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A NEW APPROACH TO BEND TESTING FOR THE DETERMINATION OF HYDROGEN EMBRITTLEMENT SUSCEPTIBILITY OF SHEET MATERIALS

PREPARED BY R. L. Jones
R. L. Jones

CHECKED BY

APPROVED BY
A. Hurlich
Research Group Engineer
[illegible] Materials Research Group

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ABSTRACT

A series of experimental programs were carried out to determine the suitability and sensitivity of a new test technique for the determination of hydrogen embrittlement susceptibility of materials. A simple bend test was used to study the effect of chemical milling and cadmium plating on hydrogen embrittlement of high strength 4340 steel sheet. The bend test consisted of loading a coupon in the form of a slender column in compression at a series of fixed bending speeds. Bend ductility was measured as the depression of column height at fracture and all data were referred back to a base line condition (non-embrittled) for comparison.

The feasibility of using this test technique for qualitative and semi-quantitative studies involving the influence of chemical milling time and various recovery treatments was adequately demonstrated.

Results of the present study were compared to those obtained on the same heat of steel where hydrogen embrittlement was determined by the use of notched rupture tests.

Although the sensitivity of this bend test technique is not as high as that found for the notched rupture test, it is quite high and is much better than any other type of bend test employed to date.

INTRODUCTION

In the last few years the trend in the Aerospace Industry has been to the use of engineering materials at ever increasing strength levels, until today many materials are being employed at strength levels in excess of 200,000 psi tensile strength. Applications of high strength materials in the form of sheet has increased markedly. The requirements of corrosion resistance and the need for the lightest weight configuration leads to the use of processing techniques such as pickling, electroplating and chemical milling. Unfortunately these processing techniques provide a ready source of hydrogen at the metal surface during the operation. It is now well established that hydrogen can be introduced into many metals during these processing operations and can lead to severe hydrogen embrittlement.

Hydrogen can have an adverse effect on the mechanical properties of steels, particularly high strength steels, some titanium alloys, and to a lesser extent some other ferrous and non-ferrous alloys. The chief effects are a marked decrease in ductility on slow straining and a propensity toward delayed failures under static loads even at stresses far below the yield strength. Delayed static load service failures have been reported in plain carbon steel springs heat treated to high strength levels and subsequently plated or pickled and in alloy steel aircraft landing gear components heat treated to high strength and subsequently plated with cadmium. Many other examples could be cited, but these are adequately documented in the literature (1, 2).

In the past, many test techniques have been used to evaluate the hydrogen embrittlement susceptibility of materials. A list of some of the tests employed divided into short and long duration tests is given in Table 1. In general, these tests have been employed throughout the aircraft industry as a go - no go quality control test of heat treated and electroplated steels. Most of these tests; however, are not adequate for a quantitative evaluation of the phenomenon, and in some instances they are not even qualitatively adequate. Perhaps the regular tensile test is most typical in this respect. That all test techniques do not possess adequate sensitivity for detecting hydrogen embrittlement was shown in a recent program carried out by an ARTC project, W-95. Most of the test techniques shown in Table 1 were compared by using the same heat of steel embrittled to the same extent (3). Of all test techniques evaluated, the sustained load notched tensile test (ambient temperature rupture test) was the most sensitive and reproducible. It is also the most expensive test technique.

Unfortunately the test specimens employed in most of the tests discussed so far have been machined from relatively large section size material and are not suitable specimen configurations for preparation from sheet material. Only the bend test and the notched rupture test appear suitable for testing for hydrogen embrittlement in sheet materials.

One interesting feature of the round notched rupture test is that by conducting tests at enough stress levels the lower critical stress (stress below which failure does not occur) can be determined with a notch of given geometry. It appears, therefore, that data of some quantitative significance can be obtained by this test technique. But since the lower critical stress is also a function of notch geometry it is difficult, if not impossible, to apply this data to actual design. Furthermore, it appears that a considerable amount of effort would be necessary before a flat notched rupture test of sheet could be proved satisfactory. Therefore, it appears justifiable to examine other test methods to determine their suitability as replacements for the sustained load notched rupture test which is very costly in terms of both time and equipment. The ideal test technique should be inexpensive, short in duration, amenable to sheet material, and sensitive to detection of hydrogen embrittlement at fairly low levels of embrittlement. Bend tests seem to satisfy all the above requirements, except the last. Bend tests, as they have been carried out in the past, have proven so insensitive that their use seemed highly undesirable. However, a new approach to bend testing was conceived a few years ago by Sachs(4). It is ideally suited to sheet material since it uses bending of thin strips. Bending of the sample is performed as a free end-loaded column at various constant strain rates. This test permits accurate measurement of the fracture strain over a wide range of embrittlement conditions. This test is further characterized by a nearly linear increase in strain with reduction in column height and is, therefore, a constant strain rate test (4, 5). This is in contrast to most bend tests which are constant bend radius tests.

Because this test technique proved quite successful in the studies carried out by Sachs, it was decided to use it in studies involving hydrogen embrittlement of materials introduced by the chemical milling process. However, it was first necessary to establish the sensitivity of the test and this is the subject of the present report.

EXPERIMENTAL PROCEDURES

Materials

One material, AISI 4340 steel, was employed in the present program. However, two heats were studied. One heat (Heat No. 7C-40) of material was purchased for the study of chemical milling and cadmium plating. The material was obtained as .040, .050 and .060 gage sheet. Material from a second heat of 4340 steel (Heat No. 3350427) was obtained from the Boeing Airplane Company and was supplied as three inch square bar stock. This material is from the same bar of 4340 steel that was used in the ARTC project 13-59 aimed at the standardization of methods of testing for hydrogen embrittlement. The chemical analysis of both heats are given in Table 2.

The as-received sheet material (Heat 7C-40) was sheared and machined into bend test samples as shown in Figure 1. Sections were saw cut from the as-received bar stock (Heat 3350427) and surface ground to 0.040 inch thickness. These sections were sheared and machined into bend test samples as shown in Figure 1. In all cases longitudinal test coupons were prepared.

The samples were sheared oversize and then ground to size to eliminate any edge effects from shearing.

Heat Treatment

After the bend test coupons were machined to size they were heat treated according to the schedules shown in Table 3. The resultant hardness and tensile properties are given in the same Table. The thermal treatment used on bend samples obtained from Heat 3350427 differed from that employed on Heat 7C-40. Hardness and tensile properties appear slightly higher in Heat 3350427. The heat treat cycle employed for Heat 3350427 was selected to correspond to that used by the Boeing Airplane Company on the ARTC industry program so that comparison of the bend test results could be made readily with the results obtained by the ARTC project.

