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Lyne et al.

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[54] **ULTRA-HIGH STRENGTH STEEL**

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[52] **U.S. Cl.** .... **75/123 R**, 75/123 C, 75/123 J
[51] **Int. Cl.** **C22c 37/00**, C22c 39/00
[58] **Field of Search** 75/123; 148/12, 39

[56] **References Cited**

UNITED STATES PATENTS

3,295,966	1/1967	Steven	75/126
2,354,147	7/1944	Scott	75/123
2,451,469	10/1948	Brophy	75/123 X

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[57] **ABSTRACT**

The present invention relates generally to ultra-high strength steel and, in more particular aspects, relates to an ultra-high strength steel that is characterized by improved fatigue life resulting from the addition of sulfur to the steel in a significant amount. It has been found that fatigue life of ultra-high strength steel may be improved by the addition of at least about 0.04 percent sulfur, preferably 0.04 to 0.25 percent and most advantageously from 0.04 to 0.15 percent sulfur.

8 Claims, 3 Drawing Figures

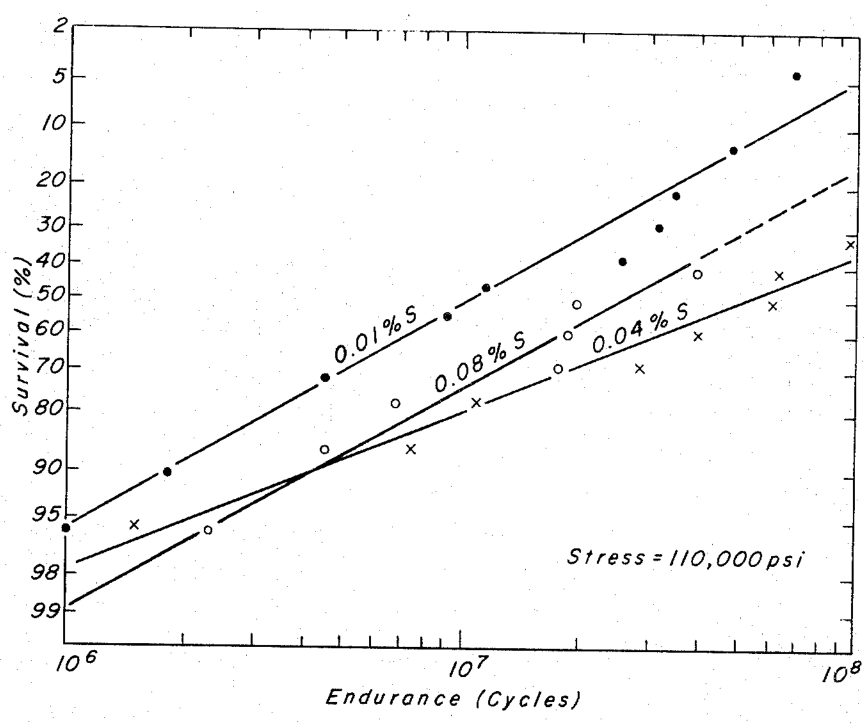

FIG. 3.

