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MATERIALS - SAE4335 (MODIFIED) STEEL - 260,000 TO 280,000 PSI HEAT TREATMENT - DEVELOPMENT OF PROCESS CONTROL AND MECHANICAL PROPERTIES FOR

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MATERIALS - SAE 4335 (MODIFIED) STEEL - 260,000 to 280,000 PSI
HEAT TREATMENT - DEVELOPMENT OF PROCESS CONTROL AND
MECHANICAL PROPERTIES FOR -

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A C K N O W L E D G E M E N T

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PHASE II - R. L. Jones

INTRODUCTION

The aircraft industry has, only in the past few years, begun to utilize the potential strength of alloy steels. A tremendous savings in weight and space could be realized by raising the maximum heat treat level of high strength steels from the normal 200,000 - 220,000 psi to 260,000 - 280,000 psi tensile strength. To accomplish this change, a necessary re-evaluation of design allowables for minimum impact, notch sensitivity and fatigue properties of aircraft structural steels was required. Previously, designers had avoided the use of high strength steels because brittleness was thought to be characteristic of steels heat treated above 220,000 psi tensile strength. However, research on SAE 4340 has shown that the higher heat treat level is acceptable for airframe applications.

There were two approaches to achieving higher tensile strength in aircraft structural steels. The first, used for SAE 4340, was to lower the tempering temperature from above 800 F to a range of 400 to 450 F. This heat treatment avoided completely the 600 F "embrittlement temperature" which is characteristic of the chromium-nickel-molybdenum steels. When tempered at 600 F, Izod impact strength for 4340 is reduced to a range of 10 - 15 ft. - lb.

The other approach, followed by Convair, was to select a different alloy possessing improved properties. SAE 4335 (Mod.) was chosen as a superior alloy over 4340. Essentially 4335 (Mod.) has the same alloying elements as 4340 with approximately twice as much molybdenum, .05% less carbon and an additional .08 - .20% vanadium. The lower carbon content was intended to improve ductility and notch impact strength. The restricted carbon range of 0.33 to 0.38% was selected because the minimum strength of 260,000 psi could be obtained after tempering at 400 F. It was felt that 0.32% carbon would not uniformly give a minimum tensile strength of 260,000 psi after plotting a large number of test data points. The maximum carbon content of 0.38% was selected because it was believed that a tensile strength of 280,000 psi or less could be consistently obtained after tempering at 450 F. The molybdenum content was increased to insure a deep hardening steel and the vanadium was added for grain refinement. Tempering temperatures in the range 400 to 500 F were investigated to determine whether the required 260,000 - 280,000 psi tensile strength range could be obtained. In the investigation for a suitable heat treatment to develop optimum mechanical properties for SAE 4335 (Mod.), no one particular property, other than the desired 260,000 psi tensile strength was emphasized at a loss to another. At this high heat treat level it was anticipated that notch impact strength and transverse ductility would be a problem. On this basis, it was decided to analyze the heat treating variables from test results obtained for tensile, notch tensile, and impact tests.

MATERIALS - SAE 4335 (MODIFIED) STEEL - 260,000 TO 280,000 PSI

HEAT TREATMENT - DEVELOPMENT OF PROCESS CONTROL AND MECHANICAL PROPERTIES FOR

PURPOSE:

The purpose of this investigation was to develop the best heat treat processing method for SAE 4335 (modified) steel heat treated to the 260,000 - 280,000 psi range, and to determine the mechanical properties of the steel in this condition.

SUMMARY:

Present aircraft requirements have necessitated the departure from the customary 200,000 - 220,000 psi heat treat level for alloy steels, to a new high of 260,000 - 280,000 psi tensile strength. This higher strength has been attained by lowering the tempering temperature and in some instances, the selection of new or modified alloy steels.

Lowering of the tempering temperature produces the desired increase in tensile strength, but is accompanied by an undesirable decrease in ductility. As a result, the impact and transverse elongation properties become quite critical in aircraft design considerations. Convair, Ft. Worth, selected an alloy steel, SAE 4335 modified with .08 - .20% vanadium for investigation as a possible improvement over the standard 4340 previously used. The reduction of carbon content tends to benefit impact resistance and ductility, while additions of vanadium and molybdenum tend to improve hardenability.

In order to establish the reliability of SAE 4335 modified for applications in the 260-280 ksi heat treat range this investigation was initiated to (1) develop a heat treating procedure that would provide optimum mechanical properties and (2) obtain data for establishing design allowables using this heat treat procedure.

Phase I of this project was therefore concerned primarily with the evaluation of austenitizing temperatures, quenching cycles, tempering temperatures, and durations of these cycles. An integrated series of tests indicated that the heat treatment to produce the best combination of properties was as follows:

1. Austenitize at 1525 F for one hour per inch of section size.
2. Quench in agitated oil to room temperature.
3. Temper at 465 F for two hours.
4. Air cool to room temperature.

Properties determined in this phase of the project, not included in the mechanical testing section, were:

1. Notch strength/ultimate strength .88 - 1.02
2. Izod impact strength, ft-lbs. 16 - 17

Phase II consisted of the determination of mechanical properties obtainable from modified SAE 4335, heat treated by the process established in Phase I. The average mechanical properties were:

1. Tensile Properties

	Longitudinal	Transverse
a. Ultimate stress, psi	265,000	253,000
b. Yield stress, psi	228,000	221,000
c. Yield/ultimate ratio	.86	.87
d. Elongation, %	10.5	3.9
e. Reduction of area, %	42.6	7.3
f. Elastic modulus, psi	29,600,000	30,900,000
g. Hardness	50.7Rc, 498 BHN	50.3Rc, 488 BHN

2. Compression Properties

a. Yield stress, psi	227,000
b. Elastic modulus, psi	31,800,000

3. Double Shear Properties

Outside diameter/wall thickness	Ultimate stress, psi
1	166,000
3	160,000
5	148,000
7	140,000
9	135,000
11	130,000

4. Bearing Properties - Ultimate Stress

(e/d = 1.0)	213,000 psi
(e/d = 1.5)	353,000 psi
(e/d = 2.0)	460,000 psi

5. R. R. Moore Rotating Beam Fatigue Properties - (Smooth ground finish)

Fatigue strength at endurance limit (10^7 cycles) - 118,000 psi.

A series of tests were performed on rotating beam fatigue specimens which were processed with a variety of surface treatments. In general, it can be said that shot peening improved the fatigue characteristics of modified SAE 4335 while a chromium plating treatment over a finish ground surface was extemely detrimental. However, specimens shot peened, chromium plated, and finish ground after plating showed practically no reduction in fatigue strength.

Sustained load properties to evaluate hydrogen embrittlement were determined using a test specimen which was developed during an investigation of failures which occurred in static loaded B-36 landing gears. Test results indicated that modified SAE 4335 was susceptible to the hydrogen embrittlement resulting from cadmium plating. Brittle failures were obtained in specimens loaded as low as 70% of the ultimate strength. However, limited test results indicate that shot peening before plating reduces embrittlement in cadmium plated specimens. When using shot peening prior to chromium plating, no specimens failed after 60 days of testing at 90% of ultimate tensile strength.

Mechanical properties of arc welded modified SAE 4335 were also determined to be:

	Type Electrodes	
	Arcos 5M	P & H 21
Ultimate stress, psi	202,000	206,000
Yield stress, psi	182,000	187,000
Elongation, %	5.8	4.4
Reduction of area, %	28.8	15.4
Weld strength/parent metal strength, %	76	78

Of these two welding electrodes, Arcos 5M (Special High Carbon) has the most desirable properties from a viewpoint of ductility and weldability.

To test a fabrication process used by a landing gear manufacturer, hollow tensile specimens were flash welded at Menasco Mfg. Co. The specimens failed, when loaded in tension, at an average ultimate stress of 205,000 psi with no measurable elongation.

MATERIALS - SAE 4335 (MODIFIED) STEEL - 260,000 TO 280,000 PSI

HEAT TREATMENT - DEVELOPMENT OF PROCESS CONTROL AND

MECHANICAL PROPERTIES FOR

OBJECT:

Phase I:

To develop the best heat treat processing method for modified SAE 4335 alloy steel in order to obtain optimum mechanical properties at the 260,000 to 280,000 psi heat treat level.

Phase II:

To determine the mechanical properties of this steel, heat treated by the process established in Phase I.

TEST SPECIMENS:

The test specimens used in Phase I, were as follows:

Tensile test specimen	Figure 1
Notch tensile specimen	Figure 2
Izod impact specimen	Figure 3
Hardenability specimen	Figure 4
Quench crack specimen	Figure 5

The test specimens used in Phase II, were as follows:

Tensile test specimen	Figure 1
Compression test specimen	Figure 6
Solid double shear specimen	Figure 7
Hollow double shear specimen	Figure 8
Bearing specimen	Figure 9
Sustained load specimen	Figure 10
Flash welded tensile specimen	Figure 11
Uniweld tensile specimen	Figure 12
Round axial fatigue specimen	Figure 13
Round axial notch fatigue specimen	Figure 14
R. R. Moore fatigue specimen	Figure 15

The modified SAE 4335 steel was purchased from the Earl M. Jorgensen Company of Los Angeles, to the requirements of Convair specification FMS-0024. The compositions certified by mill acceptance were as follows:

	Heat #75679	Heat #75680	Spec. FMS-0024
C	.35	.35	.33 - .38
Mn	.75	.72	.60 - .90
Si	.27	.30	.20 - .35
P	.016	.012	.040 max.
S	.018	.016	.040 max.
Cr	.76	.76	.65 - .90
Ni	1.77	1.82	1.65 - 2.00
Mo	.42	.43	.35 - .50
V	.12	.14	.08 - .20

All specimens were rough machined .020" oversize from the bar sizes shown in Table XX, heat treated and final machined or ground depending on tolerances required. When the specimens were finish ground, they were stress relieved for 4 hours at 375 F following the grinding operations. For all specimens tempered at temperatures less than 400 F, the stress relieving temperature was 25° less than the indicated tempering temperature.

PROCEDURE:

Phase I:

Standard Jominy hardenability specimens, shown in Figure 4, were machined from 6" and 1 1/4" dia. bars to determine whether both sizes had equivalent hardenability response. A Sunbeam atmosphere furnace was used for these and all subsequent austenitizing treatments. A low temperature salt bath was used for tempering. The specimens were final ground after being heat treated at four austenitizing temperatures, 1550, 1600, 1650, and 1700 F.

Part A:

To determine the optimum austenitizing temperature and holding time, one tensile specimen, Figure 1, was treated by heating to each of the following temperatures, oil quenched and tempered at 450 F for 2 hours:

Austenitizing temperature, °F	Holding time, hours
1500	1, 2, 4
1550	1, 2, 4
1600	1, 2, 4
1650	1, 2, 4

After heat treatment and final machining each of the specimens were tested in accordance with standard tensile testing procedures.

Part B:

Using the best austenitizing temperature determined in Part A, one tensile, two notch tensile, and three impact specimens were tempered at each of the following temperatures for the times indicated and tested for mechanical properties:

Tempering temperature, °F	Time at each temp., hours
400	2, 4, 8, 12, 16, 24
425	same
450	same
475	same
500	same

Part C:

Because retained austenite is an undesirable constituent in steels heat treated to a high strength level, this section of the testing was originated to determine the quenching and tempering cycle which would produce the least amount of retained austenite. Employing a theory of Professor M. Cohen of MIT, a high tensile yield strength to ultimate strength ratio was considered as indicative of low retained austenite. In addition to this criteria for evaluating the best quenching and tempering cycle, impact and notch tensile tests were also used in the determination.

One tensile, two notch tensile and three impact specimens were treated at each of the following conditions after austenitizing at 1525 F for one hour:

1.

Quenching temp, °F	Holding time, hrs.	Cooling cycle	Tempering Cycle °F
550	2	Air cool to room temp.	550 (2 hrs)
500	4	"	500 "
450	2	"	450 "
400	2	"	400 "
350	2	"	350 "
300	2	"	300 "
250	2	"	250 "

2.

Quenching temp, °F	Holding time, hrs.	Cooling cycle	Tempering Cycle, °F
550	2	-120 (2 hrs.)	550 (2 hrs.)
500	4	"	500 "
450	2	"	450 "
400	2	"	400 "
350	2	"	350 "
300	2	"	300 "
250	2	"	250 "

3.

Quenching temp, °F	Holding time, hrs	Cooling Cycle °F	Tempering Cycle °F	Cooling Cycle °F	Tempering Cycle °F
550	2	-120 (2 hrs.)	550 (2 hrs.)	-120 (2 hrs.)	550 (2 hrs.)
500	4	"	500 "	"	500 "
450	2	"	450 "	"	450 "
400	2	"	400 "	"	400 "
350	2	"	350 "	"	350 "
300	2	"	300 "	"	300 "
250	2	"	250 "	"	250 "

Standard mechanical testing followed heat treatment and final machining. All tensile tests were performed on a Baldwin, 120,000 lb. capacity, universal test machine, equipped with a Tate-Emery load indicator and automatic load-strain recorder. All impact tests were performed on a Riehle impact test machine.

Part D:

The susceptibility of the final process, determined from an analysis of the three preceeding sections, to quench cracking was determined by the use of quench crack specimens as shown in Figure 5. Ten specimens were heated to the austenitizing temperature of 1525 F, held for one hour, and quenched in agitated oil. As soon as the specimens had cooled to the temperature of the oil, 82 F, they were given a rough metallographic polish across the flat faces. The specimens were then examined for cracks with the aid of a binocular microscope.

Phase II:

Specimens in this phase of testing, as determined from Phase I, were treated as follows:

1. Austenitize at 1525 F for one hour.
2. Quench in agitated oil at room temperature.
3. Temper for two hours at 465 F.
4. Air cool to room temperature.

The Sunbeam atmosphere furnace was used for the austenitizing treatment and tempering was performed in a Hevi Duty Temperite furnace. The Temperite furnace was used rather than the laboratory salt bath furnace because improved temperature control could be obtained.

Part A:

Tensile tests were performed on seven longitudinal and six transverse specimens of the type shown in Figure 1. All tests were performed in accordance with standard test procedures. Ultimate stress, yield stress, percent elongation, percent reduction in area, modulus of elasticity, and Rockwell C hardness values were determined for each specimen. A load rate of 10,000 lb/min was maintained throughout all testing.

Part B:

Compression yield strength tests were performed on five specimens of the type shown in Figure 6. Three AB-7 strain gages were mounted on each specimen at 120° intervals on the circumference at the center and parallel to the longitudinal axis. The strain gages on each specimen were wired in parallel to obtain an average strain reading. A modified Brown Recorder provided a continuous record of load versus strain.

Part C:

Four solid shear specimens, Figure 7, were loaded and tested to failure in the jig shown in Figure 46. Shear faces of the jig were one diameter from each end of the specimen. The jig and specimens were designed with tolerances specified to obtain a press fit. A dial gage was used to measure the load deflection curve for each specimen. All tests were performed on a 600,000 lb. Baldwin universal test machine.

Part D:

At least two hollow shear specimens of each type (Figure 8), having diameter to wall thickness ratios of 3, 5, 7, 9, and 11, were tested to failure in the same jig used for solid shear specimens. The testing procedure was identical to that used for solid shear specimens with the exception that part of the tests were conducted in a 120,000 lb. Baldwin universal test machine.

Part E:

Three lug type bearing specimens, Figure 9, of each type having edge distance/bearing hole diameter ratios of 1.0, 1.5, and 2.0, were tested to failure in the jig shown in Figure 47. Two dial gages were used to measure the average movement of the bearing pin during loading.

Part F:

1. Six sustained load specimens, Figure 10, were tested in specially designed jigs, as described in Convair, Ft. Worth Report No. MR 52-8. Two specimens were loaded to each stress equal to 70, 80 and 90% of the ultimate strength. Individual Rockwell hardness measurements were used to estimate the respective tensile strengths of the specimens. After initial loading, the specimens were periodically checked for load changes once per week until failure occurred or until 1440 hours expired. (See Figure 10A for description of sustained load test jig.)
2. Eight sustained load specimens were cadmium plated and baked per P. S. 73.01* and tested at 60, 70, 80 and 90% of the ultimate strength stress levels. Testing followed the same procedure as outlined above for bare specimens.
3. Eight sustained load specimens were shot peened by the Metal Improvement Company of Los Angeles, in accordance with the following specifications:

   a. Shot peen all surfaces except the inside of the holes per Mil-S-13165 with .019" nominal dia. shot.
   b. Almen "A" intensity of .006 to .010".
   c. The method of determining intensity and the Almen "A" test specimen shall conform to Mil-S-13165.
   d. The shot used shall conform to Mil-S-851B, type 1A or 1B, Class 1.

*Note: P.S. 73.01 is a GD/FW process standard based on, and containing, the requirementsof Spec. QQ-P-416.

e. Parts shall not be subjected to processing temperatures in excess of 400 F.
f. Magnaflux inspect parts before and after peening.

Following shot peening, six of the parts were chromium plated at Convair per P. S. 73.04* with the exception that the baking temperature was limited to 450 F maximum. Two of the specimens were cadmium plated and baked per P. S. 73.01. The cadmium plated specimens were loaded at 80 and 90% of the ultimate strength stress levels and the chromium plated specimens were tested at 70, 80 and 90% of the ultimate strength stress levels.

4. Two additional sustained load specimens were chromium plated and baked at 450 F with no prior surface treatment and tested at 70% of ultimate strength.

Part G:

This portion of the testing was concerned with the weldability of modified SAE 4335 and tensile properties after heat treatment.

1. Ten tensile specimens, Figure 1, were arc welded (using standard inert gas welding procedures) using the following electrodes and machine settings.

   a. Arcos 5M (Special High Carbon) - 25 volts, 125 amps, electro positive.
   b. P & H 21 - 25 volts, 125 amps, electro positive.

   The material was preheated to 400 - 600 F and postheated to 1350 F. Heat treatment was the same as that used for the other type specimens. Standard tensile tests were performed on the specimens after final machining.

2. Seven sets of flash weld test specimens, Figure 11, were prepared at Convair and sent to Menasco Mfg. Co. at Burbank for welding. Details of the welding process are unknown. Due to the size of the specimen and the nature of the failure, Baldwin extensometers could not be used to measure strain during the tensile tests. A dial gage was clamped to the specimen to measure deformation over a one inch gage length including the weld.

NOTE: P.S. 73.04 is a GD/FW Process Standard based on, and containing, the requirements of Spec. QQ-C-320.

3. One set of Uniweld test specimens, Figure 12, was sent to Menasco for Uniwelding. However, difficulty was encountered in welding and this portion of the testing has not been completed. An analysis of the welding problems by Menasco can be found in the discussion section of this report.

Part H:

Modified SAE 4335 was scheduled to be tested under two types of fatigue applications. The axial fatigue test using a Sonntag SF-1-U fatigue testing machine with a 5 to 1 multiplying fixture, has been delayed pending re-work of a fixture. The notched and unnotched specimens are shown in Figures 13 and 14.

The second type was the rotating beam, for which R. R. Moore fatigue test machines and specimens, Figure 15, were employed. Testing was performed in accordance with standard procedures. Ten specimens, each having the following surface conditions were fatigue tested to establish suitable S-N curves:

1. Smooth machined to a 250 rms surface finish.
2. Smooth machined to a 100 rms finish and cadmium plated per P. S. 73.01.
3. Smooth machined to a 100 rms finish and shot peened according to the procedure outlined under sustained load tests.
4. Smooth machined to a 40 rms finish, shot peened, chromium plated per P. S. 73.04, baked at a temperature not over 450 F, smooth ground to a 16 rms finish and a final plating thickness of .002 in., and baked at 375 F for 4 hours.
5. Same as (4) above, except the shot peening was eliminated.
6. Smooth ground to a 16 rms surface finish and baked at 375 F for 4 hours.
7. Finished per AIA-ARTC-W76 which essentially was:

    a. Finish ground to a 16 rms finish.
    b. Bake at 375 F for 4 hours.
    c. Polished longitudinally in four stages with 0, 00, 000, and 0000 grade emery paper until no circumferential tool marks were visible at 20X magnification.

RESULTS:

Phase I:

Jominy hardenability results for 6" dia. and 1 1/4" dia. bars are shown in Table I and Figure 16.

The effects of various austenitizing temperatures upon the tensile properties are shown in Table II and Figures 17 & 18.

The effects of various tempering temperatures and holding times upon the tensile properties are shown in Table III and Figures 19 and 20. The notch tensile properties at various tempering temperatures and holding times are shown in Table IV and Figure 21. The variation of Izod impact strength with different tempering temperatures and holding times is shown in Table V and Figure 22.

The effects of various tempering and quenching cycles upon the tensile properties are shown in Table VI and Figures 23 and 24. Notch tensile test results are shown in Table VII and Figure 25. Izod impact test results are shown in Table VIII and Figure 26.

A summation of all the test results obtained in this phase of testing is contained in Table IX and Figure 27.

The quench crack test results are shown in Table X.

A recheck on the Izod impact tests was made to ascertain the effect of 450 F and 475 F tempering temperature since this range seemed the probable choice for the heat treatment of SAE 4335 (Mod.). The results are shown in Table XI.

Phase II:

The longitudinal and transverse tensile test results are shown in Table XII and Figures 28 and 29.

The compression test results are shown in Table XIII and Figure 30.

The shear test results for solid and hollow specimens are shown in Table XIV and Figures 31 and 33. Figure 32 shows the effect of wall thickness upon the ultimate shear strength of hollow tubes. A typical failed specimen is shown in Figure 46.

The bearing test results for 1.0, 1.5 and 2.0 edge distance/diameter ratios are shown in Table XV and Figure 34. Typical bearing failures for e/D = 2.0 specimens are shown in Figure 48.

The sustained load test results for bare, cadmium plated, chromium plated, and chromium plated after shot peening specimens are shown in Table XVI and Figure 35. Typical failed specimens are shown in Figure 49.

The tensile test results for specimens arc welded, with Arcos 5M (Special High Carbon), and P & H 21 electrodes are shown in Table XVII and Figure 36.

The tensile test results for Menasco flash welded specimens are shown in Table XVIII and Figure 37.

No tensile test results are reported for Uniweld specimens due to the difficulty Menasco had in welding SAE 4335 by this process. Menasco attempted twice to weld the specimens supplied by Convair, but each weld was rejected on chip examination for excess white zone.

Menasco has initiated a test program on the Uniwelding of 4335 which to date has not produced satisfactory welds.

The test results for rotating-beam fatigue specimens having various surface treatments and finishes are shown in Table XIX and Figures 38 thru 45. Figure 38 shows the effect of the various surface treatments upon the fatigue properties of 4335 (Mod.).

Fatigue test results for axially-loaded tension compression specimens are incomplete because of difficulties in applying a true tension-compression load with the existing test fixtures. A new fixture is being designed to assure accurate test results. When this fixture becomes available, the fatigue testing will be completed and reported as an addendum to this report.

DISCUSSION:

Phase I:

Initially, the austenitizing temperature and time at temperature were studied. Varying the temperature in 50° increments from 1500 to 1650 F and varying holding time between one to four hours had very little effect on the ductility. However, the yield strength decreased with increasing austenitizing temperature and holding time as shown in Figure 17.

The ultimate strength was similarily affected but to a lesser degree. The results indicated that a desirable yield to ultimate strength ratio would be obtained by austenitizing for one hour at 1525 F.

The variation of tempering temperatures in increments of 25° between 400 and 500 F yielded very little effect upon elongation and reduction of area. Scatter in the ultimate tensile strength results was severe, with no apparent trend being established. Only one tensile specimen was tested at each set of conditions. Thus, slight variations in homogeniety might significantly affect the test results. The yield strength increased approximately 10,000 psi over the tempering range studied for all tempering times except the 24 hour period. Tempering at 475 F was particularly beneficial in increasing the yield strength. The notch strength ratio generally decreased slightly with higher tempering temperature. The definite advantage of a short tempering cycle of 2 hours at 450 F can be seen in the sharp rise of Izod impact strength in Figure 22. Although these values were found by later tests (Table XI) to be somewhat high, the general trend remained unchanged. Since the best impact properties were obtained at 450 F and the best yield to ultimate ratios were obtained at 475 F, a 465 F tempering temperature was chosen to produce the best combination of properties. The effect of tempering on hardness and microstructure are shown in Figure 50.

The third part of the development of a suitable heat treating cycle was concerned with various tempering and quenching cycles which would promote maximum transformation of austenite to martensite while minimizing residual stresses and possible cracking. A small percentage of retained austenite is undesirable in a high strength steel because at any time during stressing, it may transform into martensite which has greater volume and hardness. The resulting induced stress and reduction in ductility could be sufficient to cause a premature service failure. The work of Cohen at MIT indicates that the tensile yield to ultimate ratio is a good indication of the percentage of retained austenite. The heat treating processes examined to promote optimum properties were:

1. Marquenching at various holding temperatures within the M_s- M_f range.
2. Marquenching followed by subzero quenching (-120 F).
3. Same as process (2) except double subzero quenching and double tempering.

The theory behind the first process was to minimize residual stresses by reducing the severity of the quench, but at the same time, allow martensitic transformation to begin. It has been shown that the rate of cooling affects the percent retained austenite, slower cooling rates being more undesirable in this respect. Marquenching consists essentially of rapidly cooling a steel from above its critical temperature, past the "knee" of the TTT (time-temperature-transformation) curve, to a temperature within the Ms-Mf range and holding it there long enough to allow temperature equalization throughout the section. The steel is then cooled to room temperature to complete the transformation. Quenching temperatures were varied in 50° increments between 550 and 250 F to more fully evaluate this treatment.

The theory of double tempering and single or double subzero treatment is that martensite forms from austenite during the cooling cycle. Thus, the multiple cooling following tempering and subzero cooling should aid in the formation of martensite from any retained austenite. In addition to the evaluation of tensile yield to ultimate ratios for the estimation of percentage retained austenite, impact and notch tensile properties were also considered.

Comparing Figure 24 to Figure 20, it can be seen that all of the quenching and tempering cycles investigated produced tensile yield to ultimate ratios which were inferior to those produced by quenching to room temperature and tempering by standard procedures. In general, the double tempering and double subzero treatment gave the best properties with the single marquench and temper producing the lowest. Impact test results were somewhat erratic, however, the treatment of quenching to a raised temperature followed by air cooling and tempering produced impact strengths which were superior to those of the other treatments investigated. In the final evaluation, shown in bar chart, Figure 27, it was decided that none of the marquenching treatments of this phase of testing improved the mechanical properties or reduced the retained austenite as effectively as the simple quench to room temperature followed by tempering.

Since no failures occurred in the specimens of the quench crack tests, it was felt that the room temperature oil quench would not set up sufficient stresses in a part to cause crack formation.

Phase II:

The results of tensile tests on longitudinal test specimens, heat treated by the process determined in Phase I, showed good mechanical properties. A yield to ultimate ratio of .86 was obtained at an average ultimate strength of 265,000 psi. Average elongation of 10.5% and reduction of area of 42.6% were obtained at this strength level. Comparing these results to data obtained for SAE 4340 heat treated to 260,000 - 280,000 psi (Table XXI), the ultimate and yield strengths are slightly lower despite practically the same heat treating procedures. This can be explained by the lower carbon content. The ductility properties are significantly improved by this alloy modification. The compression yield strength of 227,000 psi differed very little from the tensile yield strength value.

