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THESIS

DEVELOPMENT OF A TESTING TECHNIQUE FOR THE
YIELD STRENGTH DETERMINATION OF 5 INCH
STEEL CARTRIDGE CASES

by

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Development of a Testing Technique for the Yield Strength Determination of 5 inch Steel Cartridge Cases

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ABSTRACT

The standard Navy method for determining the yield strength of 5 inch steel cartridge cases is shown to overestimate the actual circumferential yield strength of the case by about 40 percent. An expanding ring testing apparatus was developed to measure the actual yield strength. Comparison of this strength with the yield strength measured at different stages of the standard flat tensile sample preparation method revealed that the major cause for the difference is the stress relieving treatment given to the flattened tensile specimens. The increase in the strength during the stress relieving is believed to be due to the precipitation of epsilon carbide and the resulting precipitaion hardening.

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I. INTRODUCTION

Current Navy testing procedures for steel cartridge cases require one percent of a lot to be proof fired, with 0.1 percent to be mechanically tested for information only. This thesis is one in a series of experimental programs designed to provide the information necessary to validate a mechanical testing procedure for steel cartridge cases [Ref. 1]. Mechanical testing methods can result in as much as a factor of four in cost savings over the current proof firing acceptance method. The proof firing acceptance procedure entails loading each case with a full powder charge, installing a dummy projectile, and firing the assembled round. Each case is then evaluated on ease of extraction and checked for splitting. A standard for minimum acceptable yield strength would be the basis for any alternate testing method developed. However, the present proposed test specimen preparation technique outlined in Appendix A can alter the yield strength in several ways: 1) additional coldworking from ring straightening and basic tensile specimen machining, 2) additional coldworking in the bottom three base area samples due to thickness machining, and 3) thermally induced strength changes from the 610F (321C) stress relief.

An expanding ring test apparatus has the potential for allowing the actual circumferential yield strength of the cases to be measured. The research reported herein has developed and used an expanding ring test to measure the actual yield strength of several 5 inch steel cartridge cases and compares these results to the mechanical properties as determined by the currently recommended testing method.

II. BACKGROUND INFORMATION

A. CARTRIDGE MANUFACTURE

Five inch cartridge cases are made from an aluminum killed MIL-S-3289 (AISI 1030) plain carbon steel, with a nominal carbon content between 0.27 and 0.33 percent carbon. Cases are deep drawn from a disk shaped billet in several thermo-mechanical processing steps. The most important steps are these which are designed to give the critical areas of the cases their final mechanical properties. These steps in the processing are the final steps and occur sequentially as follows:

1) Austenization at 1620 F (882 C) followed by a quench in brine at 65 F (18 C). This is designed to produce a hard martensitic structure.

2) Taper anneal at 1120 F (604 C) for 7 min to the upper sidewall. This influences properties begining above 10.5 in (26.76 cm) from the base. The less critical areas of the case are softened in preparation for the final tapering.

3) Final mechanical tapering to bring the case to its final required shape. [Ref. 1]

These processes result in a case with a large variation in mechanical properties and wall thickness along its length. The most important region of the case is the lower (base) region extending from the base of the case to 10.5 in (26.7 cm) from the base. This area will have the highest yield and ultimate tensile strength in the case. The next five inches (12.7 cm) are of lesser importance and will have significantly lower yield and ultimate tensile strengths due to the taper annnealing process. Properties beyond this mid-length area are of no particular importance to case performance during firing, however, the upper 3 inches (7.6 cm) area must be soft enough to allow the crimping of the powder plug.

Radial dimensions in the base region are displayed in Figure 1, showing the large changes in thickness over the initial 4 inches (10.2 cm) of the base area. The thickness decrease is accompanied by an increase in the inner diameter and a decrease in the outer diameter. These variations produce case walls with non-parallel sides near the base of the case and sides that are parallel in the upper base region.

B. CARTRIDGE RESPONSE DURING FIRING

When a round is fired, the cartridge case begins an elastic expansion due to the internal pressure. This unresisted expansion continues until contact is made with the gun barrel, at which time a gas seal is formed and the case and barrel continue expanding together. Expansion of the barrel is entirely elastic but the cartridge case reaches its elastic limit and undergoes plastic deformation. As the gas pressure subsides, the barrel and case elastically respond. However, the case has undergone some permanent plastic deformation and will be larger than its original size. The amount of plastic deformation in the case depends on the yield strength of the case and the size difference between the case and the gun barrel. An example stress-strain plot is shown in Figure 2 [Ref. 2].

If the plastic deformation is too large at the base region the case will be difficult to extract, termed a sticker, and can put the gun mount out of service. In addition if the ultimate tensile stength is to low the case may actually split during firing, resulting in loss of projectile accuracy and possible loss of service of the gun mount.

C. QUALITY ASSURANCE REQUIREMENTS

From the manufacturer's lot of 5000 cases the Navy requires 50 to be proof fired. This entails loading and firing each cartridge case to ensure adequate performance of the lot. 5 cases are desgnated from those remaining cases to be mechanically tested in accordance with a standard procedure; Appendix A provides the details of this procedure. The proposed requirement would provide that 30 cases be mechanically tested for yield strength only and no proof firing would be necessary. Through statisical analysis of tensile tests performed on test samples made by the standard method (Appendix A) the Navy has established specific standards for case yield strength in the base area and in the sidewall area, Figure 3. These minimum requirements are designed to ensuring adequate elastic response during firing and adequate ductility during manufacturing. The minimum yield strength requirement for the base area is 135 kPsi (931 MPa) and for the sidewall area is 90 kPsi (621 MPa). [Ref. 1]

III. DISCRIPTION OF TESTING APPARATUS

A. EXPANDING RING TESTER

1. Mechanical

The heart of the test system is the expanding ring apparatus as shown in Figures 4 and 5, and as detailed in Figure 6. Support for the ring and seal are provide by the base, the central shaft, and the securing nut, the base and central shaft are also provide the transport of the fluid to the seal. Hydraulic fluid is provided by a hand operated pump and is monitored by a pressure transducer and a direct reading gauge. The two system valves enable the system to be isolated into two segments to allow for transducer calibration, seal air bleeding, and personnel safety. System components are rated for pressures of up to 10,000 Psi (69.0 MPa) which is above the maximum 9000 Psi (62.1 MPa) output for the pump, preventing over loading of any system component. Figures 7 and 8 display the rubber hydraulic seal which is designed to transmit the hydraulic fluid force to the ring test specimen. Internal pressure helps maintain the seal on the central shaft by forcing the inner seal lip against the central shaft. A significant amount of the air in the seal can be bled out through the air bleed port in the central shaft, reducing the problems of air compressibility.

2. Electronics

Pressure monitoring is done with the use of a strain gauge type pressure transducer and its associated amplifier, both an analog and digital output are provided. Displacement measurements were made with a strain gauge type extensometer with a circumferential chain attachment. These two inputs were fed to an X-Y recorder to produce a load displacement diagram for each test. Calibration of the pressure monitoring equipment was completed using a dead weight tester in accordance with ASTM E4 procedures and the displacement monitoring equipment was calibrated with a dial micrometer and voltmeter in accordance with ASTM E83 procedures. Figure 4 displays the standard mechanical and electrical equipment set up for an expanding ring test.

B. TENSILE TEST APPARATUS

No mechanical modification were made to the standard Instron testing machine but to get an accurate measure of specimen displacement an extensometer was required. A decision was made to use the same extensometer and bridge amplifier as for the ring tests using the standard tensile test specimen mounting attachment. Since this equipment is not compatible with the Instron recorder, an X-Y recorder was used with the load input being taken from the Instron's load cell. A low pass filter was also necessary to remove spurious noise from the machine and provide a usable input to the recorder. Calibration of the testing machine was accomplished using the calibration weights in accordance with ASTM E4 procedures and the extensometer was checked using a dial micrometer in accordance with ASTM E83 procedures. Figure 9 diagrams the basic equipment set up for the standard tensile tests.

IV. EXPERIMENTAL PROCEDURES

A. EXPANDING RING TESTER

A standard procedure for operation of the ring test apparatus involves four basic sub-level operations, these include: an initial set-up phase and three sections that comprise the actual run operations.

1. Initial Set-up

A 15 minute warmup period is required for the extensometer, so the first action is to connect the extensometer and amplifier unit, and then turn on the amplifier power. At this time the other electronic components may also be turned on and checked for proper operation. All electrical connections should be checked and a scaling for the load-displacement plot chosen. To set the Y-axis scaling, zero the Y-axis and close the hydraulic supply valve. Pump this small section of the system to maximum expected pressure as read on the analog pressure display, and then adjust the Y vernier to correctly scale the output. When the bridge amplifier has warmed up check the excitation voltage to insure it is at the same value used for calibration of the extensometer. Using the scaling control, a voltage output may be obtained and then, using the calibration curves, a corresponding diplacement can be found. This signal is then fed into the X-axis and the vernier is adjusted to conform to the desired scaling. The pump reservior should be filled and the threads of the apparatus coated with anti-sieze compound. An initial check of the extensometer chain should be conducted to insure its length is commensurate with the ring size and extensometer gauge limits.