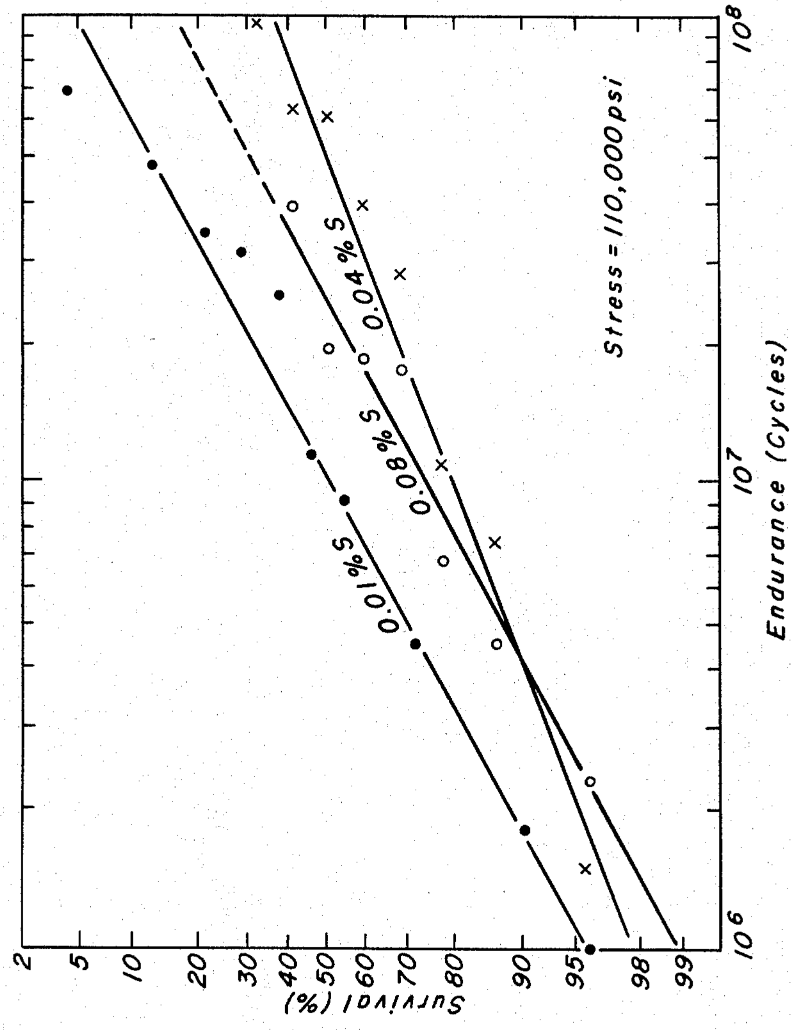

FIG. 1.

