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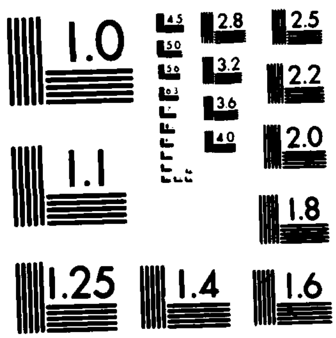
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AD-A145 526

The Effect of Two Strength Reducing Techniques on the Ultimate Tensile Strength of AISI 4130 Steel: Rocket Motor Case Venting

by
M. S. Wright
Ordnance Systems Department
and
R. F. Kubin
Research Department

JUNE 1984

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

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FOREWORD

This report is the result of a study conducted to investigate the tensile strength reduction to rocket motor case material, AISI 4130 steel, caused by two strength reducing techniques. Either of these two methods may be used in the preferential insulation technique for causing a case rupture if the rocket motor were subjected to an external fire. This study was initiated to determine if suitably weakened rocket motor cases could still be used as pressure vessels.

The study was performed for John O'Malley, Program Manager, Advanced Design Concepts of the Naval Weapons Center Cookoff Program in the Propulsion Systems Division, Ordnance Systems Department. It was funded under the Naval Air Systems Command Program (63262N-W0592) Air Task A310310L/054C/4W059100.

This report was reviewed for technical accuracy by Michael Martyn.

Approved by
E. B. ROYCE, Head
Research Department
15 April 1984

Under authority of
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(U) The venting of rocket motors in an external fire is an important concern of the Navy. This study was to investigate the tensile strength reduction in rocket motor case material, AISI 4130 steel, caused by an electron beam weld pattern or a patterned series of 0.006 inch diameter microholes. These two methods are under investigation as ways to nonexplosively vent rocket motors subjected to an external fire. The results indicate that the microhole pattern has little effect on the tensile strength but does reduce elongation of the steel. The rocket motor case with the microhole patterns will function as a pressure vessel as intended. The electron beam results were inconclusive in that there was measurable strength reduction as well as greatly reduced elongation. Two welding methods, cosmetic and noncosmetic, were investigated.

CONTENTS

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The authors thank Michael Martyn of the Materials Engineering Branch for several discussions concerning metal welding technology.

INTRODUCTION

This work is part of a continuing program to find an economical, but safe and reliable, way to vent rocket motors subjected to an external fire. In this study, the effect on the ultimate strength of rocket motor case material of two methods of strength reduction was investigated. The venting of the rocket motor cases makes use of a preferential insulation technique in conjunction with a strength reduction method.

One method changes the morphology of the motor case by use of an electron beam weld. Venting using this method is accomplished by preferentially insulating around the weld on the outside of the case but not over the welded area. When subjected to an external fire, large thermal stresses would be induced and would break out the welded area.

The second method makes use of a series of patterned microholes drilled into the motor case using a laser beam. Insulation is applied around the outside of the microhole pattern. Again, if subjected to an external fire, large thermal stresses should cause the microhole pattern to crack and break out. Additionally, in this method when the rocket motor liner starts to decompose in a fire, the decomposition products that are coming out of the microholes will ignite. Once these product gases ignite, they act like small cutting torches and tend to cut out the drilled pattern. This method has been successfully tested on Sidewinder rocket motor cases (Reference 1). These tests indicate that the cutting action of the ignited combustion products may be quite sufficient to cause the case to rupture in the microhole pattern without use of the preferential insulation technique.

The results of this work indicate that the microhole pattern does not weaken the motor case. The elongation decreases nominally. Thus, a motor case with several microhole patterns in it still can serve as a pressure vessel. In the electron beam welded samples there was a small reduction in ultimate tensile strength and a large reduction in elongation. We felt that more work needed to be done with the electron beam weld method because of the high ridge pattern produced on the back side of the test coupons indicating almost complete melting through the coupon. In this regard, a somewhat lower temperature with a less extensive melt zone would probably be better and would still function as intended.

