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Material Analysis and Tests on Three Samples of Retaining Springs in the Fuse Components of the Antipersonnel Obstacle Breaching System

by Howard E. Horner

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Army Research Laboratory
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Material Analysis and Tests on Three Samples of Retaining Springs in the Fuse Components of the Antipersonnel Obstacle Breaching System

Howard E. Horner
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Abstract

Fuse tests were conducted on the fuse components of the Antipersonnel Obstacle Breaching System (APOBS) to evaluate three slightly varied spring designs of the u-shaped stainless steel retaining spring samples. Few failures occurred with the spring samples. With one particular spring design, popping out occurred during the tests; whereas, the spring samples of the other two designs did not fail. A material investigation was performed to determine why one spring design would cause occasional failures during the fuse tests. The primary cause of a few spring failures was due to the fact that the failed spring design did not allow full engagement of the spring in the fuse components of the APOBS.

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1. INTRODUCTION

Fuse tests were conducted on the fuse components of the Antipersonnel Obstacle Breaching System (APOBS) to evaluate three slightly varied spring designs of the u-shaped stainless steel retaining spring (Marine Corps drawing no. 87012E3134) samples (see Figure 1). A few failures occurred with the spring samples. With one particular spring design, popping-out occurred during the tests; whereas, the other spring samples of the other two designs did not fail. Material analysis and various tests were performed on the spring samples of three different designs in order to determine why one spring design would cause occasional failures during the fuse tests. A special spring compression test was devised to determine the approximate spring rate for the spring samples of different designs for comparative purposes.

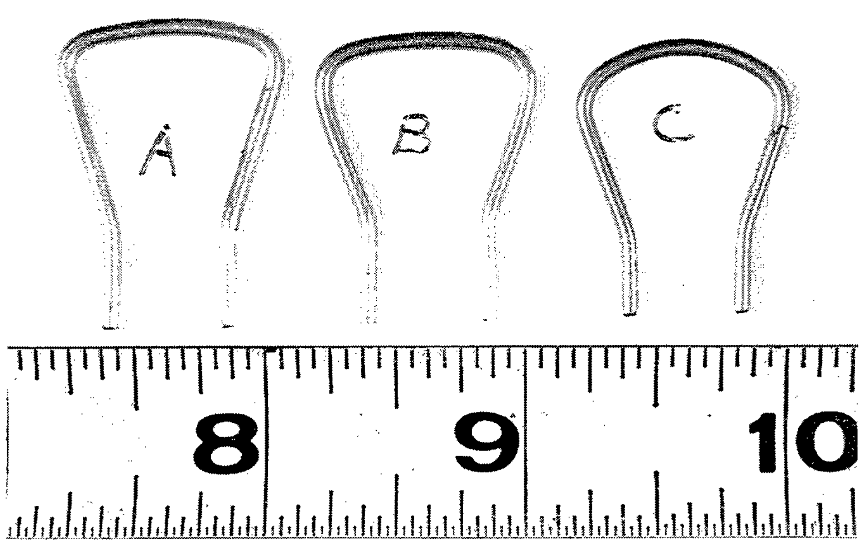

Figure 1. View of three APOBS stainless steel retaining spring samples based on slight variations of the design configuration.

The work on the APOBS retaining spring samples was done for the Mine Neutralization Branch, Night Vision and Electronic Sensors Directorate (AMSRL-RD-CD-MN), U.S. Army Communication-Electronics Command, Fort Belvoir, VA.

1.1 Samples. Eight samples (two As, three Bs, and three Cs) of the u-shaped retaining springs, based on slightly varied spring designs, were received for material investigation. Spring-A design was the one that caused occasional failures during the fuse tests, spring-B design conformed to the design and dimensions on Marine drawing 87012E3134, and spring-C design was proposed for use in the APOBS fuse components.

1.2 Test Methods. In addition to standard test procedures to determine the alloy and properties of the spring samples, a special spring compression test was devised to determine the approximate spring rate. This test is described in more detail later in this report.