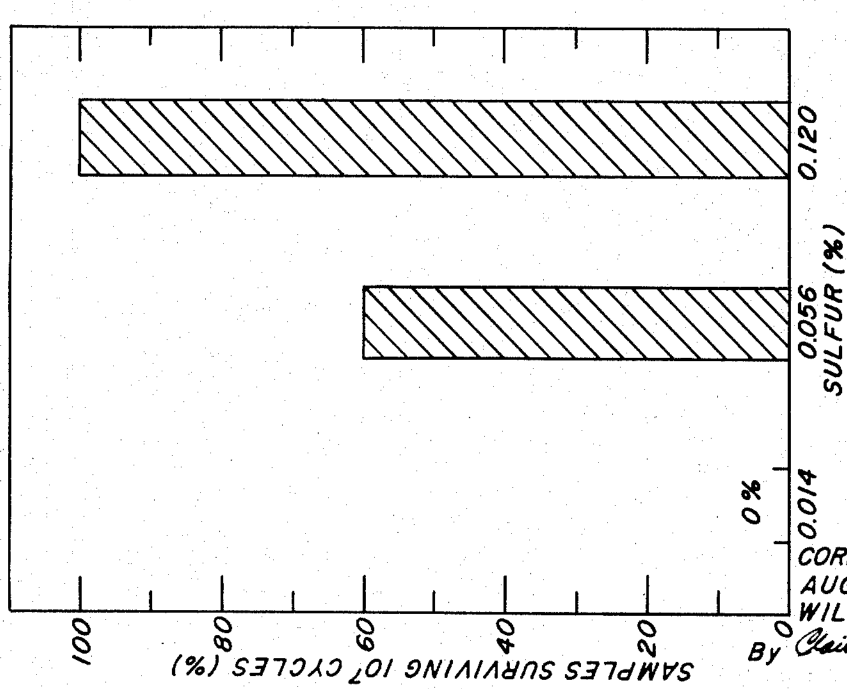

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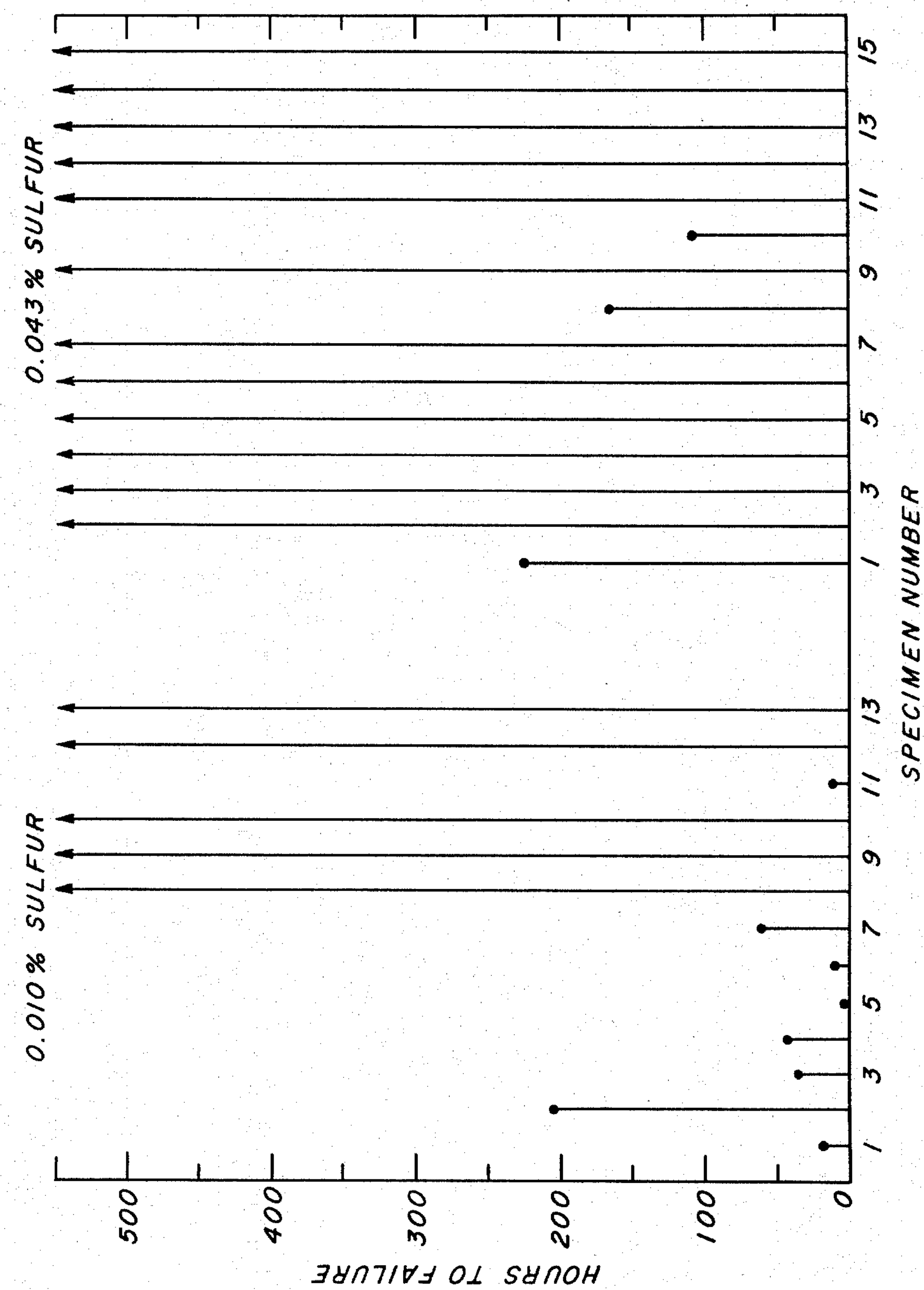
FIG. 2.



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ULTRA-HIGH STRENGTH STEEL

In ultra-high strength steels used in the manufacture of bearings, it is desirable that the steel be characterized by good fatigue life and deep hardenability. Deep hardenability is a particularly important property in steels used for the manufacture of large bearings. Fatigue life or fatigue strength is required to enable a bearing to resist cracking as a result of the repeated loading imparted to it during service.