The transverse tensile properties were somewhat less than the longitudinal properties, particularly elongation and reduction of area. The average elongation dropped to 3.9% and average reduction of area was only 7.3%. The yield to ultimate ratio was practically the same as that obtained for longitudinal sections although the ultimate strength dropped to 253,000 psi.

From Figure 32 it may be seen that the double shear strength of 4335 hollow tubes varied along a smooth curve with the shear strength increasing with increasing wall thickness. The shear strength of a solid cylinder of the same size was 166,000 psi.

Increasing the ratio of the distance from the center of the hole to the edge of the specimen to the hole diameter caused practically a linear increase in ultimate bearing strength. From Figure 34 it may be seen that considerable resistance to deformation was gained by increasing the e/d ratio from 1.0 to 1.5, while very little increase was attained in the 1.5 to 2.0 increment. However, the ultimate bearing strength was increased from an average of 213,000 psi for e/d = 1.0 to 460,000 psi for the e/d = 2.0 specimens.

The sustained load tests were devised for a previous test program to study the embrittling effect of hydrogen absorption during cadmium and chromium plating in the presence of a stress raiser. The test specimen was designed to simulate the walking beam of the B-36 landing gear, which had failed due to hydrogen embrittlement. Cadmium plating applied per Process Standard 73.01 embrittled 4335 despite the baking treatment of 3 hours at 375 F. Sustained loading above 60% of the ultimate tensile strength caused the specimens to fail at times from 6.2 hours to 469 hours depending upon the load. A definite curve of load versus time to failure could not be established from the data because of excessive scatter as shown in Figure 35. Five of the six specimens which failed, failed through the smaller, supporting hole rather than the bearing hole as shown in Figure 49. This is difficult to explain since theoretically twice the stress is required for this type of failure as compared to the normal failure. However, it was felt that the smaller holes were oversize, resulting in high stress concentration at the point of contact with the supporting pin. Macroscopic inspection of the failure zone did not reveal any inclusions which would have weakened the section. Shot peening lowered the susceptibility of 4335 to hydrogen embrittlement resulting from cadmium and chromium plating as may be seen in Table XVI. One peened, cadmium plated specimen did not fail at 80% of the ultimate load and another loaded to 90% of the ultimate tensile strength had a life of 633.6 hours. The unpeened, cadmium plated specimens failed after 86 - 110 hours at 80% load and had a life of 6.2 to 469 hours at 90% load.

Chromium plating had no detrimental effect on the sustained load properties of the peened specimens. Unpeened specimens tested at 70% of ultimate strength, did not fail after 60 days of testing. Further testing of unpeened specimens at higher load levels was not performed, so no direct comparison can be made of the effect of shot peening on the sustained load properties of chromium plated specimens. The higher baking temperature of 450 F maximum probably aided in the removal of hydrogen after the chromium plating treatment. A possible explanation which applies to the cadmium plated specimens as well as the chromium plated specimens is that the shot peening reduced the rate of hydrogen diffusion into the steel during the chemical and electro-chemical treatments. Possibly the compressive surface stresses established by the shot peening operation resulted in a lowered tensile stress distribution giving rise to increased sustained load life.

The inadequacies of the sustained load test method should be noted here. Due to the process of load application via turnbuckles, and the technique of load calculation by calibrated strain gage links, considerable error was introduced into the test results. The loads were checked once a week and generally it was found that the load had decreased either by yield of the specimen or the fixture or by creep in the glue used to attach the strain gages.

However, despite these errors, the general trend of results is believed to be valid.

The arc welding of 4335 with Arcos 5M (Special High Carbon) and P & H 21 electrodes produced weldments having tensile strengths of 76% and 78% of parent metal tensile strength respectively. These results were somewhat lower than the 80% weld efficiency determined for 4340 in Convair Fort Worth Report No. MR 54-3. Fifty percent of the failures in the 4335 test occurred at the weld junction. Figure 51 shows typical photomicrographs of weld junctions for both type electrodes. A combination of weld junction failures (resulting possible from base metal to weld deposit carbon diffusion), porosity and slag inclusions produced tensile properties which were not truly representative of the mechanical strengths possible with Arcos 5M and P & H 21 electrodes. Examples of these defects can be seen in the photograph of fractured surfaces in Figure 52. Welding operator technique is felt to be the strongest contributing factor to these low results. Of the two electrodes, Arcos 5M had better properties from the viewpoint of ductility and weldability.

Menasco flash welding techniques were successful for tubular specimens of 4335. A weld strength of 205,000 psi was attained, giving a weld efficiency of 77%. No yield and elongation were measured; however, these properties are reported to be typical of Menasco's flash welding process. Menasco has not been successful in Uniwelding 4335. From correspondence with Mr. M. C. MacCluer of Menasco it was learned that all Uniwelds have been rejected after chip examination because of an excess oxygen enriched zone. Initially it was thought that the welding failure resulted from improper technique. When the same results were obtained after the second welding attempt, it was assumed that the material was responsible for the welding difficulties, since this same procedure had produced good welds in 4340. Menasco has undertaken a test program to study the weldability of 4335 by the Uniweld method.

Generally speaking, 4335 compared favorably to 4340 in rotating beam type fatigue tests for specimens having no notch. This can be seen by referring to Figure 38 and comparing the curve for smooth ground 4335 specimens to the curve for smooth ground 4340 specimens. An improvement over 4340 can be noted at the lower stress levels. Shot peening improved the fatigue characteristics of 4335, increasing the endurance limit from 118,000 psi to 125,000 psi.

The largest benefit from shot peening was imparted to the chromium plated specimens. Figure 53 shows the surface of a shot peened specimen with its typical impressions resulting from the peening action. For specimens shot peened prior to chromium plating and finish grinding, only a slight reduction in fatigue strength resulted at the higher stress as compared to unplated, shot peened specimens. However, for chromium plated specimens having no peening, a drastic reduction in fatigue strength was obtained. This was due probably to the residual stresses induced by the plating and grinding operations.

Cadmium plating imparted only a slight decrease in fatigue life at the higher stress levels. Rough machining to a 250 rms surface finish produced a notch effect which slightly reduced the fatigue strength and endurance limit. An example of a typical notch produced during this machining operation is shown in Figure 53.

CONCLUSIONS:

Phase I:

1. The best heat treatment for optimum combination of all mechanical properties of SAE 4335 at the 260,000 - 280,000 psi strength level is:

    a. Austenitize at 1525 F for one hour
    b. Quench in agitated oil to room temperature
    c. Temper at 465 F for two hours
    d. Air cool to room temperature

2. Normal oil quenching from the austenitizing temperature to room temperature followed by a single tempering operation was sufficient to produce maximum austenitic transformation. Neither marquenching, subzero quenching, or double tempering treatments improved the mechanical properties of 4335 sufficiently to warrant their use in the heat treating cycle.

3. Oil quenching will not produce quench cracks in heat treated parts of 4335; however, tempering should follow quenching with as little delay as possible.

Phase II:

The results of tests to determine the mechanical properties of SAE 4335 heat treated to the tensile strength level of 260 - 280 ksi in accordance with the procedure outlined in Phase I above indicate the following:

1. SAE 4335 has superior ductility and impact properties to SAE 4340 when heat treated to the 260 - 280 ksi level.
2. The baking cycle of 3 hours at 375 F was not sufficient to remove the embrittling effect of cadmium plating upon SAE 4335. A sustained load of 60% of ultimate strength was the maximum load which cadmium plated specimens could withstand without failure in 60 days. Limited test results indicate that the higher baking temperature of 450 F used for chromium plating apparently was effective in reducing hydrogen embrittlement since no brittle failures occurred during sustained load tests at 70% of ultimate tensile strength during the testing interval.
3. Shot peening improved the sustained load strength of cadmium plated specimens, increasing the maximum allowable stress from 60 to 80% of the ultimate tensile stress.
4. Welding efficiency of approximately 77% can be achieved in arc welded SAE 4335 using Arcos 5M (Special High Carbon) and P & H 21 electrodes. The same efficiency is possible with Menasco's flashwelding technique although the weld has very little ductility.
5. SAE 4335 is not weldable by Menasco's Uniweld process using techniques estabiished for 4340. However, an investigation is being conducted by Menasco to develop a suitable Uniweld procedure.
6. SAE 4335 has superior fatigue properties to 4340 at stress levels below 140,000 psi. Above this stress level there is little difference between the two steels when heat treated to the 260-280 ksi level.
7. Chromium and cadmium plating lowered the fatigue strength of 4335, chromium plating being particularly severe. However, the chromium plating tests included finish grinding the plating to .002" thickness. Therefore, the reduced fatigue properties could be due to residual stresses induced by chromium plating and grinding.
8. Shot peening improved the fatigue strength of 4335, increasing the endurance limit from 118,000 to 125,000 psi. Shot peening was particularly beneficial in improving the fatigue properties of ground, chromium plated 4335; the life at 130 ksi was increased from 18,000 cycles to 1,700,000 cycles by shot peening.

RECOMMENDATIONS:

The conclusion of this evaluation of SAE 4335, heat treated to 260 - 280 ksi, should not be considered as the final answer to airframe requirements for ultra high strength steels. The continuing demands for higher performance, particularly in the missile field, necessitates further investigations of new and improved alloy steels.

Many steel companies recognize the need for improved alloy steels and are cooperating with the aircraft industry to provide steels which will meet the higher requirements of the future. It is recommended that Convair examine some of the new alloys which have been produced since the beginning of the 4335 program. Among these are:

1. Vacuum melted 4340 (E.G. Ferrovac 4340) - the cleanliness and closer chemical composition control possible with vacuum melting have increased impact and fatigue properties.

2. Hot work die steels (E.G. Vascojet 1000, Potomac M) - It is possible to obtain 260-280 ksi ultimate stress in hot work die steels using tempering temperatures of 1000 to 1100 F. This higher tempering temperature would permit utilization of high strength die steels in applications where temperatures exceed the normal tempering temperature of structural alloy steels.

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4. Weiher, E. R., "A Discussion on the Use of High Tensile Steel on the B-58 Airplane", Convair, Ft. Worth Report September 1954.

5. Sachs, Geo. and Beck, Walter, "Survey of Low-Alloy Aircraft Steels Heat Treated to High Strength Levels - Part I. Hydrogen Embrittlement", WADC TR 53-254, June 1954.

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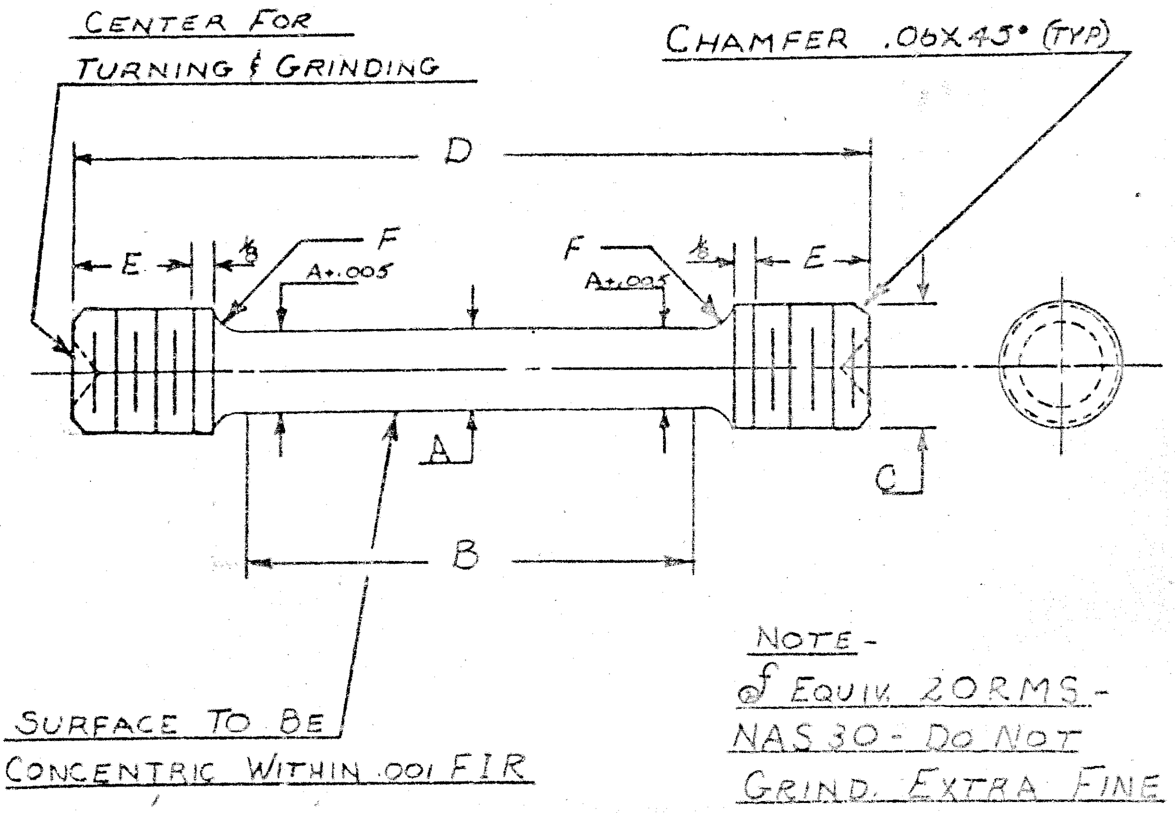
7. Sands, J. W. and Miller, O. D., "Ultra High Strength Steels - Present and Future", Materials and Methods, March 1956.

8. Sands, J. W., "Super - High Strength Steels for Aircraft Applications", Proceedings of the 1955 Sagamore Research Conference, August 1955.

DIAGRAM SHEET 23 FWP 2000—2-54 Department 6

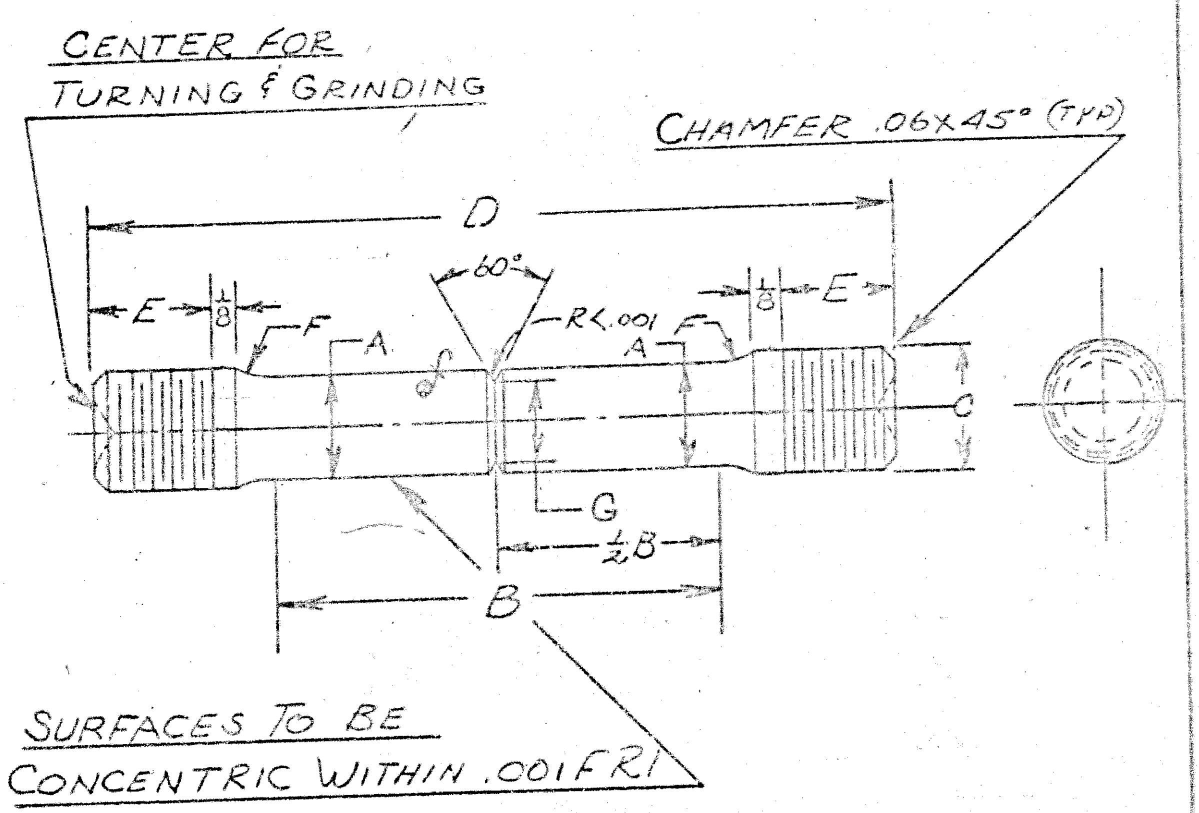


NOTE -
∫ EQUIV. 20RMS - NAS 30 - DO NOT GRIND. EXTRA FINE MACHINE FINISH. NO VISIBLE TOOL MARKS.

— NO.	A	B	C	D (APPROX)	E	F (MIN)
-6	.505	2 1/4	3/4 - 10 N.C.	5	7/8	3/8
~~-20~~	~~.357~~	~~2 1/4~~	~~5/8 - 11 N.C.~~	~~4 1/2~~	~~3/4~~	~~1/4~~
~~-22~~	~~.252~~	~~1 1/4~~	~~1/2 - 13 N.C.~~	~~3 7/8~~	~~5/8~~	~~7/16~~
~~-39~~	~~.200~~	~~1 1/8~~	~~5/16 - 24 N.F.~~	~~1 7/8~~	~~5/16~~	~~1/16~~

DRAWN	C. Cathey	DATE	ROUND TENSILE COUPON	FTJ 4751
CHECKED				FULL SCALE
ENG.				SHEET - 6
PROJECT			CONVAIR FORT WORTH DIVISION — FORT WORTH, TEXAS	FIGURE 1

ISSUED: REVISED:



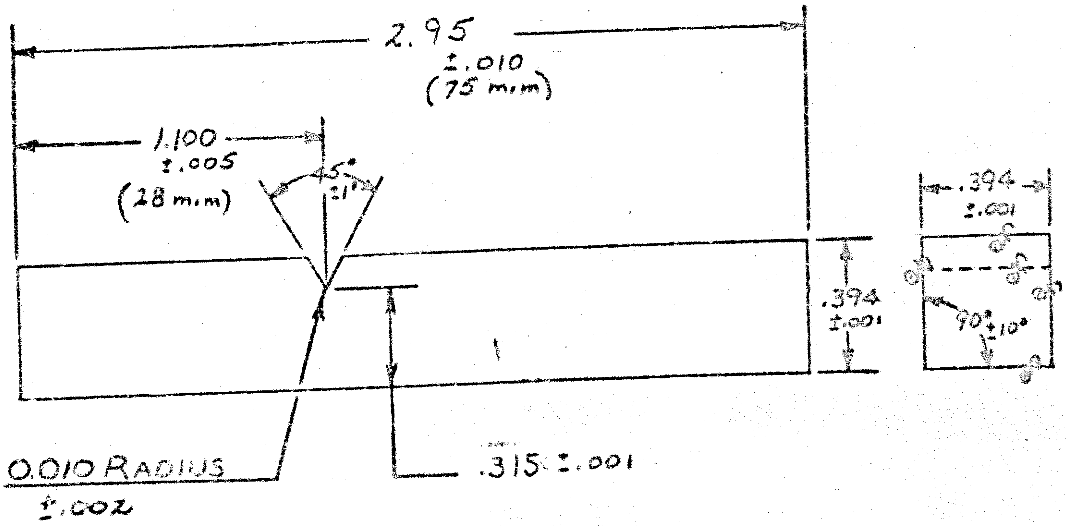
NOTE-

S EQUIV. 20 RMS - NAS 30 - DO NOT GRIND EXTRA FINE MACHINE. NO VISIBLE TOOL MARKS

DASH NO.	A	B	C	D(APPROX)	E	F	G
~~-18~~	~~.712~~	~~2 1/4~~	~~3/4-10 NC~~	~~5~~	~~7/8~~	~~3/8~~	~~.505~~
-19	.505	2 1/4	5/8-11 NC	4 1/2	3/4	1/4	.357
~~-21~~	~~.357~~	~~1 1/4~~	~~1/2-13 NC~~	~~3 1/8~~	~~5/8~~	~~3/16~~	~~.252~~

DRAWN		DATE	ROUND NOTCH TENSILE COUPON	FTJ 4751
CHECKED				FULL SCALE
ENG.				SHEET 7
PROJECT			CONSOLIDATED VULTEE AIRCRAFT CORPORATION FORT WORTH DIVISION - FORT WORTH, TEXAS	FIGURE 2

ISSUED: REVISED:

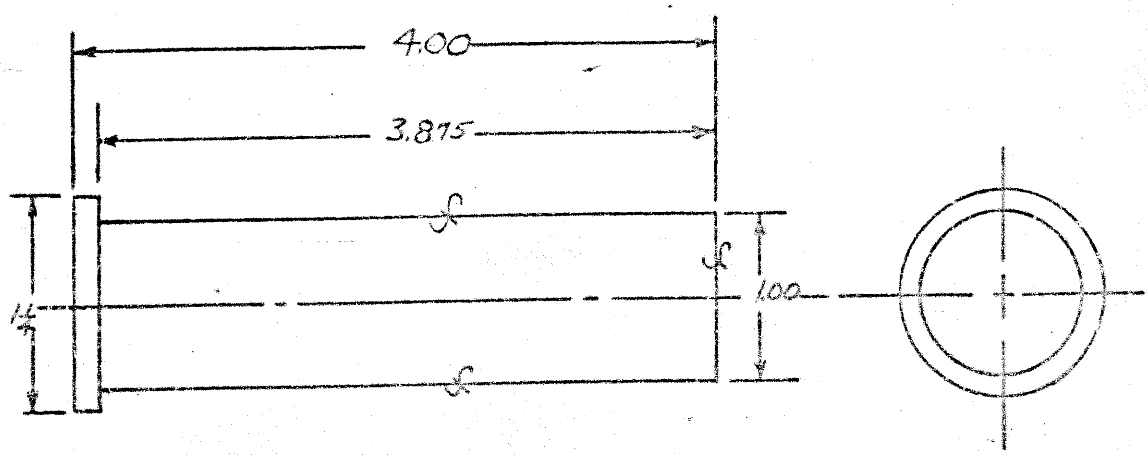


NOTE-
∮ · EQUIV. TO 20 RMS - 30 NAS - GRIND

(-10)

DRAWN	R. Cadez	DATE	SQUARE IZOD SPECIMEN	FTJ 4751
CHECKED				DOUBLE SCALE
ENG.			CONVAIR FORT WORTH DIVISION — FORT WORTH, TEXAS	SHEET - 10
PROJECT				FIGURE 3

ISSUED: REVISED:

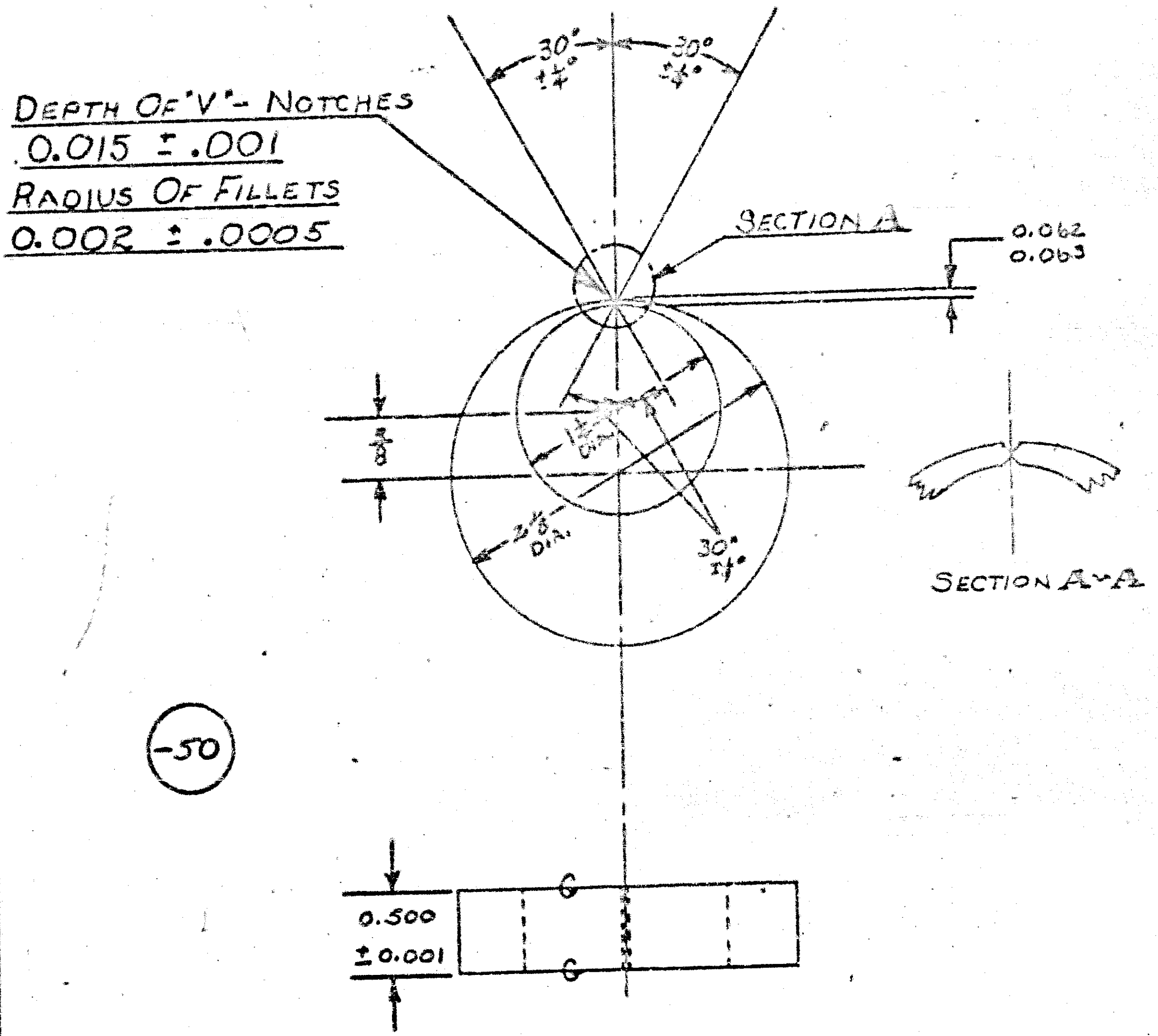


NOTE -
ƒ - VERY FINE MACHINE FINISH

-49

DRAWN	R. Cathey	DATE	HARDENABILITY SPECIMEN	FTJ 4751-
CHECKED				FULL SCALE
ENG.			CONVAIR FORT WORTH DIVISION — FORT WORTH, TEXAS	SHEET - 23
PROJECT				FIGURE 4

ISSUED: REVISED:

