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RAPID HEATING TENSILE TESTS OF HYDROGEN-CHARGED HIGH-ENERGY-RATE-FORGED 316L STAINLESS STEEL (U)

INTRODUCTION

316L stainless steel is a candidate material for construction of equipment that will be exposed to tritium. Proper design of the equipment will require an understanding of how tritium and its decay product helium affect mechanical properties. This memorandum describes results of rapid heating tensile testing of hydrogen-charged specimens of high-energy-rate-forged (HERF) 316L stainless steel. These results provide a data base for comparison with uncharged and tritium-charged-and-aged specimens to distinguish the effects of hydrogen and helium. Details of the experimental equipment and procedures and results for uncharged specimens were reported previously.[1]

SUMMARY

Rapid heating tensile tests of hydrogen-charged HERF 316L stainless steel specimens showed that internal hydrogen had very little effect on strength and ductility.

DISCUSSION

Experimental

Round bar specimens were machined from high-energy-rate-forged 316L stainless steel. The gage diameter was 0.11 inch (2.9 mm) and the gage length was 0.87 inch (22 mm). Specimens were charged with hydrogen by heating them for eight days at 350^{o}C in a vessel pressurized with hydrogen at 1200 psi. Calculations made with a finite-difference program for diffusion of hydrogen in stainless steels indicated that the hydrogen concentration was uniform along the specimen radius at 3.1 cc per cc of metal.[2] Rapid heating tensile testing of these hydrogen-charged specimens was used to determine the effects of internal hydrogen on mechanical properties.

Derivative Classifier J. P. Howell

Rapid heating tensile tests up to 1017°C were performed on an Instron tensile testing machine equipped with an environmental chamber connected to an off-gas exhaust system to remove evolved tritium and a quartz lamp heater to heat the specimen.[1] Temperatures were controlled and monitored with small thermocouples spot-welded to the specimens. Specimens were heated in air to the desired test temperatures within about a minute and held at constant temperature (within 20°C) for testing.

Ultimate tensile strength, 0.2% offset yield strength, total elongation, uniform elongation and nonuniform elongation were determined from load-time recordings. Strength values are reported in thousands of pounds per square inch (ksi). Uniform elongation was considered to occur under uniaxial tension up to the point of maximum load where necking usually begins. Necking introduces triaxial stresses that cause nonuniform elongation until failure occurs. Reduction-in-area values were determined from both optical microscope(OM) and scanning electron microscope(SEM) measurements of specimen diameters at the points of fracture. Reduction-in area and elongations are reported as percentages. Images showing topography of fracture surfaces were recorded by scanning electron microscopy.

Results

Photographs of the fractured specimens are shown in Figure 1. All the specimens failed in a ductile manner. Specimens tested at room temperature, 346 and 631°C exhibited cup-and-cone fractures. Extensive necking (plastic attenuation) occurred for specimens tested at 829 and 1017°C. SEM images of fracture surfaces are shown in Figure 2. All fracture surfaces exhibited dimpled, transgranular rupture. (The specimen tested at 1017°C had been drawn almost to a point which was damaged during subsequent handling. However, a region about 50 micrometers across had dimpled topography.)

Figure 3 shows the variations in strength values with temperature. At room temperature, values of 98.1 and 62.2 ksi were determined for ultimate tensile strength and offset yield strength, respectively. Values of ultimate tensile strength and offset yield strength exhibit parallel decreases with increasing temperature to 62.2 and 32.9 ksi, respectively, for the test at 631°C. Between 631 and 829 °C, ultimate tensile strength decreases significantly to 32.4 ksi while offset yield strength decreases only slightly to 29.3 ksi. For the test at 1017°C, ultimate tensile strength (10.9 ksi) was only slightly higher than offset yield strength(10.0 ksi).

Changes in ductility with temperature as indicated by values of reduction-in-area, total elongation, uniform elongation and nonuniform elongation are shown in Figure 4. Reduction-in-area remains fairly constant at about 80% between room temperature and 631°C but increases to near 100% at 829 and 1017°C. Total elongation, which has values of about 33% for tests at room temperature and 1017°C, has a minimum value of 21.3% for the 631°C test. Uniform elongation decreases from 24.1% to 15.1% between room temperature and 631°C and is the major contributor to total elongation in this temperature range. Between 631 and 829°C, uniform elongation decreases sharply to 4.0% and remains low at 5.1% up to 1017°C. In contrast, nonuniform elongation, which has low values of 5.9-8.8% below 631°C, increases sharply to 19.3% at 829°C and 28.1% at 1017°C and is the main component of total elongation above 829°C.

Load-time recordings for the test at 631°C exhibited serrations in the uniform elongation portions caused by dynamic strain-aging (the Portevin-LeChatelier effect).[3]

Comparisons of Results With Those For Uncharged Specimens

The ductile fractures (Figure 1) and the transgranular, dimpled rupture surfaces (Figure 2) observed for hydrogen-charged specimens were like those observed for uncharged specimens. [1]

The effects of internal hydrogen on a specific mechanical property are conveniently visualized by overlay graphs of results for uncharged and hydrogen-charged specimens as shown in Figures 5 through 10.

Ultimate Strength

Figure 5 shows a comparison of ultimate tensile strength versus temperature for hydrogen-charged and uncharged HERF 316L stainless steel. For room temperature tests, the slightly lower value of 98.1 ksi for hydrogen-charged specimens compared to 100.9 ksi for uncharged specimens is considered statistically significant. In tests at higher temperatures, the decrease in ultimate tensile strength with increasing temperature is the same for both hydrogen-charged and uncharged specimens.