It is accordingly an object of the present invention to provide an ultra-high strength steel, particularly suitable for the manufacture of bearings, that is characterized by improved fatigue strength over steels conventionally used for the purpose.

It is another object of the invention to provide a bearing steel that is characterized by the desirable combination of good fatigue strength and deep hardenability.

Yet another object of the invention is to provide a bearing steel that is characterized by good fatigue strength without the addition of costly metal alloying elements in amounts greater than those used in conventional bearing steels.

These and other objects of the invention, as well as a complete understanding thereof, may be obtained from the following description and drawings, in which:

FIG. 1 is a graph showing the effect of increased sulfur on the fatugue life of bearing steels as demonstrated by the Rotating Beam Fatigue Test,

FIG. 2 is a graph showing the results of a high-sulfur steel of the invention when compared with a conventional bearing steel in a Rolling Fatigue Bearing Test, and

FIG. 3 presents curves showing the improved fatigue life of the high-sulfur steel of the invention when compared with bearing steel not having a significant sulfur addition in accordance with the present invention.

In its broadest aspects, the invention consists of adding at least 0.04 percent sulfur to a conventional ultra-high strength steel. The term ultra-high strength steel is intended to encompass steels having a minimum tensile strength of about 200,000 psi in the quenched and tempered condition. The required strengthening is achieved by the use of strengthening additions of elements such as, for example, chromium, molybdenum, tungsten, titanium, vanadium, zirconium, columbium, and tantalum. Broadly, any strengthening element achieving the desired result by forming nonmetallic or intermetallic compounds could be used in combination with a sulfur content in accordance with our invention.

It has been found, as will be shown and described in detail hereinafter, that the addition of sulfur to a steel of the type described above results in a drastic improvement in fatigue life. For this purpose, sulfur is present in amounts of at least about 0.04 percent and preferably within the range of 0.04 percent to 0.25 percent or most advantageously from 0.04 percent to 0.15 percent. By maintaining the sulfur within these limits the desired improvement with respect to fatigue life is achieved without causing the formation of unduly large sulfide inclusions in the final steel product. These sulfur limits are also preferred for use in the compositions listed in Table I, which are preferred compositions for bearing-steel applications. Steels 2 and 3 of Table I are especially preferred because they provide excellent "deep-hardening," which is an important property in bearing steel applications.

TABLE I

	Steel 1	Steel 2	Steel 3
Carbon	0.75 to 1.10	0.95 to 1.10	0.75 to 0.95
Manganese	0.25 to 1	0.25 to 0.45	less than 1
Silicon	up to 0.9		0.60 to 0.90
Chromium	up to 2	1.30 to 1.60	up to 2
Molybdenum	up to 1.2		0.50 to 1.10
Sulfur	at least 0.04	at least 0.04	at least 0.04
Chromium + Molybdenum	at least 0.50		
Iron	balance	balance	balance

Until the present invention, in the manufacture of bearing steels it was thought advantageous to maintain sulfur at an extremely low limit, e.g., about 0.01 percent. It was thought that significant sulfur contents in these types of steels would result in loss of ductility.

In contrast to the commonly accepted view that sulfur is detrimental in bearing steels, we have found that increased amounts of sulfur unexpectedly and significantly improve the fatigue life of ultra-high strength steels.

The compositions listed in the following Table II were produced for testing with respect to fatigue life.

TABLE II

Steel	C	Mn	S	Si	Cr
A	1.01	0.33	0.014	0.16	1.41
B	0.97	0.33	0.056	0.15	1.39
C	0.98	0.33	0.120	0.16	1.41
D	1.02	0.30	0.010	0.18	1.45
E	1.00	0.37	0.043	0.32	1.47

The melting was done in three steps. First, a 17-pound ingot of the base composition was poured. Then a sulfur addition in the form of elemental sulfur was made to bring the melt to a sulfur level of 0.05 percent. The sulfur was allowed to mix in the melt, and a second ingot was then cast. Another sulfur addition was made (to the 0.12 percent level) and the procedure was repeated. In this manner, three ingots, all with the same base composition except for the sulfur content, were obtained. These are indicated as Steel A, B, and C in Table II. These ingots were forged to five-eighths-inch-square bars from which test specimens were prepared. The specimens were heat treated to a hardness of about R_c 61 to 62 by austenitizing at 1,550°F, oil-quenching and tempering at 350°F.