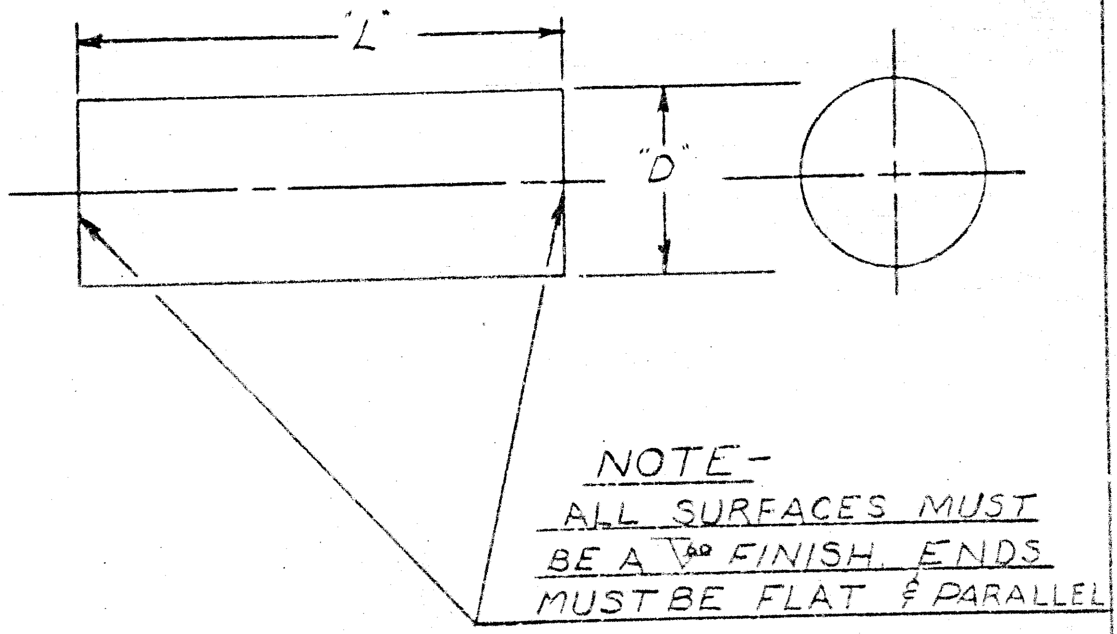


NOTE-

EXTREME CARE MUST BE TAKEN IN PROUDCING THE NOTCHES

DRAWN	R. Cuchay	DATE	"QUENCH" CRACK TEST SPECIMEN	FTJ 4751-
CHECKED				FULL SCALE
ENG.				SHEET - 24
PROJECT			CONVAIR FORT WORTH DIVISION — FORT WORTH, TEXAS	FIGURE 5

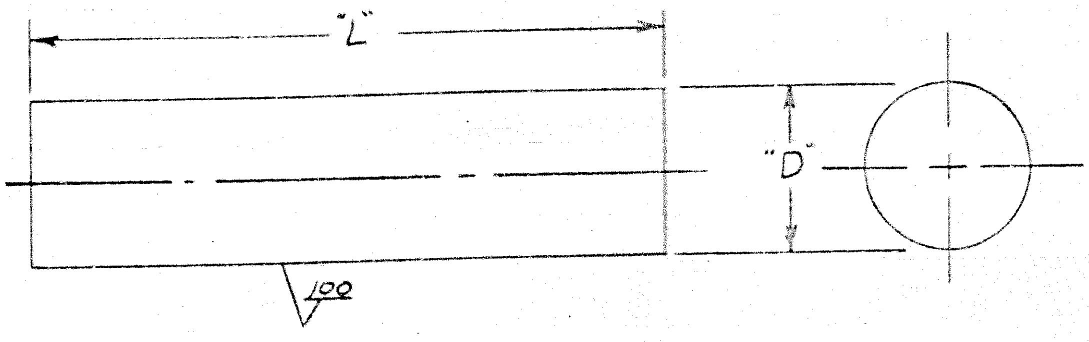
ISSUED: REVISED:



DASH NO	"L"	"D"
~~-61~~	~~1.000~~	~~1.125~~
~~-62~~	~~2.375~~	~~0.798~~
-63	3.000	1.000
~~-64~~	~~3.375~~	~~1.125~~
~~-65~~	~~6.375~~	~~0.798~~
~~-66~~	~~12.500~~	~~1.250~~

DRAWN	R. Cathey	DATE	ROUND COMPRESSION SPECIMEN	FTJ- 4751
CHECKED				FULL SCALE
ENG.				SHEET- 27
PROJECT			CONVAIR FORT WORTH DIVISION — FORT WORTH, TEXAS	FIGURE 6

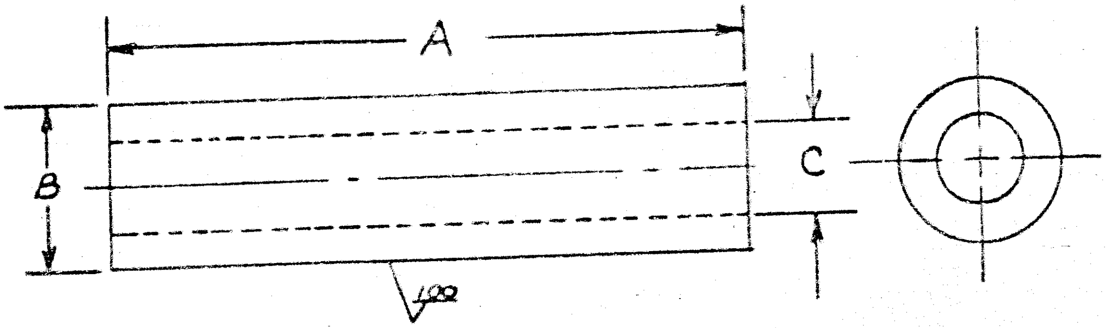
ISSUED: REVISED:



DASH NO	"L"	"D"
-67	3.9964 +.0000 -.0008	.9991 +.0000 -.0008

DRAWN R. Cathay	DATE	SOLID DOUBLE SHEAR PIN	FTJ-4751
CHECKED			FULL SCALE
ENG.			SHEET-28
PROJECT		CONSOLIDATED VULTEE AIRCRAFT CORPORATION FORT WORTH DIVISION - FORT WORTH, TEXAS	Figure 7

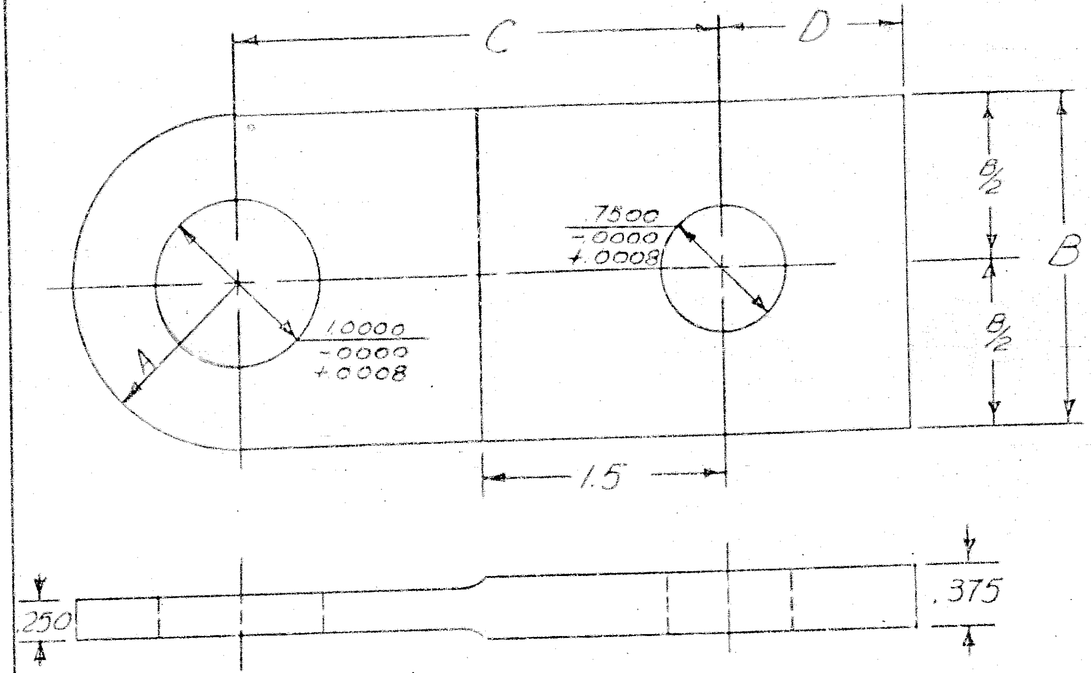
ISSUED: REVISED:



DASH No.	"A"		"B"		"C"	
-68	3.9964	+.0000 -.0008	.9991	+.0000 -.0008	.3331	+.0000 -.0008
-69	3.9964	+.0000 -.0008	.9991	+.0000 -.0008	.6001	+.0000 -.0008
-70	3.9964	+.0000 -.0008	.9991	+.0000 -.0008	.7137	+.0000 -.0008
-71	3.9964	+.0000 -.0008	.9991	+.0000 -.0008	.7771	+.0000 -.0008
-72	3.9964	+.0000 -.0008	.9991	+.0000 -.0008	.8175	+.0000 -.0008

DRAWN	Q. Cathey	DATE	HOLLOW DOUBLE SHEAR PIN	FTJ-4751-
CHECKED				FULL SCALE
ENG.			CONVAIR FORT WORTH DIVISION — FORT WORTH, TEXAS	SHEET-29
PROJECT				FIGURE 8

ISSUED: REVISED:

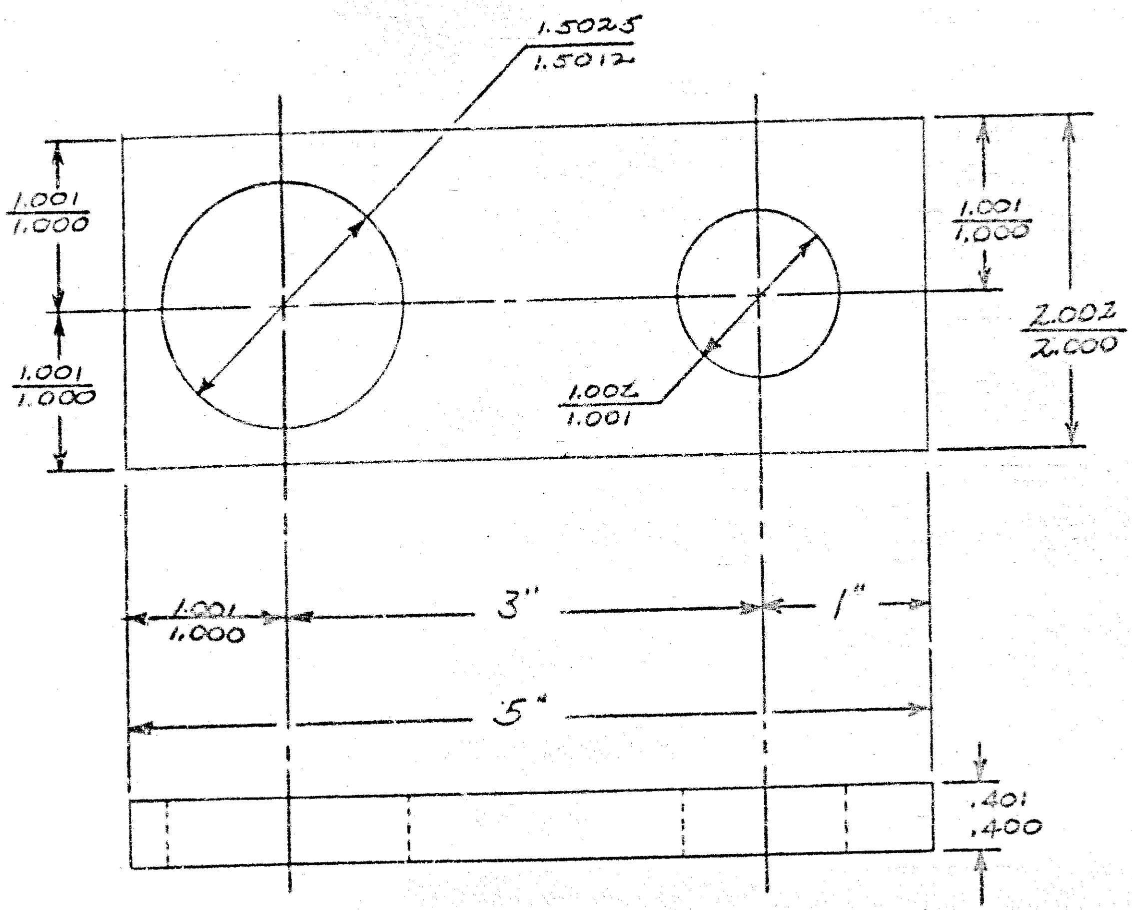


DASH No.	A	B	C	D
-73	1.000	2.000	3.000	1.125
-74	1.500	3.000	3.500	1.625
-75	2.000	4.000	4.000	2.125

NOTE:

1. 20 ▽ FINISH ALL OVER
2. END RADIUS MUST BE CONCENTRIC WITH HOLE

DRAWN	R. Cathey		BEARING (LUG) SPECIMEN	FTJ-4751
				FULL SCALE
				SHEET 30
				FIGURE 9



-5

NOTE -
1. 20√ FINISH ALL OVER
2. ¢ OF HOLES MUST BE PARALLEL TO & EQUIDISTANT FROM SIDES

DRAWN	R Catlay	DATE	SUSTAINED LOAD TEST SPECIMEN	FTJ 4751
CHECKED				FULL SCALE
ENG.			CONVAIR FORT WORTH DIVISION — FORT WORTH, TEXAS	SHEET - 5
PROJECT				FIGURE 10

ISSUED: REVISED:

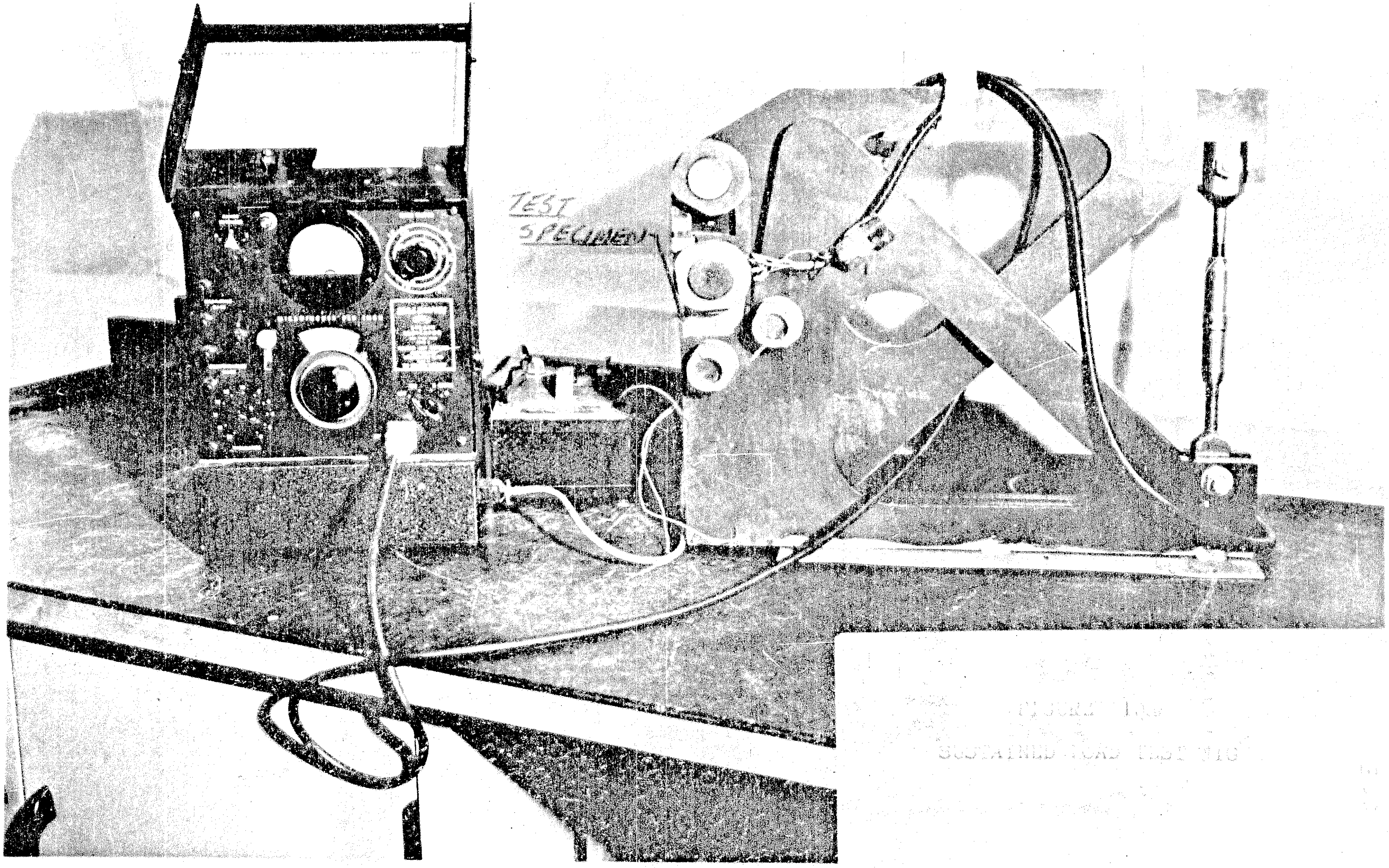
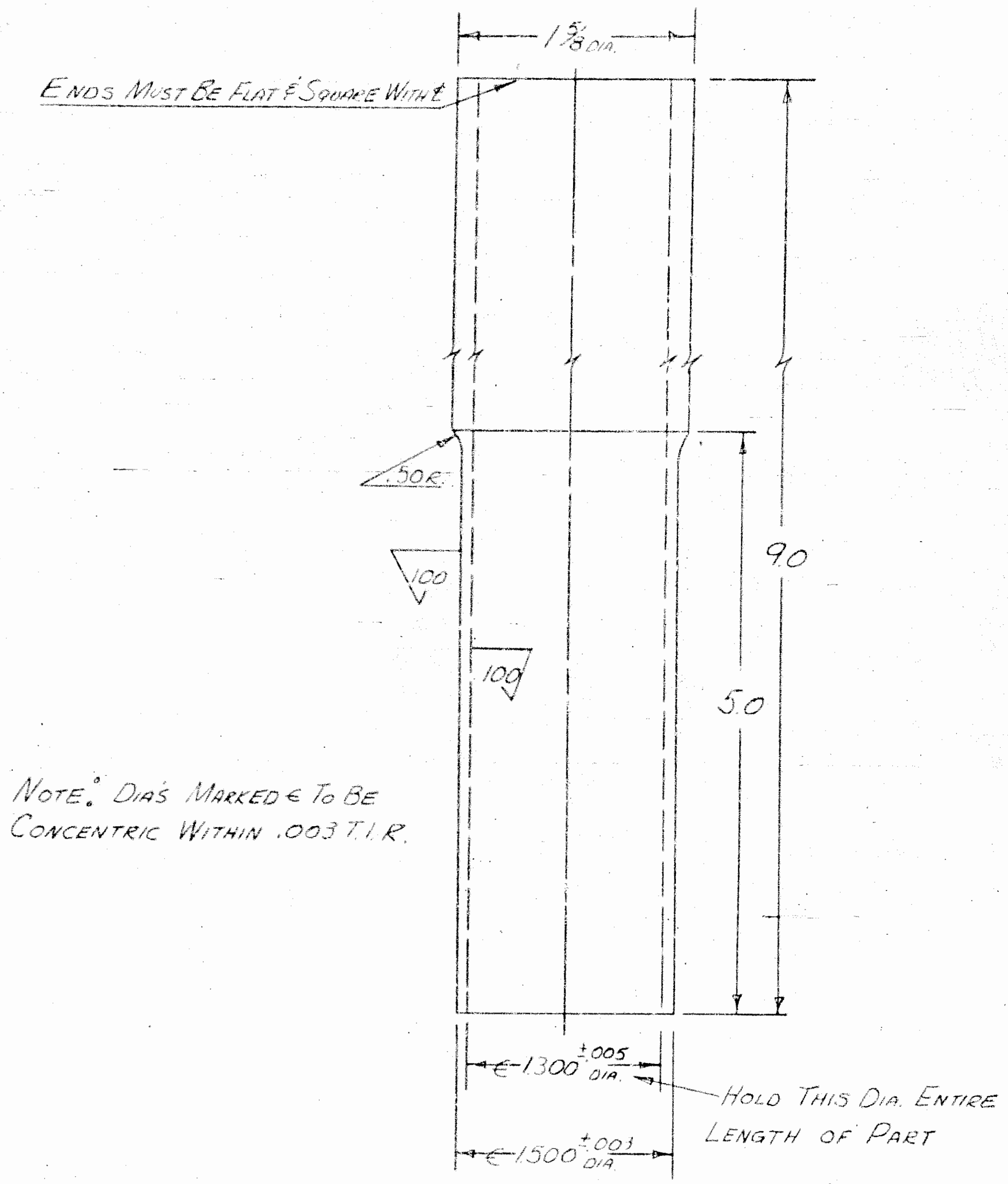


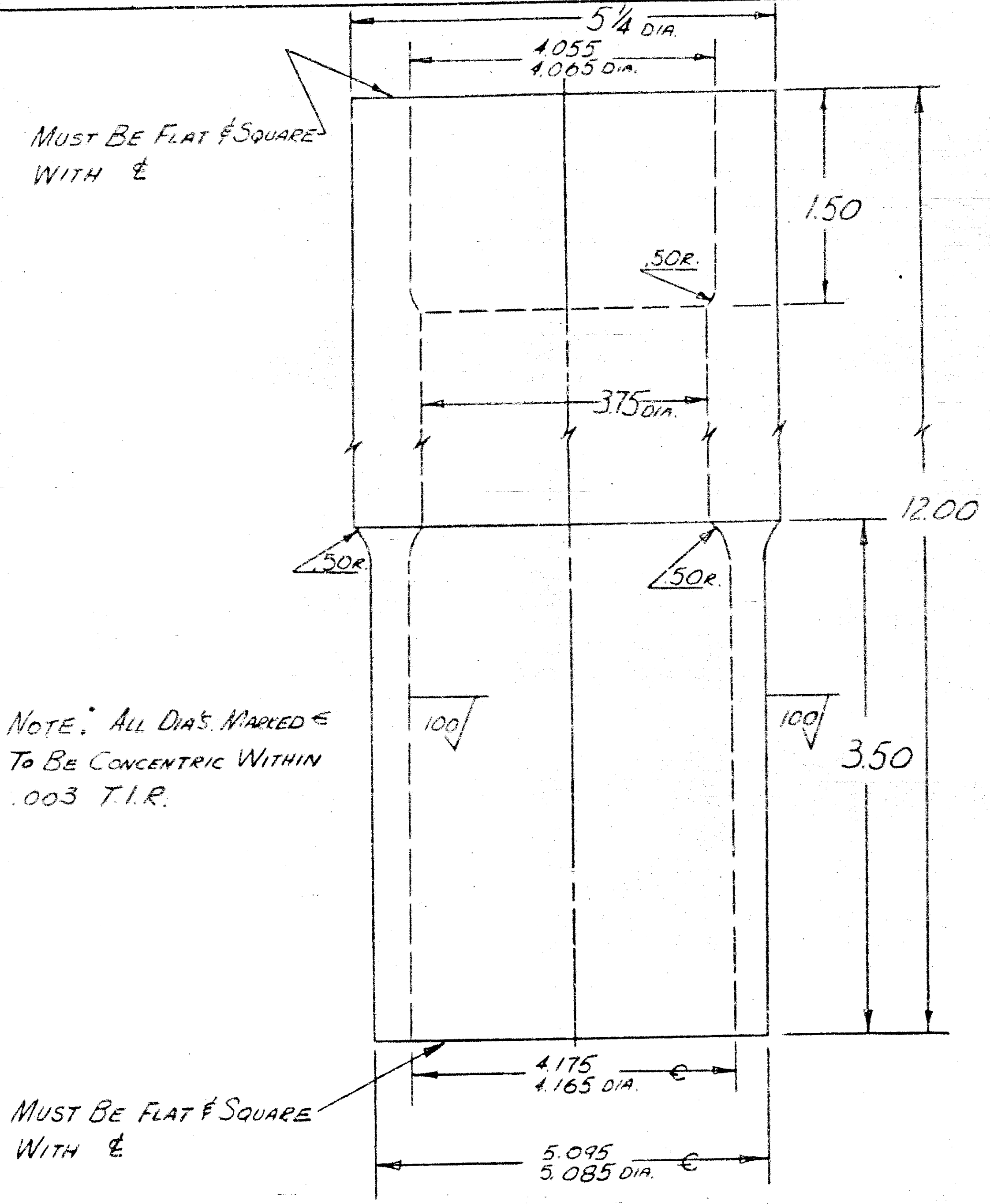
FIGURE 16

SUSTAINED LOAD TEST RIG



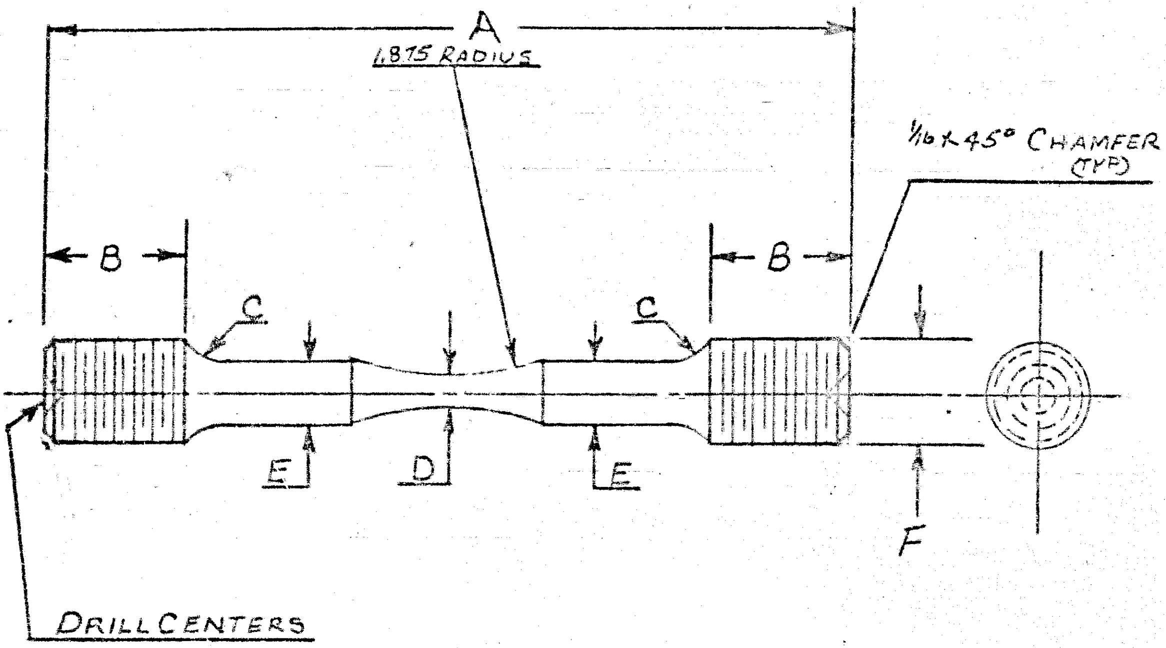
FLASH WELD TEST SPECIMEN

FIGURE 11



UNIWELD TEST SPECIMEN

FIGURE 12



NOTE-

100 √ - FINISH ON ALL SURFACES EXCEPT LARGE RADIUS WHICH MUST BE POLISHED. ENDS OF SPECIMEN MUST BE PARALLEL

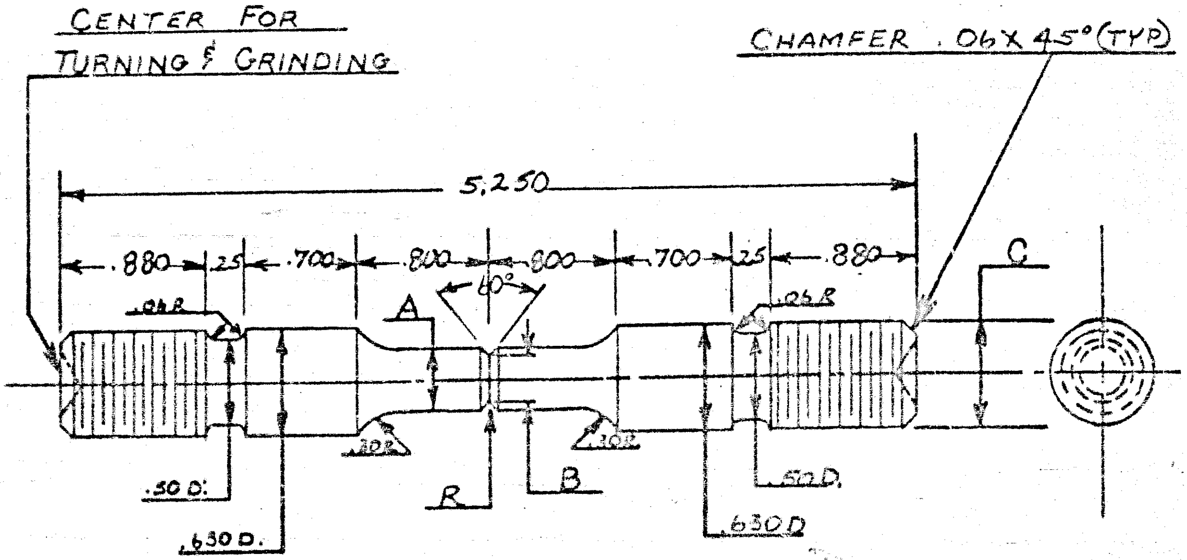
DASH NO.	A	B	C	D	E	F	Kt
-52	5.000	.833	.30	.208	.417	5/8 x 18NF	1