2. RESULTS

Figure 1 shows three u-shaped retaining springs of slightly different design configurations. Based on the fuse tests performed on the APOBS fuse components, few failures occurred with spring-A design; whereas, the other two designs did not fail. Marine drawing 87012E3134 specified the retaining spring to be made of a chrome-nickel stainless steel conforming to American Society for Testing and Materials (ASTM) A313, Type 302, Condition B, which means severely cold-worked to spring temper. The diameter of the wire specified on the drawing for the spring was 0.071 $\pm$ 0.003 in. After the spring was fabricated to shape, it was to be stress-relieved at 600° F for 30 min. According to the information provided on the spring samples, the design-C springs, which were proposed for use in the fuse components, were supposed to be made of precipitation-hardening steel 17-7PH, Condition CH900, which means severely cold-worked, fabricated to shape, and then aged at 900° F for 1 hr to higher strength.

Chemical analyses and a number of tests were performed on the spring samples to obtain pertinent data about their alloy and properties. Tests such as hardness tests, tension tests, spring compression tests, and spring integrity tests were done on the samples. In addition, wire diameter measurements and a microstructural examinations were performed on the samples.

The results of chemical analyses and tests on the APOBS retaining spring samples are given in Tables 1–7. The composition of spring-A design samples was similar to Type 302 chrome-nickel stainless steel as specified on the Marine drawing. However, because of higher chromium contents, spring-B design samples appeared to be made of Type 304 stainless steel, instead of Type 302. Meanwhile, the composition of spring-C design samples was similar to 17-7PH precipitation-hardening stainless steel as stated by the spring vendor.

The special spring compression tests were performed on the spring samples in order to obtain the approximate spring rate in terms of pounds per inch. The spring rate may be affected by the slight variations in the spring design configuration among these spring shapes seen in Figure 1. The typical setup of the test is shown in Figure 2. One straight end of the spring sample was clamped tightly in the upper corner jaws of the machine vice (see Figure 3 for a close-up view), which was placed underneath the compression crosshead of the testing machine. A small steel plunger with a small diameter tip end was placed on top of the spring's free end at the slight bend to push it under the load toward the clamped end (see Figure 4). A deflectometer was used to record the spring free end deflection vs. the applied compression load.

The compression tests were repeated several times on the same spring samples to obtain average values. The load vs. deflection curves obtained for each sample were not straight, but rather slightly convex. Nevertheless, the average spring rate for each sample was determined for 0.10-in deflection of the spring's free end. On the average, the spring rates determined were 45–46 lb/in for the A springs, 55–62 lb/in for the B springs, and 53–57 lb/in for the C springs. It should be noted that the failed spring-A design had the lowest spring rate values.

Table 1. Composition of APOBS Stainless Steel Retaining Spring Samples

	Sample (No.)						ASTM A 313 (Type)		
	A 60	A 101	B 1	B 2	C 12	C 18	302	304	631 (17-7PH)
Carbon	0.09	ND	0.081	ND	0.09	ND	0.15 Max	0.08 Max	0.09
Manganese	1.14	1.05	1.33	1.42	0.80	0.76	2.00 Max	2.00 Max	1.00 Max
Nickel	8.12	8.23	8.67	8.38	7.75	7.82	8.00–10.00	8.00–10.50	6.50–7.75
Chromium	18.43	18.61	19.70	19.34	17.24	17.21	17.00–19.00	18.00–20.00	16.00–18.00
Molybdenum	0.40	0.34	0.12	0.16	0.09	0.09	—	—	—
Copper	0.27	0.24	0.02	0.05	0.32	0.31	—	—	—
Aluminum	ND	ND	ND	ND	ND	ND	—	0.75–1.50	—

Note: Each spring sample was heated to red hot in the flame and then flattened large enough with a hammer to cover the small maskhole of the sample holder in the x-ray spectrometer. Carbon was determined by the carbon analyzer using the combustion method. Other elements were determined by x-ray fluorescence method using the x-ray wavelength dispersive spectrometer.

ND = Not Determined.

Table 2. Spring Samples Received

Sample	No.
A	60 and 101
B*	1, 2, and 3
C	12, 18, and 22

* Note: They have no identification labels, but they conformed to the design configuration and dimensions on the Marine drawing.