EXPERIMENTAL

AISI 4130 steel was heat treated per MIL-H-6875 to R_c32 nominal. Every coupon was tested at each end on the long axis and the average value for all samples was $R_c = 29 \pm 2$. The stock was a nominal 0.060 inch thick and was fabricated into tensile test coupons as shown in Figure 1. Fifteen samples were used for control; 15 samples had the electron beam weld pattern; and 14 samples had the laser drilled microhole pattern.

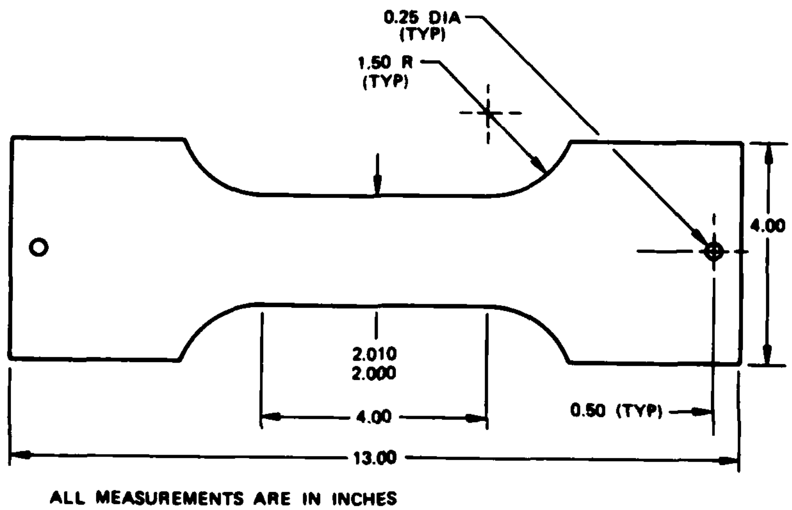
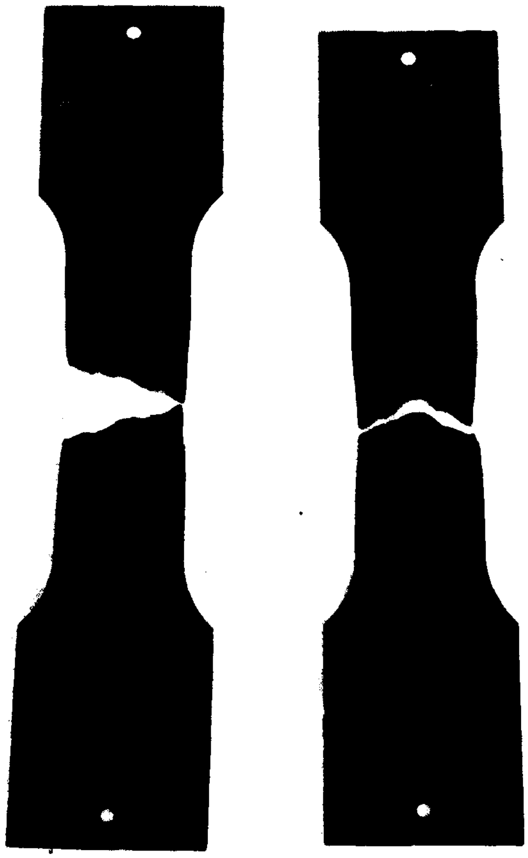


FIGURE 1. Dimensions and Shape of the Tensile Test Coupons.