DRAWN	R. Catley	DATE	ROUND FATIGUE SPECIMEN
CHECKED			FTJ 4751-
ENG.			FULL SCALE
PROJECT			SHEET - 26

CONSOLIDATED VULTEE AIRCRAFT CORPORATION
FORT WORTH DIVISION - FORT WORTH, TEXAS

FIGURE 13

ISSUED: REVISED:

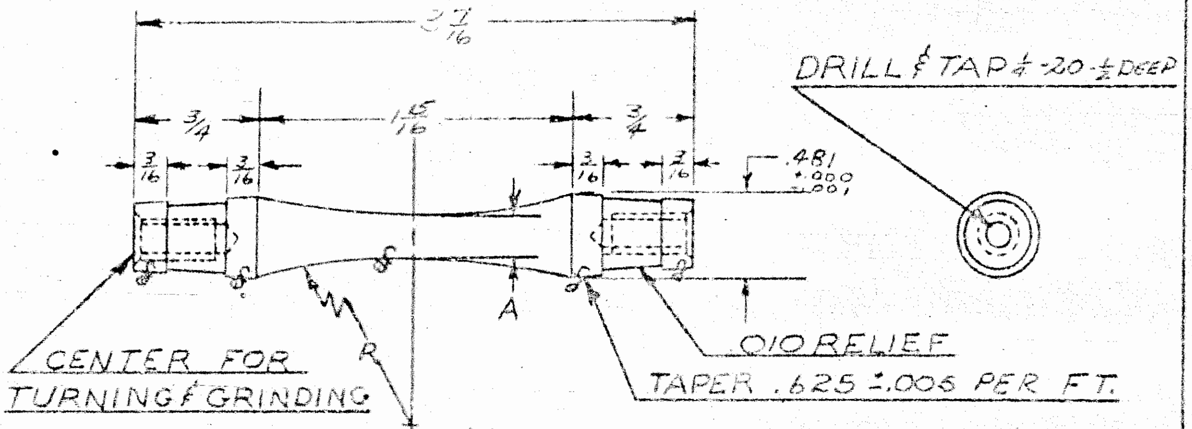


NOTE –
FINISH ON ALL SURFACES, EXCEPT NOTCH WHICH SHALL BE POLISHED (REF. ASTM "MANUAL ON FATIGUE TESTING" PGS. 34-37) ENDS OF SPECIMEN MUST BE PARALLEL

DASH NO	K_t	A	B	R	C
~~-1~~	~~2.0~~	~~.350~~	~~.250~~	0.035	5/8 x 18 N.F
-53	3.0	.300	.200	0.010	5/8 x 18NF
-54	1.6	.300	.200	0.060	5/8 x 18N.F
-55	1.2	.400	.200	0.180	5/8 x 18N.F

DRAWN	Q. Corley	DATE	NOTCH FATIGUE SPECIMEN	FTJ 4751-
CHECKED				FULL SCALE
ENG.				SHEET – 1
PROJECT			CONVAIR FORT WORTH DIVISION — FORT WORTH, TEXAS	FIGURE 14

ISSUED: REVISED:



NOTE-
8 EQUIV. TO 20 RMS - 30 NAS GRIND

DASH NO. (1)	STRESS LEVEL RANGE (2)	ROUGH MAC. DIAM "A" (3)	FINISH DIAM "A" (4)	RADIUS R (5)
-15	76,000 - 229,000	.215 ±.005	.200 ±.003	3.42 +.00 -.03
~~-26~~	~~39,000 - 117,000~~	~~.265 ±.005~~	~~.250 ±.003~~	~~4.13 +.00 -.03~~
~~-27~~	~~22,500 - 68,000~~	~~.315 ±.005~~	~~.300 ±.003~~	~~5.35 +.00 -.03~~

MANUFACTURE:

1. RAW MATERIAL - AS PER REQUIREMENTS OF TEST.
2. CENTER ENDS AND REMOVE ALL BURRS - CENTER HOLES MUST BE CONCENTRIC.
3. ROUGH MACHINE TO DIAMETER IN COLUMN (3).
4. REMOVE AND HEAT TREAT AS REQUIRED.
5. FINISH SPECIMENS TO DIAMETER SHOWN IN COLUMN (4).
6. STRESS RELIEVE AS REQUIRED.
7. POLISH CIRCUMFERENTIALLY IN THREE STAGES WITH 0, 00, and 000 GRADE EMERY PAPER. POLISH UNTIL ALL MARKS FROM PREVIOUS POLISHING STAGE ARE REMOVED.
8. FINAL POLISH - LONGITUDINALLY WITH A 000 GRADE EMERY PAPER UNTIL NO CIRCUMFERENTIAL MARKS ARE VISIBLE AT 20X MAGNIFICATION.

DRAWN	R Cathey	DATE	RR MOORE FATIGUE SPECIMEN	FTJ-4751
CHECKED				FULL SCALE
ENG.				SHEET 13
PROJECT			CONSOLIDATED VULTEE AIRCRAFT CORPORATION FORT WORTH DIVISION - FORT WORTH, TEXAS	FIGURE 15

ISSUED: REVISED:

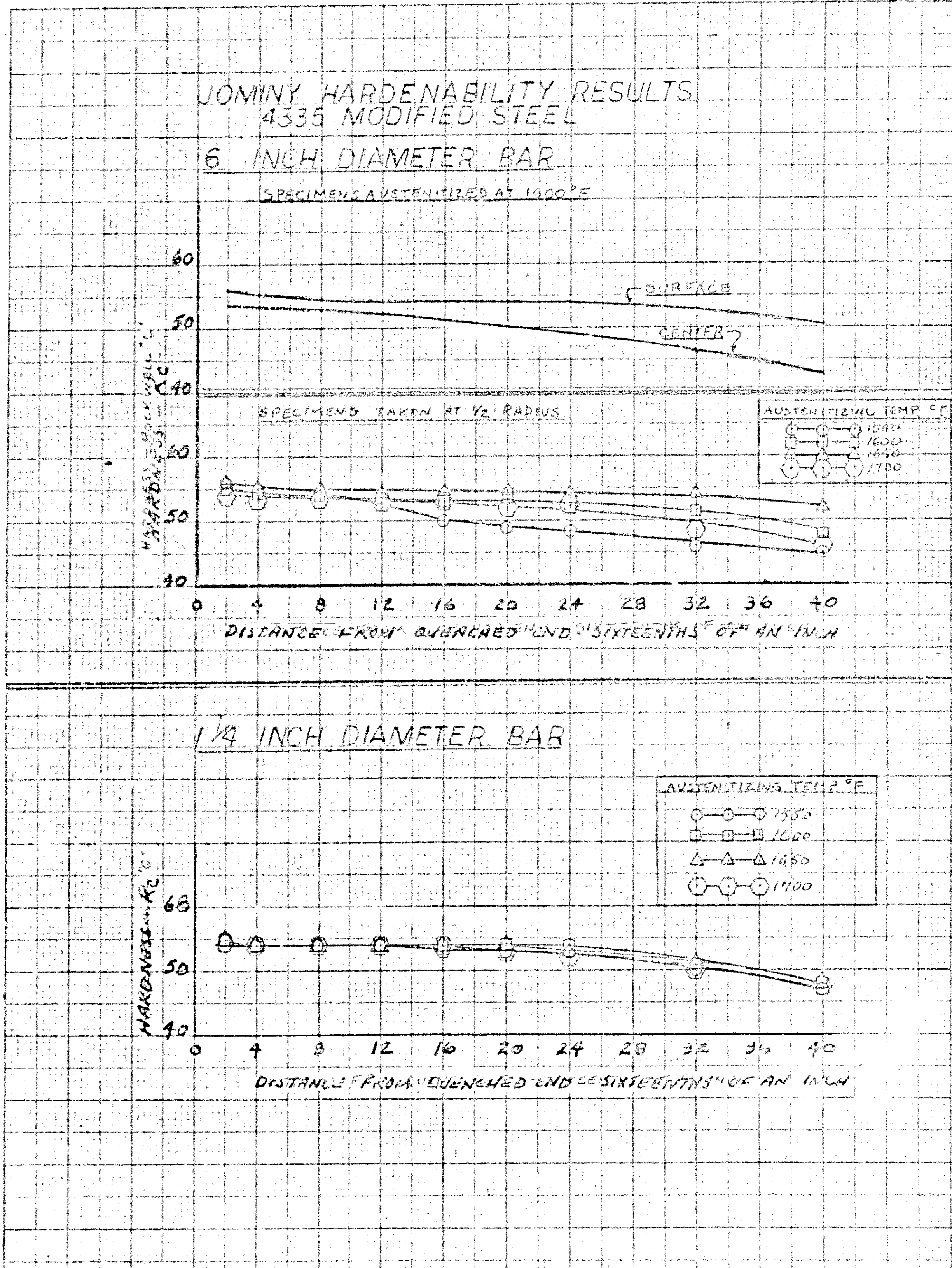
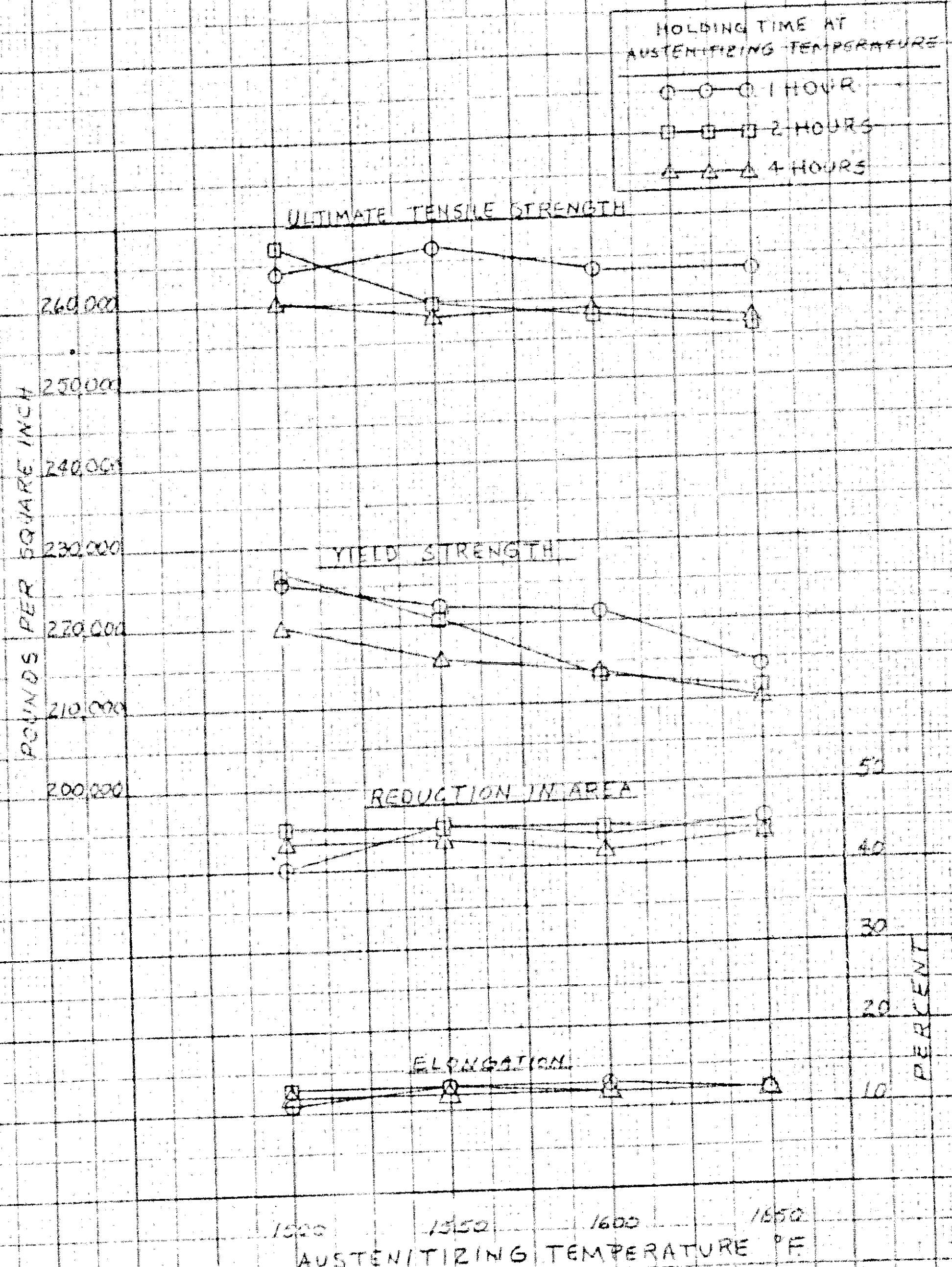

JOMINY HARDENABILITY RESULTS
4335 MODIFIED STEEL
6 INCH DIAMETER BAR
SPECIMENS AUSTENITIZED AT 1600°F
SURFACE
CENTER
SPECIMENS TAKEN AT 1/2 RADIUS
AUSTENITIZING TEMP °F
1550
1600
1650
1700
60
50
40
0
4
8
12
16
20
24
28
32
36
40
DISTANCE FROM QUENCHED END SIXTEENTHS OF AN INCH
1 1/4 INCH DIAMETER BAR
AUSTENITIZING TEMP °F
1550
1600
1650
1700
HARDNESS Rc
60
50
40
0
4
8
12
16
20
24
28
32
36
40
DISTANCE FROM QUENCHED END SIXTEENTHS OF AN INCH

FIGURE 16

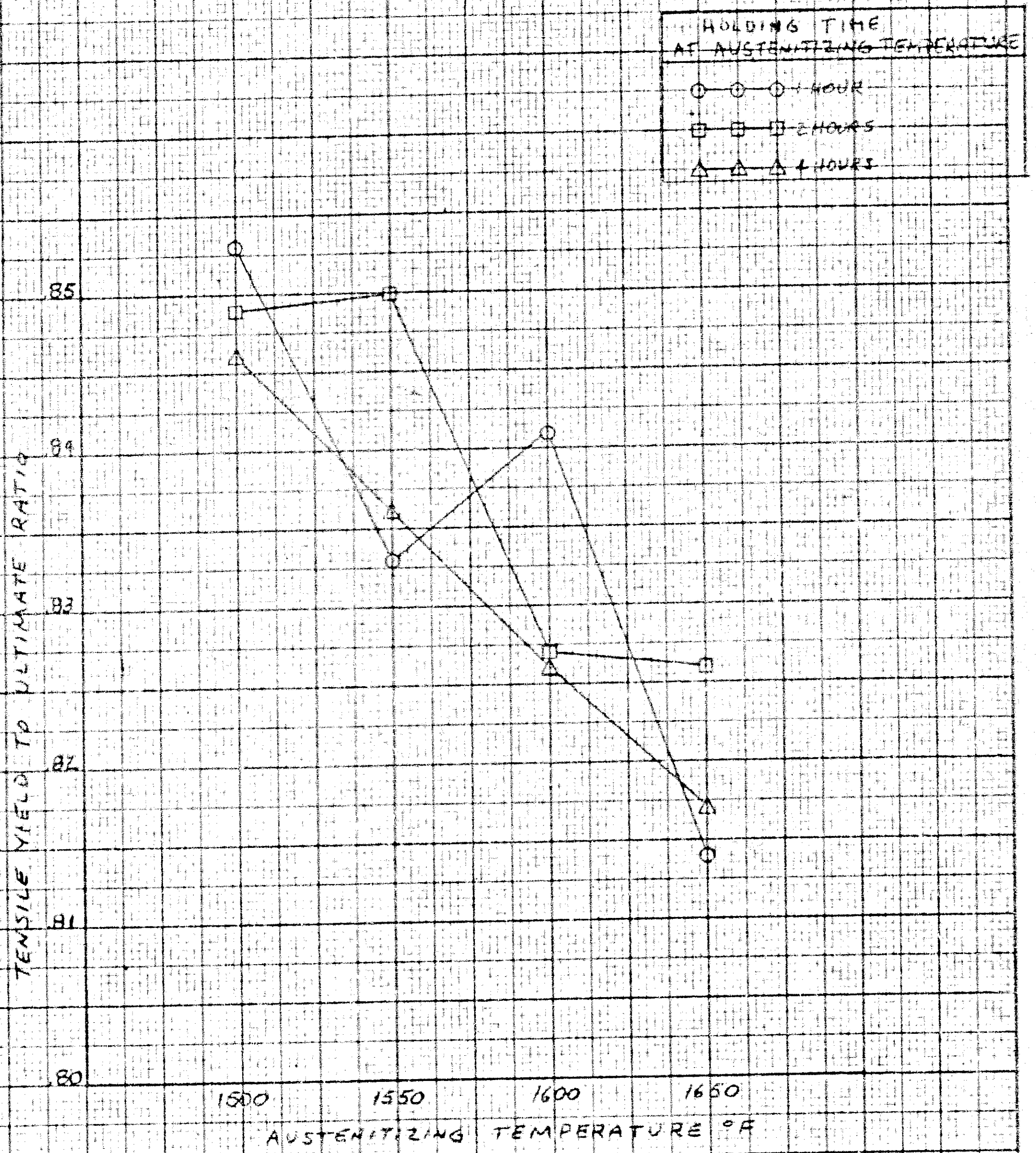
PHASE I PART A
TENSILE PROPERTIES AT VARIOUS AUSTENITIZING TEMPERATURES AND HOLDING TIMES



NOTE: ALL SPECIMENS OIL QUENCHED FROM AUSTENITIZING TEMPERATURE AND THEN TEMPERED AT 450°F FOR 2 HOURS.

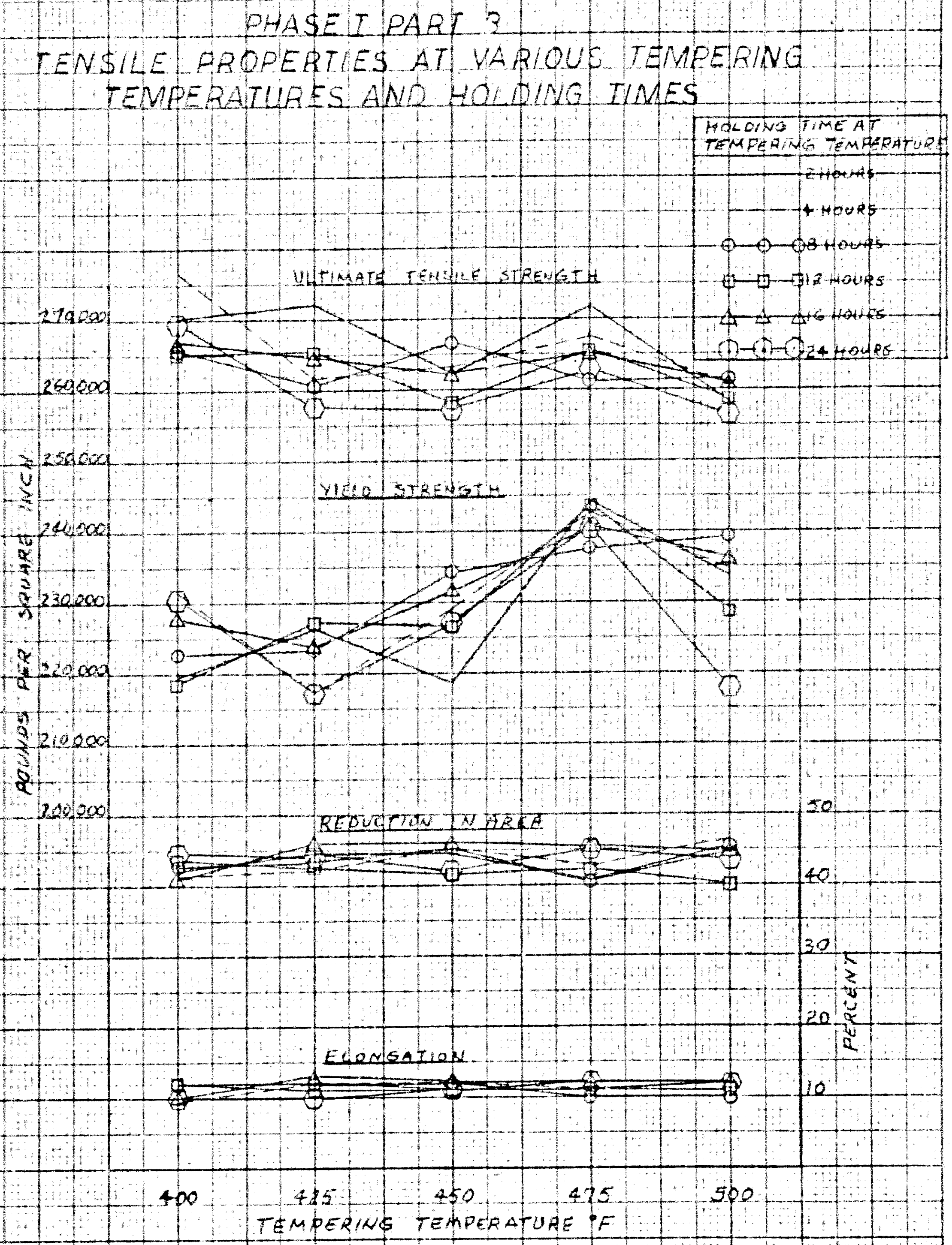
FIGURE 17

PHASE I PART A
TENSILE YIELD TO ULTIMATE RATIO AT VARIOUS AUSTENITIZING TEMPERATURES AND HOLDING TIMES



NOTE: ALL SPECIMENS OIL QUENCHED FROM AUSTENITIZING TEMPERATURE AND THEN TEMPERED AT 450°F FOR 2 HOURS

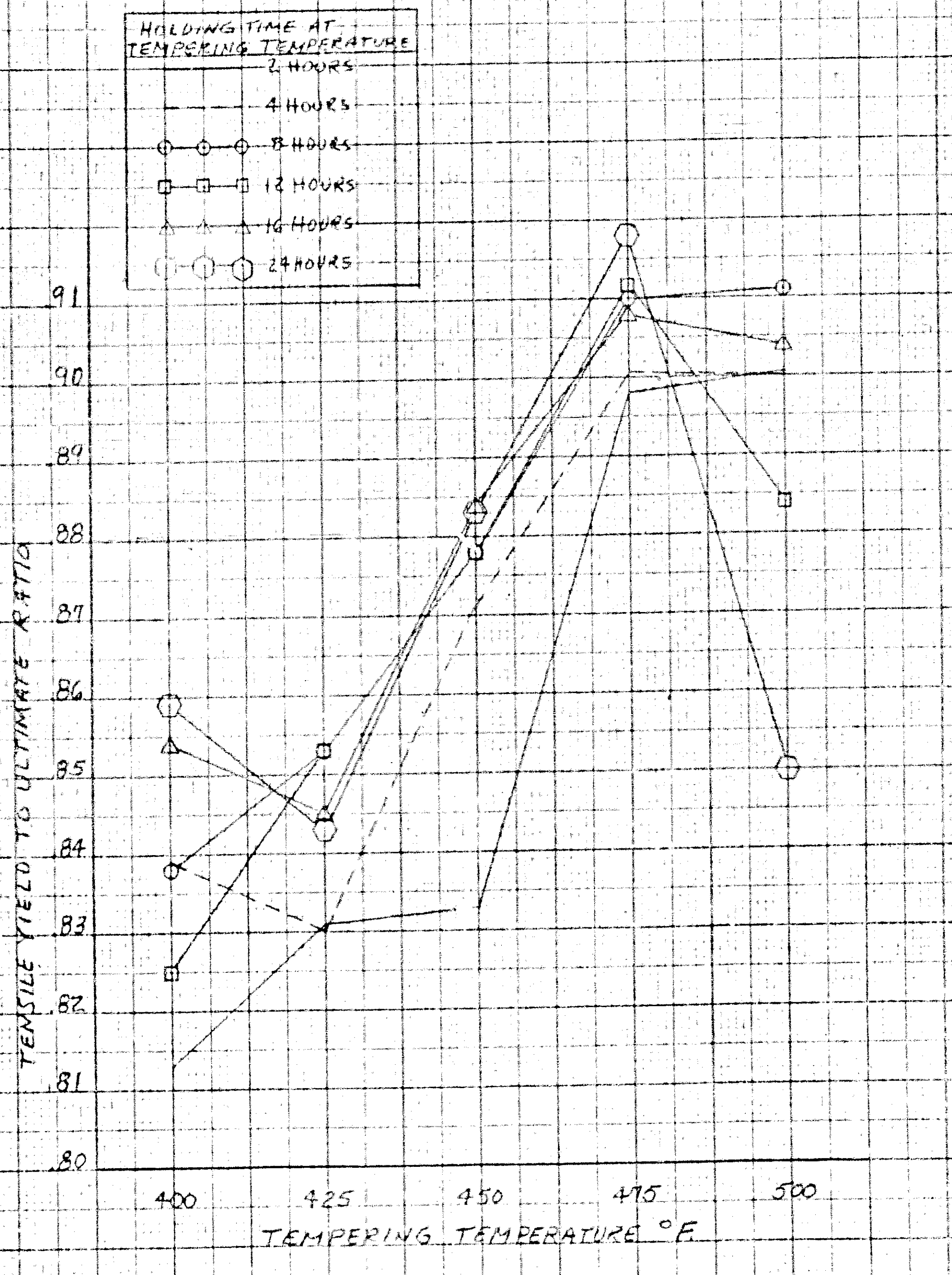
FIGURE 18



NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F - 1 HOUR AT TEMPERATURE, THEN OIL QUENCHED AND TEMPERED AS INDICATED.