2. Mounting Procedures

Coat seal with oil and work it into place inside the test ring, then work the seal onto the apparatus shaft. When seal is flush with the lower platen slide the upper platen and spacer ring onto the seal. Check the extensometer for proper length and then attach chain around the test ring. Open the vent valve and screw the securing nut into place. Before tightening the nut, center the chain at the mid-ring height, and balance the extensometer, this enables the nut to be tighten and possible compressive strains to be detected with the extensometer output. An alternative to using securing nut is to use the large cross bar and its accompaning bolts, with the addition of a large spacer ring.

3. Test Procedures

Recheck the extensometer position and bridge balance, then open the fill and vent valves. Pump fluid through the system until flow from the vent line is bubble free, stop pumping and secure the vent valve. Make a final check of system alignments and insure recorder is on with pen down. Pump fluid, monitoring system pressure and recorder response until desired strain is achieved. Normally rings were not expanded beyond 1.0 percent strain. Stop pumping and bleed system pressure through the vent valve. Turn the pen off and the extensometer excitation voltage off while removing the extensometer. Insure appropriate scaling information is recorded on the load-displacement curve and place recorder in standby.

4. Disassembly

Close supply valve, remove securing nut, spacer ring, and platen, and work seal to top of shaft threads. Siphon as much fluid from the seal as possible and then remove the seal. Close the vent valve and work the seal and ring apart checking for any damage to the seal. After a brief clean up the system is ready for another test. Experience shows an average test usually requires 25 minutes.

5. Stress in an Internally Pressurized Cylinder

Each ring cut from the case may be idealized as a thin walled tube, since its thickness is less than one tenth its inner radius. This simplification follows from the analysis of the stress states in the wall of a cylinder. No longitudinal forces exist therfore no longitudinal stresses exist, and the thinness of the wall produces the assumption that the radial stresses are negligible. With these two simplifications the problem is now one of uniaxial stress in the circumfrential direction. Futher analyis of the geometry results in a very simple equation for the calculation of the circumfrential (hoop) stresses. [Ref. 3]

$$\text{stress} = (P * r) / t \qquad \text{(eqn 1)}$$

P -- internal pressure
r -- inner radius
t -- wall thickness

B. TENSILE TESTER

Despite the different load monitoring system, the tensile test procedures are similar to those normally used. Although the extensometer is in a different configuration for the tensile tests the set-up and scaling procedures are the same as for the ring test apparatus.

1. System Set-up

Electrical connection are made to the load monitoring system and all equipment is turned on. Scaling the Y-axis is done through the machines internal calibration system by first calibrating the Instron's chart recorder then adjusting the x-y recorder to match the scaling. This can be difficult due to the Instrons output of -1.0 to 0.0 VDC. Extension rate is set to 0.2 inches per minute and the wedge type grips are installed.

2. Test Procedues

Grips are positioned to allow installation of the test specimen and then tightened securely. The extensometer is mounted on the specimen and the bridge is checked for balance. With pen positioned down and axes zeroed the machine can begin extension. This continues until 2.0 percent strain is reach where the excitation voltage to the extensometer is turned-off and the extensometer is removed to avoid damage. Load monitoring continues until the sample breaks, the recorder is placed in standby, and the Instron is stopped. Scaling information and sample identity are recorded and the broken sample is removed from the grips. The system is now ready for another test.

V. TEST MATRIX DETERMINATION

A. RING SIZE DETERMINATION

Selecting a ring sample size proved to be a key factor in the overall developement of the testing scheme. Limiting factors proved to be testing appparatus size and the size of a seal that could easily be manufactured. These two were parallel to the needs to keep sample size small to avoid problems with the variable geometry of the cartridge case. From these constraints a 2 in (5.08 cm) height for the samples was selected, enabling a maximum number of samples to be obtained from each case while allowing for a practical seal design. In addition, samples could be easily and accurately cut on a lathe. Ring sample preparation techniques are outlined in Appendix A while Figures 7 and 8 show the final seal design.

B. TEST PROGRAM

A test program was needed that could not only compare the ring and straight tensile samples, but that could be used to compare new data with previously reported data. These requirements coupled with the designed ring size resulted in the two sampling plans shown in Figure 10. Combining these two plans provided a complete analysis of the base area of the case allowing, not only for both ring and tensile samples at each reference position, but also ring and tensile samples from the same case.

Three testing procedures were selected as the best method to analyze the separate and combined effects of machining, straightening, and stress relieving:

1. No Stress Relief

Undisturbed ring samples from this segment would produce the actual yield strength of the case. Tensile specimens were prepared in accordance with the standard procedure but no stress relieving heat treatment was performed thus providing an accurate indication of the effects of straightening and machining on the yield strength.

2. Stress Relief

Both rings and prepared tensile samples were subjected to the same 610 F (321 C) stress relief for the requisite 30 minutes. A four fold comparison could now be made to calculate the effects of heat treatment and machining plus heat treatment.

3. Austenitize and Quench

Since the base area of the case is never tempered following the austenizing treatment it was thought that a determination of the as-quenched properties should allow the strength increase from the final tapering operation to be estimated.

A full comparison could now be made between the actual strength of the cartridge case and the presumed strength found in the standard tensile test method. A sampling matrix was then determined through statistical analysis and is detailed in Figure 11.

C. SYSTEM VERIFICATION

As a verification of the ring test apparatus and sample preparation techniques three additional test cases were prepared and the following test procedures performed.

1. Case I1

All rings were tested as cut from the case to evaluate seal performance, sample preparation techniques, system accuracy, and system stiffness.

2. Case I2

Ring C was undisturbed, ring A was machined to constant thickness to evaluate the effects of the geometry change and cold work added to the ring. Ring K was stress relieved to give an estimate of expected yield for other cases and an initial indication of the effects of the stress relief heat treatment.

3. Case I3

Both rings A and C were austenitized and quenched to get an estimate of the as heat treated yield strength. Ring A was additionally subjected to the stress relief heat treatment to evaluate its effect on a non-cold worked sample.

VI. RESULTS AND DISCUSSION

Validation of the apparatus, paricularly the seal, was accomplished with the testing of rings T1 and T2. Tables 1, 3, and 5 present the results of the ring tests conducted while Tables 2, 4, and 6 compile the results of the corresponding flat tensile specimens. Tables 7, 8, and 9 present a summary of data from the preceding six tables to permit an easier comparison of the relevant information.

A. EFFECTS OF VARIABLE EXTENSION RATES

To improve the correlation between ring and tensile data the extension rate for each process was held constant. This rate was based on the rings extension rate calculated to be .2 in/min (.508 cm/min), a strain rate of .012 in/in/min, however the standard test requirements specify an extension rate of .05 in/min (.127 cm/min), a strain rate of .05 in/in/min [Ref. 1]. A second set of tensile samples were tested at the standard rate and the comparison provided in Table 7 show no significant variation in yield or ultimate tensile strength for the two sets of samples.

B. EFFECTS OF TENSILE SAMPLE PREPARATION

Comparison of the average yield strength in the G and K positions of the samples not subjected to the stress relief provides an estimate of the increase in yield strength due to straightening and tensile gauge size machining since these two locations have no additional cold work from thickness machining. Table 8 combines the relevant data from Tables 1, 2, 3, and 4 to show the tensile specimens have only a 3.5 percent higher value than the ring specimens.

Analysis of the standard deviations and mean yield strengths based on the two distributions being normal [Ref. 1], using the standard paired-sample t test indicates the differences in the the mean yield strengths cannot attributed to the natural distribution of the data. [Ref. 4], The only additional information that can be gained is that the mean yield strengths for the rings are smaller than those for tensile samples. Reference 5 has demonstrated through X-ray diffraction line broadening techniques that the tensile specimen straightening effects are negligible, but this method would be unable to detect the very small changes found in this comparison. The amount of yield strength increase that can be attributed to the straightening process alone is not acertainable with the data taken, but it is evident that the cold work from straightening has added only a small increment to the overall yield strength of the tensile samples.

C. EFFECTS OF THICKNESS MACHINING

Standard preparartions outlined in Appendix A require the first three tensile specimens (A,B,C) in the base area to be machined on both sides to produce parallel specimen surfaces with subsequent nominal thicknesses of between .060 - .080 in (.152 - .203 cm). All the specimens are then subjected to the same straightening and machining to final ASTM E8 specifications. To unmask these effects a comparison of yield and ultimate tensile strengths for the machined specimens A, B, and C and the non-machined specimens G and K from Tables 1, 2, 3, and 4 is presented in Table 8. For the ring samples the yield strengths for the G and K positions are 4.3 percent less than for the A, B, and C positions while the average values for the corresponding tensile specimen position is 15.2 percent lower. The ultimate tensile strength and hardness values are not altered to any significant extent by the straightening or machining. By subtracting the 4.3 percent increase from the 15.2 percent increase results in an approximate increase in yield strength due to thickness machining of 11.0 percent.

Figures 12 and 13 demonstrate these two effects through the stress-strain curves from case T1 and T2. In Figure 11 rings A, C, and K have the same shape but the machined rings A and C have a slightly higher yield strength than position K, (no machining). In Figure 13 ring C is an undisturbed test while ring A was machined to a constant thickness and shows the marked increase in yield strength found in the tensile samples. Ring K will be discussed later.

Further analysis of these machining effects is hampered by the different amounts of machining required for each position and each ring. An overall effect of this variability is to add more scatter to the data for the three lower positions in the base region. This is evident in a comparison of the two different regions of the case, the lower three positions A, B, and C have larger standard deviations than do the upper two positions G and K. It can be stated however, that the required machining increases the apparent yield stress of the test specimens over and above that increase created by straightening the flat tensile specimens. This strengthening effect can be seen in the stress relieved specimens through the same analysis.