ELECTRON BEAM METHOD

An electron beam welder running at a 20 milliampere current was used to trace a 1-inch diameter circular pattern in the steel samples. The trace is essentially a casting included within the rolled steel plate. Within the melt zone, recrystallization is columnar from both edges into the melt zone and is coarser grained. This change in the microstructure of the steel plate causes the localized material to exhibit mechanical properties similar to cast rather than forged material. Then, when subjected to high thermal loads, stresses are induced by the preferential insulation technique and local fracture will occur venting the motor casing. The circular patterns were made by two methods of welding (cosmetic and noncosmetic). Cosmetic welding is accomplished at reduced power with slower travel speeds and generally lower penetration with the purpose of smoothing the surface of a previously made weld. Here the penetration was not reduced. Due to the reduced beam voltage, the beam tends to veer at start up and shut down of the welder. The pattern appears somewhat ragged and smeared out at the start/stop point. The cosmetic weld takes a much longer time to make. The cosmetic weld took about two and one-half minutes in this study; whereas, the noncosmetic weld took about one-half minute to make. Figure 2 shows the front and reverse sides of two tested samples, one cosmetic and one noncosmetic. The ragged effect can be seen in sample number 40 at about eleven o'clock in the upper part of the sample. Little difference is apparent in the surface appearance of the two methods. However, the reverse sides of both samples (lower parts of Figure 2) show the severity of the weld as indicated by the very noticeable ridge formed in the weld zone.



(a) (b)

FIGURE 2. Upper Parts are Front Side and Lower Parts are Reverse Side of (a) a Noncosmetic Weld and (b) a Cosmetic Weld.

MICROHOLE METHOD

A CO_2 laser was used to drill a series of microholes, approximately 0.006 inch in diameter, on the circumference of a one-inch circle. Twelve holes spaced about one-fourth inch apart were used. Figure 3 shows enlarged top and side views of a typical microhole. Figure 4 is a close up showing the microhole pattern on a pulled sample.

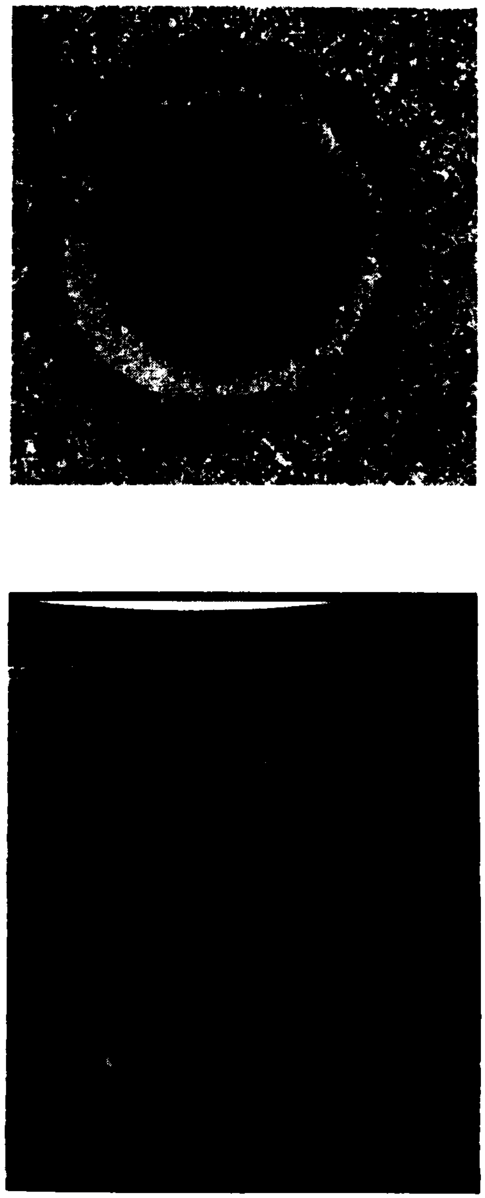


FIGURE 3. Photomicrographs of Transverse and Longitudinal Sections of Typical Microholes. The top (transverse) picture is magnified 240X and the bottom (longitudinal) picture is magnified 60X.