Offset Yield Strength

The decrease in offset yield strength with increasing temperature is the same for both hydrogen-charged and uncharged specimens as shown in Figure 6. The higher value of 43.8 ksi for the hydrogen-charged specimen tested at 346^{o}C compared to 38.5 ksi for the uncharged specimen tested at 315^{o}C may be statistically significant and represent a strengthening effect of hydrogen.

Reduction in Area

Figure 7 shows a comparison of reduction-in-area versus temperature for hydrogen-charged and uncharged specimens. Between room temperature and 600^{o}C, values for reduction-in-area determined for hydrogen-charged specimens were generally several percent lower than values determined for uncharged specimens. Although standard deviations are probably on the order of several percent (based on multiple determinations at room temperature), these differences may be real and represent a decrease in ductility caused by the hydrogen. The increase in reduction-in-area to near 100% for tests above 800^{o}C appears to be nearly identical for both hydrogen-charged and uncharged specimens.

Elongation

Variations in total elongation, uniform elongation and nonuniform elongation with increasing temperature for hydrogen-charged and uncharged specimens are shown in Figures 8, 9 and 10, respectively. Hydrogen appears to have no statistically significant influence on any of these ductility parameters over the temperature range of the tests.

Steels generally exhibit minima in total elongation versus temperature. Resolution of total elongation into uniform and nonuniform components explains the reason for this. As shown in Figure 9, uniform elongation decreases with increasing temperature with a steep drop between 600 and

800°C. In contrast, nonuniform elongation, which has low values between room temperature and 600°C, increases sharply with temperature above 600°C as shown in Figure 10. The minimum in total elongation occurs in the transition temperature range where the major component is changing from uniform elongation to nonuniform elongation.

CONCLUSIONS

These rapid heating tensile tests have shown that internal hydrogen has very little effect on strength and ductility of HERF 316L stainless steel. Possible effects include a slight decrease in ultimate tensile strength at room temperature, a slight increase in offset yield strength near 350°C and a small decrease in reduction-in-area between room temperature and 600°C.

The 600-800°C transition region in HERF 316L stainless steel manifests itself in nonuniform elongation, reduction-in-area and, possibly, ultimate tensile strength which are influenced by the onset of necking.

FUTURE STUDIES

The results of rapid heating tensile tests will be compared with results of similar test on tritium-charged-and-aged specimens to determine the effects of internal helium on strength and ductility of HERF 316L stainless steel.

ACKNOWLEDGEMENTS

Initial stages of sample preparation and equipment development were supervised by P. E. Zapp, K. E. Kain-Slaughter and A. K. Birchenall. The rapid h eating tensile testing equipment was developed by L. J. Harpring and E. R. Selden. Special appreciation is express to R. L. Cone for assembly and checkout of the equipment and performance of the tests.

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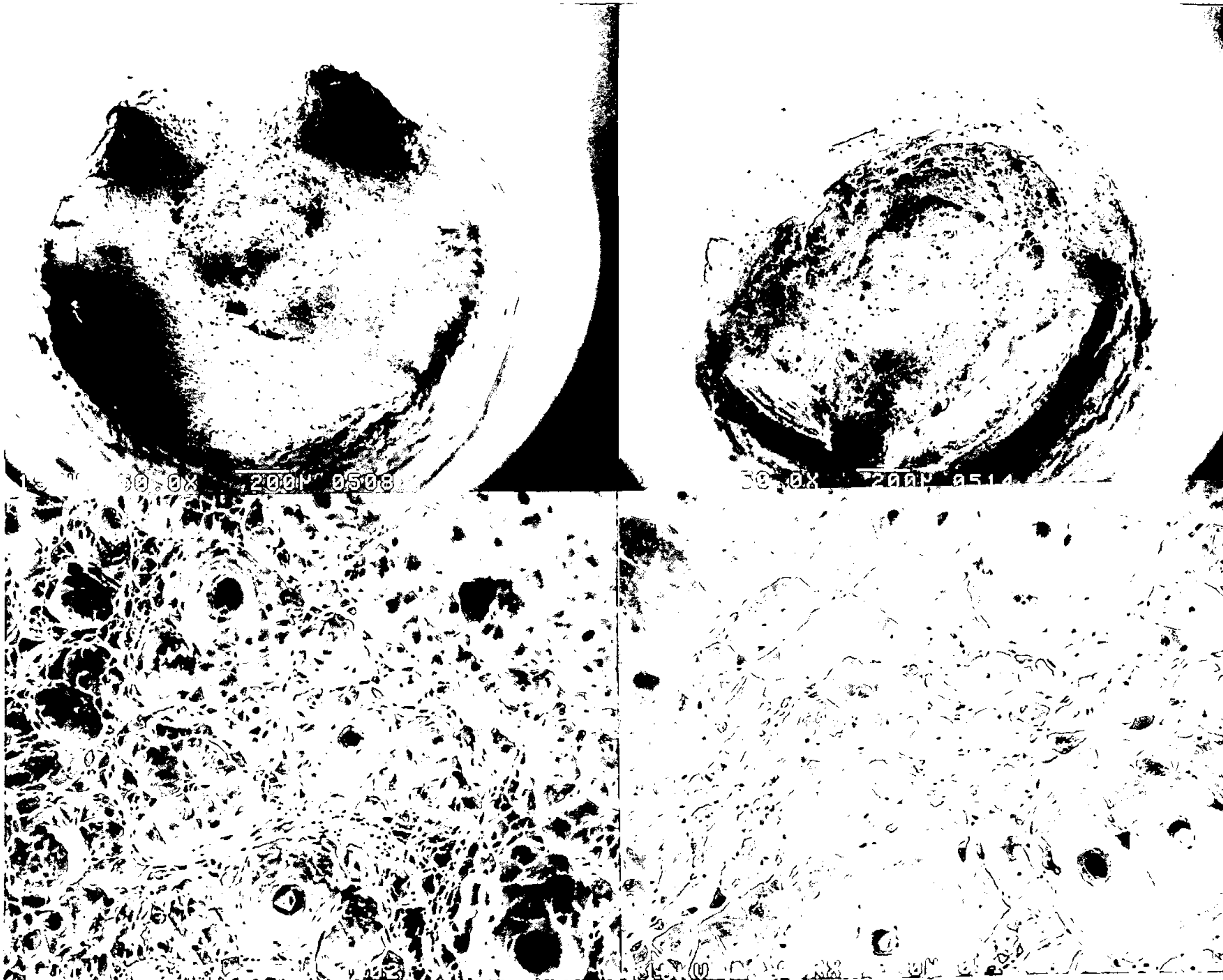
1. W. C. Mosley, Rapid Heating Tensile Tests, DPST-87-591, August 12, 1987.