D. EFFECTS OF STRESS RELIEF HEAT TREATMENT

As provided in the sampling plan both ring and tensile specimens were subjected to the same required 610 F (321 C) stress relief. Analysis of these data and that from the non-stress relieved samples reveals this to have the most significant effect on the yield strength. A 32 percent increase in yield strength is seen in the ring specimens while a 27 percent increase in the tensile specimens, however both types of specimens show an actual increase of approximately 35 Ksi (172 MPA). Figure 13 demonstrates both the effect on yield strength and the change in shape of the stress-strain curve; ring C is an undisturbed sample while ring K has been stress relieved. Not only does ring K have a marked higher yield strength, but it displays a more pronounced yield point.

1. Epsilon Carbide Precipitation Hardening

Strengthening effects of a fine precipitate are well known in many alloys, including medium carbon martensitic steels. The classic precipitation process; GP zones - coherent precipitates - semicoherent precipitates - incoherent precipitates occurs in these steels with the primary area of importance to this study being the semicoherent phase. In martensitic steels the transient epsilon carbide phase is the semicoherent phase and occurs when carbon from the martensite diffuses to form clusters of extremely small carbide particles [Ref. 6]. This process produces two effects within the material:

1) Depletion of small amounts of carbon from the martensite matrix thereby lowering the matrix strength [Ref. 7].

2) Formation of a fine precipitate that acts to srengthen the structure through inhibiting interface and dislocation motion [Ref. 8].

E. COMBINED THERMO-MECHANICAL TREATMENT AFFECTS

Combination of these seperate effects into an overall change in yield strength through superposition of each individual effect is possible since the individual processes do not appear to interact with each other. These contributions produce the comparison in the tensile specimens shown in Figure 15 and summarized below.

Process	% diff	KPsi diff	MPa diff
E8 size machining	3.5	3.7	25.5
Thickness machining	11.2	12.2	84.1
Stress relief	26.9	32.4	223.4
Combined	41.6	48.3	333.5

If this total combined increase is now subtracted from the average yield strength found using flat tensile samples from the bottom three locations a yield strength of 108.0 KPsi (745 MPa) results, and if the combined increase (without the added machining effects) is subtracted from the average yield strength from test locations G and K, a yield strength of 111.2 KPsi (745 MPa) results. These values are very close to the actual measured values of 111.0 KPsi (765 MPa) and 106.4 KPsi (734 MPa) respectively indicating the process effects are addative and have little affect on each other.

F. EFFECTS OF AUSTENIZATION AND QUENCH

The results for the flat tensile specimens are invalid due to improper quenching procedures which caused some samples to cool faster than others. Data for these tests are included for completness, but cannot be used for comparison. Additionally the tests indicated that the rapidly quenched samples were extremely brittle displaying at most 1.5 percent elongation at fracture. Only one ring test was completed; brittle fracture occurred resulting in the destruction of the extensometer during the test. Plans were to limit elongation to a maximum of 1.0 percent to ensure a fracture did not occur. However, the ring did fracture at 0.85 percent elongation and the resultant force broke the extensometer before the release mechanism activated. It is, however, interesting to note that the seal remained intact. Yield and ultimate tensile strengths for this ring are much higher than those in the as-recieved cases; thus, the heat treatment performed by the manufacturer has not been duplicated and these results would be useless anyway.

G. HARDNESS TESTING

The hardness of each flat tensile sample was tested as described in Appendix A; six readings were made and averaged to determine the specimens hardness. In the non-stress relieved samples the hardness readings were slightly higher on the side that was originally on the ring exterior. This may be attributed to the slight increase in the amount of cold work on the exterior of the ring due to the roll-straightening operation. Variations of this nature did not appear in the stress relieved or austenitized and quenched specimens. Comparing data from Tables 2 and 4 shows less than a two percent change in the hardness readings which corresponds to a two percent change in the ultimate tensile strengths, further analysis of the respective standard deviations indicates these changes could be attributed to the scatter in the data. This behavior is to be expected since hardness is a better indicator of ultimate tensile strength than of yield strength. Improper quenching procedures for the austenitized and quenched specimens produced the extremely wide variation in readings noted in Table 6. The readings however, were consistent with the variations in ultiamte tensile strengths from the specimens.

H. SYSTEM STIFFNESS

Elastic moduli for each ring were measured based on the slope of the curve during the relaxation of stress on each ring. These values indicate the expanding ring apparatus is a very stiff system although it was later noted that the slope of the curve during relaxation was, to a small degree, dependent on the load relaxation rate for the test.

VII. OBSERVATIONS AND CONCLUSIONS

1) An expanding ring test apparatus can be used to obtain an accurate circumferential yield strength of steel cartridge cases.

2) Straightening and machining of tensile samples to their final ASTM E8 size adds a small increase to the yield strength of the specimens, but the exact amount could not be determined.

3) Machining of flat tensile samples to produce parallel surfaces adds 12.2 KPsi (84.1 MPa) to the base yield strength.

4) Stress relieving at 610 F (321 C) produces a precipitation hardening reaction through the presence of epsilon carbides. This accounts for the largest increase in tensile sample strength, an addition of 32.4 Ksi (223.4 MPa)

5) The combined effects of these three strength additions account for the significant differences between the Navy's standard tensile tests and the actual yield strength of the cartridge cases. (Navy's method over estimates the yield strength by about 40 percent.)

6) Other caliber ammunition may be tested similarly with only a modification to the seal and adjustment of the extensometer.

7) Ring samples require significantly less time and less equipment to prepare than the standard tensile samples.

8) An expanding ring system may also be used to test for ultimate tensile strength without loss of seal integrity.

VIII. RECOMMENDATIONS

1) If the flat tensile tests are to be used, the stress relief heat treatment should not be conducted and the cold work from surface machining to a uniform thickness should be minimized.

2) Use an expanding ring test apparatus to replace the less accurate and more time consuming tensile testing procedures.

3) A motor driven hydraulic pump should be used to insure accurate and constant loading rates.

TABLE 1. Non-Stress Relieved Ring Specimens

Specimen	YS (Ksi)
1A	-----
2A	115.3
7B	110.6
8B	111.7
9B	108.1
1C	113.0
2C	107.5
7G	108.3
8C	105.6
9G	104.4
1K	106.0
2K	107.6

Ring(s)	Mean YS	s
A	115.3	---
B	109.9	2.6
C	110.3	3.9
G	105.0	0.9
K	106.8	1.1
A+B+C	111.0	3.0
G+K	106.4	1.6
ALL	108.9	3.4

TABLE 2. Non-Stress Relieved Tensile Specimens

Specimen	UTS (Ksi)	YS (Ksi)	Hard (Rc)
7A 7A*	162.9 174.6	136.0 132.9	36.5 38.5
8A	166.5	126.7	36.3
9A	179.4	143.6	39.3
1B	160.5	107.0	36.1
2B	161.0	121.6	36.3
7C 7C*	175.2 173.8	137.8 128.4	39.3 38.0
8C	168.4	115.4	37.5
9C 9C	165.6 166.5	125.3 121.6	36.9 37.3
1G	166.2	-----	36.8
2G 2G*	156.6 164.9	109.6 103.9	33.1 33.8
7K 7K*	171.9	114.7 111.3	37.0 35.8
8K	157.3	110.5	35.3
9K 9K	161.8 -----	113.8 107.2	36.0 36.0

Ring(s)	Mean UTS	s	Mean YS	s	Mean HARD	s
A	170.9	7.5	134.8	7.0	37.6	1.3
B	160.8	0.4	114.3	10.3	36.4	0.4
C	169.9	4.3	125.7	8.3	37.9	0.9
G	162.6	5.2	106.8	4.0	35.1	1.9
K	163.7	7.5	111.5	3.0	35.7	0.9
A+B+C (1)	168.6	6.3	126.9	10.5	37.5	1.1
G+K	163.1	5.8	110.1	3.7	35.5	1.3
ALL	171.7	5.1	120.4	11.9	36.6	1.5

* standard extension rate 0.05 inch per minute
(1) tensile specimens require thickness machining

TABLE 3. Stress Relieved Ring Specimens

Specimen	YS (Ksi)
3A	149.8
4A	145.2
10B	-----
11B	140.7
12B	142.7
3C	143.9
4C	140.2
10G	146.0
11G	143.3
12G	145.3
3K	146.5
4K	142.1

Ring(s)	Mean YS	s
A	147.5	3.3
B	141.7	1.4
C	142.1	2.6
G	144.9	1.4
K	144.3	3.1
A+B+C	143.8	3.5
G+K	144.6	1.9
ALL	144.2	2.8

TABLE 4. Stress Relieved Tensile Specimens

Specimen	UTS (Ksi)	YS (Ksi)	Hard (Rc)
10A	174.0	156.0	37.0
11A	172.9	155.3	38.8
11A*	174.0	166.8	39.0
12A	171.0	157.2	37.8
3B	174.3	155.7	36.9
3B*	172.4	159.9	37.9
4B	173.2	157.3	39.5
10C	169.9	153.6	37.3
11C	169.3	155.6	39.0
11C*	167.7	149.9	38.8
12C	158.9	152.5	37.5
3G	168.5	150.2	36.6
3G*	167.1	145.2	36.0
4G	167.7	147.5	36.1
10K	166.0	147.4	36.1
11K	163.4	148.0	34.3
11K*	163.4	147.2	35.0
12K	159.8	145.7	35.4

Ring(s)	Mean UTS	s	Mean YS	s	Mean HARD	s
A	173.0	1.4	158.8	5.4	38.2	0.8
B	173.3	1.0	157.6	2.1	38.2	1.1
C	166.5	5.1	152.9	2.4	37.9	1.0
G	167.8	0.7	147.6	2.5	36.5	0.5
K	163.2	2.6	147.1	1.0	35.3	0.7
A+B+C (1)	170.7	4.5	156.3	4.4	38.1	0.9
G+K	165.1	3.1	147.3	1.6	35.8	0.8
ALL	168.5	4.8	152.8	5.7	37.2	1.4

* standard extension rate 0.05 inch per minute
(1) tensile specimens require thickness machining

TABLE 5. Austenitized and Quenched Ring Specimens

Specimen	UTS (Ksi)	YS (Ksi)
5K	207.7	195.8

NOTE: Only one test was completed due to destruction of the extensometer and potentially dangerous brittle fracture of the ring.