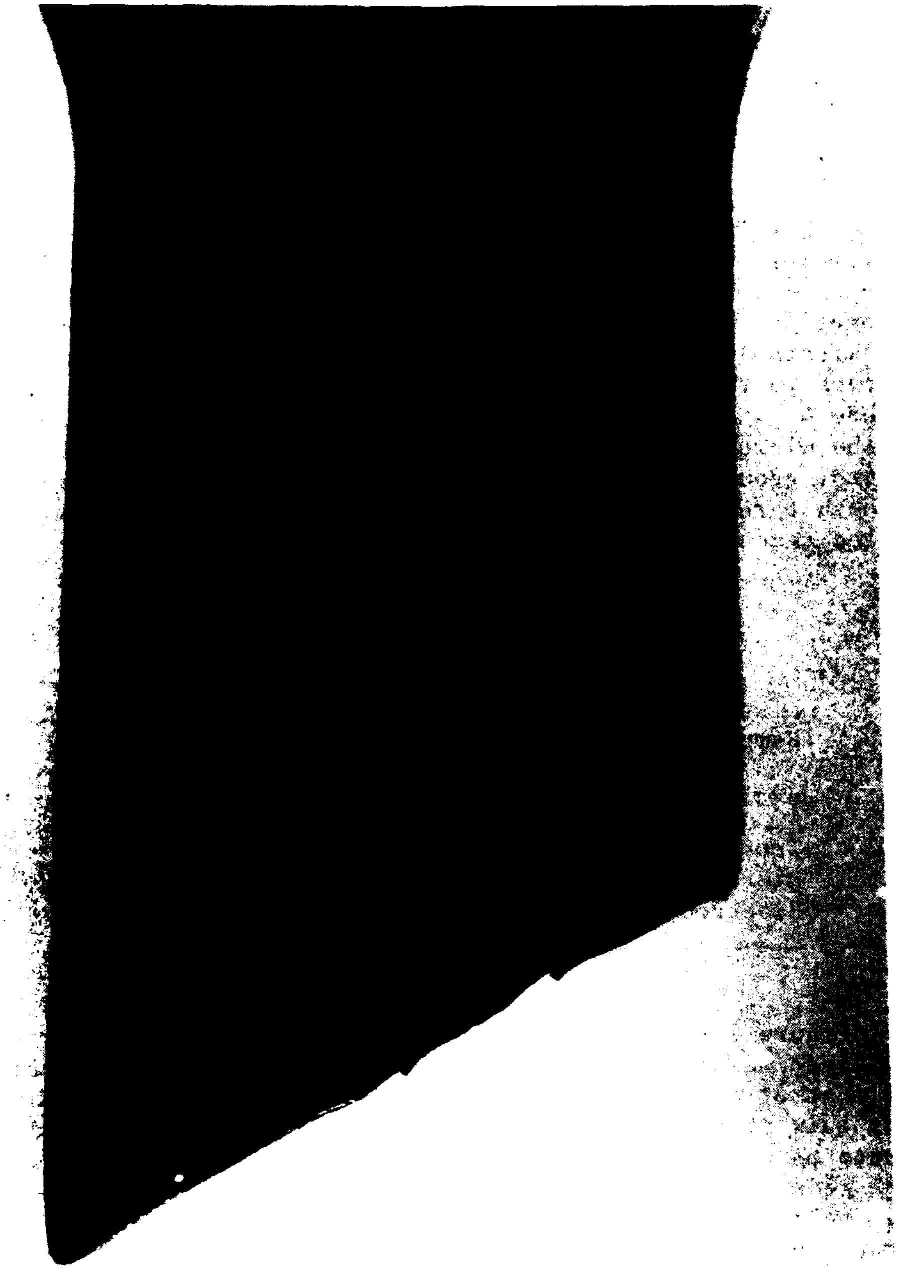


FIGURE 4. Closeup of Microhole Pattern on a Pulled Sample.

The samples were pulled in a 60,000 pound load Baldwin tensile tester that was equipped with a deflectometer.

RESULTS

Table 1 lists the results of the tensile tests on the three types of samples. These results indicate that the microholes have little effect on the ultimate tensile strength and only a 10% effect on the elongation. Figures 5 and 6 show typical results for the pulled control and microhole samples, respectively. In both cases the tear angle, with respect to the longitudinal axis, is approximately 60 degrees. Figure 4, which is an enlargement of part of Figure 6, shows the failure in the microhole sample is qualitatively similar to the failures in the control group. All but one sample failed as shown in Figure 4, i.e., through three consecutive holes around the circumference; one sample failed through the center of the microhole pattern.