Chemical Milling

Chemical milling was carried out in the laboratory using baths generally similar to those employed commercially for the various materials. The 4340 steel was chemically milled in the bath shown below at a temperature of 140°F.

HCl - 15% by volume
HNO_3 - 17%
H_3PO_4 - 31%
H_2O - 37%
Fe - 4 grams/liter

At this temperature the bath milled at a rate of about 1 mil/minute. The milling rate changed with the age of the bath, but, in general, the change was small. The milling bath was replaced with a new solution when the milling rate decreased by a factor of 10 percent.

The bend samples were chemically milled from one side only. This was accomplished by masking one side and the edges with pressure sensitive lead tape. The chemically milled surface was then made the tension side during the bend test.

The commercial proprietory chemical milling baths differ slightly from the solutions used in this investigation. Generally, small additions are made to the commercial baths to decrease hydrogen ion concentration and to improve the surface finish obtained.

Cadmium Plating

All bend samples from Heat 7C-40 were cadmium plated using the following procedure:

1. Pickle in inhibited hydrochloric acid not longer than 10 minutes.
2. Vapor blast.
3. Alkaline clean.
4. Acid dip in 10 percent hydrochloric acid for 5 seconds.

5. Cyanide dip (2 - 6oz/gal of NaCN or KCN)-in and out dip.
6. Cadmium plate using the following bath:

Sodium hydroxide	2.04 oz/gal
Cadmium oxide	3.58 oz/gal
Sodium Cyanide	18.2 oz/gal
Sodium Carbonate	1.42 oz/gal
Brightener	1 pint/25# of NaCN

Plated at 60 amp/ft^2 to 0.0003" thickness.

7. Soak in hot water (180°F) for 15 minutes.

All samples of Heat 3350427 were plated at Boeing, Wichita. The plating procedure is shown below:

1. Vapor degrease
2. Alkaline clean
3. Rinse
4. Pickle in inhibited hydrochloric acid not longer than ten minutes
5. Rinse
6. Cadmium plate using the following bath:

Cadmium metal	3.0 to 4.5 oz/gal
Total sodium cyanide	11.5 to 17.5 oz/gal
Sodium carbonate	8 maximum oz/gal
Caustic soda	2.1 to 3.2 oz/gal
Ratio total sodium cyanide to cadmium	3.8 to 4.2 oz/gal
Super XC Brightener	

7. Rinse and dry as soon as possible.

After plating some samples were tested as-plated. Others were baked for various periods of time at 375°F and then tested.

Bend Test Procedure

The test technique employed in this investigation is a free end-loaded bend test performed at a variety of fixed bending speeds. The test is shown schematically in Figure 2 and is simply a slender column loaded in compression as one would squeeze a long thin sample between the jaws of a vise. Photographs of the actual bend test machine are shown in Figures 3 and 4. The distance the jaws come together before a crack is observed or the sample completely fractures, whichever occurs first, was used as a measure of hydrogen embrittlement when compared to unembrittled base metal behavior under the same testing conditions. The comparison must be performed on materials having the same thickness in order to be completely valid.

When the sample fractured completely and fell out of the jaws, the machine stopped and the head depression was recorded automatically on a counter (see Figures 3 and 4). If cracking did not result in complete fracture and the sample remained in the jaws the head depression at the appearance of the first crack was determined from the lead verses time curve recorded automatically through a lead ring-amplifier-recorder system (see Figure 3).

Tests were carried out at four different testing speeds since detection of hydrogen embrittlement is known to be strain rate sensitive. Jaw closure rate varied in four steps: 0.001 in/min., 0.01 in/min., 0.1 in/min. and 1.0 in/min. The maximum testing time (for 2.8 inch Jaw closure) did not exceed 47 hours at 0.001 in/min., 5 hours at 0.01 in/min., 1/2 hour at 0.1 in/min. and 3 minutes at 1.0 in/min. These times correspond to the maximum jaw movement of the machine.

To compare the effects of various treatments on materials, a base line condition was established. In this investigation the bend ductility of the as-heat treated condition was established as the base line. To be completely valid all further comparisons were made to this base line using the same thickness of material. In order to investigate the effect of chemical milling, then, material was provided with thicknesses greater than the thickness of the base line material and were then chemically milled to the thickness of the base line material. The increase in thickness associated with cadmium plating was minor and comparisons were made between 0.040 gage plated and unplated specimens.

In general, between three and five samples were run at each testing speed. Tests were started immediately after chemical milling (within five minutes) or after some fixed recovery treatment. In the case of chemically milled samples the recovery treatment consisted of holding at room temperature for fixed periods of time. Unbaked cadmium plated samples were tested immediately after plating. Baking treatments were performed shortly after plating and testing was carried out as soon as possible thereafter.

RESULTS AND DISCUSSION

Chemical Milling

Chemical milling was carried out on Heat 7C-40 to determine its susceptibility to hydrogen embrittlement. Coupons from Heat 3350427 were not chemically milled. Both 0.060 gage and 0.050 gage sheet materials were chemically milled to 0.040 gage. Time in the milling bath was about 25 minutes for 0.020 inch metal removal and 10 minutes for 0.010 inch metal removal. The average values of the bend ductility of the steel tested immediately after chemical milling as a function of testing speed are shown in Figure 5.

All data are shown in Table 4. Both 10 and 20 mils metal removal resulted in hydrogen embrittlement of the steel. As might be expected, more severe embrittlement was found in samples that were in the chemical milling bath the longest time (i.e., for those samples that had 20 mils of metal removed). The influence of testing speed on the bend ductility is somewhat unusual. Generally, hydrogen embrittlement in steels shows up more readily at low and tested to determine their susceptibility to hydrogen embrittlement. This phase of the study program was carried out for two reasons: first, to further demonstrate the sensitivity of the free end-loaded bend test for detecting hydrogen embrittlement, and second, to compare the severity of hydrogen embrittlement introduced by the two processing techniques - chemical milling and cadmium plating.

The bend ductility of the plated samples as influenced by testing speed is shown in Figure 7. Data are presented in Table 6. The plotted points are average values obtained from five identical tests. Where appropriate the range obtained from the five tests is shown. The cadmium plated samples, as-plated, were severely embrittled by hydrogen as evidenced by the very low bend ductility. The severity of the embrittlement introduced by plating is much greater than introduced by chemical milling, even when 20 mils of metal were removed (compare data in Figure 6 to that of Figure 5).