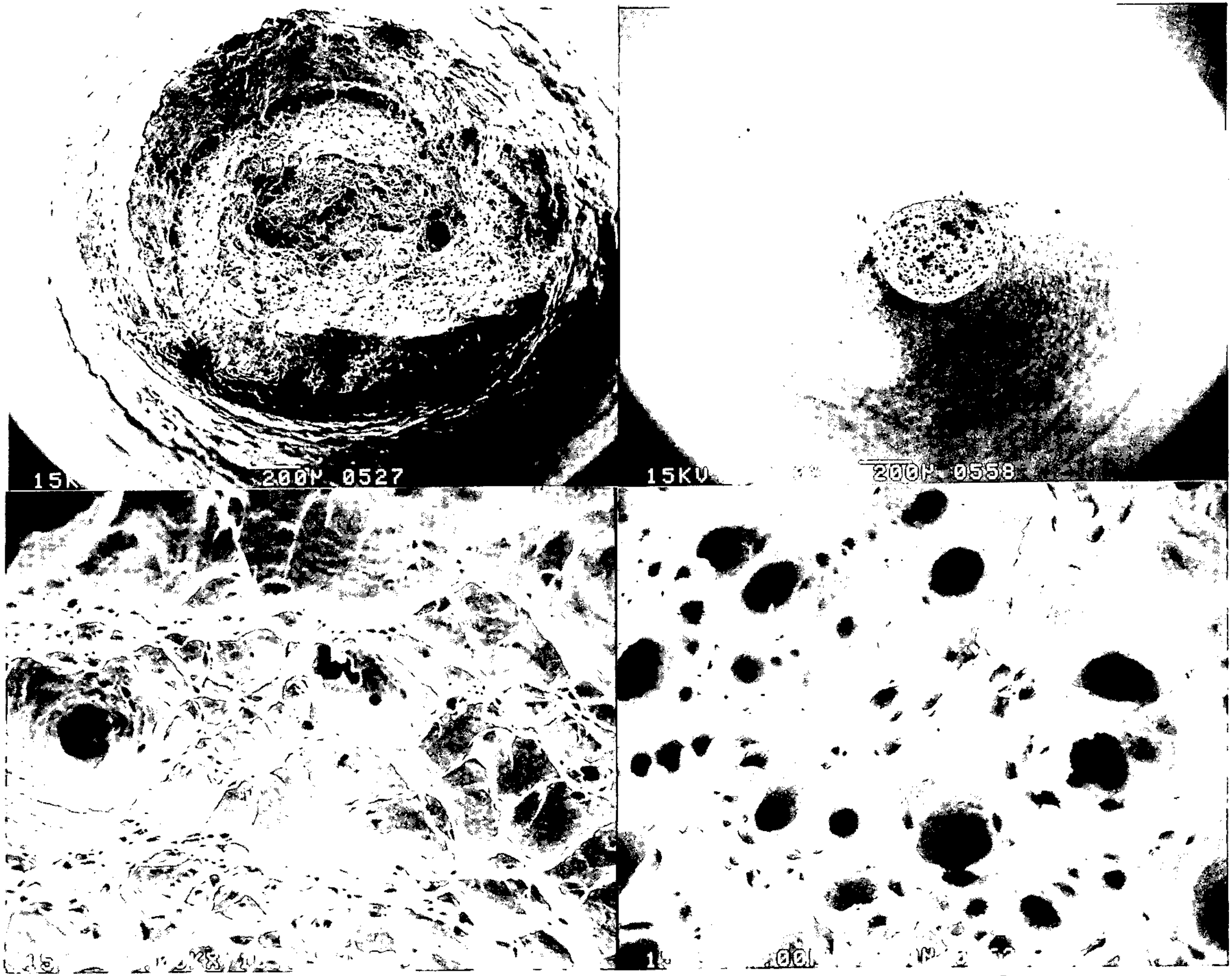
2. K. E. Kain, Finite-Difference Program for Hydrogen Diffusion, DP-1738, March 1987.