TABLE 1. Average Ultimate Tensile Strengths and Elongations of the Tested Coupons.

Sample	$\bar{F}_{tu}$, psi	σ_{n-1}	$\bar{e}$, %	σ_{n-1}
Control	122,600	2,800	11.35	0.49
Microhole	122,900	2,600	10.00	0.78
Electron beam	117,700	5,300	7.78	1.54

Figure 2 shows that the situation is quite different for the electron beam welded samples. In this case, an angle is difficult to define for most of the samples. The tear is very roughly perpendicular to the long axis of the sample and either passes through the weld pattern or around part of the circumference of the pattern. There is approximately a 4% reduction in the average ultimate tensile strength for the electron beam welded samples. However, the standard deviation indicates that the error range for these samples includes the value for the control samples at its upper limit. Also, for the electron beam welded samples there is a dramatic decrease in the percent of elongation. Again the standard deviation is large for the electron beam welded samples compared to the control and microhole samples.

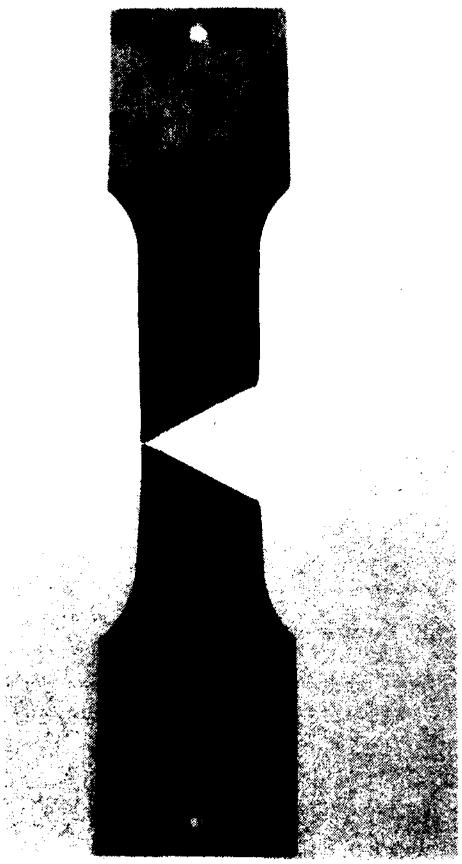


FIGURE 5. Control Sample: Top is Front Side, Bottom is Reverse Side.

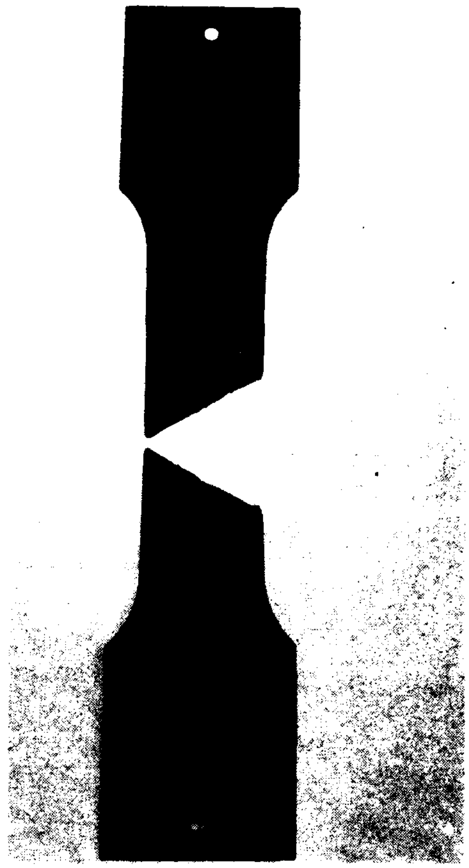


FIGURE 6. Microhole Sample: Top is Front Side, Bottom is Reverse Side.