For the purpose of additional fatigue testing, individual 100-pound heats were induction melted with sulfur contents of 0.01 percent and 0.043 percent; these steels are identified as Steels D and E, respectively, in Table II. These steels were forged to 3-½-inch-round bars. Discs were cut from the bars and machined into flat washer-shaped specimens (2-31/21-inch OD, 2-1/32-inch ID, and 7/32-inch thickness) and heat treated as described above for the samples of Steels A, B, and C.

Ten specimens each of Steels A, B, and C were tested in standard Rotating Beam Fatigue Testing machines operating at 10,000 rpm. During testing the applied stress was 130,000 psi. The tests for each specimen were carried out to failure or to "runout" at 10^7 cycles. Table III presents the results of these tests.

TABLE III

Results of Rotating Beam Fatigue Tests

Number of Cycles $(\times 10^7)^a$

Steel A (0.014% S)	Steel B (0.056% S)	Steel C (0.12% S)

0.3198	>1	>1
0.3059	>1	>1
0.2085	>1	>1
0.1049	>1	>1
0.0456	>1	>1
0.0295	>1	>1
0.0220	0.9411	>1
0.0177	0.8967	>1
0.0080	0.5322	>1
0.0068	0.1440	>1

[a]Stress: 130,000 psi

>1 indicates runout beyond 10^7 cycles

The data of Table III show that a remarkable increase in fatigue life is produced by adding sulfur to the steel. Specifically, at 0.014 percent sulfur (Steel A), none of the specimens came even close to surviving the testing cycle. At the sulfur level of 0.056 percent (Steel B), 60 percent of the specimens survived the testing cycle, and an additional 20 percent were close to the survival limit. At the sulfur level of 0.12 percent (Steel C), all specimens survived the testing cycle. The data presented in Table III are presented graphically in FIG. **1**, which is a bar graph showing the fatigue life of Steels A, B, and C.

Steels D and E of Table II were subjected to Rolling Fatigue Bearing Tests. In these tests, the test specimen is a flat washer-shaped disc of 2-31/32-inch OD, 2-1/32-inch ID, 7/32-inch thickness. The specimen is inserted into a standard thrust bearing and serves in place of the upper race of the bearing. A load of 750 pounds is applied to the bearing by means of a lever system; this results in a Hertzian compressive stress of 563,000 psi in the test specimen. Steady lubrication is provided during testing. The standard operating speed of 1,500 rpm was maintained during testing. The testing is continued to failure, which is indicated by a vibration-sensing device, or to "runout" at 50×10^6 revolutions (550 hours).

The results of the Rolling Fatigue Bearing Test on Steels D and E again show a marked beneficial effect from the presence of increased sulfur. The results of these tests are presented in FIG. **2**, which shows the relative life of 13 samples of Steel D and fifteen samples of Steel E. Specifically, at the 0.010 percent sulfur level (Steel D), 38 percent of the specimens survived the complete testing cycle. In contrast, at the 0.043 percent sulfur level (Steel E), 80 percent of the specimens survived the testing cycle. Moreover, the majority of the failures of the 0.010 percent-sulfur steel occurred in appreciably less than 100 hours; whereas, the failures of the 0.043 percent-sulfur steel occurred in more than 100 hours.

Additional tests were performed with a varied steel composition to determine and establish further the beneficial effect of sulfur with respect to fatigue life. For this purpose a 50-pound air-induction-melted heat was produced and separated into three sulfur-modified heats of about 17 pounds each. The chemical compositions of the three heats are listed in Table IV.