3. G. E. Dieter, Mechanical Metallurgy. (McGraw-Hill, New York, 1970).



Room Temperature 346°C

FIGURE 2. Fracture Surfaces of Specimens of Hydrogen-Charged HERF 316L Stainless Steel from Rapid Heating Tensile Tests



631°C

829°C

FIGURE 2 (Continued). Fracture Surfaces of Specimens of Hydrogen-Charged HERF 316L Stainless Steel from Rapid Heating Tensile Tests

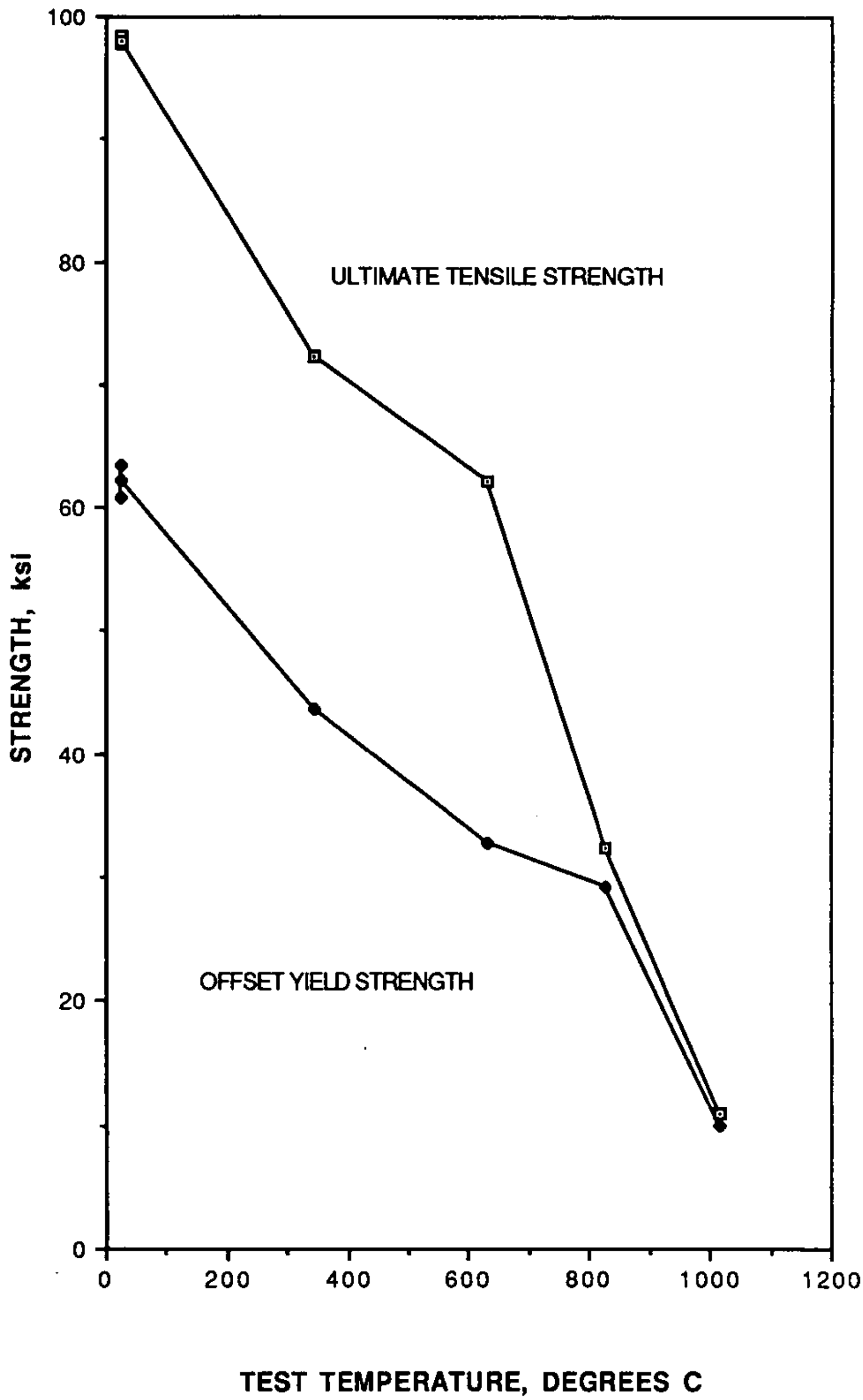


FIGURE 3. STRENGTH VERSUS TEMPERATURE FOR HYDROGEN CHARGED HERF 316L STAINLESS STEEL

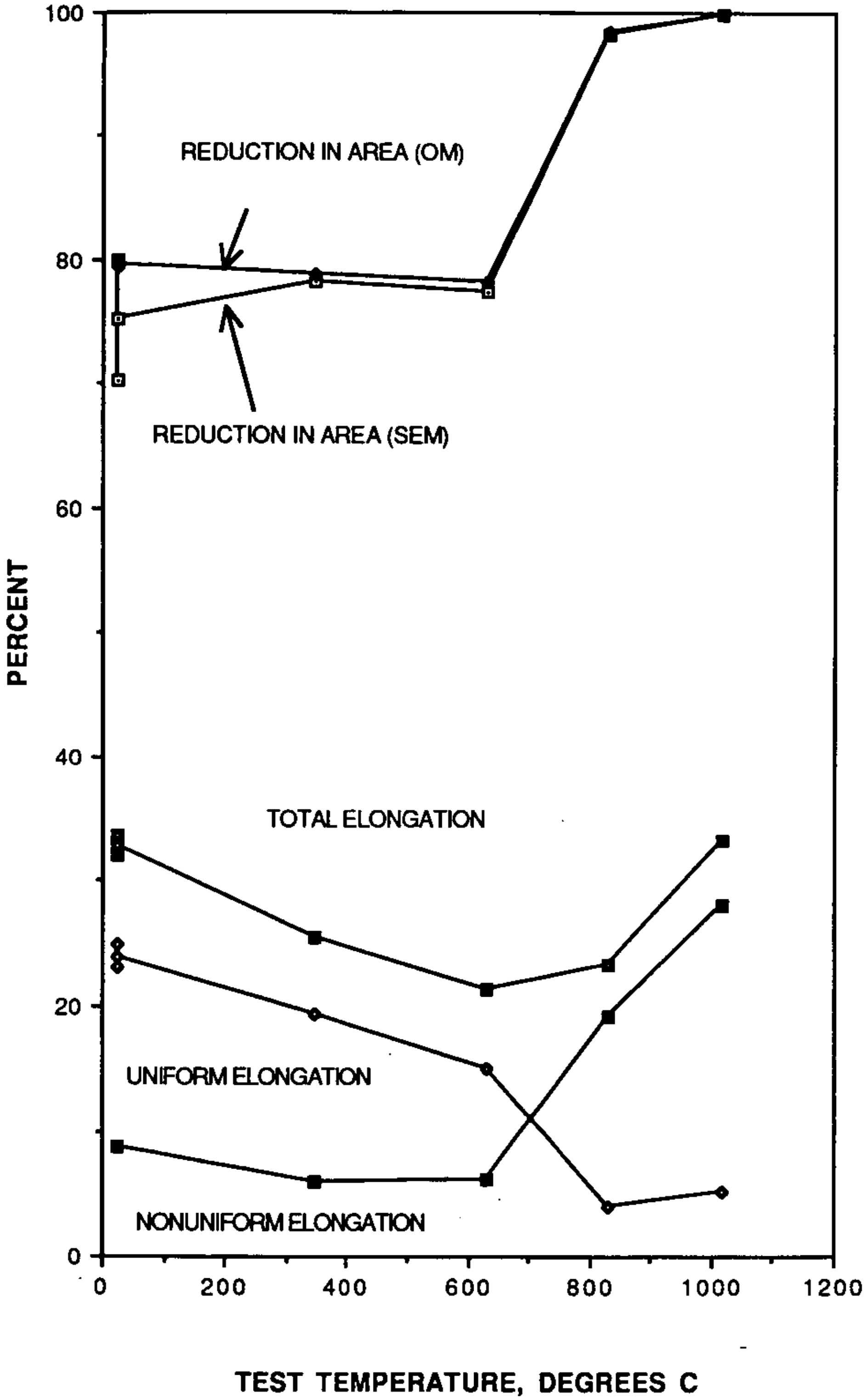