FIGURE 19

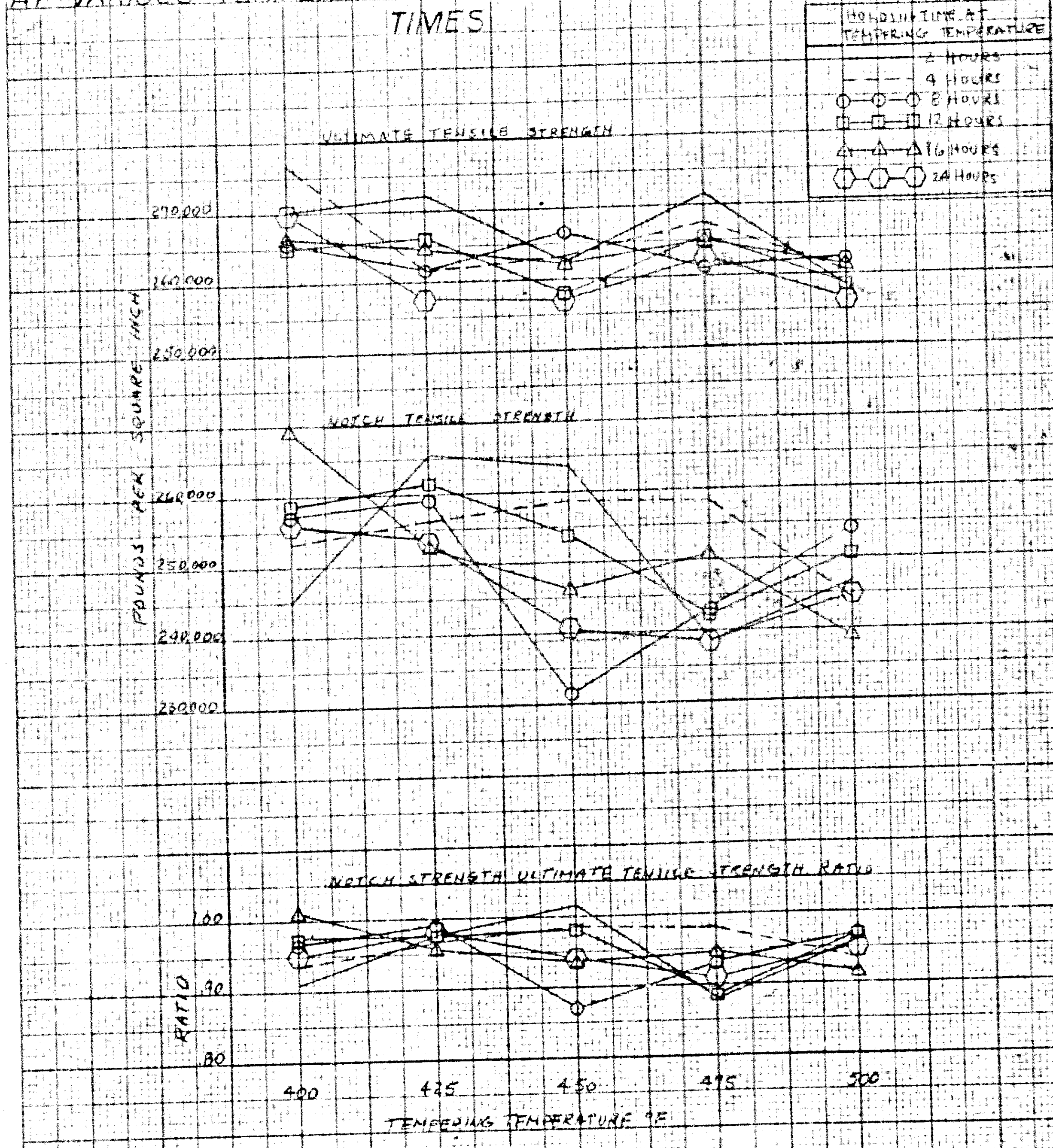
PHASE I PART B
TENSILE YIELD TO ULTIMATE RATIO AT
VARIOUS TEMPERING TEMPERATURES AND HOLDING TIMES



NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F - 1 HOUR AT TEMPERATURE, THEN OIL QUENCHED AND TEMPERED AS INDICATED.

FIGURE 20

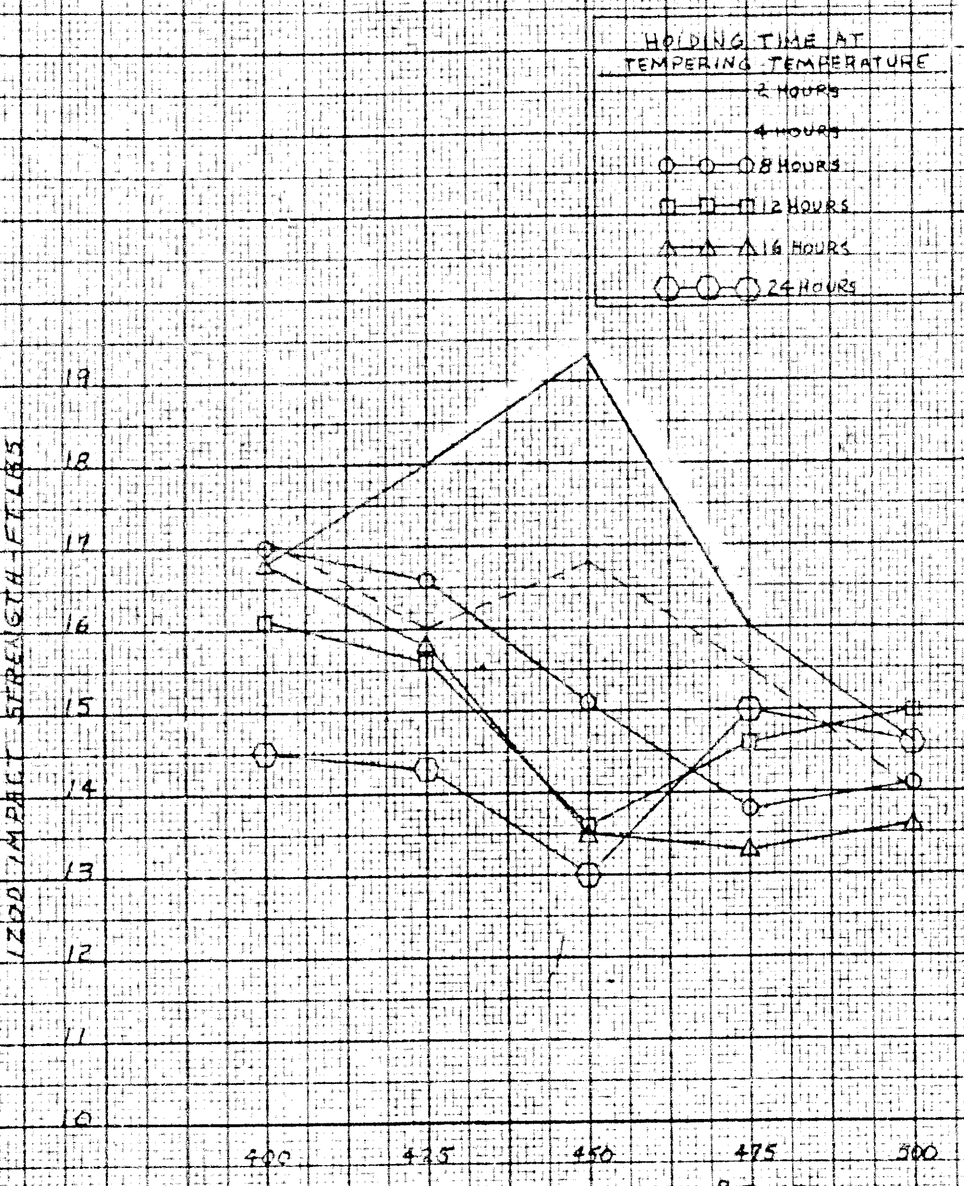
PHASE I PART B
NOTCH STRENGTH–ULTIMATE TENSILE STRENGTH
AT VARIOUS TEMPERING TEMPERING TEMPERATURES & HOLDING
TIMES



NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F – 1 HOUR AT TEMPERATURE, THEN OIL QUENCHED AND TEMPERED AS INDICATED

FIGURE 21

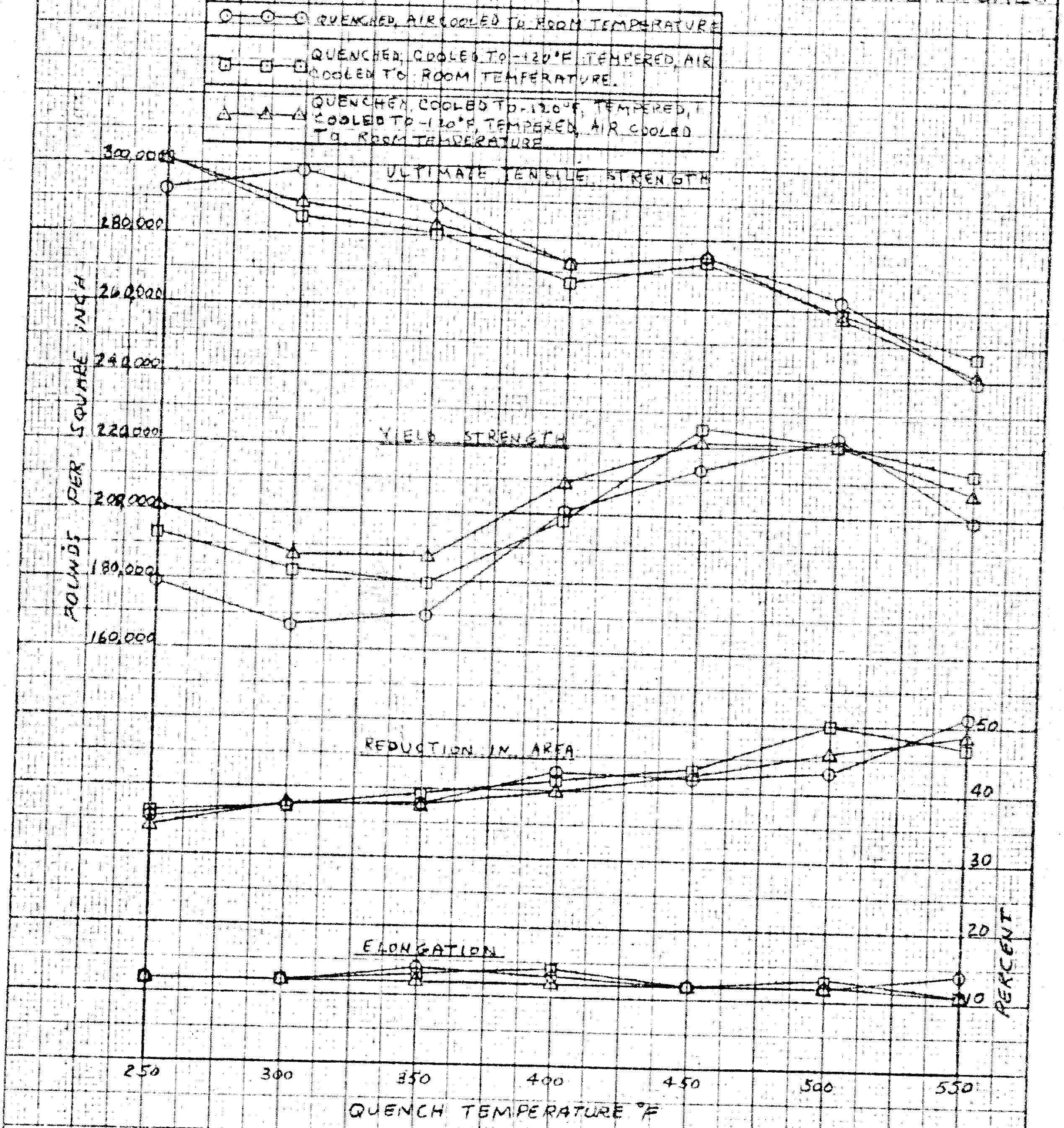
PHASE I PART B
IZOD IMPACT STRENGTH AT VARIOUS TEMPERING TEMPERATURES AND HOLDING TIMES



NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F - 1 HOUR AT TEMPERATURE THEN OIL QUENCHED AND TEMPERED AS INDICATED

FIGURE 22

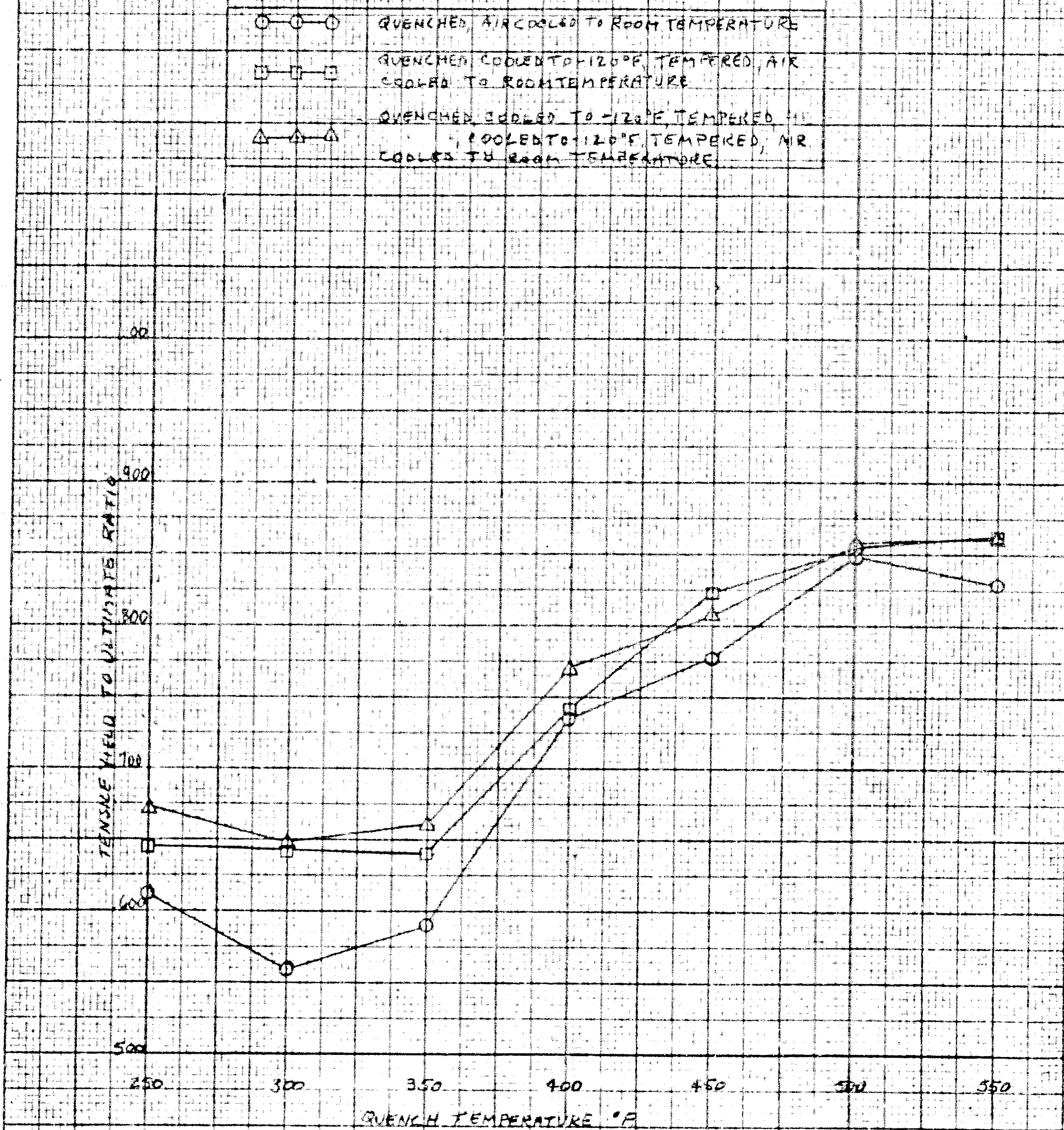
PHASE I PART C
TENSILE PROPERTIES AT VARIOUS QUENCH TEMPERATURES, HOLDING TIMES, COOLING CYCLES, & TEMPERING TEMPERATURES



NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F - 1 HOUR AT TEMPERATURE, QUENCHED AT INDICATED TEMPERATURES. HOLDING TIMES WERE 2 HOURS FOR EACH CYCLE EXCEPT 500°F QUENCH WHICH WAS 4 HOURS. TEMPERING TEMPERATURES WERE THE SAME AS QUENCH TEMPERATURES

FIGURE 23

PHASE I, PART C
TENSILE YIELD TO ULTIMATE RATIO AT VARIOUS QUENCH TEMPERATURES, HOLDING TIMES, COOLING CYCLES, & TEMPERING TEMPERATURES

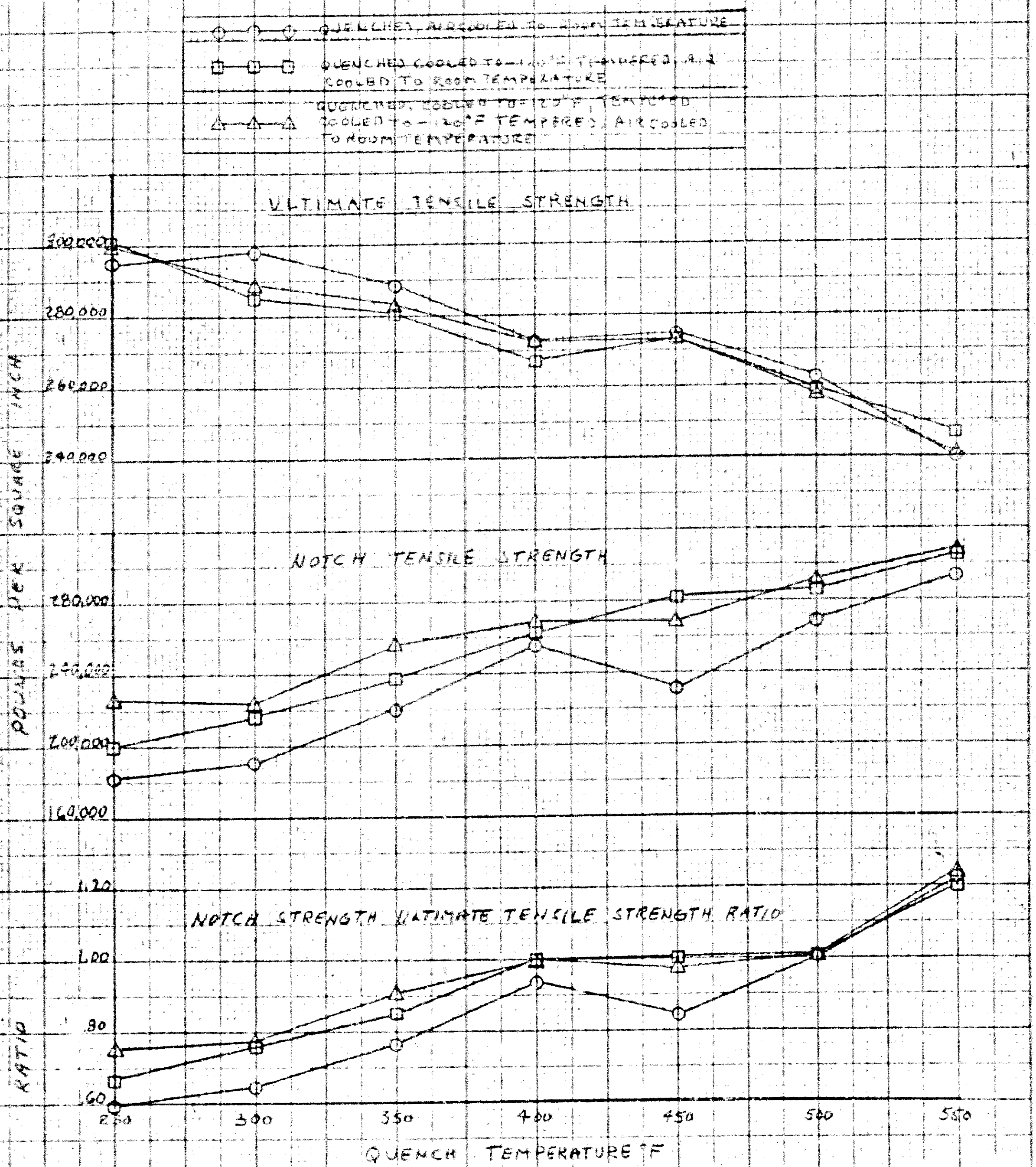


NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F - 1 HOUR AT TEMPERATURE, QUENCHED AT INDICATED TEMPERATURES. HOLDING TIMES WERE 2 HOURS FOR EACH CYCLE, EXCEPT 500°F QUENCH WHICH WAS 4 HOURS. TEMPERING TEMPERATURES WERE THE SAME AS QUENCH TEMPERATURES

FIGURE 24

PHASE I PART C

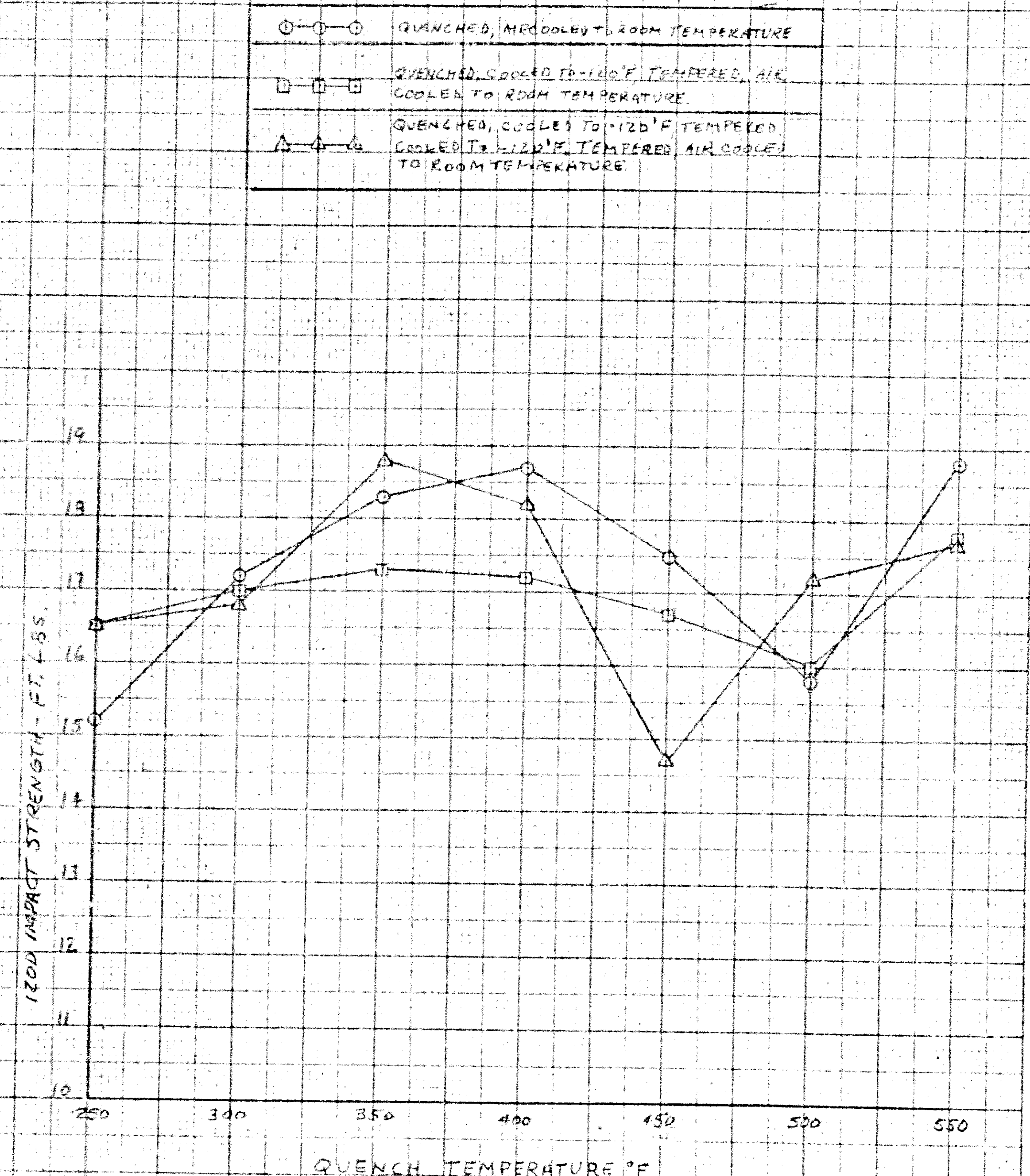
NOTCH TENSILE-ULTIMATE STRENGTH AT VARIOUS QUENCH TEMPERATURES, HOLDING TIMES, COOLING CYCLES, & TEMPERING TEMPERATURES



NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F - 1 HOUR AT TEMPERATURE, QUENCHED AT INDICATED TEMPERATURES. HOLDING TIMES WERE 2 HOURS FOR EACH CYCLE, EXCEPT 500°F QUENCH WHICH WAS 4 HOURS. TEMPERING TEMPERATURES WERE THE SAME AS QUENCH TEMPERATURES.