Table 3. Diameter and Length Measurements

No.	Diameter (in)	Length (in)
60	0.0694 and 0.0707	2.996
101	0.0694 and 0.0707	ND
1	0.0713	2.835
2	0.0713	ND
3	0.0713	2.843
12	0.0684 and 0.0687	2.634
18	0.0684 and 0.0687	ND
22	0.0684 and 0.0687	2.629

Note: Samples 60, 101, 12, 18, and 22 were not perfectly round; hence, two diameter measurements at 90° apart. Lengths of the spring samples were measured after they were made straight for the tension tests.

Table 4. Spring Compression Tests

No.	Approximate Spring Rate (lb/in)	Tests
60	44.79	6
101	46.25	4
1	62.50	3
2	53.13	4
3	54.58	6
12	52.54	3
18	56.25	4
22	56.88	4

Note: Repeated tests on the same samples, averaged values.

Table 5. Spring Integrity Tests (Note 4 on Marine Drawing 87012E3134)

	Gap Before Inserting (in)		Gap After Inserting (in)		Change (in)	
No.	Outside	Inside	Outside	Inside	Outside	Inside
101	0.501	0.358	0.526	0.384	+0.025	+0.026
2	0.514	0.369	0.546	0.396	+0.022	+0.027
3	0.505	0.369	0.532	0.384	+0.027	+0.024
18	0.518	0.379	0.524	0.384	+0.006	+0.005
22	0.505	0.365	0.513	0.372	+0.008	+0.008

Note: The opening dimensions (gap at the ends) of each spring sample were measured on the outside and inside of the gap with a caliper before and after the spring was inserted over a 0.570-in diameter rod and then removed from the rod. The difference in the original spring opening before and after the insertion was the change due to apparent permanent deformation of the spring. The drawing specified that the spring opening shall return to its original opening dimension ± 0.010 in after passing completely over the test rod.

Table 6. Hardness Tests (Tukon Knoop Hardness Tester with 1-kg load)

No.	Knoop Hardness Number (HK)	Equivalent Rockwell C Hardness Number (HRC)
60	498	47.3
101	487	46.5
1	481	46.0
2	462	44.5
12	585	52.5
18	574	52.0

Table 7. Tension Tests (After the Spring Samples Were Made Straight)

No.	Tensile Load (lb)	Tensile Strength (ksi)	ASTM A 313	Tensile Strength Requirements (ksi)
60	925	240	Type 302 Class 1 and 304	252 min - 281 max (0.063–0.075-in diameter)
101	925	240		
2	950	238		250 min - 278 max (0.061–0.075-in diameter)
3	970	243		
12	1025	278	Type 631 (17-7PH) Condition CH-900	297 min - 327 max (0.061–0.071-in diameter)
18	985	267		
22	990	268		

The spring integrity tests (in accordance with Note 4 on the Marine drawing) were performed on the spring samples to determine the change in the spring's end opening (gap) dimension after

