu	P	S
11832	Bar Stock	0.10	0.43	0.41	8.57	0.86	0.23	----	0.010	0.020
18479	Tube	0.11	0.48	0.75	8.42	0.98	0.37	0.12	0.013	0.013

RESULTS

The results of the tests to evaluate the three materials investigated are presented in individual sections.

Specimens Supplied for Report Number 167

The intent of these tests was to check the low creep strength for Sicromo 9M in Report 83. Originally it was thought that the specimens tested were the same as those used for Report 83. Subsequent checking indicated that they were from the group supplied to complete the tests for Report 167. Hardness tests on two specimens carried out for this report gave values of 163-170 BHN.

Three creep tests and one rupture test were carried out at 1100°F with the following results:

Stress (psi)	Duration (hours)	Creep Rate (%/1000 hrs) at Indicated Time Periods (hrs)							
		500	1000	1500	2000	2500	3000	3500	
3500	1494	0.0093	0.0042	(discontinued)					
4500	5922	0.016	0.009	0.009	0.004	0.006	0.007	0.007	
6000	7859	0.028	0.021	0.020	0.019	0.014	0.014	0.014	
25000	Ruptured in 6.7 hours with 56% elongation and 85% reduction of area.								
		4000	4500	5000	5500	6000	6500	7000	7500
4500 (Continued)		0.007	0.008	0.008	0.006				
6000 (Continued)		0.012	0.012	0.011	0.011	0.010	0.010	0.010	0.012

These creep rates are compared in Figure 1 with those from Report 83. The comparative creep strengths for a rate of 0.01 percent per 1000 hours at 1100°F were as follows:

	Test Duration	
	1000 hrs	7859 hrs
Present Tests	4700	6000
Report 83	2100 psi	*

Note: Testing time for Report 83 was 1000 hours.

It is therefore quite evident that the material tested for the present investigation had more than twice the creep strength as that in Report 83.

The creep curves are included at the end of the report as Figures 2 and 3.

The one rupture tests at 1100°F had a rupture time somewhat less than the time indicated by the curve in Report 83.

Tensile tests conducted at room temperature after creep testing gave the results shown in Table 1. There was some increase in yield strength after testing but little or no change in tensile strength on ductility. Two impact tests on modified specimens from original material gave erratic results. Creep testing for 6610 hours, however, apparently reduced the impact strength to about 45 foot-pounds from 56-78.

The microstructures of the original material and the specimen from the 5922 hour creep test at 4500 psi are shown by Plates 1 and 2. There was very little change in structure during the creep test.

Bar Stock from Heat 11832

The general objective was to check the properties of another heat of Sicromo 9M in comparison to the results in Report 83.

Four rupture tests were conducted at 1100°F with the following results:

Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Reduction of Area (%)
22,000	7.3	71.0	85.5
20,000	31.2	83.0	88.0
16,000	91.1	60.5	90.0
13,000	891.0	93.0	92.0

The stress-rupture time curve obtained is shown in Figure 4A. The rupture strength are compared in Table II with those from Report 83.

All of the rupture curves obtained for this investigation together with available total deformation data are shown in Figure 5.

One creep test at 1100°F under 4300 psi was conducted for 6610 hours. The time elongation curve is shown in Figure 6. The creep rates observed were:

Creep Rate - %/1000 hours at Indicated Time Periods

500 hrs	1000 hrs	1500 hrs	2000 hrs	2500 hrs	3000 hrs	3500 hrs	4000 hrs
0.030	0.013	0.012	0.010	0.009	0.009	0.007	0.006

4500 hrs	5000 hrs	5500 hrs	6000 hrs	6500 hrs
0.006	0.006	0.006	0.006	0.006

When plotted on Figure 1, these creep rates indicate the following creep strength:

Testing Time (hours)	Creep Strength - %/1000 hours (psi)
1000	3900
6610	5000

These creep strengths are also substantially higher than those in Report 83.

The impact strength for the modified specimens used decreased from about 100 to 65 foot-pounds as a result of creep testing for 5922 hours (Table I).