TABLE IV

Steel	Heat	Bar	C	Mn	S	Si	Cr	Mo
F......	1×96	66–383	0.90	0.28	0.01	0.84	0.80	0.58
G.....	1×97	66–384	.91	.29	.04	.86	.90	.58
H.....	1×98	66–385	.92	.28	.08	.85	.80	.58

The three sulfur-modified ingots from the heats of Table IV, which are designated as Steels F, G and H, were forged into 5/8-inch-round bars, which were annealed by heating slowly to a temperature of about 1,450°F. The ingots were then equalized, cooled at approximately 15°F per hour to 1,300°F, furnace cooled to 400°F, and finally air cooled to room temperature. In the manner described hereinabove, fatigue specimens were produced and subjected to Rotating Beam Fatigue Testing. The specimens were heat treated to a hardness of $62R_c$ by austenitizing at 1,600°F, then oil quenching and tempering at 500°F for four hours. All of the tests were conducted at room temperature on Rotating Beam Fatigue Testing machine operating speeds of 10,000 rpm. All the specimens were stressed for testing at 110,000 psi for 10^8 cycles or until failure occurred. The results of these tests are presented in Table V and FIG. **3**.

TABLE V

	Number of Cycles ($\times 10^8$)		
Specimen	Steel F (0.010% S)	Steel G (0.040% S)	Steel H (0.080% S)
1	67.4	100	100
2	47.9	100	100
3	34.1	100	100
4	31.0	93.5	100
5	25.4	62.2	39.4
6	11.4	59.7	19.4
7	9.0	38.7	18.4
8	8.7	27.8	17.4
9	4.5	10.8	6.7
10	0.3	7.4	4.5
11	0.2	1.5	2.3
12	0.05		

As was the case with the first series of tests discussed and described hereinabove, the data presented in Table V and FIG. **3** also show that a marked improvement is obtained in fatigue life by the addition of a significant amount of sulfur to the steel.

It may be seen from the above-presented data that sulfur is effective for the intended purpose of improving fatigue life in ultra-high strength steels containing for the purpose of strengthening, elements such as chromium and molybdenum. As pointed out hereinabove, other strengthening elements would also be suitable.

Although various preferred embodiments of the invention have been described herein, it is obvious that other adaptations and modifications may be made by those skilled in the art without departing from the scope and spirit of the appended claims.

What is claimed is:

1. An ultra-high strength steel, particularly suited for the manufacture of bearings, consisting essentially of, in percent, about 0.75 to 1.10 carbon, 0.25 to 1 manganese, up to 0.9 silicon, up to 2 chromium, up to 1.20 molybdenum, with the sum of chromium and molybdenum being at least 0.50, more than 0.04 to 0.25 sulfur, and the balance iron.

2. The steel of claim **1** having sulfur within the range of more than 0.04 to 0.15 percent.

3. An ultra-high strength steel, particularly suited for the manufacture of bearings, consisting essentially of, in percent, about 0.95 to 1.10 carbon, 0.25 to 0.45 manganese, 1.30 to 1.60 chromium, more than 0.04 to 0.25 sulfur, and the balance iron.

4. An ultra-high strength steel, particularly suited for the manufacture of bearings, consisting essentially of, in percent, about 0.75 to 0.95 carbon, less than 1 manganese, 0.60 to 0.90 silicon, 0.50 to 1.10 molybdenum, up to 2 chromium, more than 0.04 to 0.25 sulfur, and the balance iron.

5. Bearings made from bearing steels consisting essentially of 0.75 to 1.1 percent carbon, 0.25 to 1 percent manganese; up to 2 chromium; up to 1.2 percent molybdenum; up to 0.9% silicon; more than 0.04 to 0.25% sulfur; and the balance iron and incidental impurities.

6. Bearing steels having high strength and fatigue resistance and a hardness greater than 50 Rockwell C, said bearing steels consisting essentially of 0.75 to 1.1% carbon; 0.25 to 1% manganese; up to 2% chromium; up to 1.2% molybdenum; up to 0.9% silicon; more than 0.04 to 0.25% sulfur; and the balance iron and incidental impurities.

7. The bearing steels of claim **6** wherein the sulfur content is between more than 0.04 and 0.15% by weight.

8. The bearings of claim **5** wherein the sulfur content is between more than 0.04 and 0.15% by weight.

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