Baking cadmium plated samples 8 hours at 375°F markedly decreased the severity of the embrittlement of the as-plated samples. However, some embrittlement is evident in the curve shown in Figure 6. It is especially evident at low testing speeds in terms of both the low bend ductility and the rather wide range of values obtained from five identical tests. Although the scatter of data is high, there is no doubt that embrittlement exists even after baking 8 hours at 375°F.

The severity of the embrittlement found in the plated and baked samples appears to be similar to that found in chemically milled samples after 10 mils metal removal or after 20 mils metal removal and a 4 hour recovery treatment (compare Figures 4, 5 and 6). Thus, it is apparent that the severity of hydrogen embrittlement associated with cadmium plating is normally higher than that associated with chemical milling, even when large amounts of metal are removed. In addition, it is much more difficult to relieve the embrittlement of cadmium plated material.

4340 Steel (Heat 3350427)

The effects of cadmium plating and baking treatments were studied further using a second heat of 4340 steel (Heat 3350427). The bend ductility of unplated, plated and plated and baked bend test samples was determined. Several baking periods were employed. Data are presented in Table 7. The average values of bend ductility as a function of testing speed are plotted in Figure 8. Where appropriate the range of values obtained from triplicate tests is shown.

As expected, the as-plated samples show a very high degree of hydrogen embrittlement. As shown in Figure 7, this was detectable at all the strain rates investigated. Only a small amount of bending occurred before fracture took place; the amount of bending decreased as strain rate decreased as might be expected from the well known effect of strain rate on hydrogen embrittlement susceptibility. When the plated samples were baked for various times, the amount of hydrogen in the samples was decreased and the degree of hydrogen embrittlement decreased correspondingly. This is shown in Figure 7, by the increase in the amount of bending in the plated and baked samples before fracture. As the baking time increased the bend ductility tends to approach that of the uppermost curve which represents the non-embrittled (no plate) condition.

Baking 4 hours at 375°F reduced the degree of embrittlement slightly. However, only two samples were tested at the lower strain rates. Baking 8 hours at 375°F further reduced the embrittlement of the plated samples. Only the two lower strain rates were investigated, but embrittlement is apparent at both strain rates. It is more readily detected at the lowest strain rate. Even after baking 23 hours at 375°F the plated samples show a small degree of susceptibility to hydrogen embrittlement. The difference in bend ductility between the plated samples baked 23 hours at 375°F and the non-embrittled samples shows up best at the lowest strain rate. The range of values obtained for the plated and baked samples and the non-embrittled samples overlap at all but the lowest strain rate. In spite of this, the curve based on the average values falls below the unembrittled curves and is good evidence that some hydrogen embrittlement remains. At the lowest strain rate the range of values obtained in triplicate tests do not overlap and a fairly large difference in average values exists. Thus, there is certainly some degree of hydrogen embrittlement remaining in samples baked as long as 23 hours at 375°F.

Some idea of the maximum sensitivity of this type of bend test can be obtained by comparing the bend test results obtained in the present program to the results obtained on round notched rupture tests carried out on the same heat of material by ARTC project 13-59 (6). The results of sustained load notched rupture tests using a variety of notch radii are presented in Figure 9. All samples were cadmium plated and baked 23 hours at 375°F. As can be seen, hydrogen embrittlement was readily detected in all tests. However, the sensitivity of the notched rupture test was considerably higher when sharp notches were employed. According to these results even after baking at 375°F for as long as 23 hours fairly severe embrittlement remained in the cadmium plated samples.

The bend tests also showed that embrittlement remained in cadmium plated samples of the same heat of 4340 steel baked as long as 23 hours at 375°F. However, the detection of this embrittlement was difficult and is just about at the limit of the sensitivity of this test technique. Therefore, it appears that the maximum sensitivity of the free end-loaded bend test technique is considerably below that of the notched rupture test. This may not be the actual situation since another factor must be taken into account when these data are compared. Because of sample size consideration it was necessary to machine the bend test coupons from the longitudinal direction of the original bar material wherein the notched rupture coupons were obtained from the transverse direction. In general, steels show a much higher susceptibility to hydrogen embrittlement when tested in the transverse direction than when tested in the longitudinal direction. Consequently, it is reasonable to assume that a higher degree of hydrogen embrittlement susceptibility would have been found in plated and baked bend test coupons if they could have been prepared from the transverse direction. Thus, this type of test is actually more sensitive than the initial comparison of the two sets of data indicates.

CONCLUSIONS

The ability of the free end-loaded bend test to detect hydrogen embrittlement in chemically milled or cadmium plated 4340 steel sheet has been adequately demonstrated. Although the sensitivity of this test technique is not as high as that found for the notched rupture test, it is quite good and is much better than any other type of bend test employed to date.

The possibility of using this test technique for qualitative or semi-quantitative studies involving the influence of plating variables, chemical milling variables, recovery treatments and other factors effecting hydrogen embrittlement susceptibility has been adequately demonstrated in the various studies carried out to date.

Less severe hydrogen embrittlement is introduced into 4340 steel from chemical milling than from cadmium plating. Furthermore, hydrogen, and consequently hydrogen embrittlement, is more easily removed from chemically milled material.

Baking treatments as long as 23 hours at 375°F did not completely eliminate hydrogen embrittlement from cadmium plated high strength 4340 steel.