FIGURE 25

PHASE I PART C
IZOD IMPACT STRENGTH AT VARIOUS QUENCH TEMPERATURES, HOLDING TIMES, COOLING CYCLES, & TEMPERING TEMPERATURES



NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F - 1 HOUR AT TEMPERATURE, QUENCHED AT INDICATED TEMPERATURES, HOLDING TIMES WERE 2 HOURS FOR EACH CYCLE, EXCEPT 500°F QUENCH WHICH WAS 4 HOURS, TEMPERING TEMPERATURES WERE THE SAME AS QUENCH TEMPERATURES

FIGURE 26

PHASE I
COMPARISON OF THE BEST PROCESSING METHODS

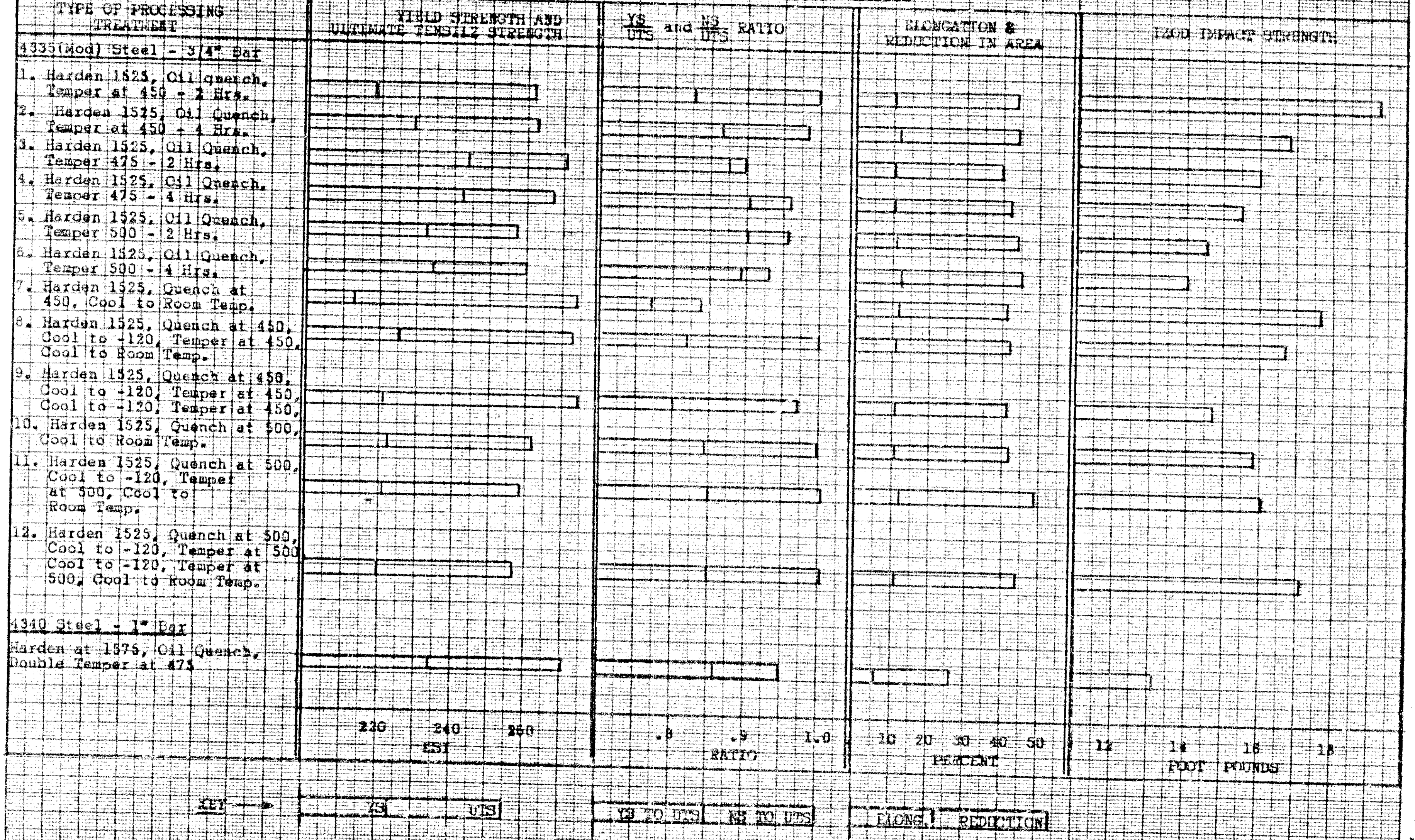


FIGURE 27

FIGURE 28 LONGITUDINAL TENSILE STRESS STRAIN DIAGRAMS

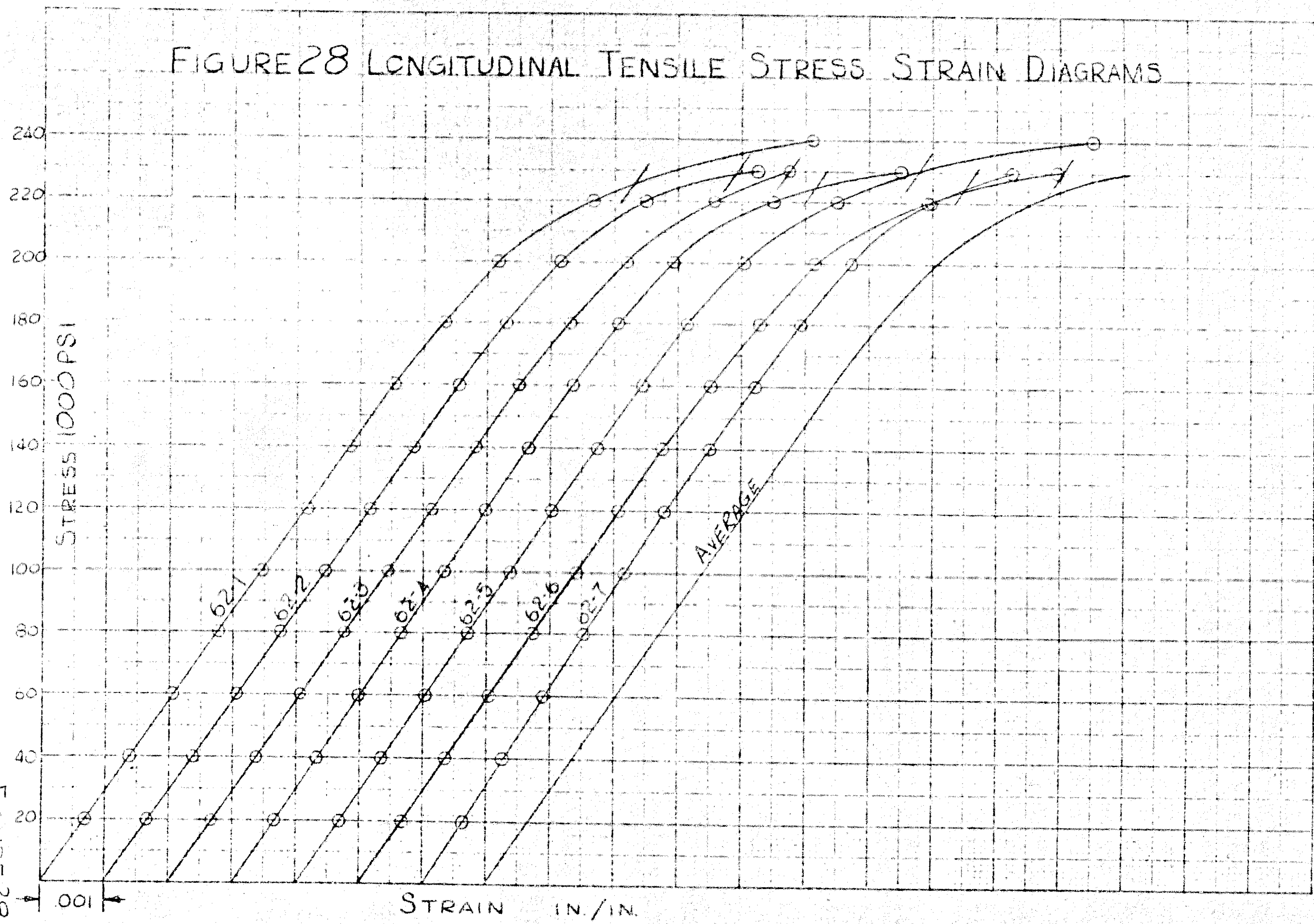


FIGURE 28

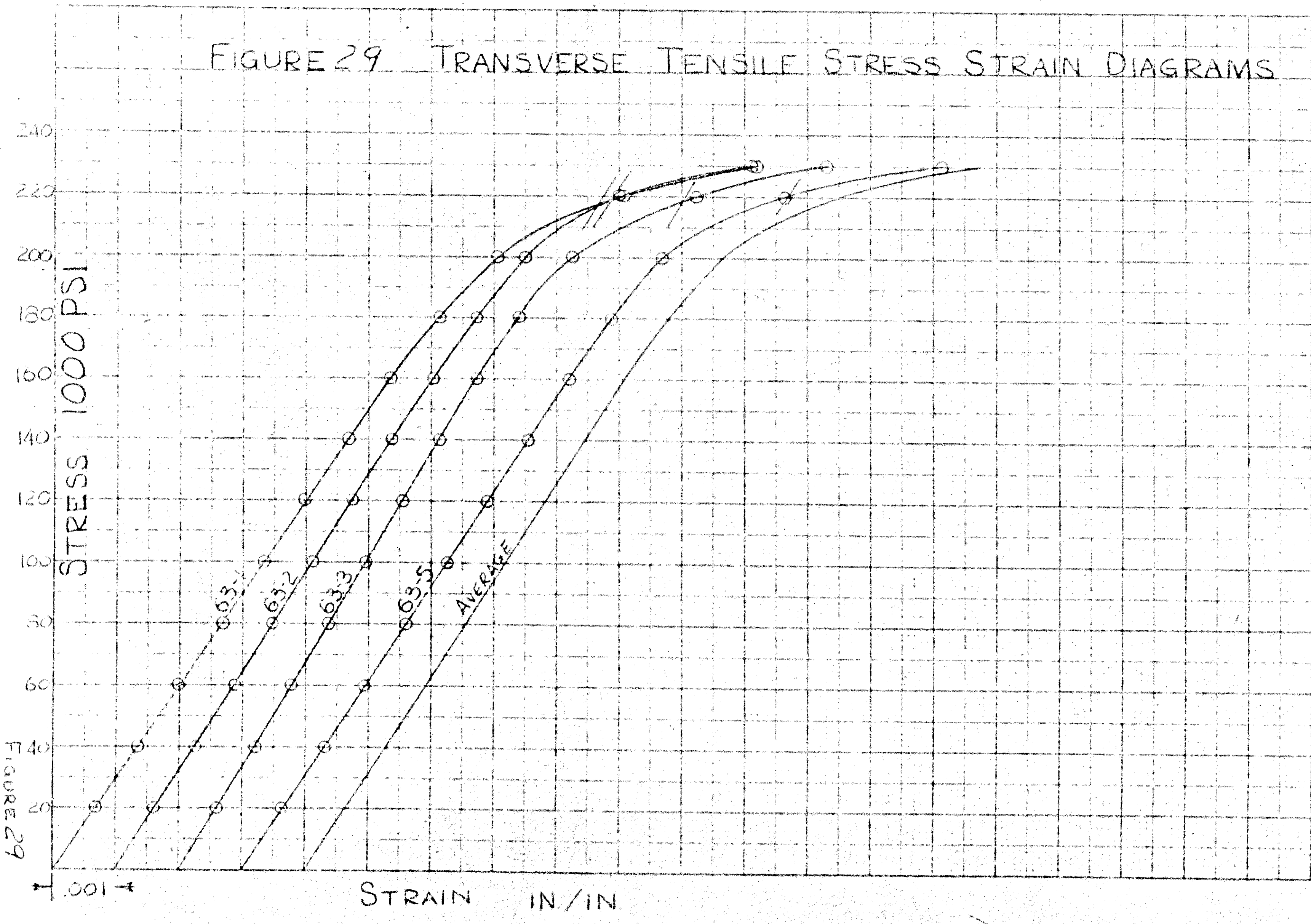


FIGURE 29 TRANSVERSE TENSILE STRESS STRAIN DIAGRAMS
STRESS 1000 PSI
240
220
200
180
160
140
120
100
80
60
40
20
63-1
63-2
63-3
63-5
AVERAGE
.001
STRAIN IN./IN.

FIGURE 29

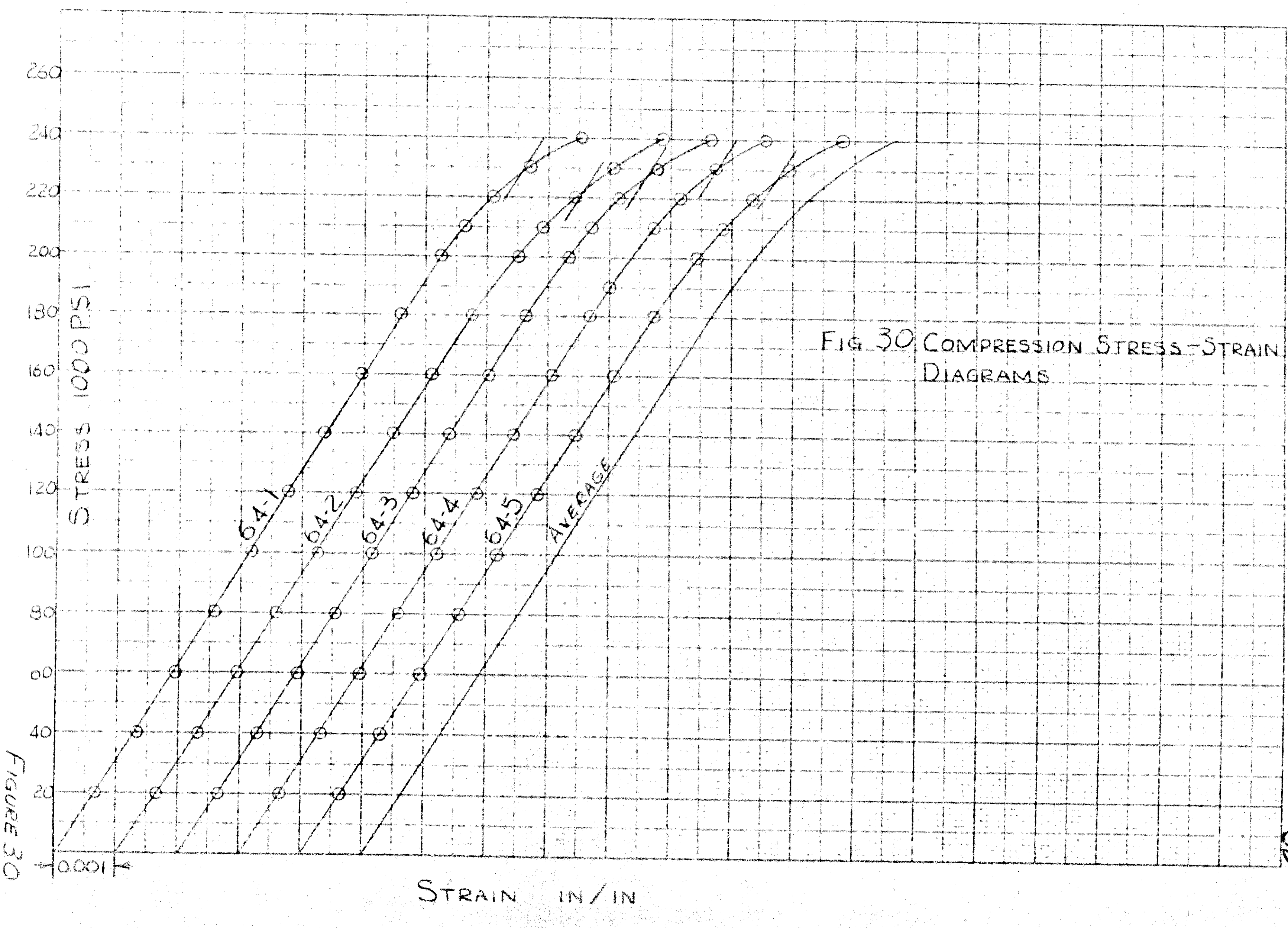


Fig 30 Compression Stress-Strain Diagrams
Stress 1000 PSI
260
240
220
200
180
160
140
120
100
80
60
40
20
64-1
64-2
64-3
64-4
64-5
Average
0.001
Strain in/in

Figure 30

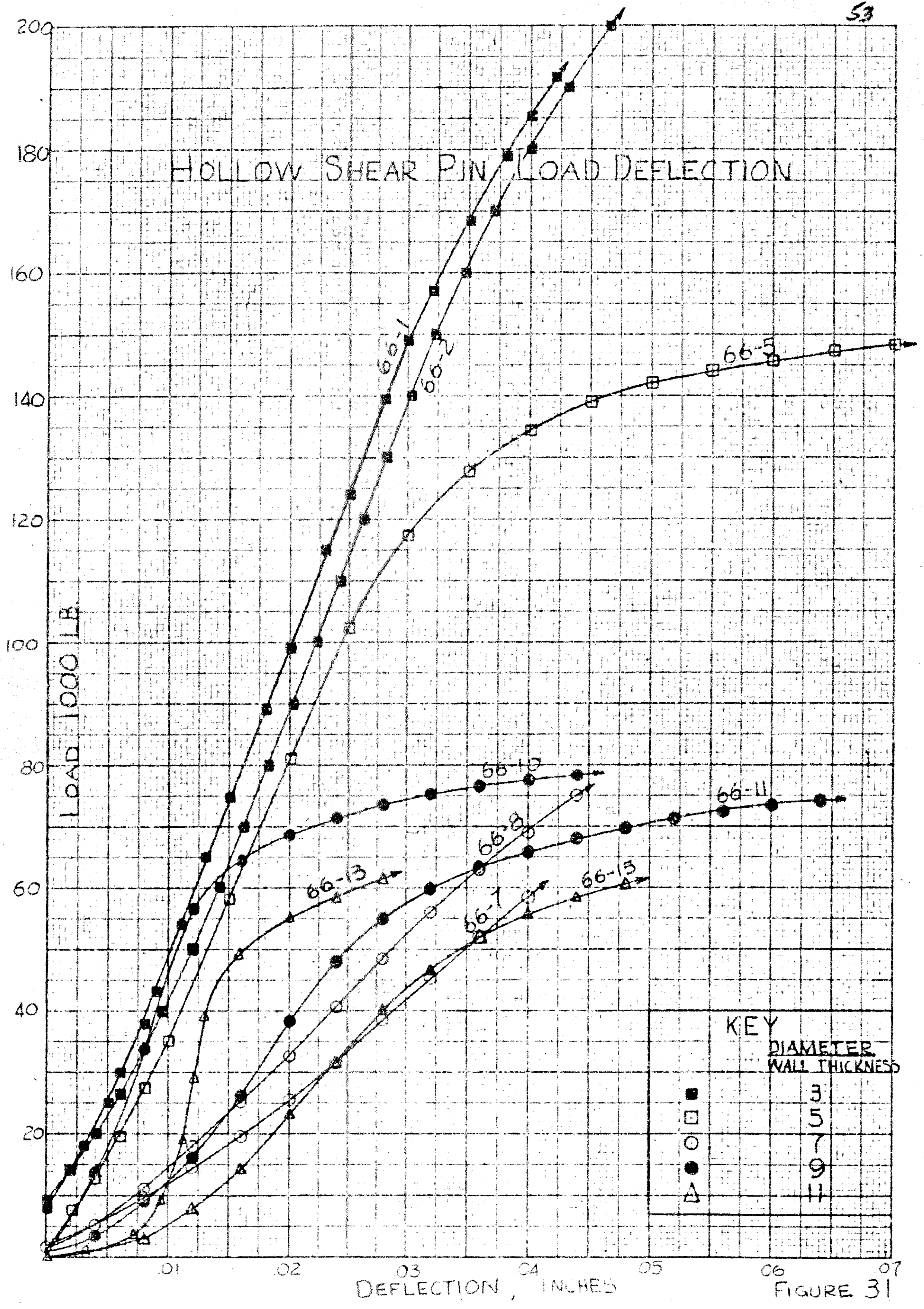

HOLLOW SHEAR PIN LOAD DEFLECTION
200
180
160
140
120
100
80
60
40
20
LOAD 1000 LB.
.01
.02
.03
.04
.05
.06
.07
DEFLECTION, INCHES
66-1
66-2
66-5
66-13
66-8
66-11
66-7
66-15
KEY
DIAMETER
WALL THICKNESS
3
5
7
9
11

FIGURE 31

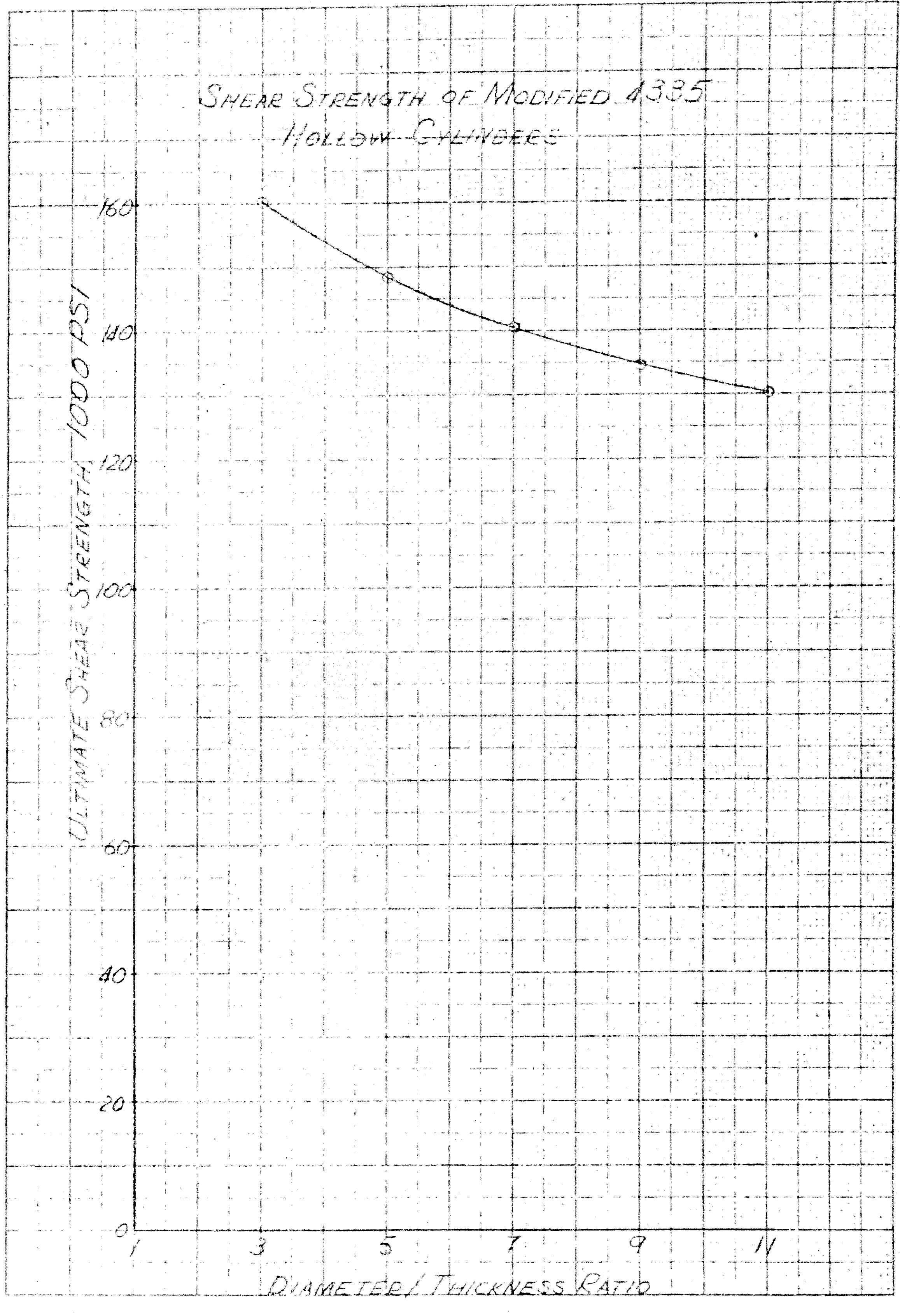

SHEAR STRENGTH OF MODIFIED 4335
HOLLOW CYLINDERS
ULTIMATE SHEAR STRENGTH, 1000 PSI
160
140
120
100
80
60
40
20
0
1
3
5
7
9
11
DIAMETER / THICKNESS RATIO

FIGURE 32

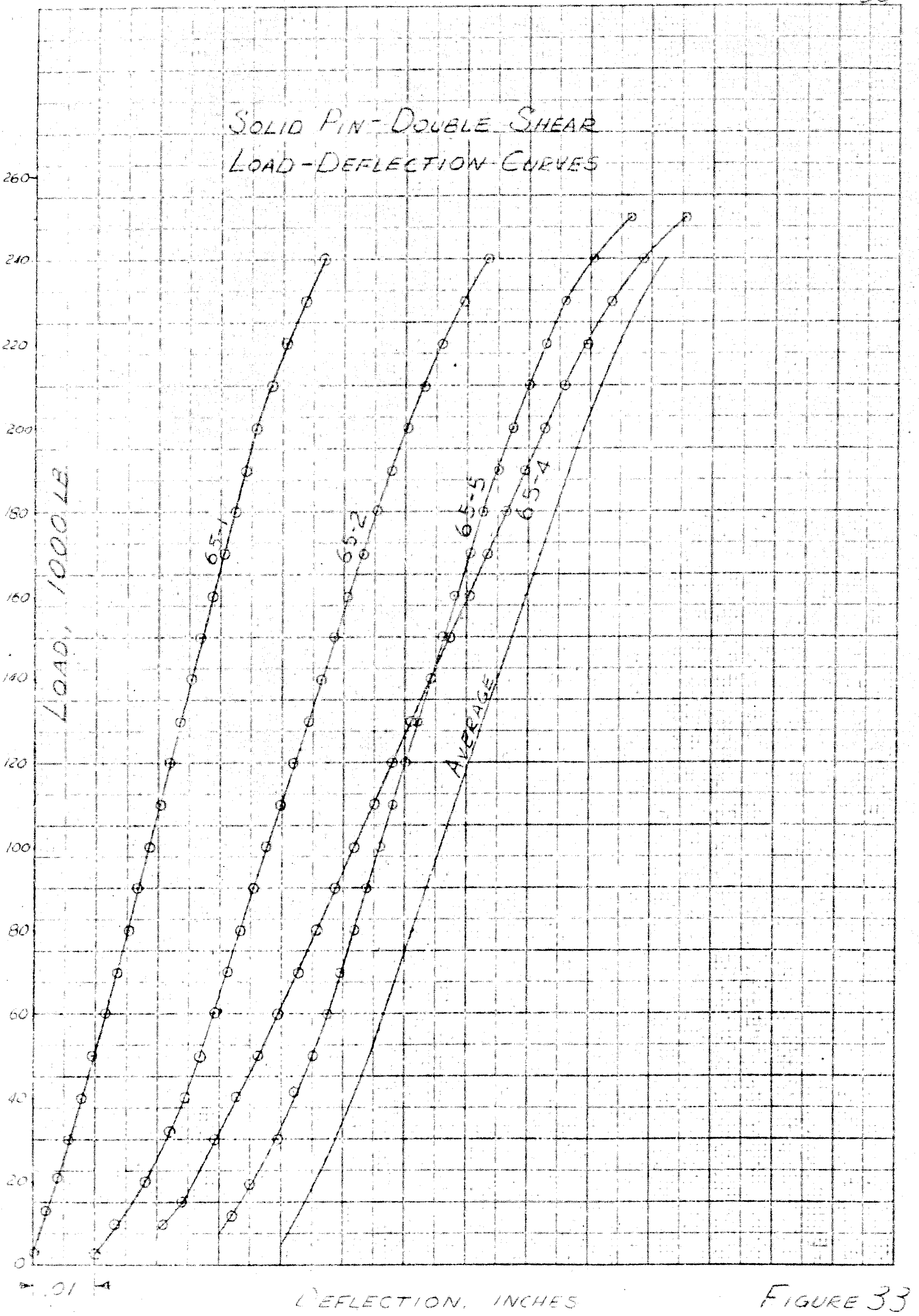

SOLID PIN - DOUBLE SHEAR
LOAD - DEFLECTION - CURVES
LOAD, 1000 LB
260
240
220
200
180
160
140
120
100
80
60
40
20
0
65-1
65-2
65-5
65-4
AVERAGE
.01
DEFLECTION, INCHES