FIGURE 4. DUCTILITY VERSUS TEMPERATURE FOR HYDROGEN-CHARGED HERF 316L STAINLESS STEEL

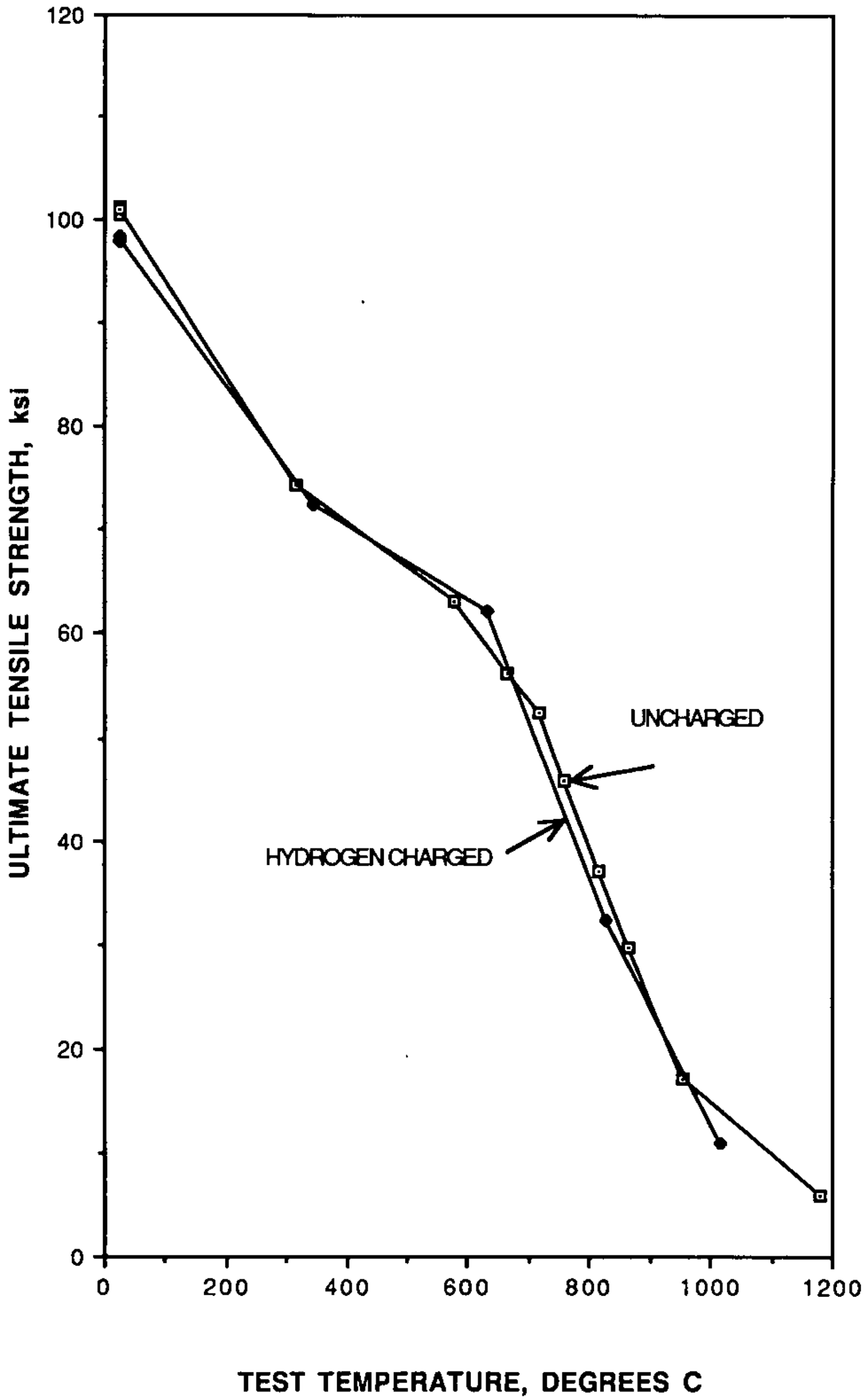


FIGURE 5. ULTIMATE TENSILE STRENGTH VERSUS TEMPERATURE FOR HERF 316L STAINLESS STEEL

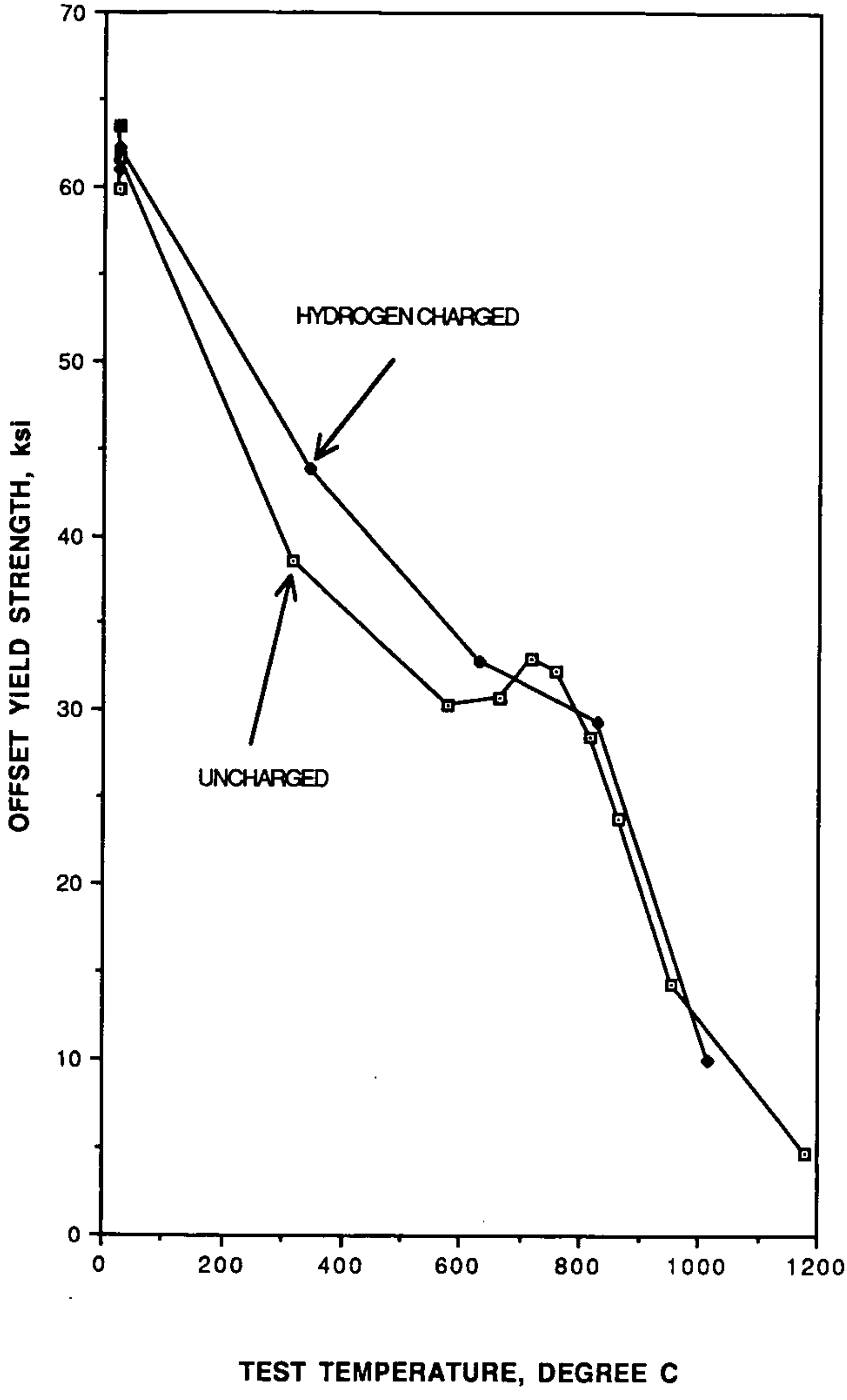


FIGURE 6. OFFSET YIELD STRENGTH VERSUS TEMPERATURE FOR HERF 316L STAINLESS STEEL