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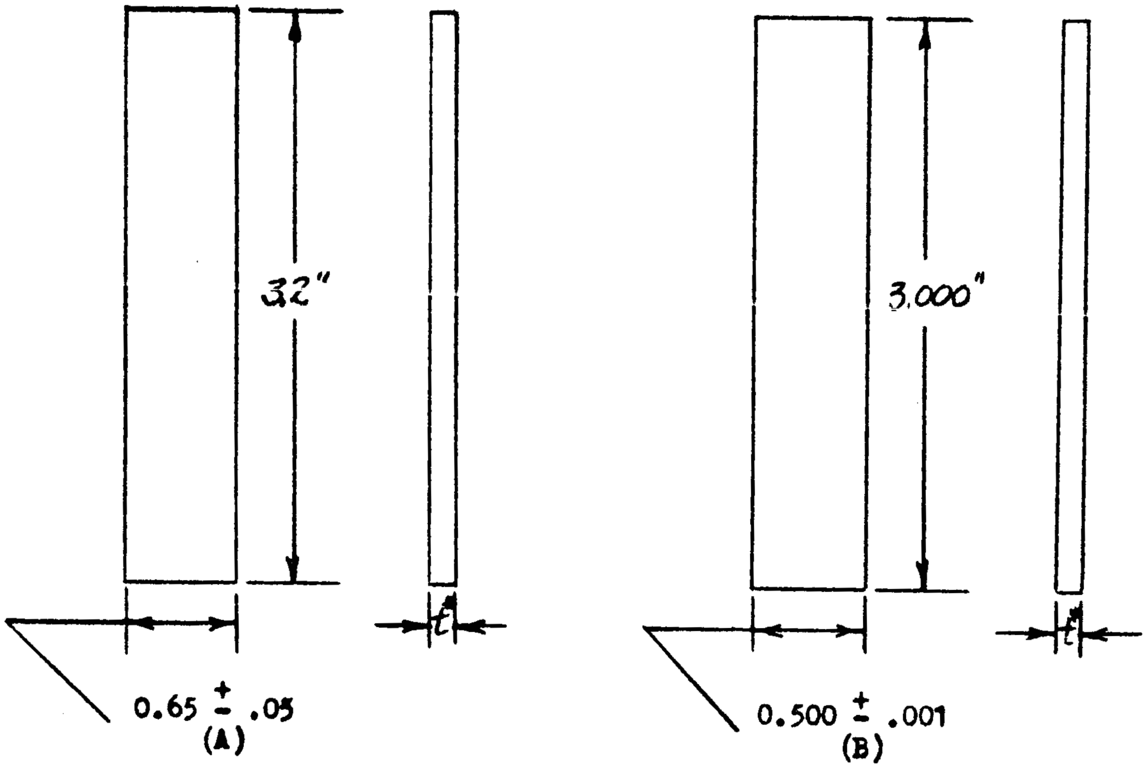
4. Sachs, G., Klier, E. P., and Beck, W., "Constant Strain Rate Bend Tests on Hydrogen-Embrittled High Strength Steels", Journal of Metals, Trans. Vol. 8, No. 10, 1956, p. 1263.

5. Tong, K., "Analysis of the Post Buckling Behavior of A Slender Column and Its Use in Ductility Measurements of Materials", WAL 893/154-15, Final Report No. 5, Jan. 1955.

6. Johnson, B. G., et. al., "Standardization of Methods of Testing for Hydrogen Embrittlement - ARTC Project 13-59. Boeing Wichita Report D3-3676, March 1961.



Size of Sheared Specimen

Size of Finished Bend Specimen

*** Sheet Thickness**

FIGURE 1. Bend Test Sample. (A) - Sheared to size. (B) - Ground to size.

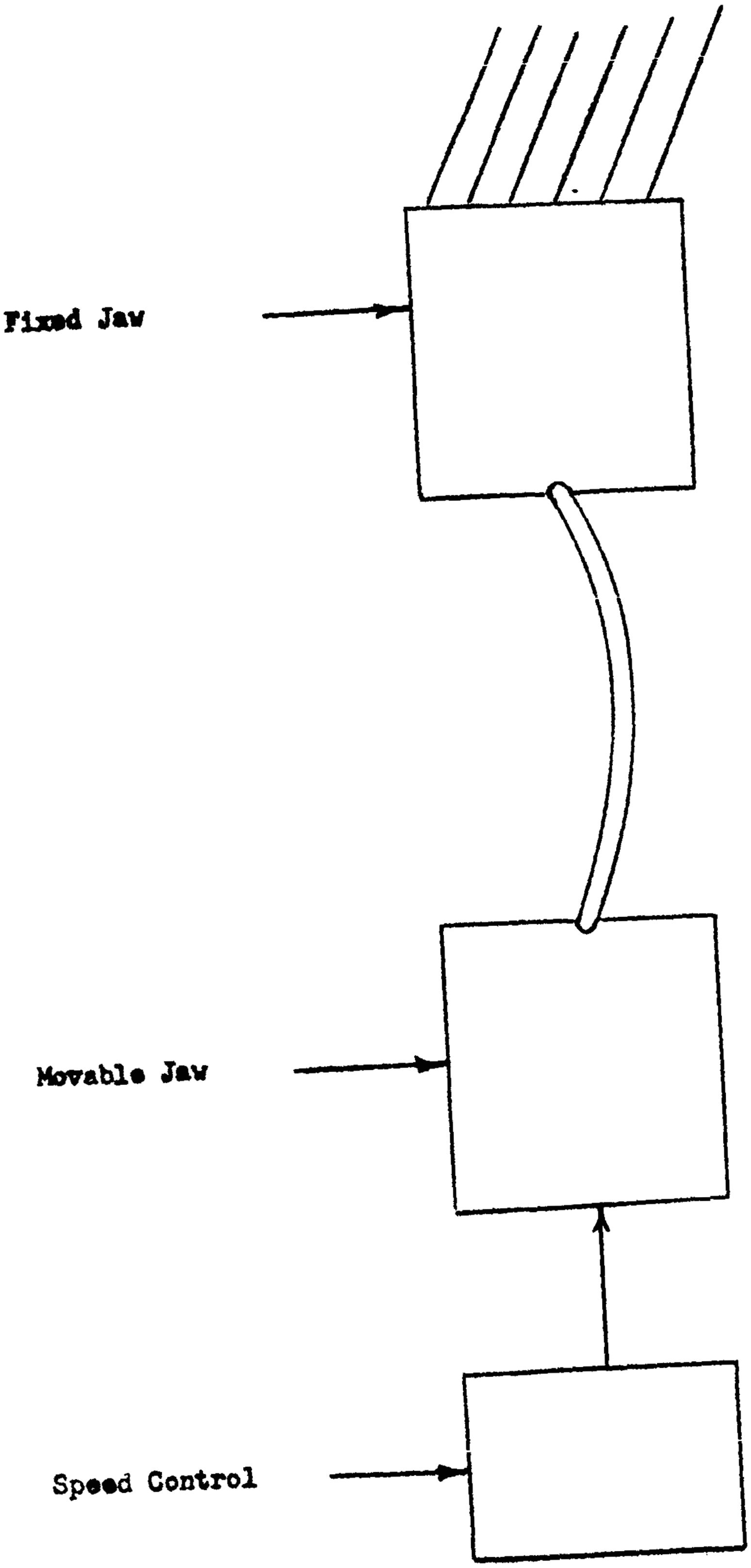


FIGURE 3. Schematic representation of free end-loaded bend test.