Microstructures are shown by Plates 3, 4 and 5 for the original material, the 13,000 psi rupture specimen and the 4300 psi creep specimen. The original material showed some evidence of incomplete pearlite with fine spheroidized carbides. Creep and rupture testing resulted in some spheroidization and agglomeration of carbides. The grain size was about 6-7 ASTM. The grains in the rupture specimen were elongated as a result of the marked elongation to fracture. The fracture was transcrystalline and there was little or no evidence of interior or surface cracking.

<u>2.0-inch O.D. by 0.231-inch wall tube</u>

The properties of the tube were established at 1100°F for comparison with data obtained for bar stock.

Rupture tests at 1100°F gave the following results:

Stress (psi)	Rupture Time (hours)	Elongation (% in 1 in.)	Reduction of Area (%)
23,000	9.2	70	88
19,000	18.8	73	91
16,000	95.7	73	90
12,000	671.0	67	91.5
9,000	5271.0	92	89

The stress-rupture time curve of Figure 4B indicated the rupture strengths given in Table II. The stress for rupture in 100,000 hours was considerably less than was obtained for the specimens from Heat 11832 bar stock and only about half that given in Report 83 for bar stock from Heat 15304. Like most tests on Sicromo 9M steel the ductility in the rupture tests was very high.

One creep test at 1100°F under 4300 psi was continued for 7975 hours with the following results:

Creep Rate - %/1000 hours at Indicated Time Periods

500 hrs	1000 hrs	1500 hrs	2000 hrs	2500 hrs	3000 hrs	3500 hrs	4000 hrs
0.047	0.026	0.023	0.023	0.024	0.023	0.024	0.020
4500 hrs	**5000 hrs**	**5500 hrs**	**6000 hrs**	**6500 hrs**	**7000 hrs**	**7500 hrs**	**7975 hrs**
0.014	0.013	0.012	0.011	0.011	0.011	0.011	0.011

The creep strengths indicated by these rates (See Fig. 1) are:

Testing Time (hours)	Creep Strength 0.01%/1000 hrs. (psi)
1000	3200
7975	4300

The creep strength at both time periods is less than was obtained for bar stock in this investigation but 50-percent higher than the strength given in Report 83.

Time-elongation curves for the 4300 psi creep test and the 9000 psi rupture test are included as Figure 7.

Data obtained from the creep and creep rupture tests are also compared as stress versus time for .1% and .2% total deformation in the curves of Figure 5 with those obtained for Report 83.

Microstructures of the original tube and completed test specimens are shown by Plates 6, 7 and 8. The original structure consisted of irregular ferrite grains and spheroidized carbides. Due to the type of structure, it is difficult to rate the grain size. It apparently was somewhat coarser than the bar stock from Heat 11832. Creep testing for 7975 hours or rupture testing for 5271 hours at 1100°F caused some agglomeration of carbides and resulted in the grain boundaries etching more distinctly. The rupture specimen showed somewhat more spheroidization with the elongated grains expected for the high elongation at fracture. The fracture was transcrystalline and there was little evidence of intergranular cracking. The oxidation on the surface was slight as is evident in the photomicrographs.

DISCUSSION

The previously available creep strengths for Sicromo 9M at 1100°F from Report 83 were much lower than were obtained in the present investigation. Available comparative values for Sicromo 9M are compared in Table III. Basing the comparative creep strengths on tests of 1000 hours duration, the tube was about 47 percent stronger, the bar stock from Heat 11832 90-percent stronger and the bar stock supplied for Report 167 was 120 percent stronger.

The reasons for the variations appear to be associated with heat treatment. Apparently the 6-hour treatment at 1500°F on the material used for Report 83 resulted in abnormally rapid creep at the end of

1000 hours. Cold drawing and tempering the tube resulted in an intermediate creep resistance after 1000 hours. The straight annealed at 40°F per hour appeared to give somewhat higher creep resistance than 100°F per hour cooling to 1350°F and 25°F per hour to 800°F in bar stock.

It will be noted that the creep strengths were increased from 1100 to 1300 psi by prolonging the testing time beyond 1000 hours. The low creep strength of the material used for Report 83 undoubtedly would have been substantially raised by testing longer than 1000 hours.