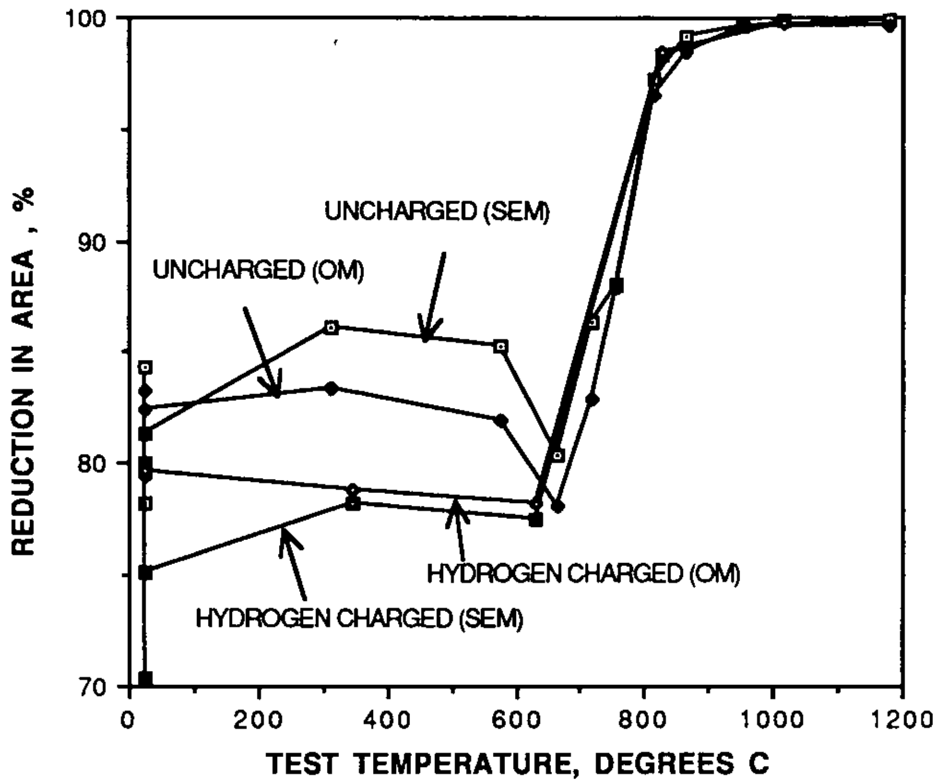


FIGURE 7. REDUCTION IN AREA VERSUS TEMPERATURE FOR HERF 316L STAINLESS STEEL

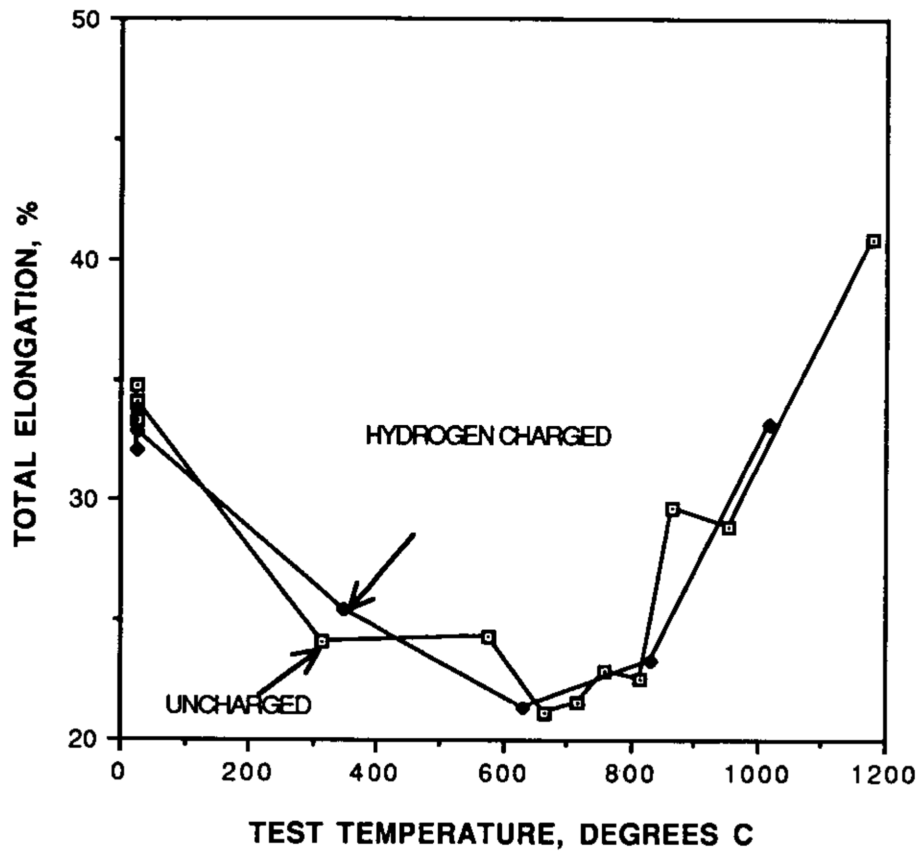


FIGURE 8. TOTAL ELONGATION VERSUS TEMPERATURE FOR HERF 316L STAINLESS STEEL