Figures 7-9 show typical tensile strength curves for the control, microhole, and electron beam welded samples. Figure 9 shows two typical curves for the the electron beam welded samples. The large spread in the data for the latter samples appears related to the welding method. Though the correlation is far from perfect, the curves indicating small elongations and reduced tensile strengths are more typical of the cosmetic welded samples while the curves indicating much greater elongations and more usual tensile strengths are more typical of the noncosmetic welded samples. These data were lumped together because of the imperfect correlation. If the mechanical parameters are calculated separately, the results given in Table 2 are obtained.

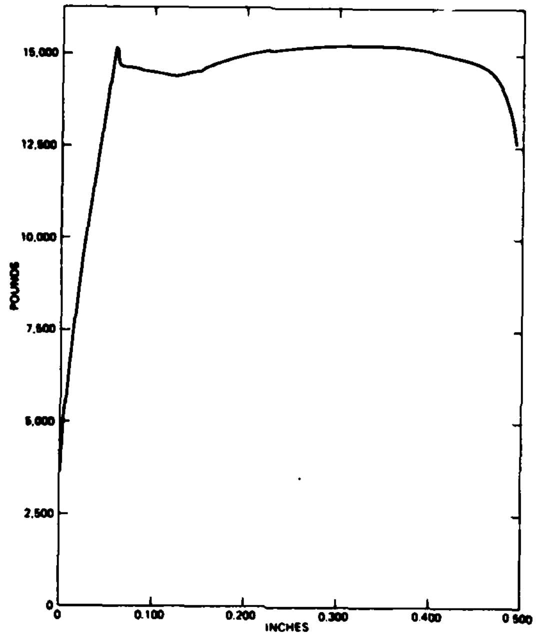


FIGURE 7. Tensile Strength Curve for a Typical Control Sample.

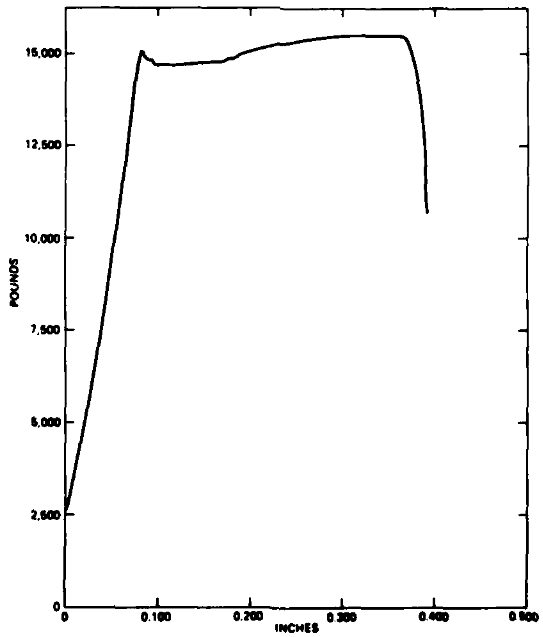


FIGURE 8. Tensile Strength Curve for a Typical Microhole Sample.