TABLE 6. Austenitized and Quenched Tensile Specimens

Specimen	UTS (Ksi)	YS (Ksi)	Hard (Rc)
13A	126.2	83.4	40.0
14A	110.2	71.4	37.7
15A	109.9	72.2	20.3
15A	143.8	101.2	50.0
5B	213.0	143.7	45.2
6B	179.6	125.3	43.0
13C	260.0	190.3	54.8
14C	102.1	73.5	49.5
15C	161.9	91.0	43.8
5G	264.0	166.4	49.5
6G	142.4	93.6	43.8
13K	103.8	69.7	45.5
14K	89.9	69.2	33.0
15K	99.2	60.7	35.5

NOTE: Large amount of scatter in data due to variation in quenching rate. No further reduction of data conducted.

TABLE 7. Variable Extension Rate Effects

PROCESS	EXTENSION RATE	
NO STRESS RELIEF	0.2 (in/min)	0.05 (in/min)
YS (Ksi)	120.4	119.0
UTS (Ksi)	166.7	171.1
# Samples	15	4
STRESS RELIEF		
YS (Ksi)	152.8	153.8
UTS (Ksi)	168.5	168.9
# Samples	13	5

Data from Tables 2 and 4.

TABLE 8. Sample Preparation Effects Summary

Position	Ring	Flat Tensile		
	YS (Ksi)	YS (Ksi)	UTS (Ksi)	Hard (Rc)
No Stress Relief				
A+B+C	111.0	126.9	168.6	37.5
G+K	106.4	110.1	163.1	35.5
Stress Relief				
A+B+C	141.9	156.3	170.7	38.1
G+K	144.6	147.3	165.1	35.8

Data from Tables 1, 2, 3, and 4.

TABLE 9. Property VS Process Summary

Property	Ring	Tensile	Tensile*	Norris**
		NO STRESS RELIEF		
UTS (Ksi)		166.7	154.4	
YS (Ksi)	108.9	120.4	133.6	
HARD (Rc)		36.6	33.5	
		STRESS RELIEF		
UTS (Ksi)		168.5	165.6	178.2
YS (Ksi)	143.4	152.8	148.8	159.0
HARD (Rc)		37.2	37.3	37.8
		AUSTENIZATION		
UTS (Ksi) &	207.7			
YS (Ksi) &	195.8			
HARD (Rc)				

Data from Tables 1, 2, 3, 4, and 6
* Data from reference 2.
** Data from manufacturer.
& Data from ring 5K only.

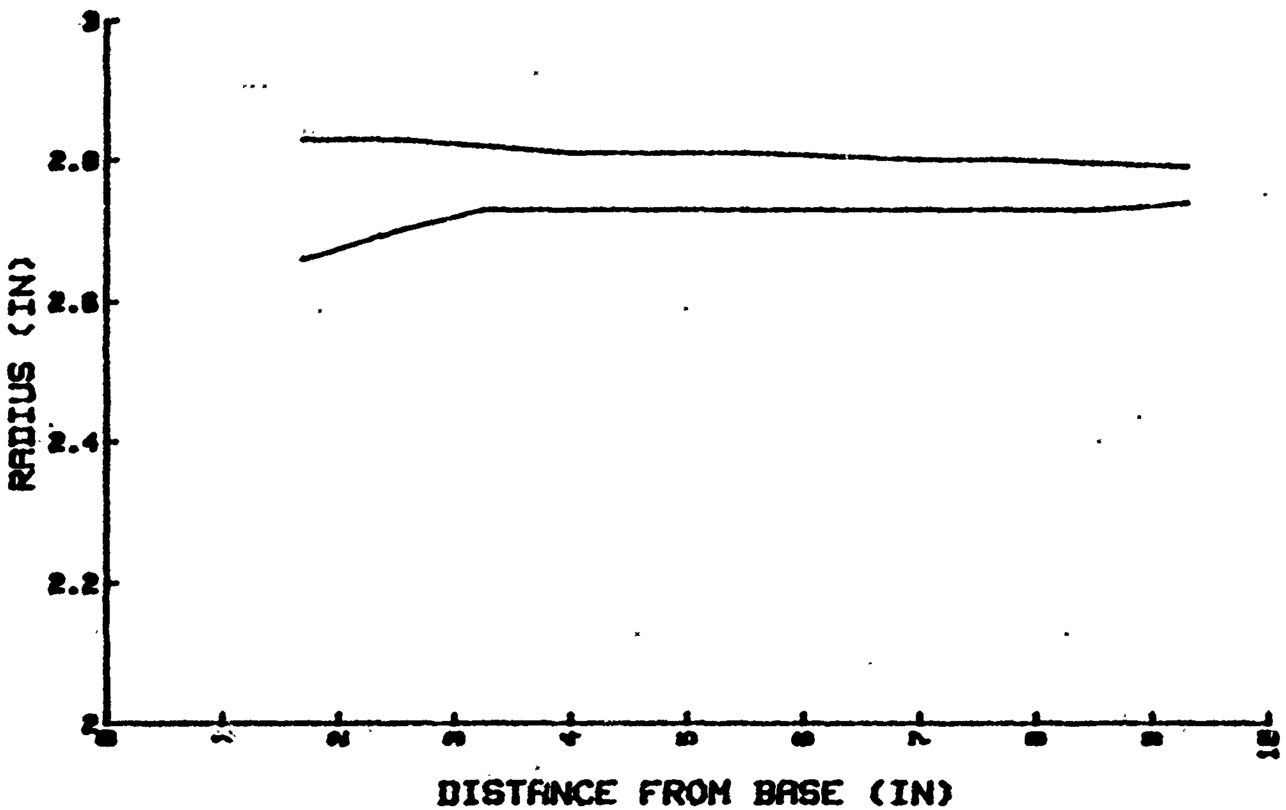
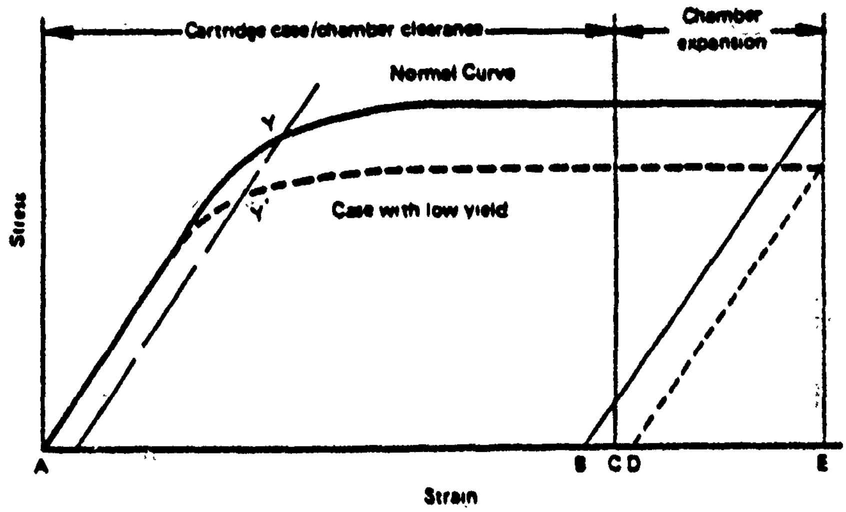
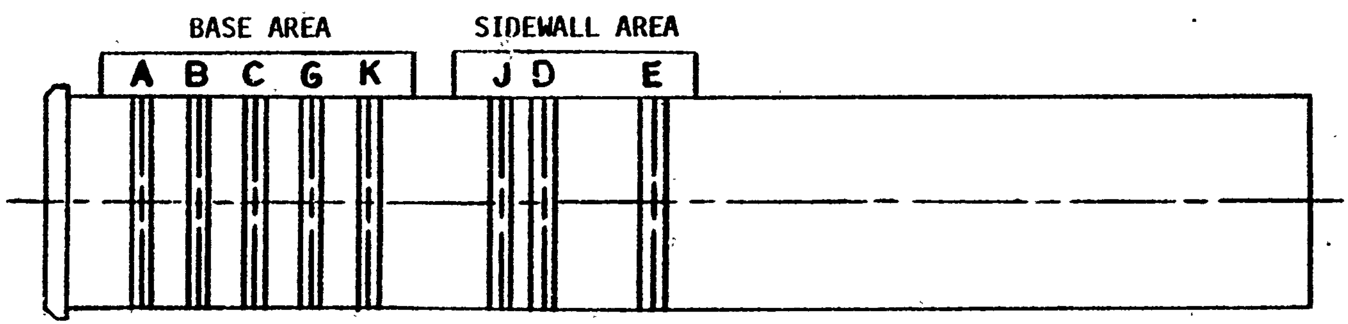