K+E 10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

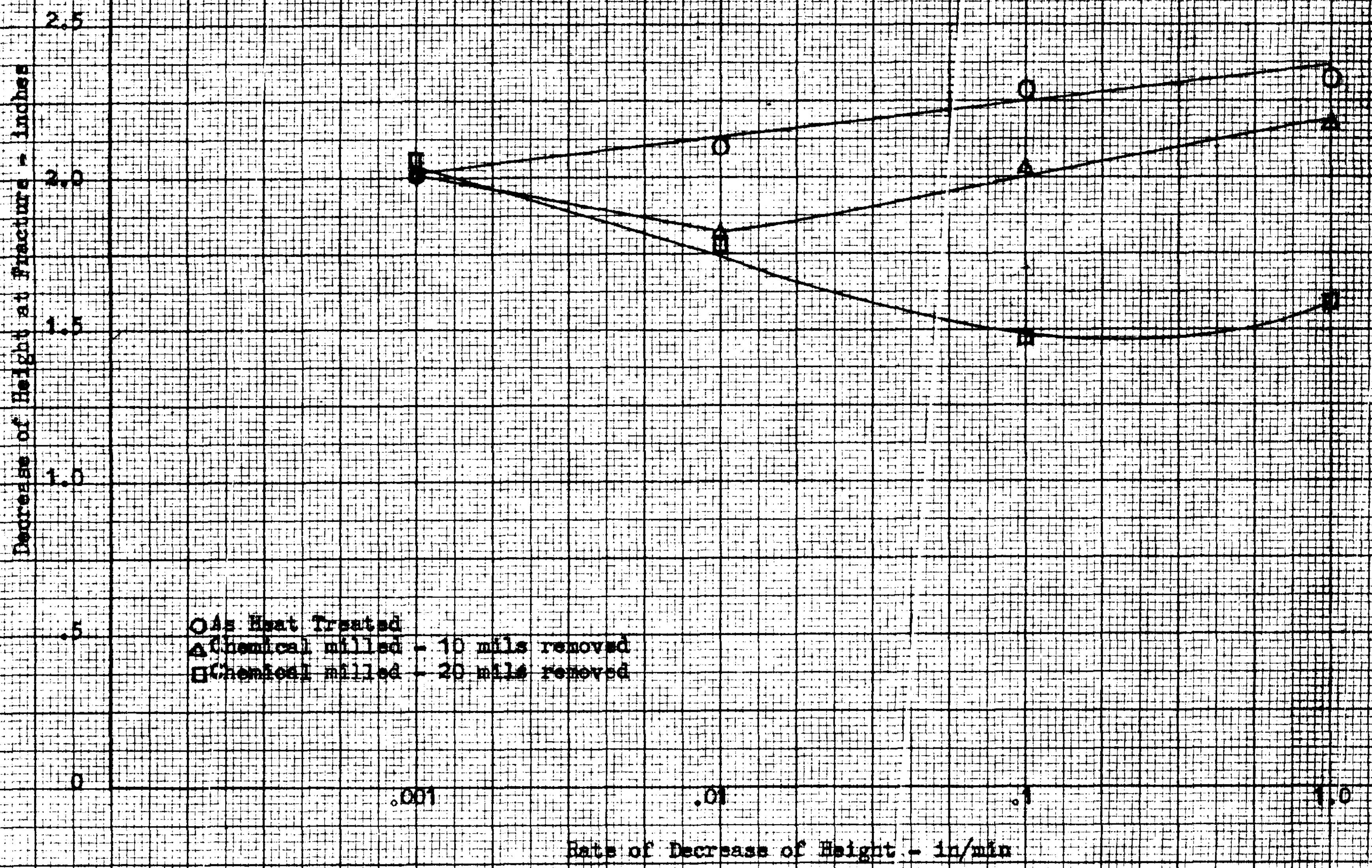


FIGURE 5. Effect of strain rate on the ductility of bend specimens of 4340. Tested immediately after chemical milling.