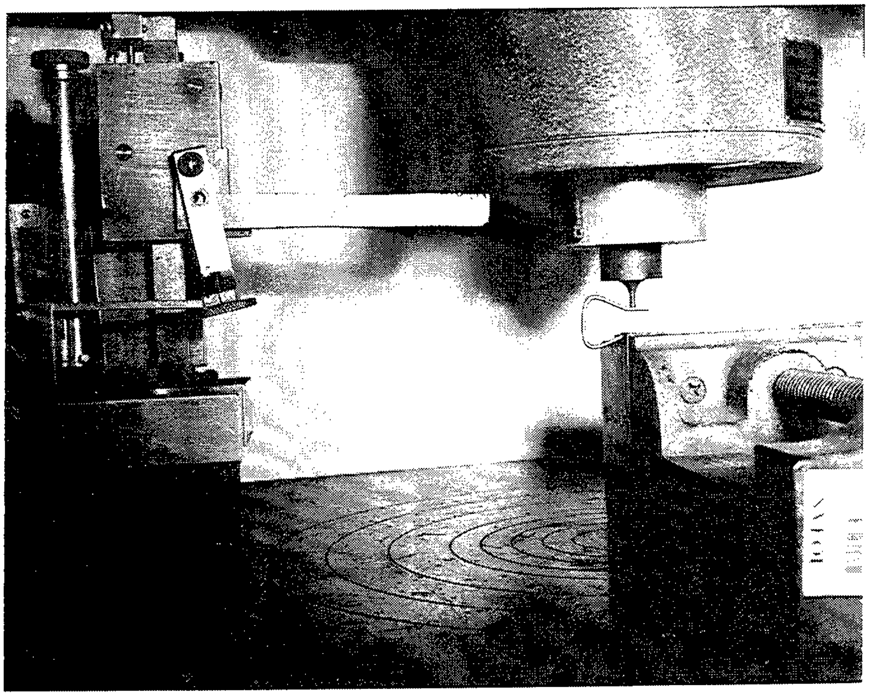

Figure 2. View of the spring compression test setup to determine the approximate spring rate in terms of pounds per inch. One end of a spring-B sample was clamped in the upper corner of the machine vise. A small plunger will push the free end closer to the clamped end when the load is applied in compression. A deflectometer on the left records the deflection of the free end during the test.

they were inserted over a 0.570-in diameter test rod. The opening measurements were made before and after the insertion of each sample over the test rod. A 6-in caliper was used for the measurements, where the values were obtained after a sample fell out after slowly opening or closing the caliper anvils for outside and inside measurements. For ease of measurements, each sample was removed from the test rod after the insertion.

According to the note on the drawing, the retaining spring opening dimension shall return to its original dimension (± 0.010 in) after passing completely over the test rod. The changes in the original opening dimensions were +0.022– +0.027 in for spring A (No. 101) and spring B (No. 2

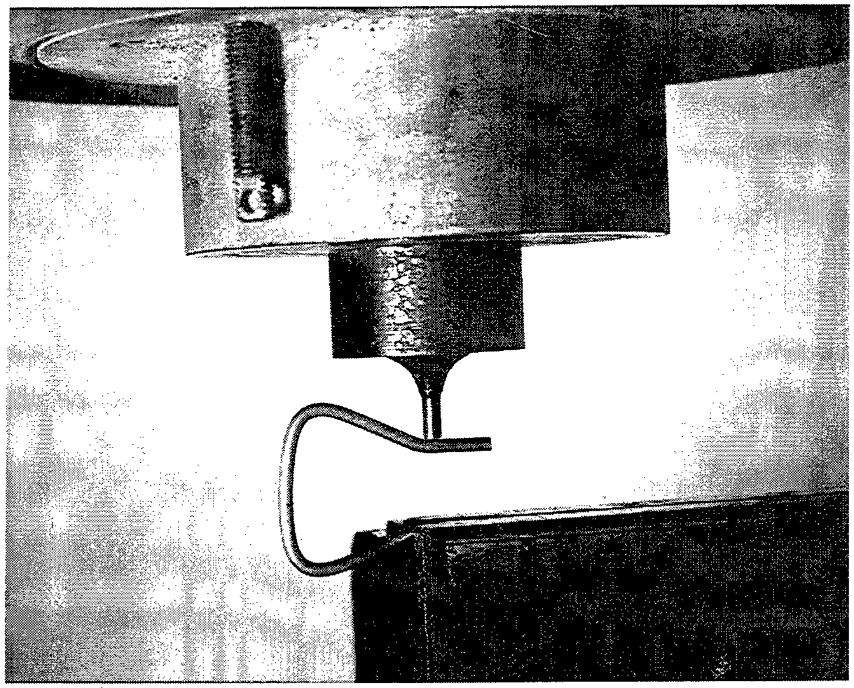

Figure 3. Close-up view of the spring sample prior to the compression test. A small plunger with the small end tip was placed between the compression head of the testing machine and the spring's free end.