FIGURE 1. Cartridge Case Dimensions



Y, Y' – Yield points
BC – Resultant gun/case clearance
CD – Resultant gun/case interference
BE, DE – Case elastic recovery
CE – Gun chamber elastic recovery
AB, AD – Case plastic deformation

FIGURE 2. Cartridge Case Response During Firing



Location from Base

A - 2.5 in (6.35cm)	K - 8.5 in (21.59cm)
B - 4.0 in (10.16cm)	J - 12.0 in (30.48cm)
C - 5.5 in (13.97cm)	D - 13.0 in (33.02cm)
G - 7.0 in (17.78cm)	E - 16.0 in (40.64cm)

FIGURE 3. Cartridge Case Reference Positions

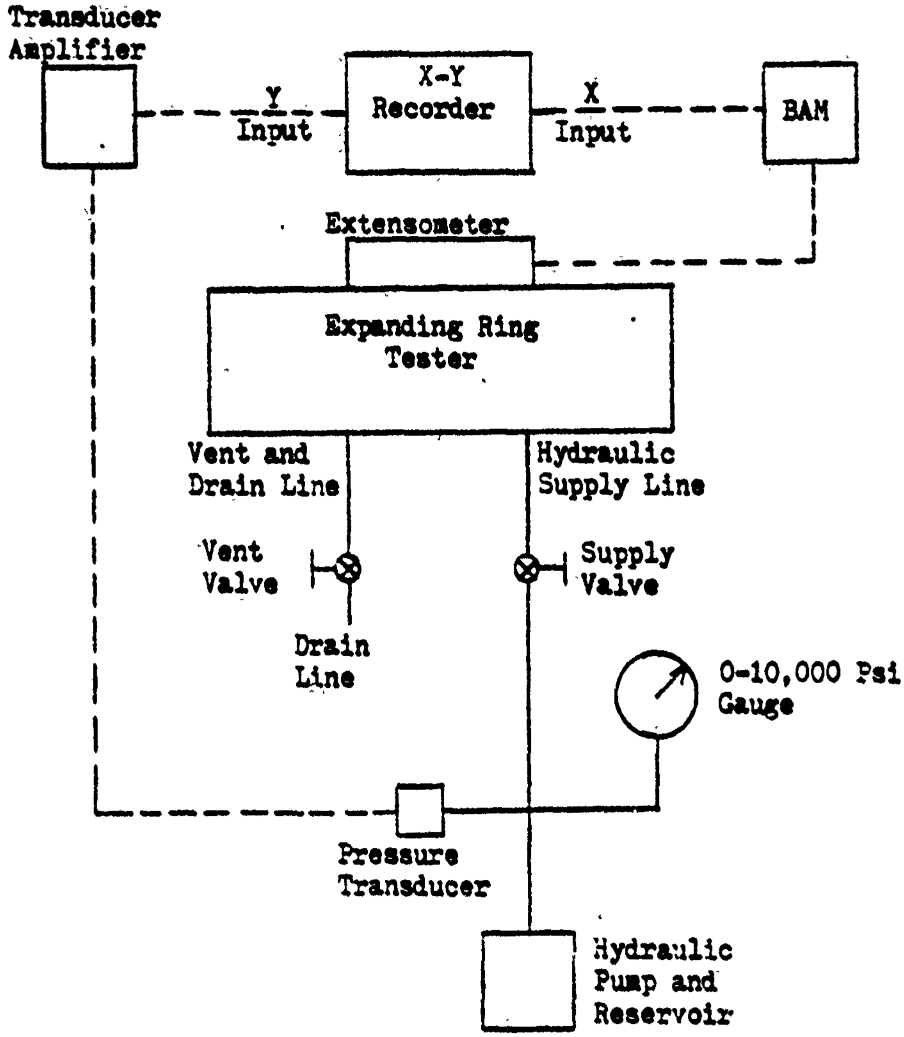


FIGURE 4. Expanding Ring System Schematic