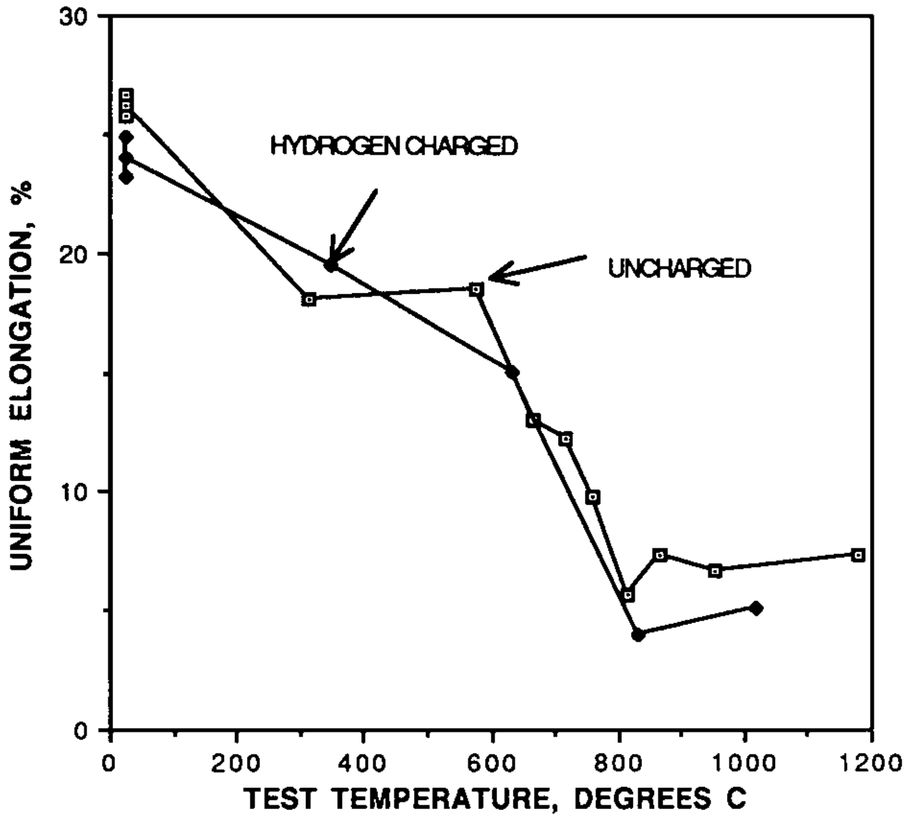


FIGURE 9. UNIFORM ELONGATION VERSUS TEMPERATURE FOR HERF 316L STAINLESS STEEL

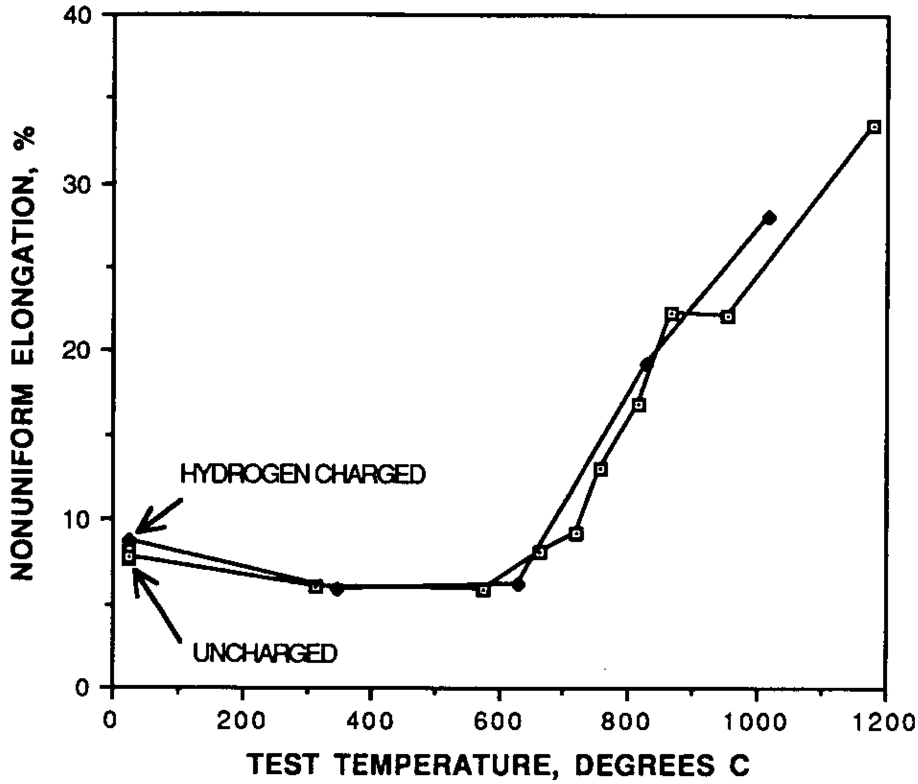


FIGURE 10. NONUNIFORM ELONGATION VERSUS TEMPERATURE FOR HERF 316L STAINLESS STEEL

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