K+E 10 X 10 TO THE 1/2 INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

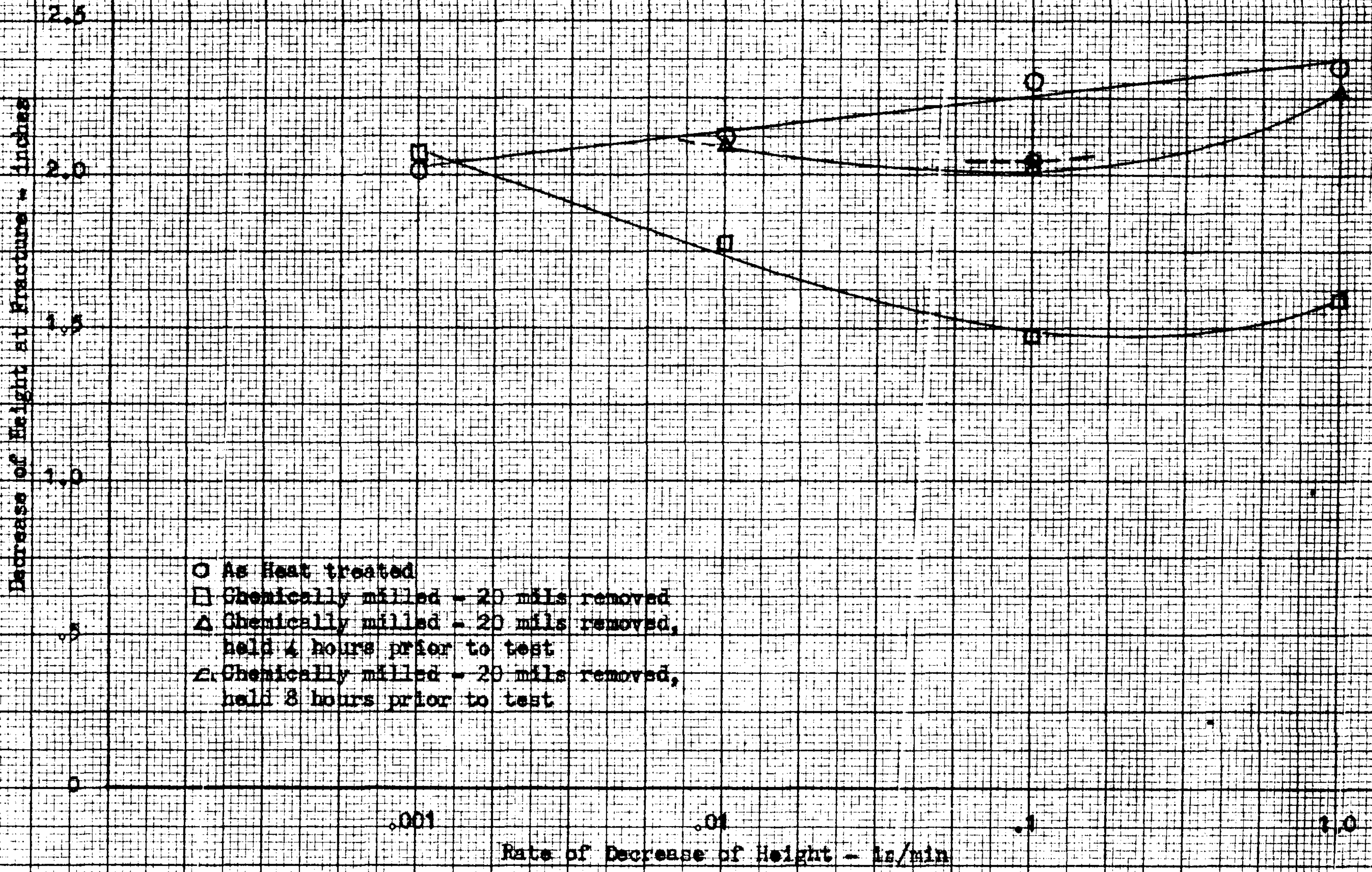


FIGURE 6. Effect of strain rate on the ductility of chemically milled bend specimens of AISI 4340 steel. Effect of recovery treatments at ambient temperatures.

K+E 10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

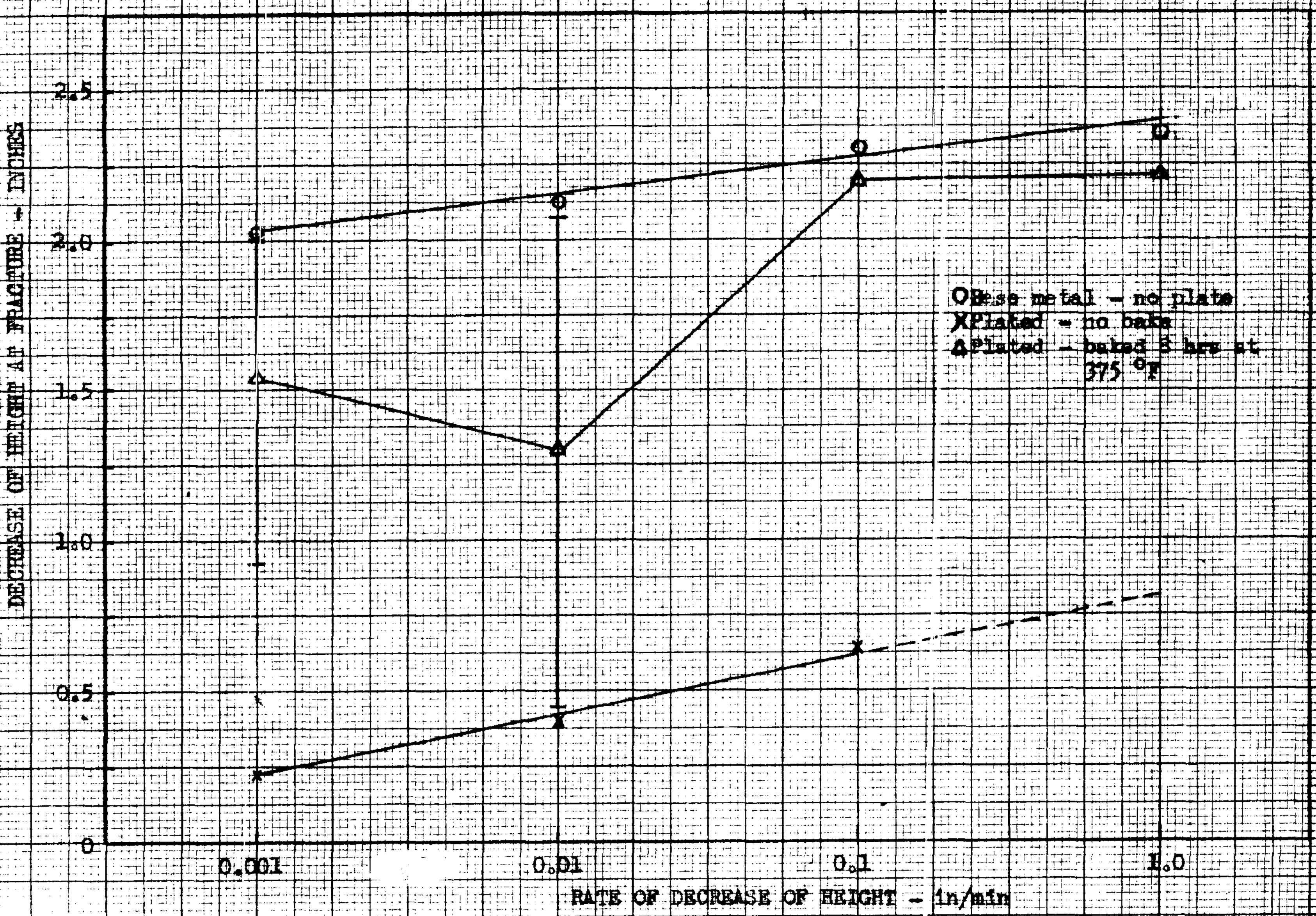


FIGURE 7. Effect of cadmium plating and thermal recovery treatments on the bend ductility of 4340 steel (Heat 7C-40).