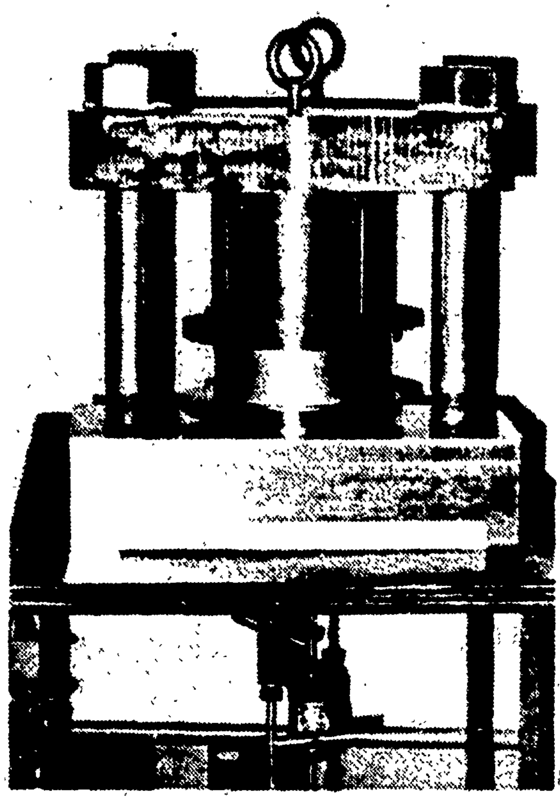


FIGURE 5. Expanding Ring Tester

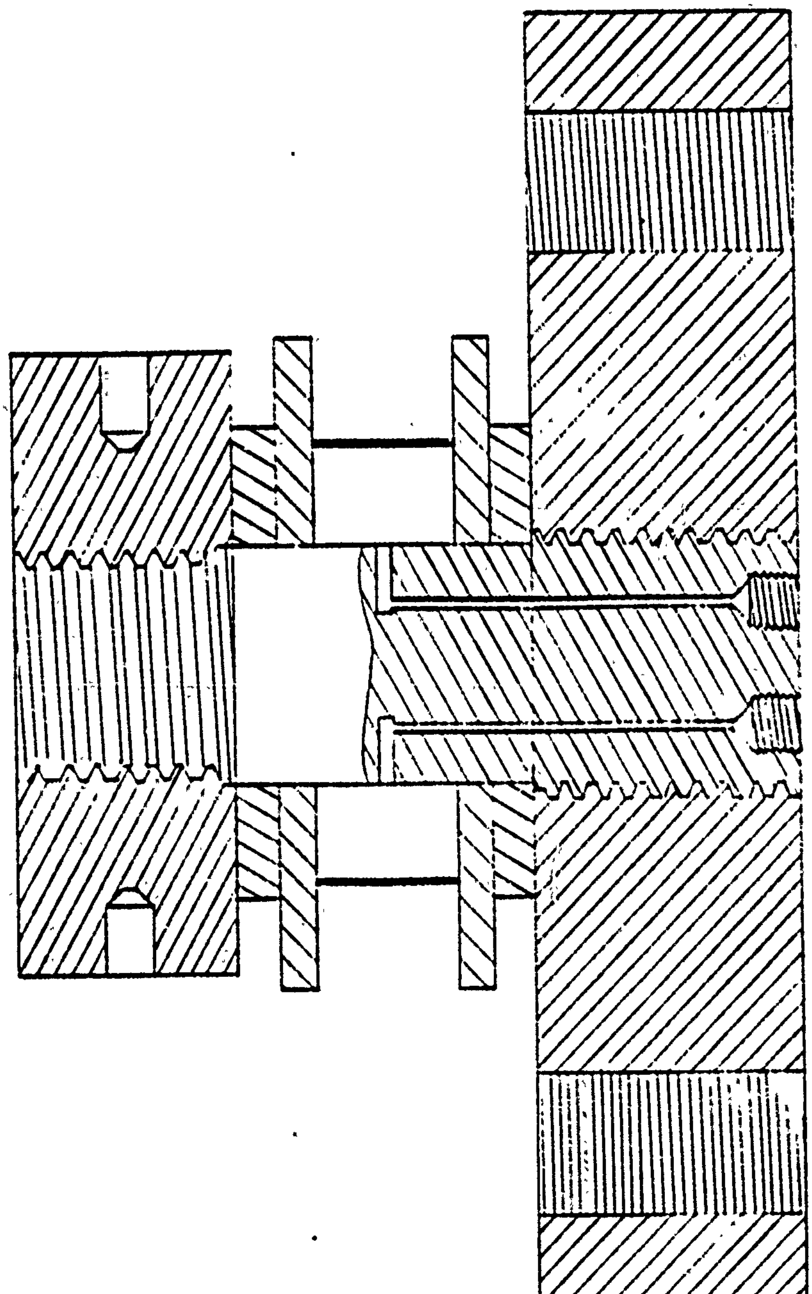


FIGURE 6. Expanding Ring Tester

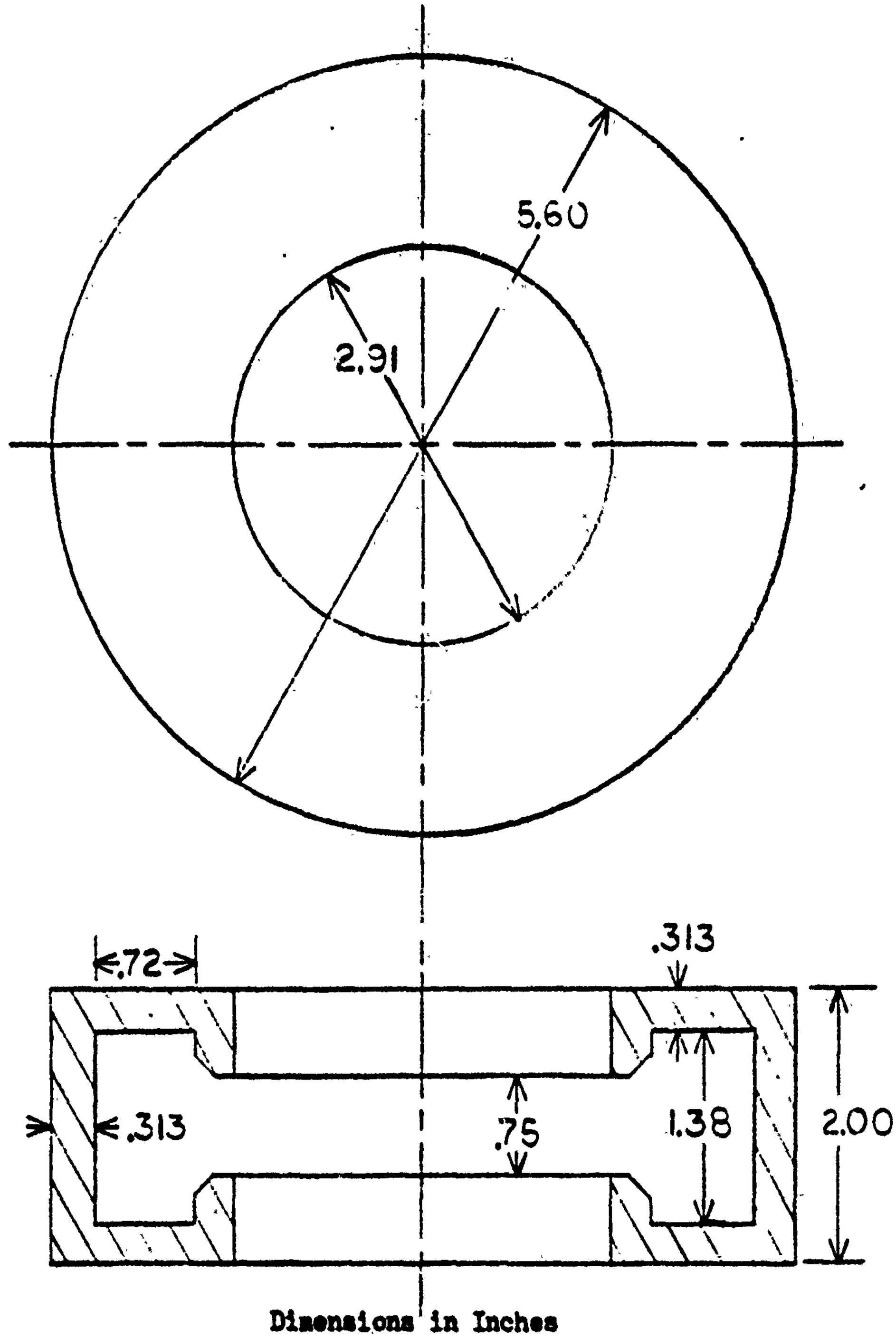


FIGURE 7. Seal Specifications

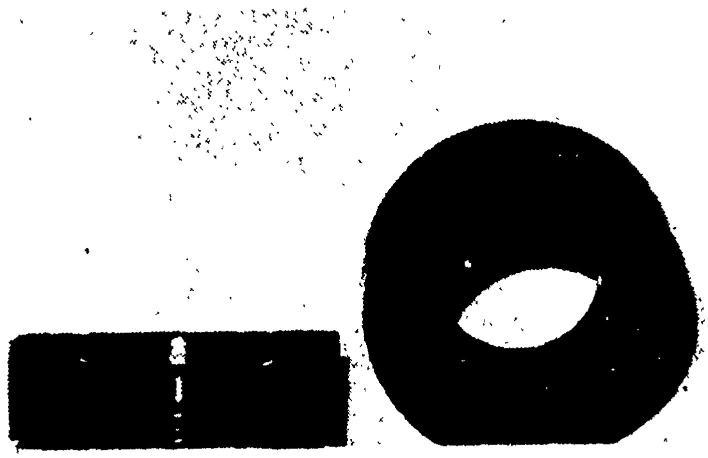


FIGURE 8. Seal

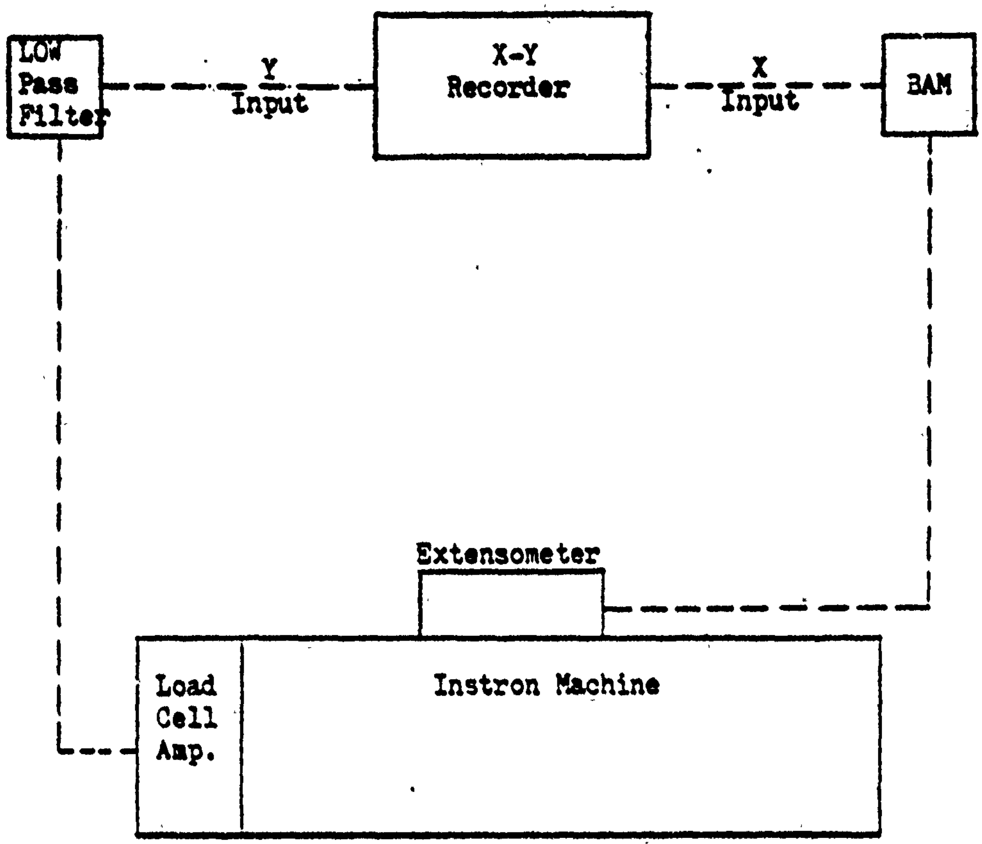


FIGURE 9. Tensile Test Schematic

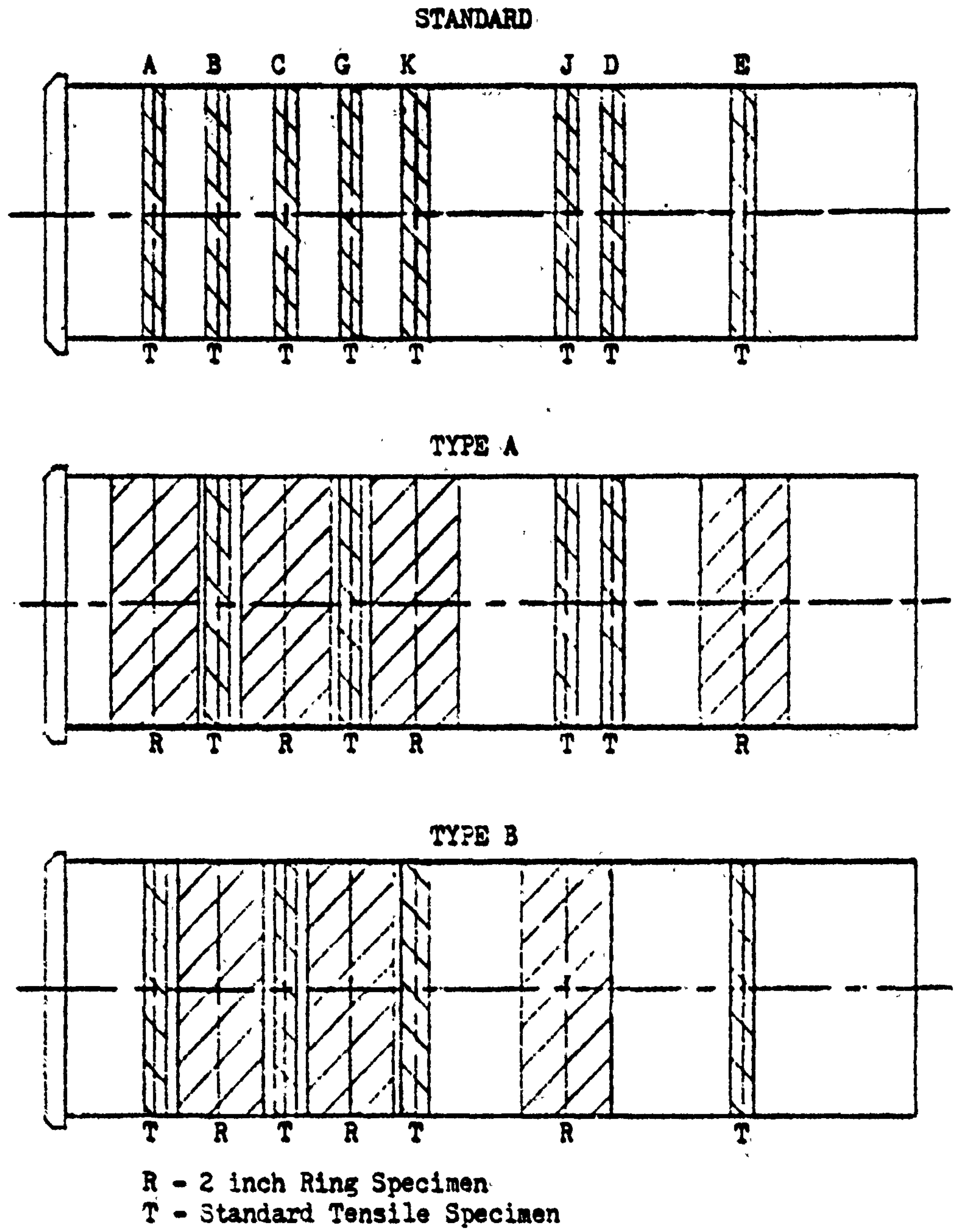


FIGURE 10. Case Sampling Schematic

		TYPE A		TYPE B	
Sample Preparation	Specimen Type	Number of Specimens	Number of Cases	Number of Specimens	Number of Cases