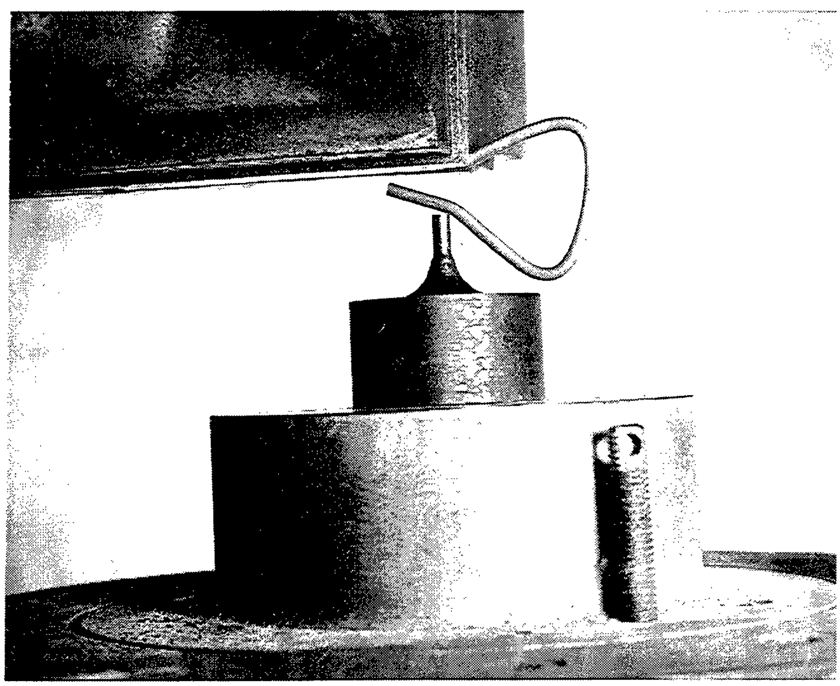

Figure 4. Close-up view of the spring sample showing the free end compressed close to the clamped end in the machine vise while under compressed load.

and 3) and +0.005– +0.008 in for spring C (No. 18 and 22), indicating less change of the opening for the 17-7PH springs. Spring-A and -B samples did not meet the spring integrity requirement.

The tension tests were performed on the spring samples after they were made as straight as possible. The tensile strengths obtained for the samples are approximations because of the short length available for the tests and breakage of spring wire test specimens in the wedge grips, which would be discarded in accordance with the tension test standard. A tensile strength of about 240 ksi was obtained for spring-A and -B samples and about 270 ksi for spring-C samples.

The microhardness tests using the Knoop indenter and 1-kg load were performed on the as-polished metallographic specimens of the spring samples. The equivalent Rockwell hardness values obtained, when converted from Knoop hardness values, were 46–47 HRC for spring-A and -B samples and 53 HRC for spring-C samples.

Microstructural examination of the etched metallographic specimens of the spring samples revealed the severely elongated grain structures, which are typically observed in the stainless steel wires that were severely cold-worked to spring temper. The 17-7PH spring wire sample still has the elongated grain structure even after being aged at 900° F for condition CH900.

3. CONCLUSIONS

Based on the findings of the material analyses and tests on the APOBS retaining spring samples, spring-A samples were made of Type 302 chromium-nickel stainless steel and spring-B samples of Type 304 because of higher chromium content, both with a tensile strength of about 240 ksi (250–252 ksi minimum) and a hardness of 45–46 HRC. The spring rates were 45.5 lb/in for spring-A samples and 56.5 lb/in for spring-B samples. The slight variations in the spring design configuration may have an effect on the spring rate values of both spring samples.

Spring-C samples were made of 17-7PH precipitation-hardening stainless steel as stated by the spring vendor. Their spring rates of 55 lb/in were comparable to that of spring-B samples. Their tensile strength and hardness were 271 ksi (297 ksi minimum) and 53 HRC, respectively.

The changes in the original opening dimension for spring-A and -B samples after the insertion of them over the 0.570-diameter test rod during the spring integrity tests were +0.025 in, which exceeded ± 0.010 in allowable, vs. 0.007 in for spring-C samples. Microstructural examination of three spring samples revealed the typical severely elongated grain structures of severely cold-worked stainless steel spring wires to spring temper condition.

It is speculated that the few failures with the spring-A samples were caused by the design configuration that was slightly different from the Marine drawing, which may not allow full engagement of the spring in the APOBS fuse components.

4. RECOMMENDATIONS

The design of the retaining spring for use in the APOBS fuse components may have to be taken into consideration if different from the original design on the Marine drawing. Determination of the spring rates for different retaining spring designs may be of help in evaluating the variations in the spring design and even in materials. The special spring compression test that was devised in this work may be used to determine the spring rate based on designs and materials.

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