K+E 10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

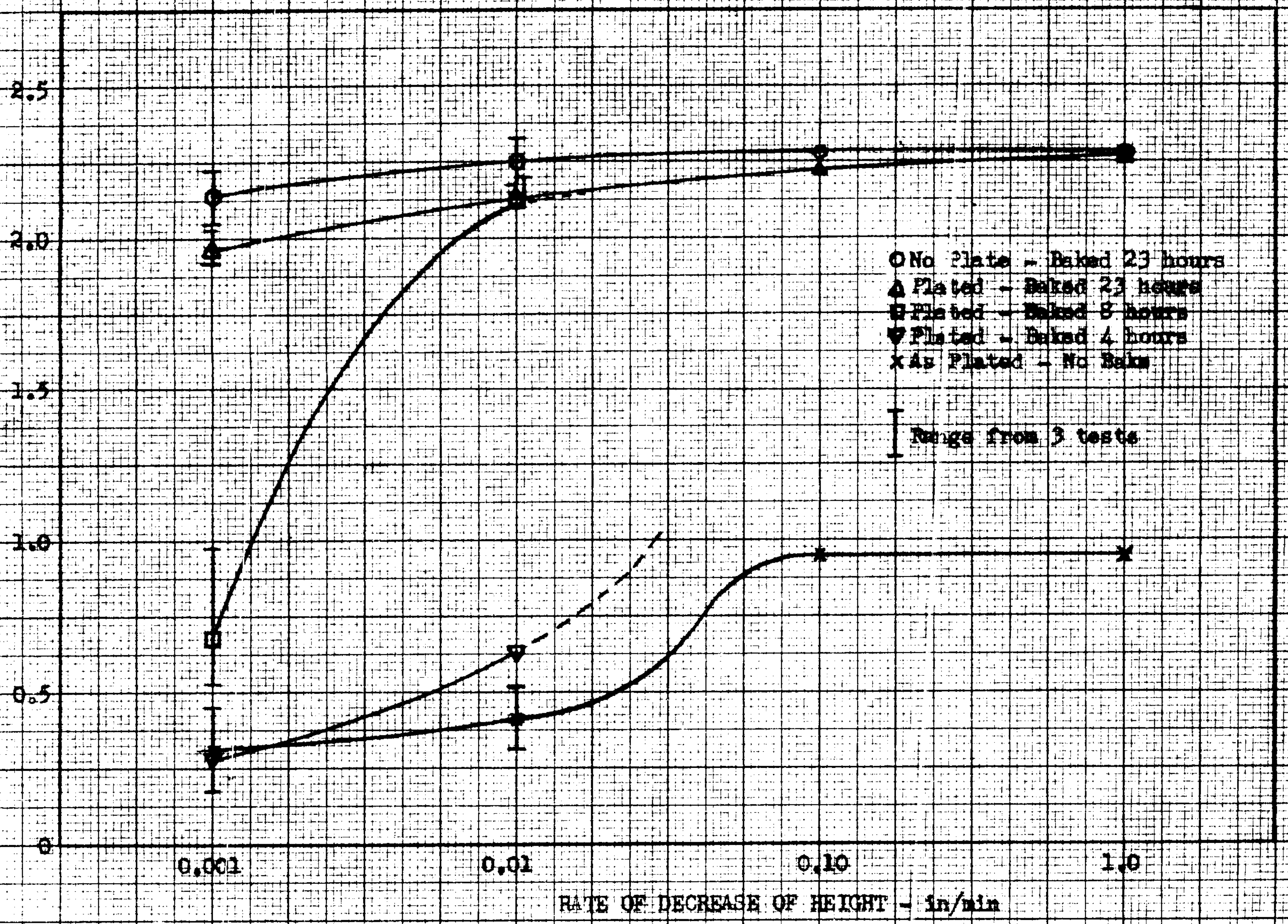


FIGURE 8. Effect of Cadmium plating and thermal recovery treatments on the bend ductility of 4340 steel (Heat 3350427).

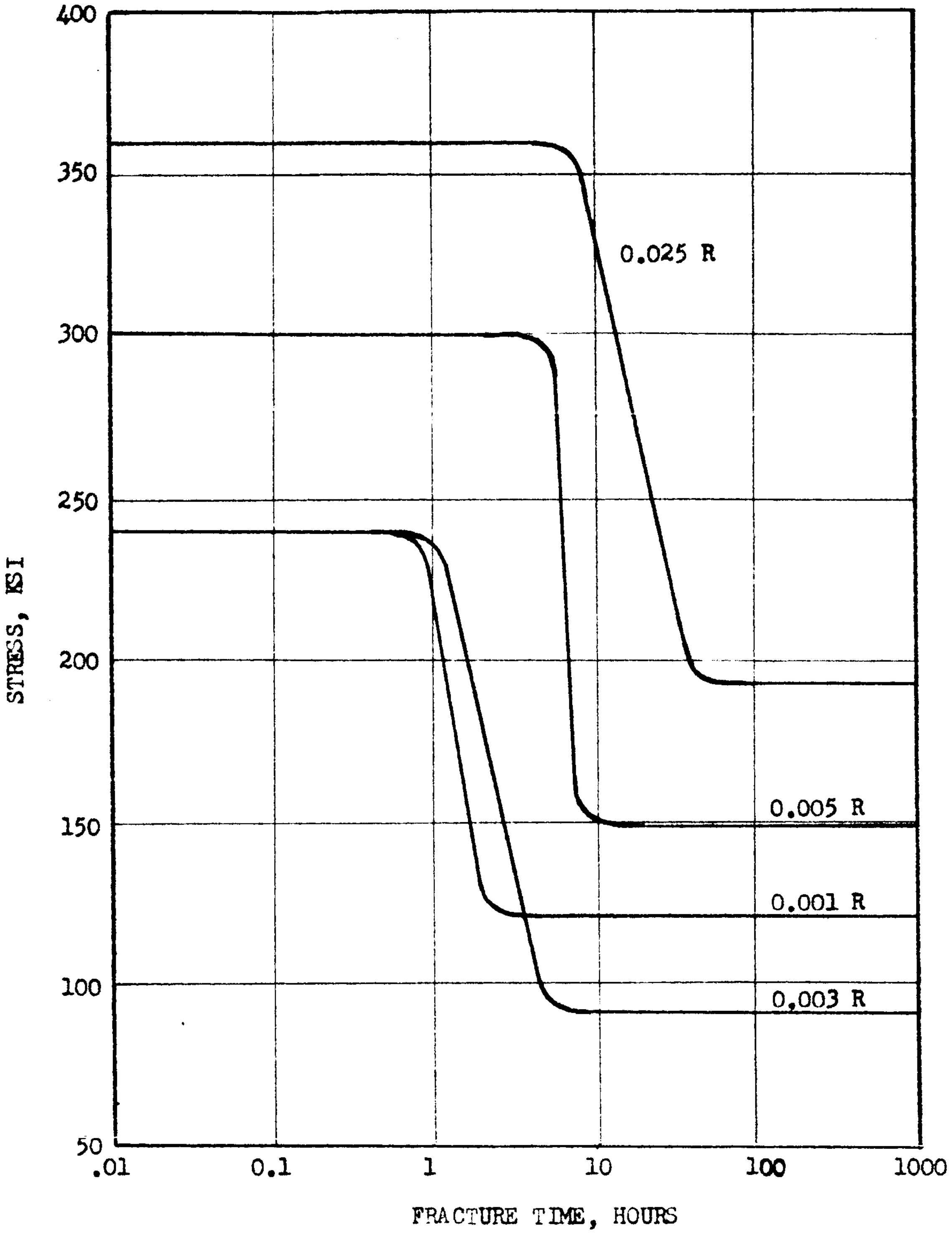


FIGURE 9. Comparison of sustained load, Boeing-plated, notched tensile tests (Data from reference 6).