Stress Relief 610 F	Ring	6	2	6	3
	Straight	8		18	
No Stress Relief	Ring	6	2	6	3
	Straight	8		18	
Austenitize and Quench	Ring	6	2	6	3
	Straight	8		18	

Case T1	All rings as cut from the case.
Case T2	Ring A Machined to constant thickness. Ring C As cut from the case. Ring K Stress relieved at 610 F for 30 minutes.
Case T3	Ring A Austenitized, quenched, and stress relieved. Ring C Austenitized and quenched.

FIGURE 11. Testing Matrix

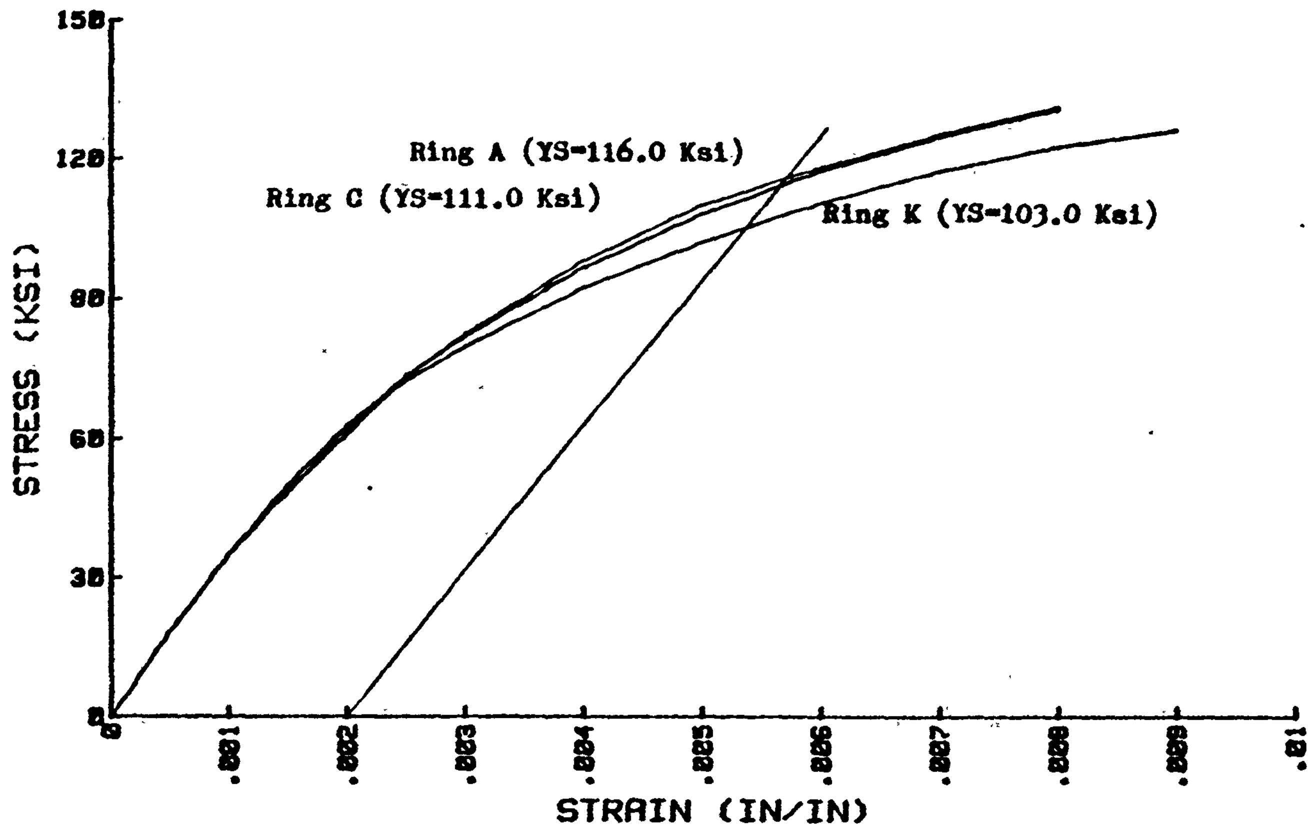


FIGURE 12. Case T1 Stress-Strain Curve

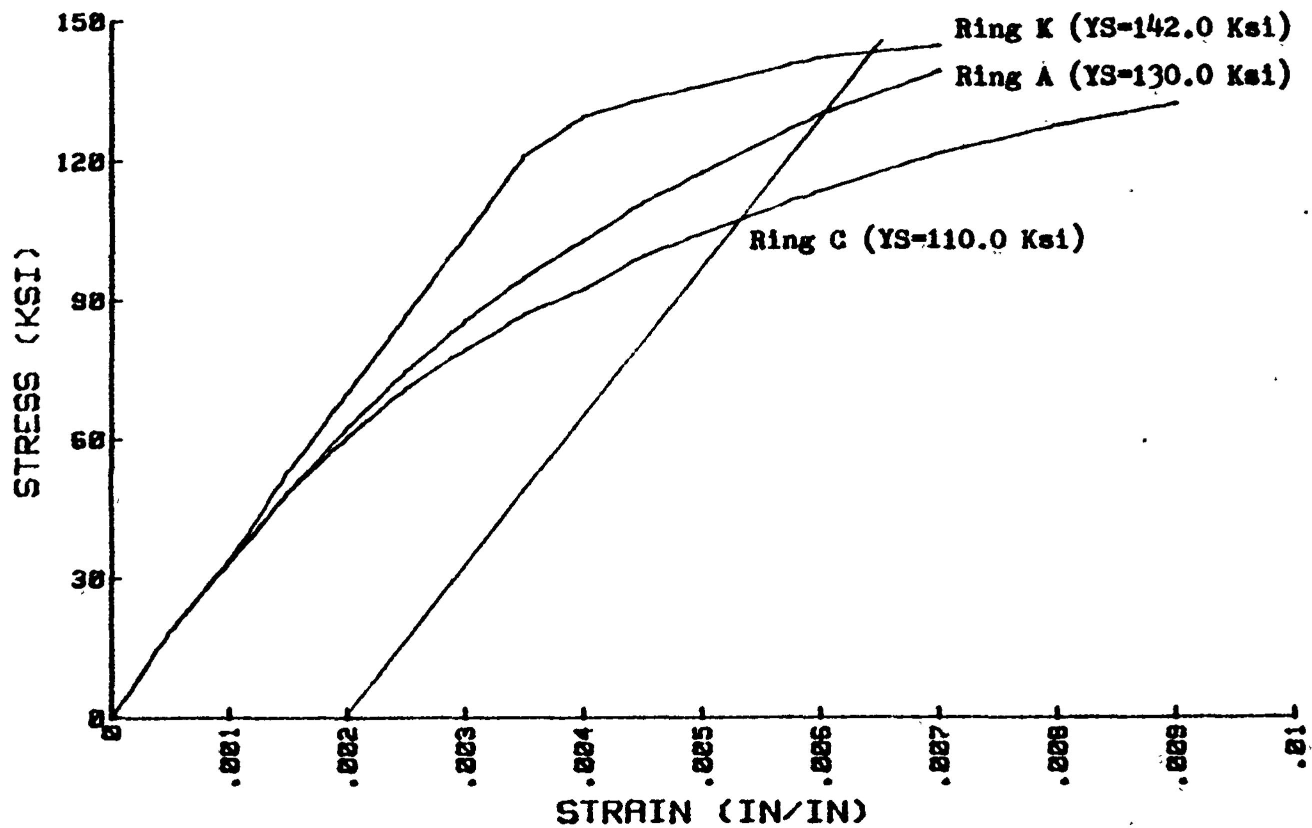
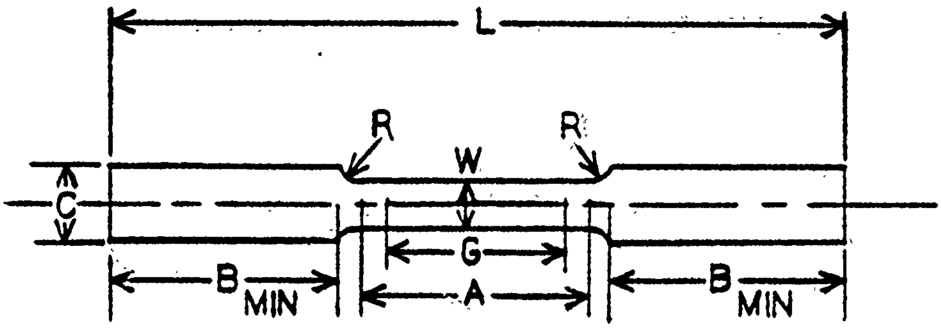