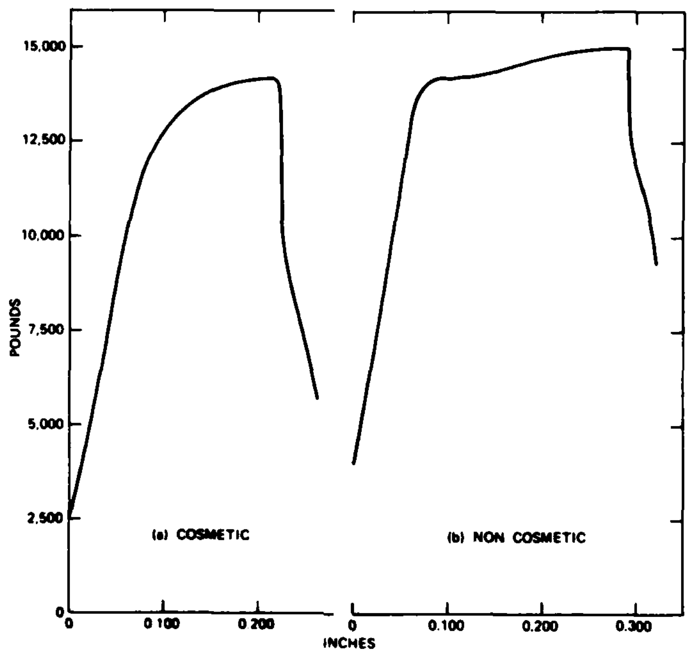


FIGURE 9. Tensile Strength Curves for the Electron Beam Welded Samples. (a) Cosmetic weld samples and (b) noncosmetic weld samples.

TABLE 2. Average Ultimate Tensile Strengths and Elongations for the Electron Beam Cosmetic and Noncosmetic Welded Samples.

Sample	$\bar{F}_{tu}$, psi	σ_{n-1}	$\bar{e}$, %	σ_{n-1}
Cosmetic	112,900	1,370	6.47	1.30
Noncosmetic	120,900	4,000	8.66	1.02

DISCUSSION

The microhole concept of venting a rocket motor case has been tested successfully (Reference 1). This work indicates that the microholes have no adverse effect on the mechanical properties of the rocket motor case steel. Thus, no effect from the use of microholes should be seen in rocket motor performance.

The electron beam welded samples were not successful in meeting the criterion of an unchanged or very slightly reduced ultimate strength. The samples used in this work had severe zone melting. By varying the intensity such that there is little or no evidence of welding visible on the reverse side of the steel we feel the tensile strength could be maintained. These electron beam welded samples were measurably more brittle. Because of the grossness of the mechanical tests, the results from the two methods of welding initially were combined in Table 1. Some explanation for the observed results as given in Table 2 could lie in the fact that the lower intensity beam used in the cosmetic welding actually put more energy into the sample per unit length of weld due to the slower travel speed. This would produce a much wider heat affected zone around the weld. The AISI 4130 used for the test coupons is a relatively high hardenable steel that can harden in thin sections even at low cooling rates. Also depending on the actual temperature reached in the weld and with a slow cooling rate the heat affected zone on either side of the weld could be severely annealed making them very soft. In either case the elongation would be much reduced. Three test coupons, one noncosmetic tested, one cosmetic not tested, and one cosmetic tested, were sectioned and Knoop hardness tests were run across the welds. These results are shown graphically in Figure 10. It seems clear that the noncosmetic weld sample is unchanged as far as hardness indicates. It is equally clear that the cosmetic samples suffered severe annealing and are quite soft in the heat affected zones on either side of the weld. When the electron beam samples were run, they were allowed to cool in vacuum for 10 minutes before removal from the welding apparatus. The samples were held in place using two C clamps so heat transfer from the sample by conduction or convection was limited. All three sections were taken parallel to the direction of pull in the tester. Figure 10 thus shows that the effect of pulling is to slightly harden the test coupon. Figure 11 is a picture of one of the three sections as typical. It is also noted that the picture indicates that for the cosmetic welded samples two passes were made--a fact unknown to the authors until these sections were made.

This work along with the results of Wright (Reference 1) show that the microhole method is a suitable one to prevent explosive venting of rocket motors exposed to an external fire yet would enable the rocket motor to perform as intended. The results for the electron beam welding method are inconclusive. More tests using less severe welding conditions, i.e., a much less penetrating weld with no apparent melt zone visible on the back side of the coupon, may also produce the desired result and retain sample strength.