TABLE 1

HYDROGEN EMBRITTLEMENT TEST TECHNIQUES

A. Short Duration

	Test	Measure of embrittlement
1.	Tensile	reduction of area
2.	Bend over mandrel	angle of bend
3.	Notched tensile	Notched tensile strength

B. Long Duration

	Test	Measure of embrittlement
1.	Stressed ring	time to failure
2.	Stressed notched "C" ring	time to failure
3.	Torqued bolt	time to failure
4.	Sustained load bend	time to failure
5.	Sustained load notched tensile	time to failure

TABLE 2

CHEMICAL COMPOSITION OF 4340 STEELS

Heat No.	Supplier	C	Mn	P	S	Si	Cr	Mo	Ni	Fe
7C-40	Zeigler Steel Service Corporation	0.41	0.67	0.008	0.018	0.27	0.80	0.21	1.82	REM
3350427	Republic Steel[1]	0.40	0.76	0.007	0.010	0.32	0.79	0.24	1.78	REM

1. Obtained from Boeing Airplane Company, Wichita Division

TABLE 3

THERMAL TREATMENT AND SOME MECHANICAL PROPERTIES OF THE 4340 STEELS

Heat No.	Thermal Treatment[1]	F_{tu}	F_{ty}	Hardness R_c
7C-40	1525 for 30 minutes, O.Q. + 4 hours at 400°F, A.C.	265	229	52
3350427	1650 for 32 minutes, F.C. + 1500 for 32 minutes, O.Q. + 1 hour at 450°F, A.C.	285[2]		54 - 55

1. All heat treatments carried out in an argon atmosphere.

2. Estimated from hardness measurement.

TABLE 4

BEND DUCTILITY OF CHEMICALLY MILLED AISI 4340 STEEL

(HEAT 7C-40)

MATERIAL CONDITION	TESTING SPEED, IN/MIN.			
	1.0	0.1	0.01	0.001
AS HEAT TREATED- .040	2.45	2.27	2.21	2.04
	2.23	2.20	2.09	1.98
	2.36	2.35	2.13	2.04
	2.41	2.30	2.02	1.99
	2.30	2.34	2.15	2.05
AVERAGE	2.35	2.30	2.12	2.01
HEAT TREATED + CHEMICALLY MILLED FROM .050 to .040, TESTED IMMEDIATELY	2.09	2.05	1.98	1.97
	2.19	2.09	1.93	2.03
	2.24	2.17	1.98	2.10
	2.16	1.81	1.96	2.01
	2.30	2.12	1.98	1.96
AVERAGE	2.20	2.05	1.83	2.01
HEAT TREATED + CHEMICALLY MILLED FROM .060 to .040, TESTED IMMEDIATELY	1.42	1.58	1.72	2.09
	1.68	1.40	1.89	2.02
	1.40	1.60	1.45	2.07
	1.57	1.32	1.91	2.10
	1.86	1.50	1.92	2.09
AVERAGE	1.59	1.48	1.78	2.07

TABLE 5

BEND DUCTILITY OF AISI CHEMICALLY MILLED 4340 STEEL

Recovery Treatments

(HEAT 7C-40)

MATERIAL CONDITION	TESTING SPEED, IN/MIN. 1.0	0.1	0.01	0.001
HEAT TREATED + CHEMICALLY MILLED FROM .060" to .040", HELD 4 HOURS AT AMBIENT TEMPERATURE BEFORE TESTING	2.45	1.98	2.16	-
	2.28	2.02	2.10	-
	2.22	2.01	2.07	-
	2.29	2.12	2.11	-
	2.30	2.01	2.03	-
AVERAGE	2.27	2.03	2.10	-
HEAT TREATED + CHEMICALLY MILLED FROM 0.060" to 0.040", HELD 8 HOURS BEFORE TESTING	-	2.03	-	-
	-	2.12	-	-
	-	2.09	-	-
	-	2.04	-	-
	-	2.07	-	-
AVERAGE	-	2.05	-	-

TABLE 6

BEND DUCTILITY OF 4340 STEEL

HEAT 7C-40, CADMIUM PLATED

WITH 0.0003 INCH PLATE

MATERIAL CONDITION		TESTING SPEED, IN/MIN			
		1.0	0.1	0.01	0.001
AS-HEAT TREATED - 0.040 GAGE		2.45	2.27	2.21	2.04
		2.23	2.20	2.09	1.98
		2.36	2.35	2.13	2.04
		2.41	2.30	2.02	1.99
		2.30	2.34	2.15	2.05
	AVERAGE	2.35	2.30	2.12	2.01
HEAT TREATED + CADMIUM PLATE - NO BAKE		-	0.60	0.42	0.22
		-	0.68	0.39	0.25
		-	0.64	0.40	0.20
	AVERAGE	—	0.64	0.41	0.22
HEAT TREATED + CADMIUM PLATE + 8 HOURS AT 375°F		2.15	2.02	0.52	1.10
		2.35	2.26	2.08	0.92
		2.23	2.17	1.34	2.00
		2.16	2.26	0.45	1.76
		2.24	2.35	2.00	2.00
	AVERAGE	2.23	2.21	1.30	1.50

TABLE 7

BEND DUCTILITY OF CADMIUM PLATED 4340 STEEL

(HEAT 3350427)

CONDITION		JAW TRAVEL SPEED			
		1.0	0.1	0.01	0.001
HEAT TREATED + BAKED 23 HOURS AT 375 F		2.20	2.24	2.29	2.11
		2.28	2.26	2.20	2.19
		2.31	2.26	2.27	2.08
	AVERAGE	2.26	2.25	2.25	2.13
H.T. + PLATE - NO BAKE		1.07	0.70	0.33	0.49
		0.81	1.18	0.52	0.20
		0.96	1.00	0.37	0.26
	AVERAGE	0.94	0.96	0.41	0.32
H.T. + PLATE + 4 HOURS AT 375°F		-	-	0.62	0.27
H.T. + PLATE + 8 HOURS AT 375°F		-	-	2.13	0.97
				2.14	0.56
				2.09	0.52
	AVERAGE			2.12	0.69
H.T. + PLATE + 23 HOURS AT 375°F		2.25	2.19	2.11	1.90
		2.40	2.25	2.21	2.01
		2.20	2.26	2.15	2.00
	AVERAGE	2.26	2.23	2.16	1.97

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