FIGURE 13. Case T2 Stress-Strain Curve



B = 1.25 inch

A = 1.25 inch

G = 1.0 ± 0.003 inch

R = 0.25 inch

C = 0.375 inch

W = 0.250 ± 0.002 inch

L = 4 inch

FIGURE 14 ASTM E8 Tensile Test Specimen

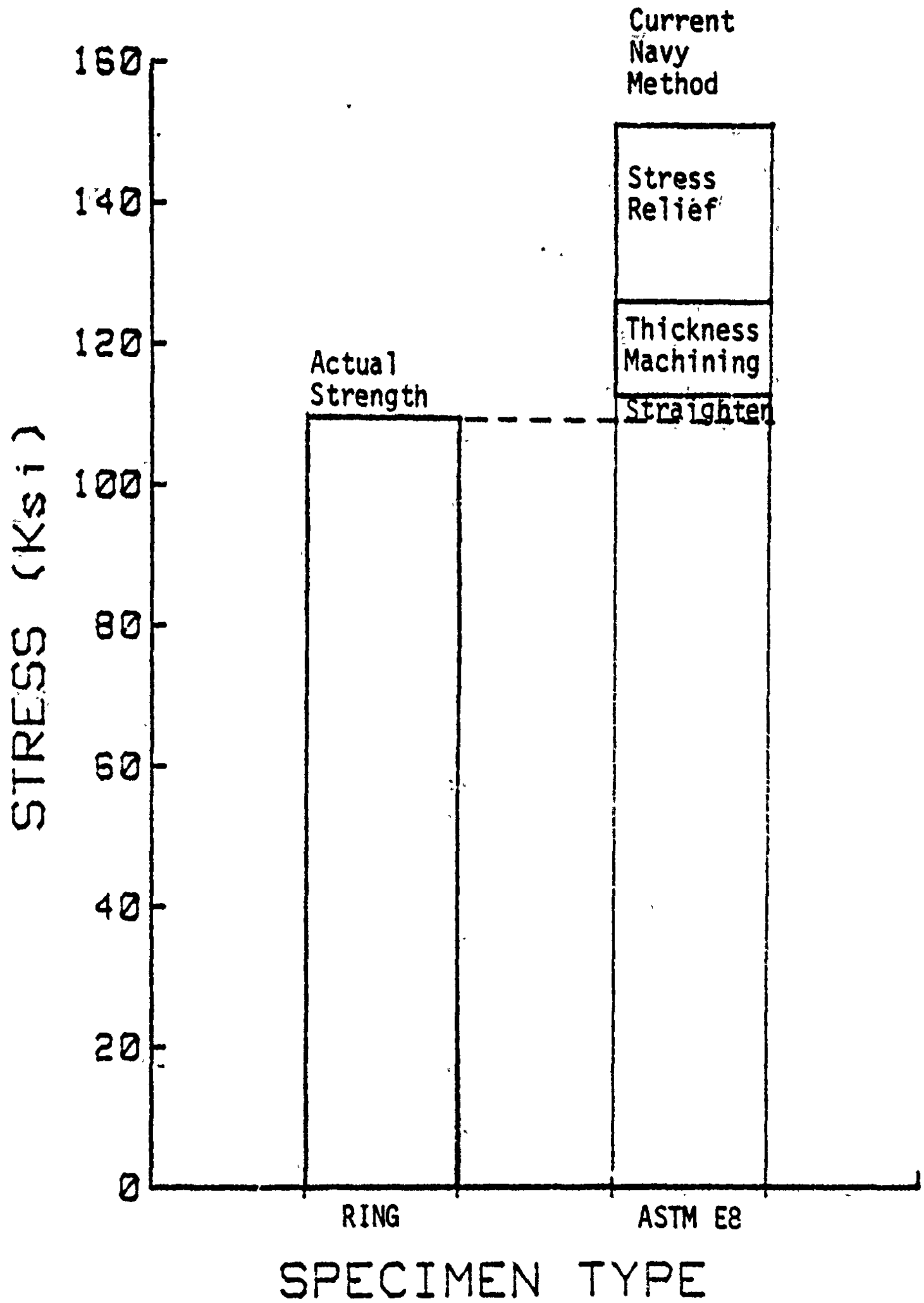


FIGURE 15. Effects Summary

APPENDIX A

TENSILE AND RING SPECIMEN PREPARATIONS

A. TENSILE SPECIMEN PREPARATION

1) Cut and identify cicumferential rings from cases in accordance with specimen location sketch (fig10) and matrix (fig 11).

2) Maintain ring widths slightly greater than the final specimen grip width to allow for subsequent shaping operations.

3) Machine both inside and outside surfaces of specimen segments A, B, and C (prior to cutting the rings) to produce parallel specimen face surfaces, nominal thickness to be between 0.060 and 0.080 inch. Note: Specimen ring segments G, K, J, D, and E will not require surface machining prior to ring cutting.

4) Cut rings in half, each half to have identical identification.

5) Retain one set of ring segments for possible retest.

6) Remove edge burrs.

7) Sand edges lightly to remove any possible stress raisers.

8) Straighten specimens by passing them through a sheet metal roller, using a minimum number of passes, until bowing cannot be detected with a straight edge.

9) Machine all specimen segments to dimensions specified in ASTM E8, subsize specimens (fig 14). Note: Several specimens may be machined at one time.

10) Individually sand the edges of the gauge section to obtain a 0.003 to 0.005 inch taper from the end to the middle of the gauge section.

11) Smooth all edges of the necked down area.

12) Stress relieve all segments at 610 +/- 10 F for 30 +/- 5 minutes.

13) Cool all segments to room temperature for a minimum of 1 hour.

B. RING SPECIMEN PREPARATION

1) Cut and identify rings in accordance with the reference position index (fig 10) and the sampling matrix (fig 11) provided.

2) Rings should be cut to 2.0 +/- 0.003 inch height with ends parallel. Note: Rings may be cut to exact height specified since no further machining is required.

3) Remove burrs and rough spots on ring edges.

APPENDIX B

TENSILE AND RING TEST PROCEDURES

A. TENSILE SPECIMEN TESTING

1) Perform hardness tests on all specimens by taking measurements in the specimen grip area of adjacent to the grip area away from the necked down area. Record all measurements.

2) Perform hardness tests in accordance with ASTM E18.

3) Record all measurements.

4) Perform tensile and elongation tests on all specimens in accordance with ASTM E8.

5) Test all tensile specimens using a head separation rate of 0.05 inch per minute.

6) Retain original stress-strain curves. Note magnification and scale on all stress-strain curves.

7) Measure gauge dimensions as accurately as possible.

8) Record gauge cross-sectional area to four decimal places.

B. RING SPECIMEN TESING

1) Mark the ends of four evenly spaced diameters on the rings. Note: This means a total of eight evenly spaced marks.

2) At each of the eight marks, on the inside and outside

of the ring make a mark at the mid-ring hieght. Note: Nominaly this should be at one inch from either side.

3) Measure the inside and outside diameters at each of the four marked diameters at mid-hieght.

4) Measure the thickness at all eight marks at mid-. height. Note: A micrometer with pointed ends should be used.

5) Record all measurements to four decimal places.

6) Perform expanding ring test on all specimens in accordance with ASTM E8 and A370.

7) All tests should be conducted with the same extension rate 0.2 inch per minute.

8) Specimens should be expanded to a maximum of 1.5 percent strain. Note: This is due to extensometer limits and for equipment and personnel safety.

9) Retain original load-displacement curve and note the scale used on each axis.

10) Caution should be used at each step of the testing procedure due to operation pressures of several thousand PSI.

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