For unexplained reasons the rupture strength of the material used for Report 83 was substantially higher than was obtained for the present investigation. The tube in turn was somewhat weaker than the bar stock supplied for this investigation (Heat 11832). The specimens tested for Report 83 had considerably less elongation in the rupture tests than those obtained in the present investigation. This again points to the difference in heat treatment as being the major factor involved. The high rupture strength in relation to the creep strength found in Report 83 suggests strongly that the creep strength would have increased more than was found in the present tests with increased testing time.

The high rupture strength of Report 83 may in part be due to an unduly long rupture time for the test under 16,000 psi. The next longest tests was only 5.67 hours. The curves and data in Report 83 suggest that the curve was actually drawn with too little slope. Apparently the curves in Report 83 for higher temperatures are correct.

The ratios of creep strengths to rupture strengths (Table III) obtained for the present investigation appear normal on the basis of the creep strengths based on 1000-hour tests. The significance of the ratios based on the prolonged creep tests is less certain. It suggests that design based on the creep strength from prolonged tests would probably result in premature third stage creep.

The comparatively low strength of the tube has previously been discussed. The results suggest that cold drawing and tempering results in lower strength for Sicromo 9M than full annealing. All the results point to the good ductility and high degree of structural stability of Sicromo 9M steel at 1100°F. This was particularly evident in the transgranular fractures and absence of intergranular cracking in the rupture specimen.

TABLE I

ROOM TEMPERATURE STABILITY TESTS ON SICROMO 9M STEEL AFTER CREEP TESTING AT 1100°F

Material	Test Condition		Tensile	Offset Yield Strength(psi)		Elong.	R.A.
	Stress(psi)	Duration(hrs)	Strength(psi)	0.1%	0.2%	(%)	(%)
Bar Stock(Ht. 11832)	As received	(Annealed)	76,300	34,000	35,200	34.0	62.0
Specimen supplied for Report 167	As received		84,400	34,000	38,400	29.5	74.0
Specimen supplied for Report 167	6000	7859	86,200	42,100	43,000	31.0	69.5
Specimen supplied for Report 167	3500	1494	85,600	40,600	41,900	31.0	69.5

Material	Stress(psi)	Duration(hrs)	Izod Impact - ft-lbs.	
			As Received	After Testing
Barstock (ht. 11832)	4300	6610	78,56	41,45
Specimen supplied for Report 167	4500	5922	100,102	61,65

TABLE II

RUPTURE PROPERTIES AT 1100°F FOR SICROMO 9M STEEL

Material	Heat No.	Stress (psi) for Rupture in--					Fracture Elongation(%)			
		10 hrs	100 hrs	1000 hrs	10,000 hrs	100,000 hrs	10 hrs	100 hrs	1000 hrs	10,000 hrs
Annealed, cold-drawn and tempered tube	18479	22,000	15,500	11,200	8,300	6,000	70	73	67	92
Annealed barstock	11832	22,000	16,600	12,700	9,800	7,500	71	61	93	--
Barstock N1750°F + 1500°F*	15304	27,000	21,900	17,900	14,500	11,800	45	--	30	--

*Data from Report 83.

TABLE III

COMPARATIVE CREEP AND RUPTURE STRENGTHS FOR SICROMO 9M STEEL AT 1100°F

Type Material	Heat Number	Heat Treatment	Test Duration(hrs)	0.01%/1000 hours Creep Strength(psi)	100,000 Hours Rupture Strength (psi)	Ratio Creep Strength / Rupture Strength
Bar	15304*	N. 1750°F + 6hrs at 1500°F	1000	2100	11,800	0.18
Bar	(Report 167 Specimens)	Ann. 1650°F at 40°F/hr.	1000	4700	--	--
Bar	(Report 167 Specimens)	Ann. 1650°F at 40°F/hr.	7859	6000	--	--
Bar	11832	Ann. 1625°F at 100°F per hr. to 1350°F and then 25°F per hr. to 800°F.	1000	3900	7,500	0.50
			6610	5000	--	--
Tube	1-8479	Ann. + cold drawn + tempered	1000	3200	6,000	0.53
			7975	4300	--	0.71

*Data from Report 83.