FIGURE 33

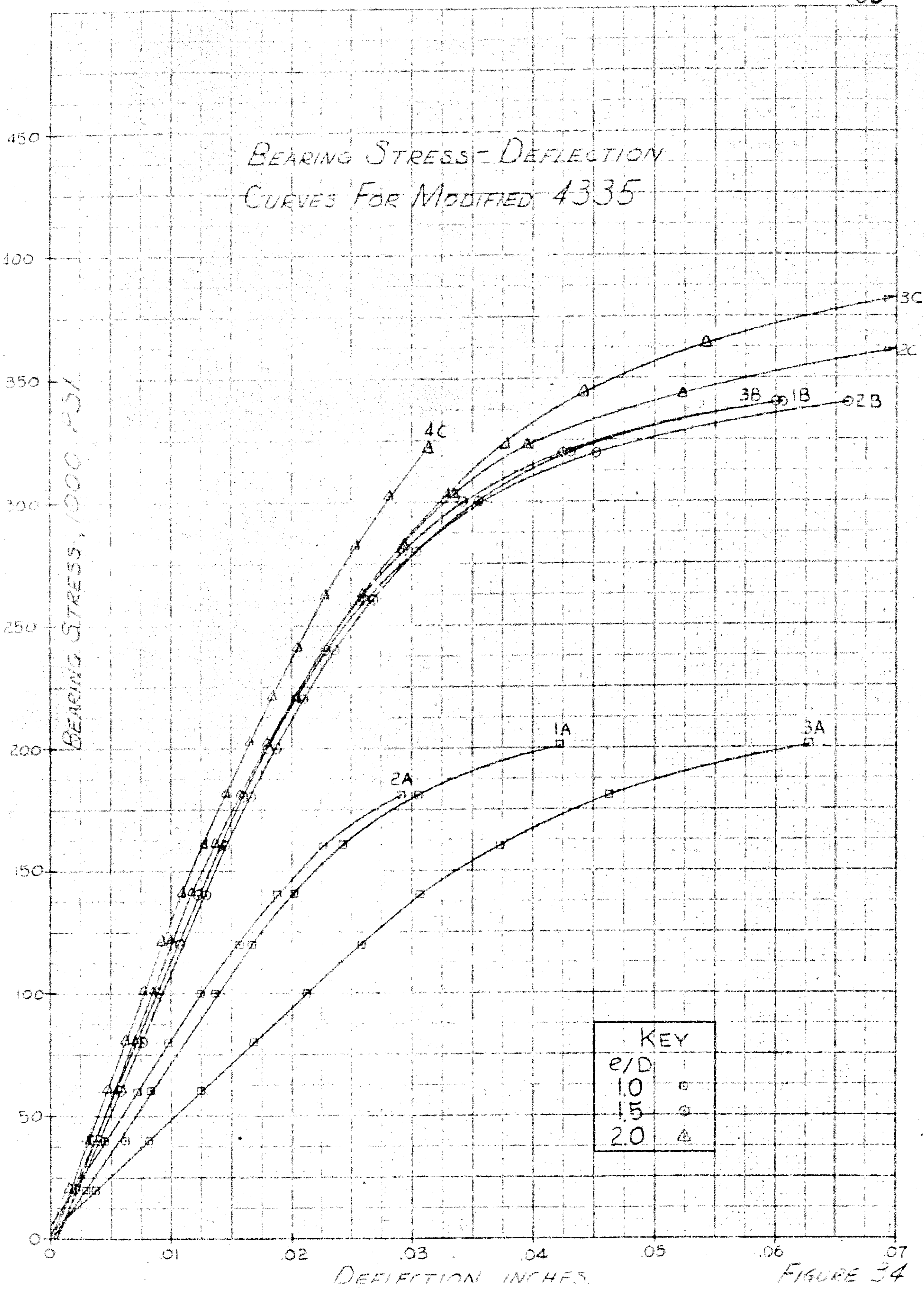
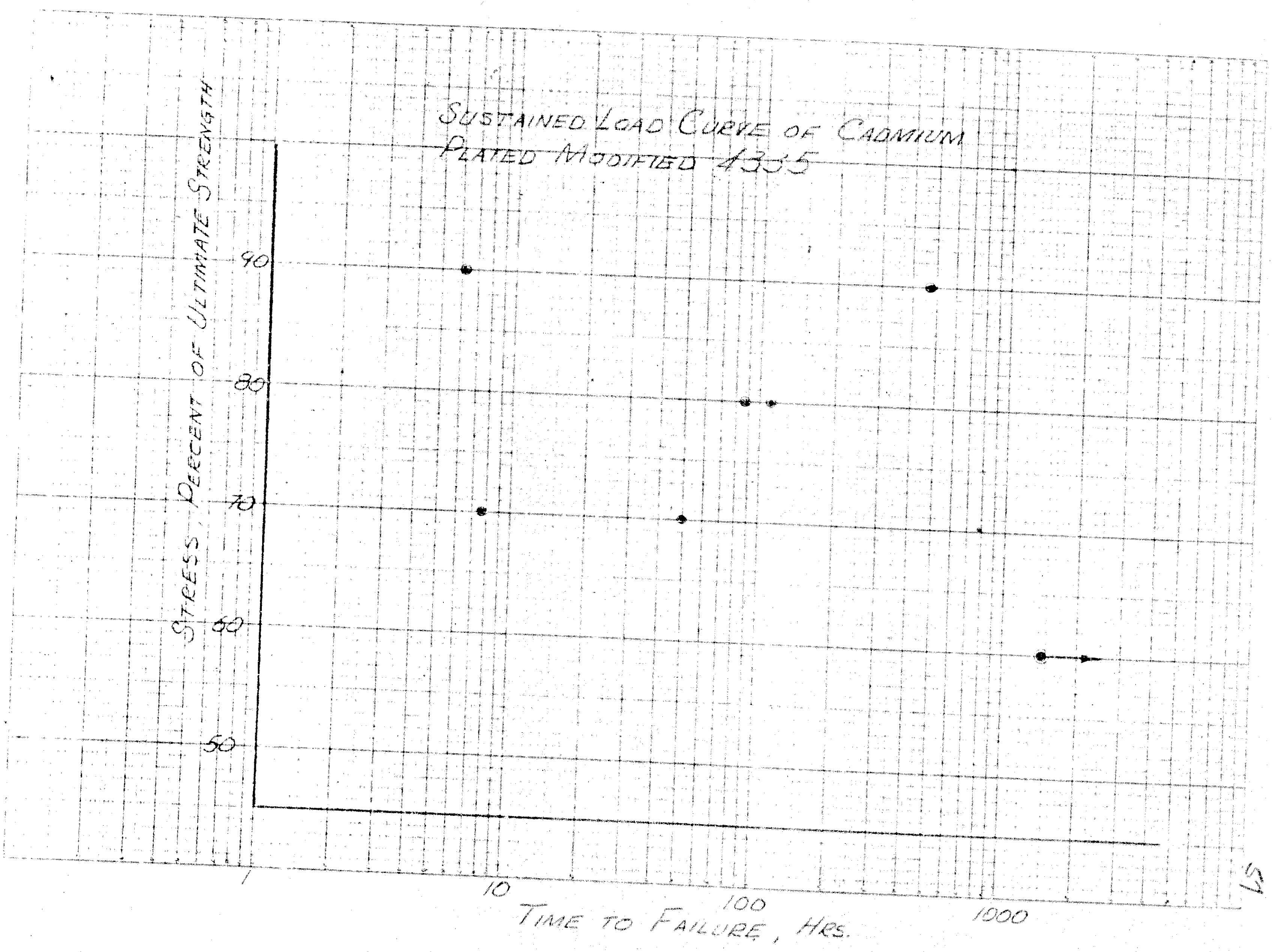

Bearing Stress - Deflection
Curves For Modified 4335
Bearing Stress, 1000 PSI
Deflection, Inches
0
50
100
150
200
250
300
350
400
450
.01
.02
.03
.04
.05
.06
.07
1A
2A
3A
1B
2B
3B
2C
3C
4C
Key
e/D
1.0
1.5
2.0

Figure 34



Sustained Load Curve of Cadmium Plated Modified 4335
Stress, Percent of Ultimate Strength
90
80
70
60
50
1
10
100
1000
Time to Failure, Hrs.

Figure 35

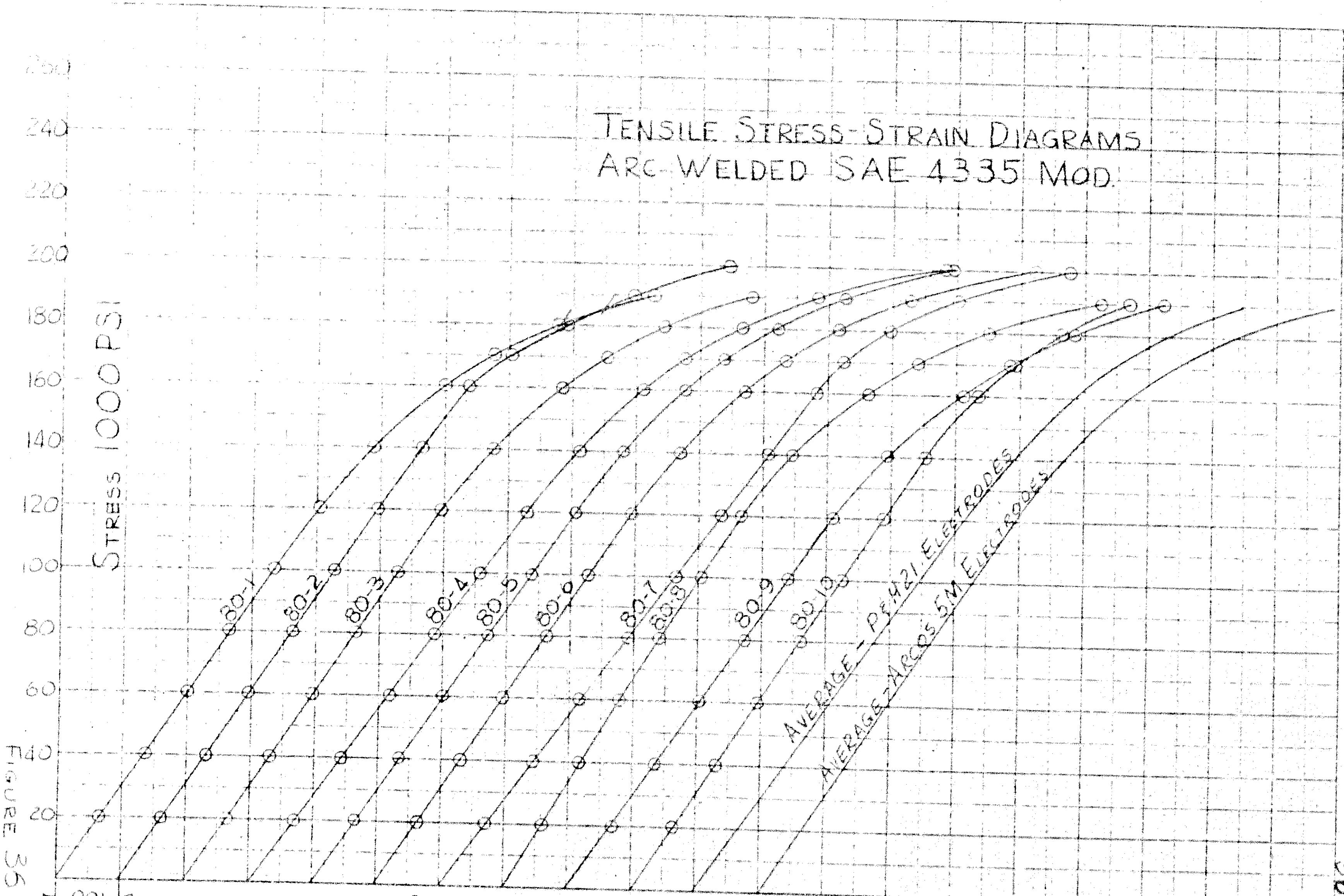

TENSILE STRESS-STRAIN DIAGRAMS
ARC WELDED SAE 4335 MOD.
STRESS 1000 PSI
260
240
220
200
180
160
140
120
100
80
60
40
20
STRAIN IN/IN.
.001
80-1
80-2
80-3
80-4
80-5
80-6
80-7
80-8
80-9
80-10
AVERAGE - P&H 21 ELECTRODES
AVERAGE - ARCOS 5M ELECTRODES

FIGURE 36

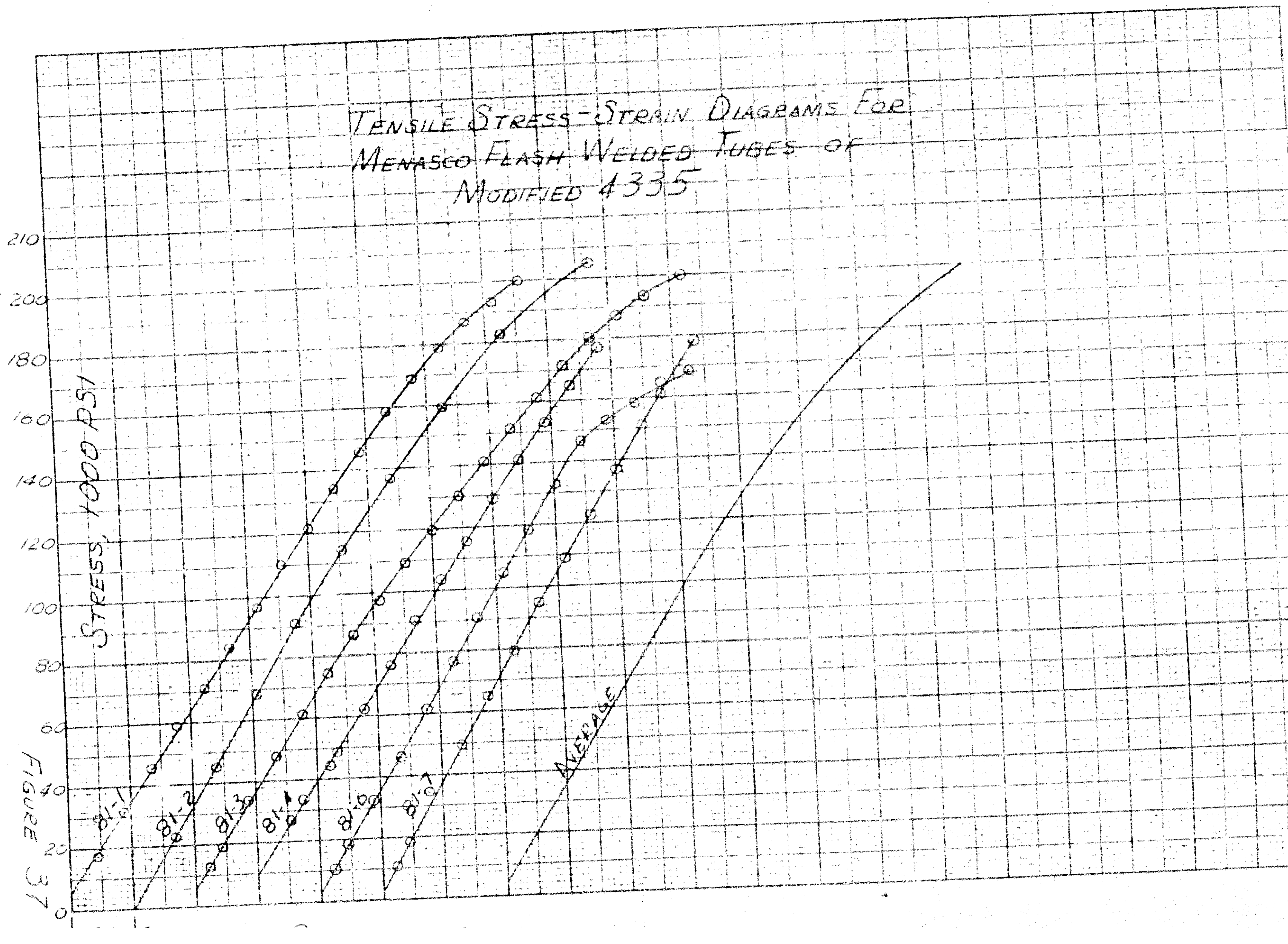

Tensile Stress-Strain Diagrams For
Menasco Flash Welded Tubes of
Modified 4335
Stress, 1000 PSI
0
20
40
60
80
100
120
140
160
180
200
210
81-1
81-2
81-3
81-4
81-00
81-7
Average

Figure 37

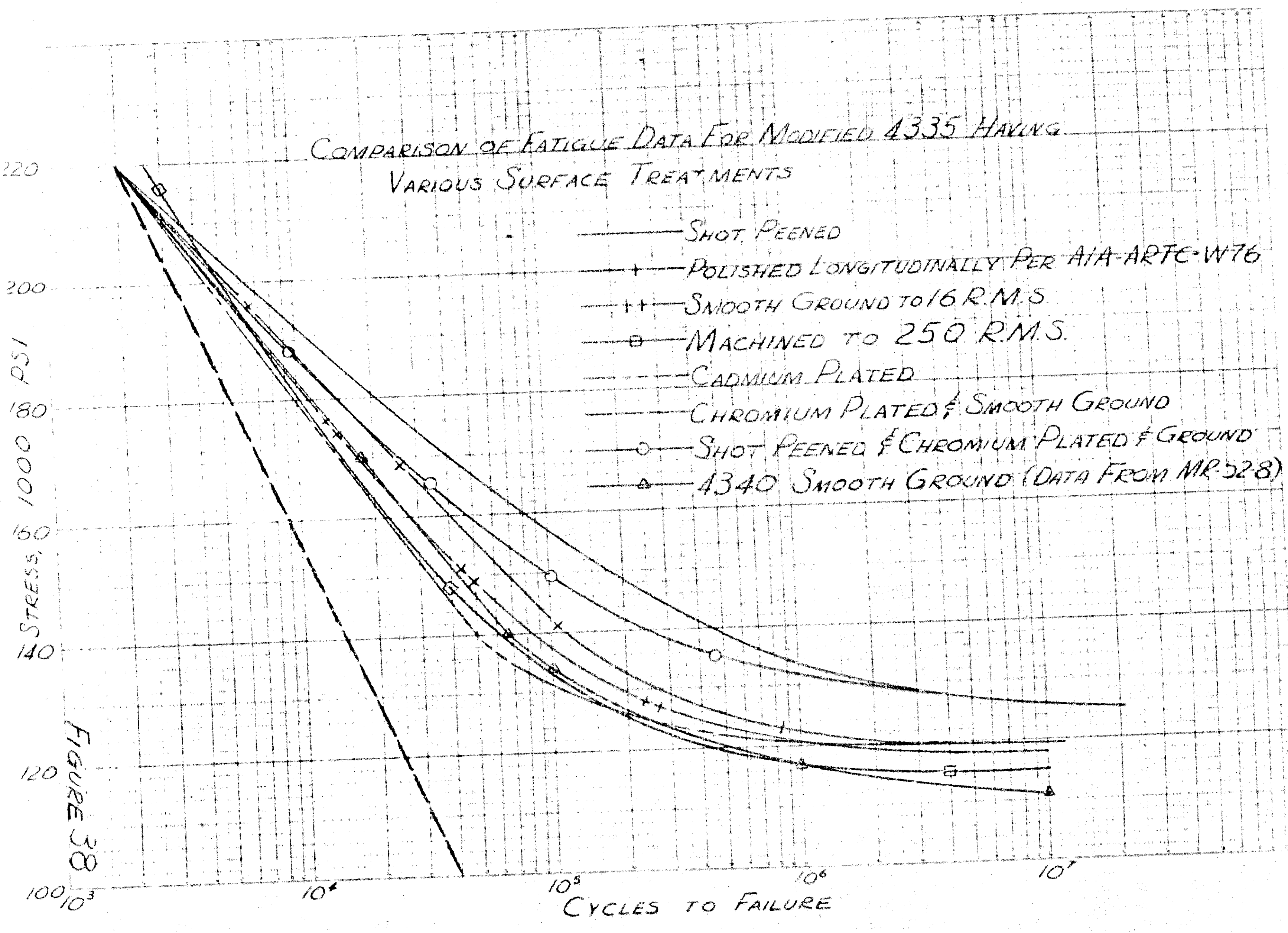
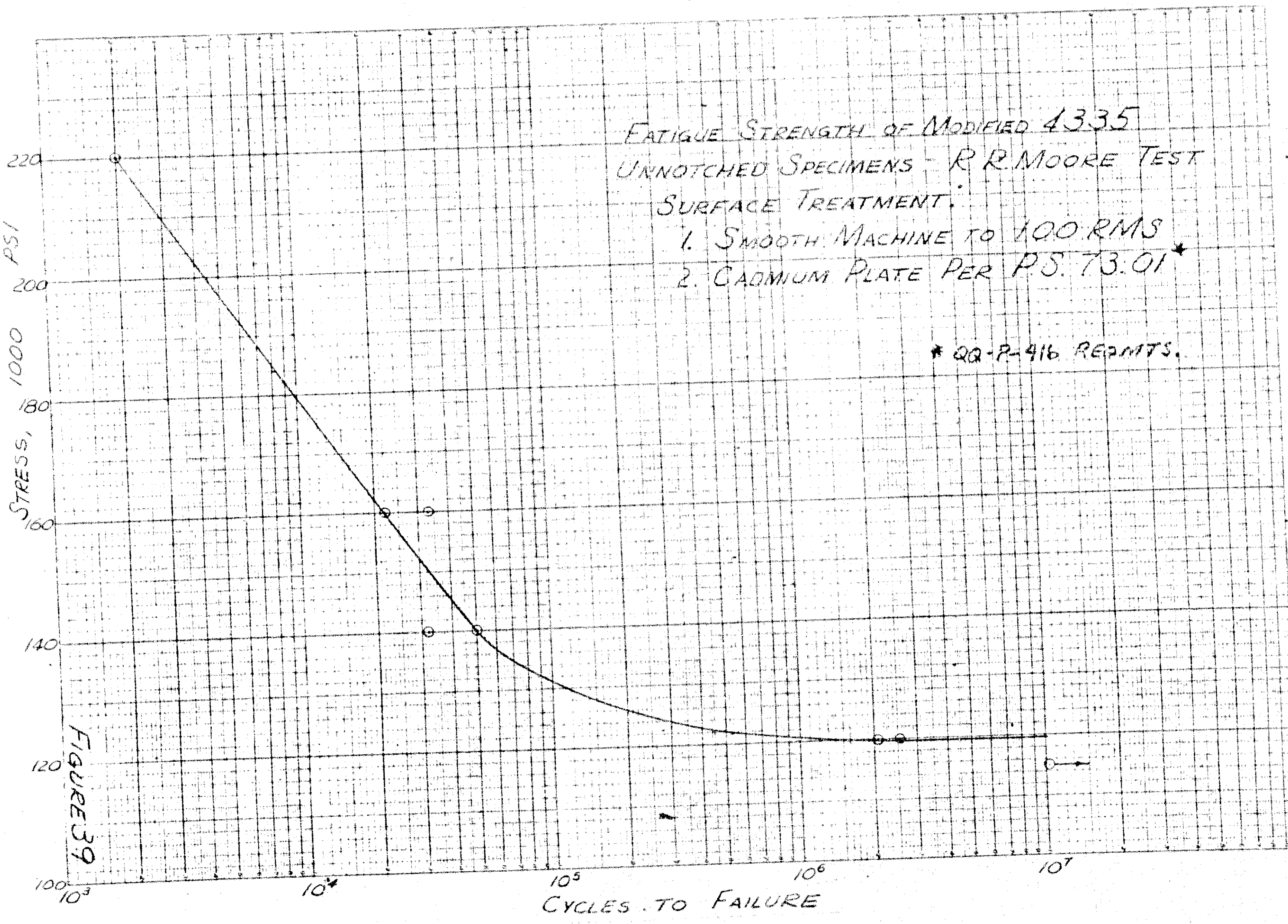
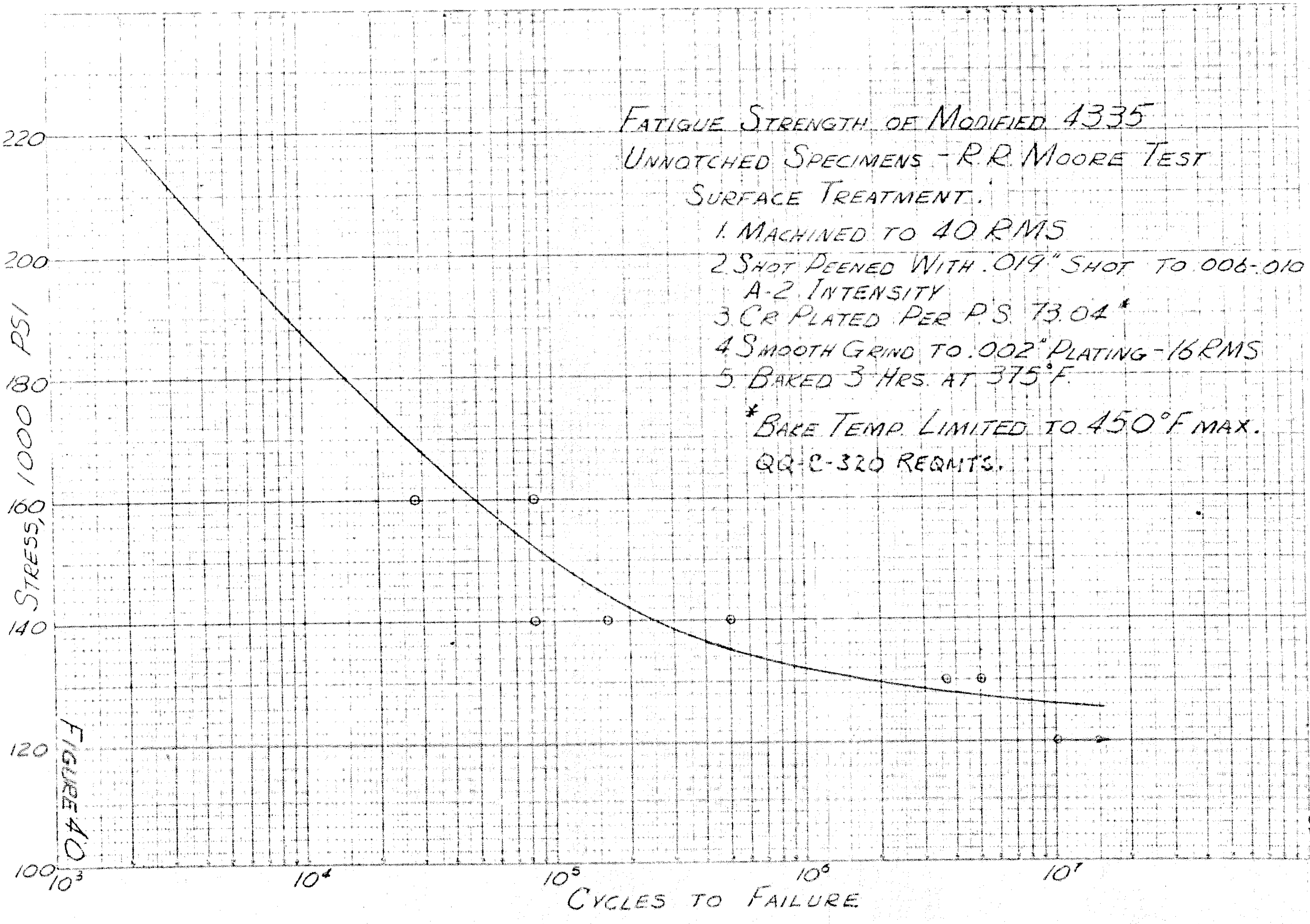