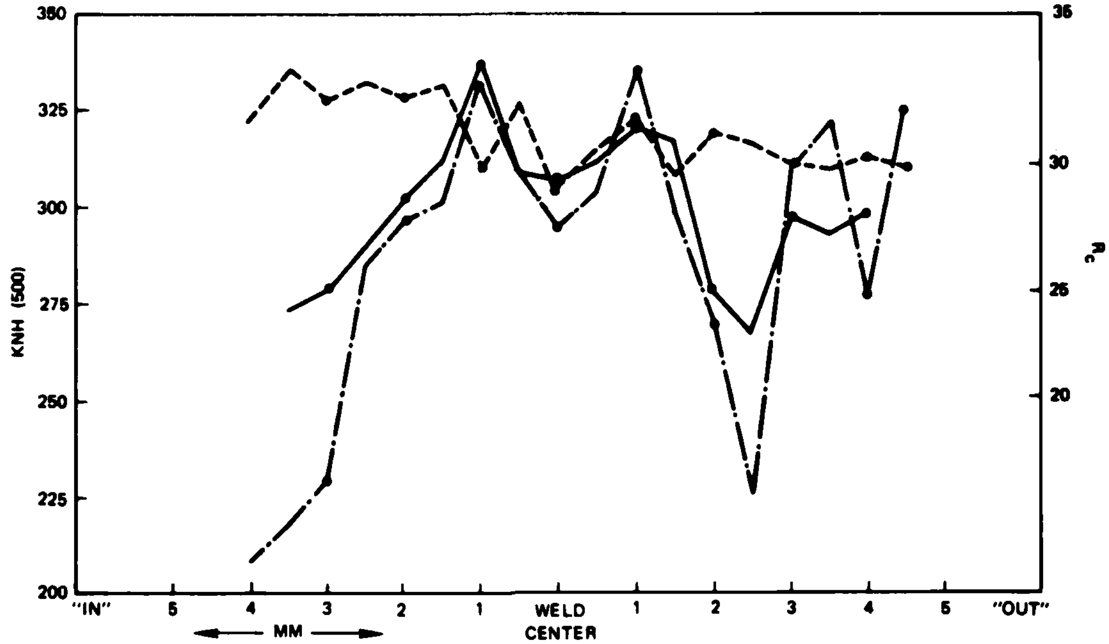


FIGURE 10. Knoop Hardness Number versus Distance From Weld Center for Electron Beam Welded Test Coupons. (a) ---non-cosmetic, tested; (b) ___ cosmetic, tested; (c) _·_ cosmetic, not tested.

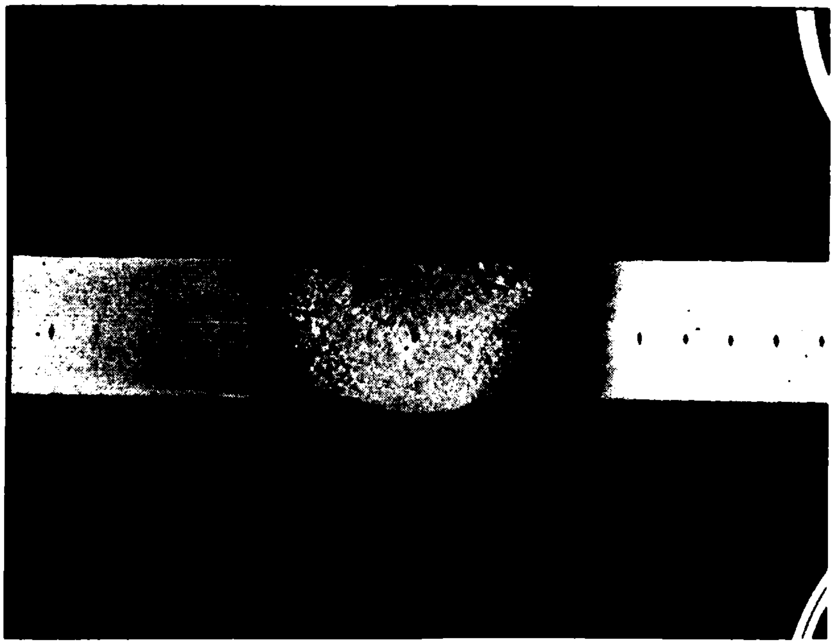


FIGURE 11. Photomicrograph of the Electron Beam Weld in a Not Tested, Cosmetic Welded Test Coupon, See Curve C in Figure 10.

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