Comparison of Fatigue Data For Modified 4335 Having
Various Surface Treatments
Shot Peened
Polished Longitudinally Per AIA-ARTC-W76
Smooth Ground to 16 R.M.S
Machined to 250 R.M.S.
Cadmium Plated
Chromium Plated & Smooth Ground
Shot Peened & Chromium Plated & Ground
4340 Smooth Ground (Data From MR-528)
220
200
180
160
140
120
100
Stress, 1000 PSI
10^3
10^4
10^5
10^6
10^7
Cycles to Failure

Figure 38



Fatigue Strength of Modified 4335
Unnotched Specimens - R.R. Moore Test
Surface Treatment:
1. Smooth Machine to 100 RMS
2. Cadmium Plate Per P.S. 73.01*
* QQ-P-416 Reqmts.
Stress, 1000 PSI
220
200
180
160
140
120
100
10^3
10^4
10^5
10^6
10^7
Cycles to Failure

Figure 39



FATIGUE STRENGTH OF MODIFIED 4335
UNNOTCHED SPECIMENS - R.R. MOORE TEST
SURFACE TREATMENT.
1. MACHINED TO 40 RMS
2. SHOT PEENED WITH .019" SHOT TO .006-.010 A-2 INTENSITY
3. CR PLATED PER P.S. 73.04*
4. SMOOTH GRIND TO .002" PLATING - 16 RMS
5. BAKED 3 HRS. AT 375°F.
*BAKE TEMP. LIMITED TO 450°F MAX. QQ-C-320 REQMTS.
STRESS, 1000 PSI
220
200
180
160
140
120
100
10^3
10^4
10^5
10^6
10^7
CYCLES TO FAILURE

FIGURE 40

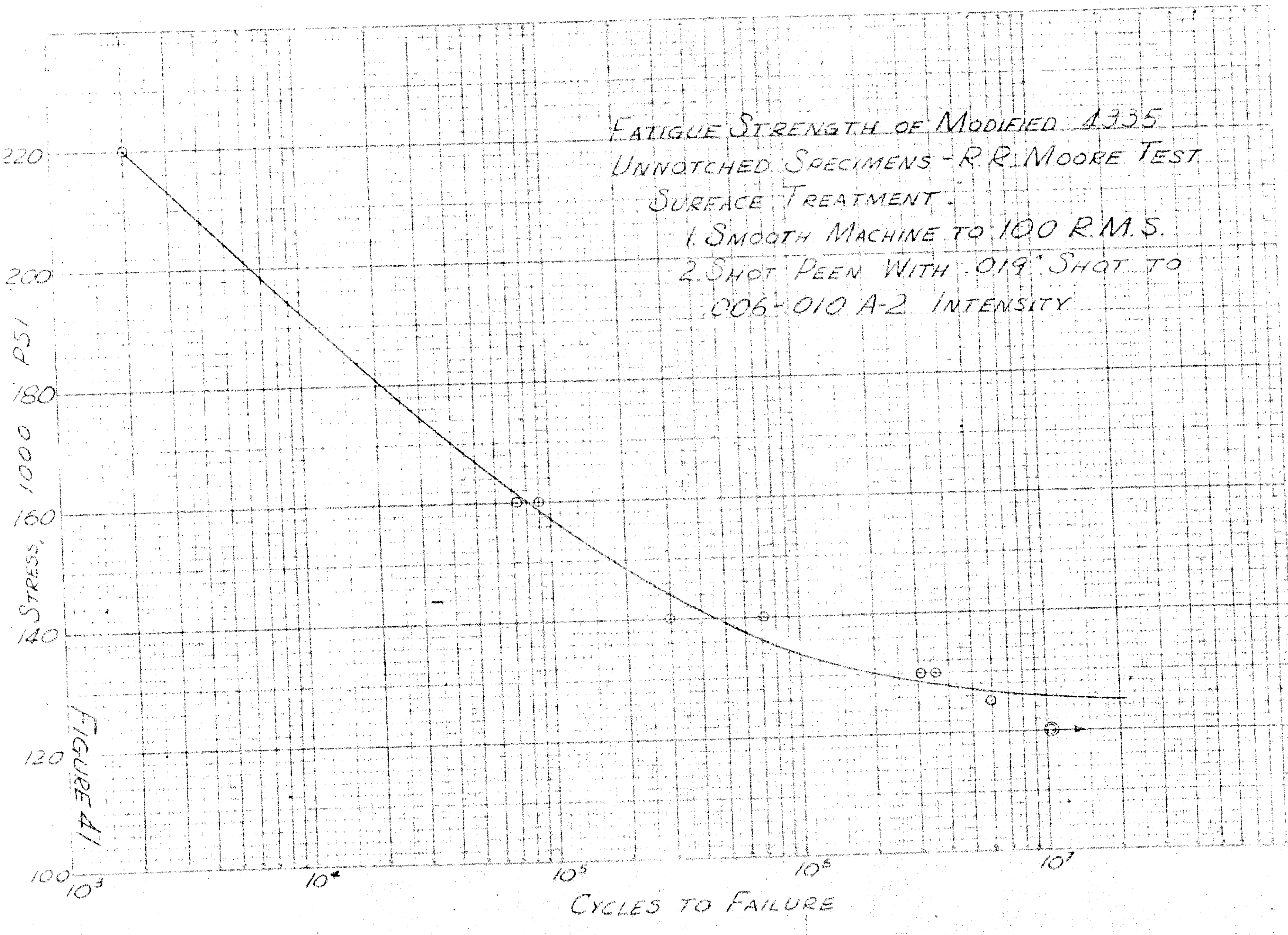

FATIGUE STRENGTH OF MODIFIED 4335
UNNOTCHED SPECIMENS - R.R. MOORE TEST
SURFACE TREATMENT -
1. SMOOTH MACHINE TO 100 R.M.S.
2. SHOT PEEN WITH .019" SHOT TO
.006-.010 A-2 INTENSITY
STRESS, 1000 PSI
220
200
180
160
140
120
100
10^3
10^4
10^5
10^6
10^7
CYCLES TO FAILURE

FIGURE 41

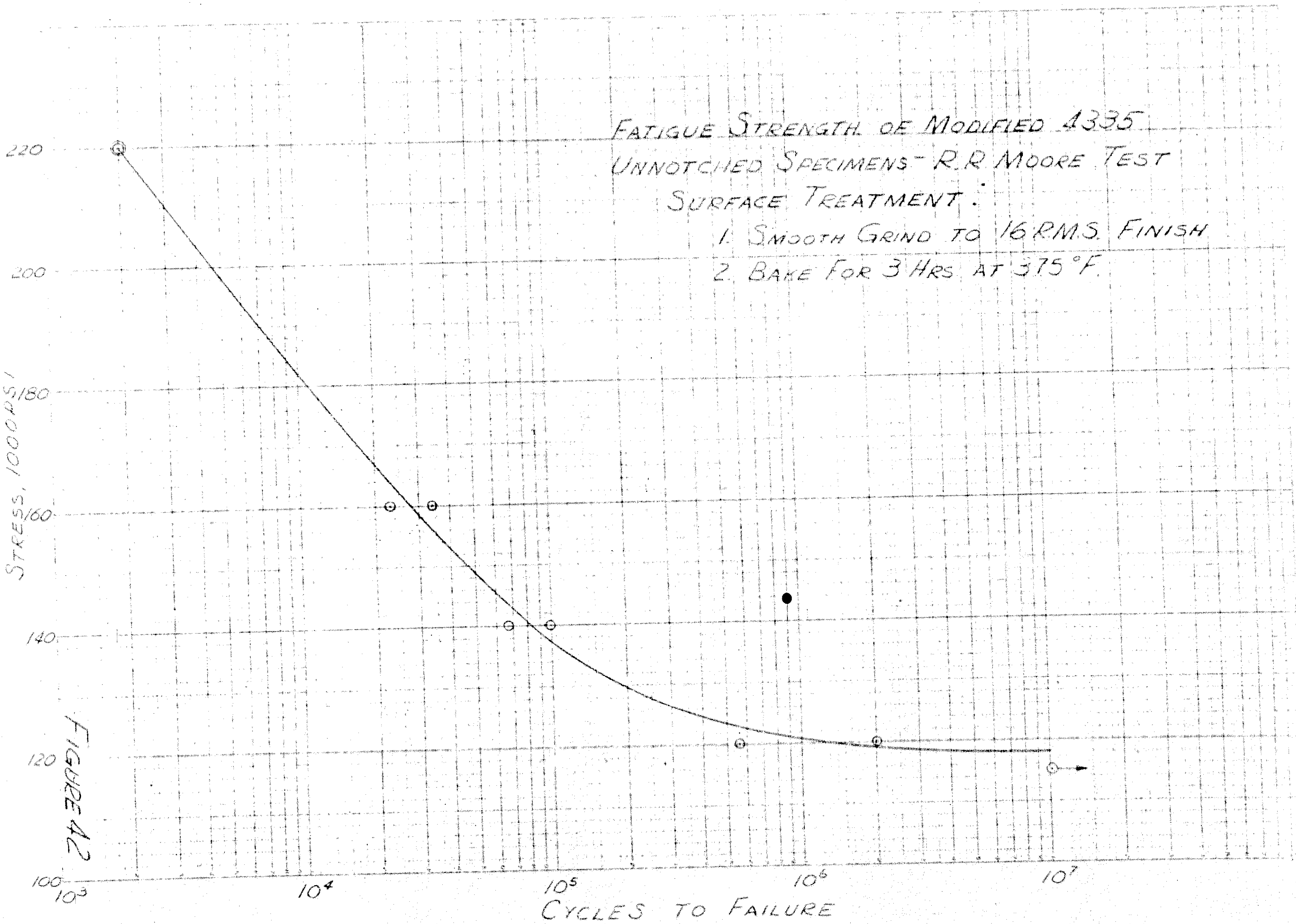

FATIGUE STRENGTH OF MODIFIED 4335
UNNOTCHED SPECIMENS - R.R. MOORE TEST
SURFACE TREATMENT:
1. SMOOTH GRIND TO 16 RMS FINISH
2. BAKE FOR 3 HRS AT 375 °F
STRESS, 1000 PSI
220
200
180
160
140
120
100
10^3
10^4
10^5
10^6
10^7
CYCLES TO FAILURE

FIGURE 42

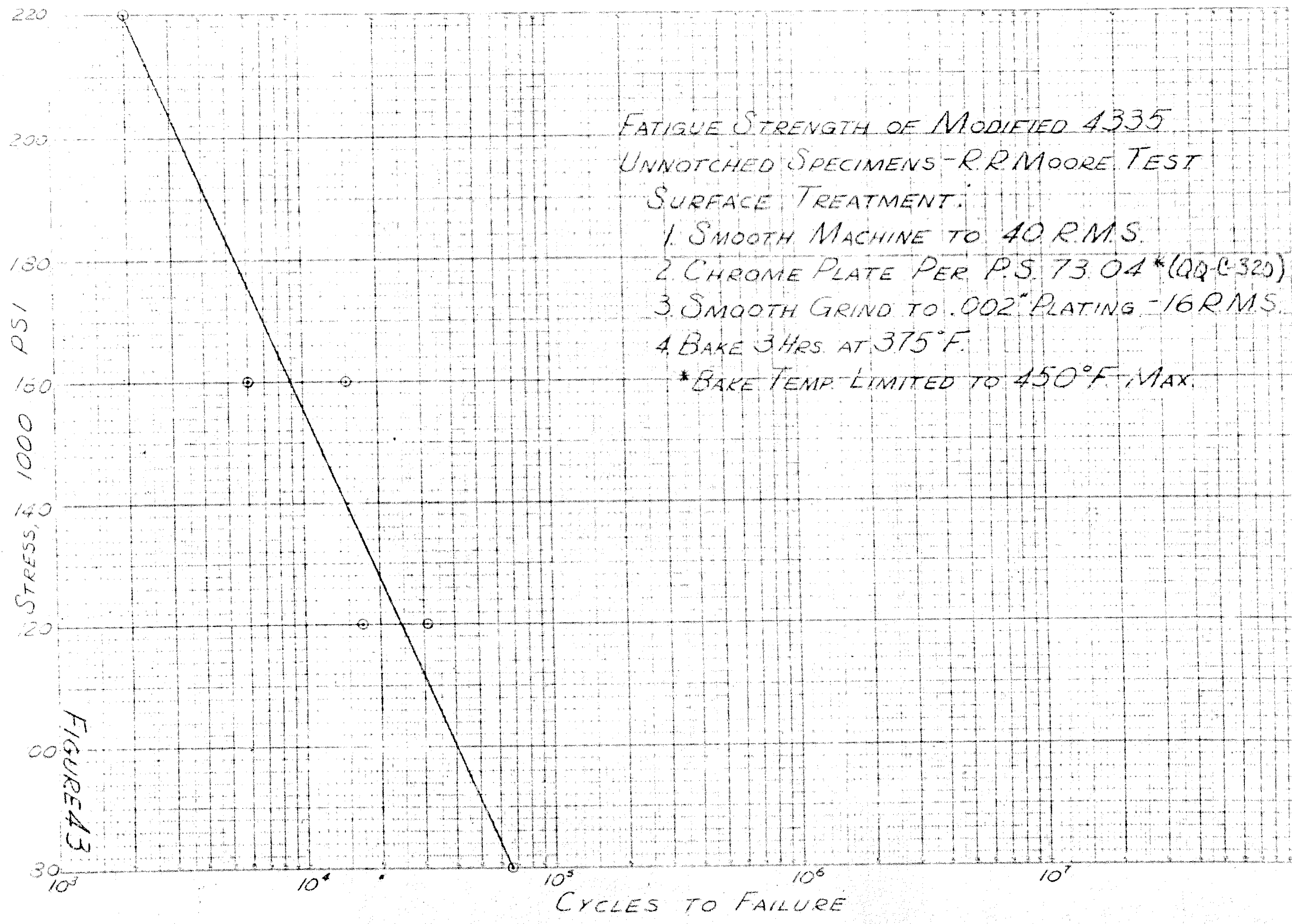

FATIGUE STRENGTH OF MODIFIED 4335
UNNOTCHED SPECIMENS - R.R.MOORE TEST
SURFACE TREATMENT:
1. SMOOTH MACHINE TO 40 R.M.S.
2. CHROME PLATE PER P.S. 73.04* (QQ-C-320)
3. SMOOTH GRIND TO .002" PLATING - 16 R.M.S.
4. BAKE 3 HRS. AT 375°F.
*BAKE TEMP. LIMITED TO 450°F. MAX.
STRESS, 1000 PSI
220
200
180
160
140
120
100
80
10^3
10^4
10^5
10^6
10^7
CYCLES TO FAILURE

FIGURE 43

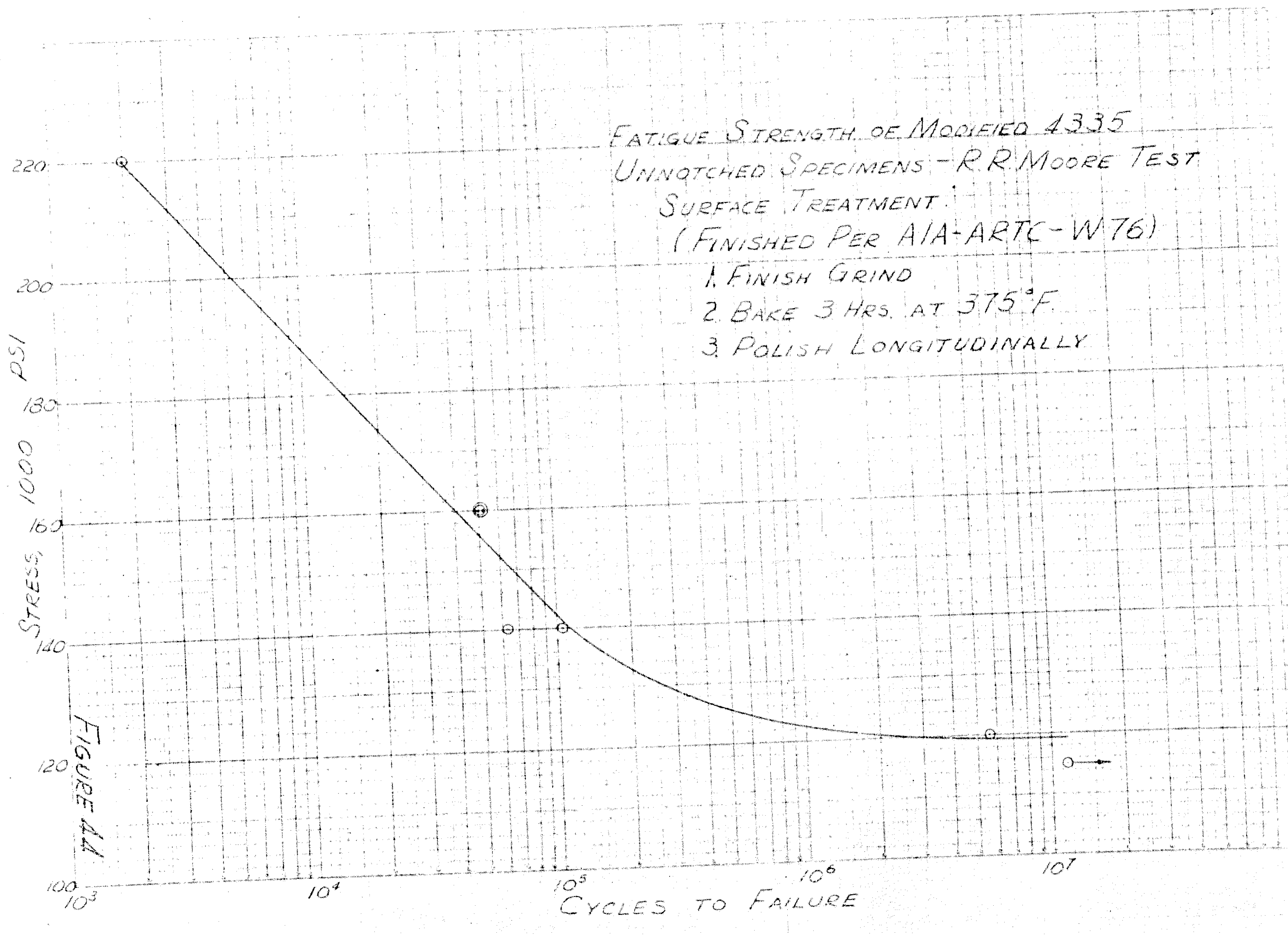

FATIGUE STRENGTH OF MODIFIED 4335
UNNOTCHED SPECIMENS - R.R. MOORE TEST
SURFACE TREATMENT
(FINISHED PER AIA-ARTC-W76)
1. FINISH GRIND
2. BAKE 3 HRS. AT 375°F.
3. POLISH LONGITUDINALLY
STRESS, 1000 PSI
220
200
180
160
140
120
100
10^3
10^4
10^5
10^6
10^7
CYCLES TO FAILURE

FIGURE 44

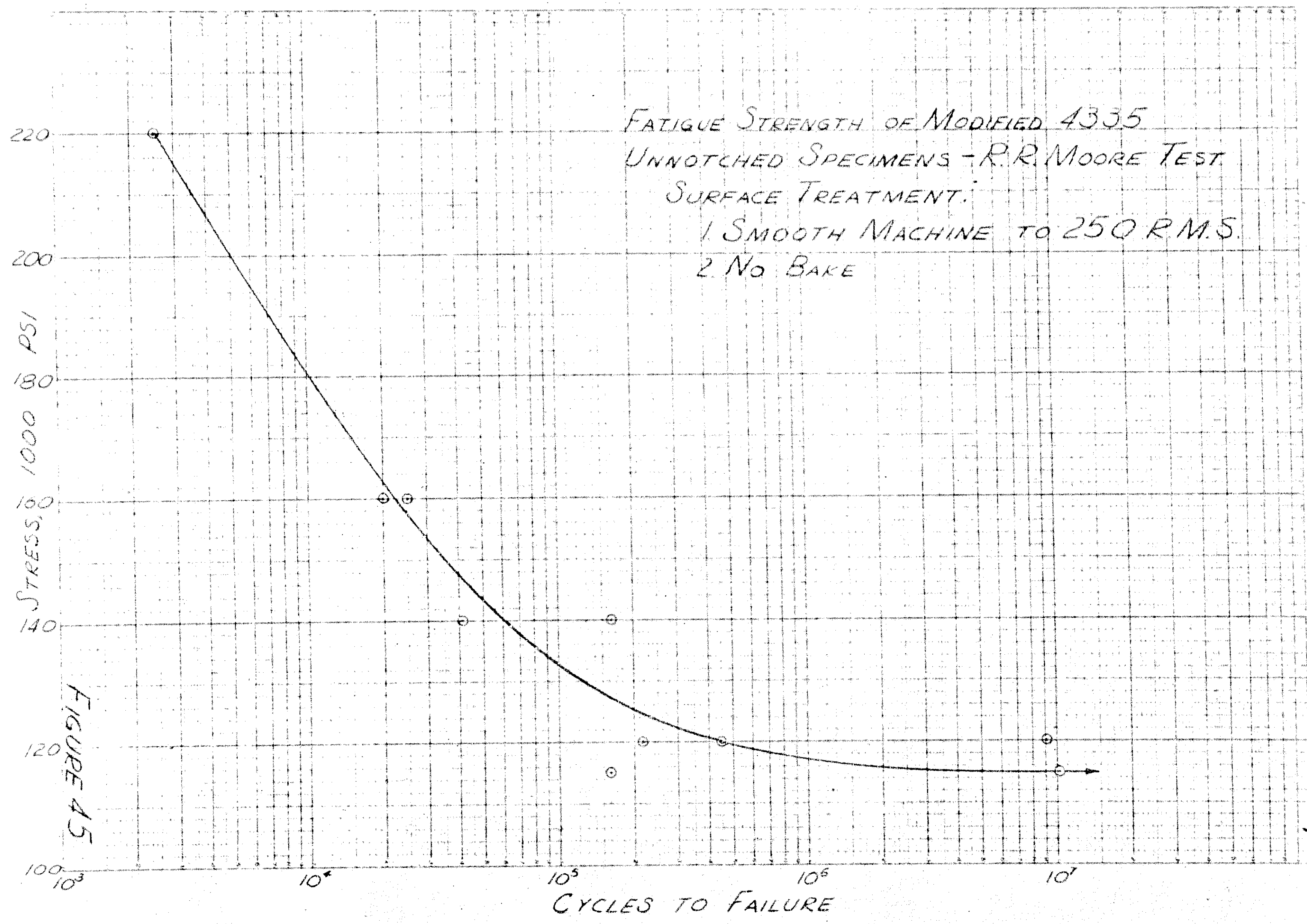

FATIGUE STRENGTH OF MODIFIED 4335
UNNOTCHED SPECIMENS - R.R. MOORE TEST
SURFACE TREATMENT.
1. SMOOTH MACHINE TO 250 R.M.S.
2. NO BAKE
STRESS, 1000 PSI
220
200
180
160
140
120
100
10^3
10^4
10^5
10^6
10^7
CYCLES TO FAILURE

FIGURE 45

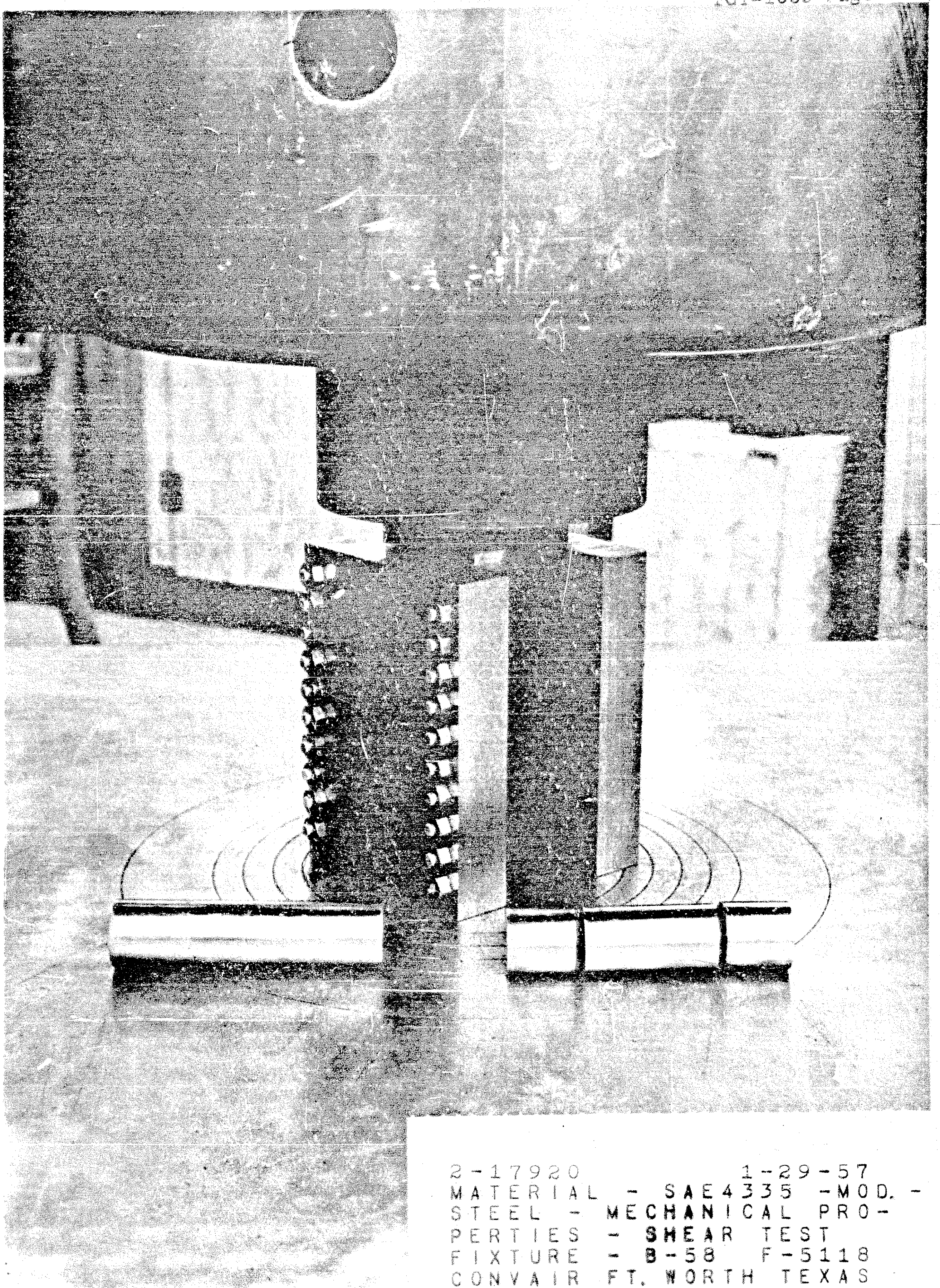
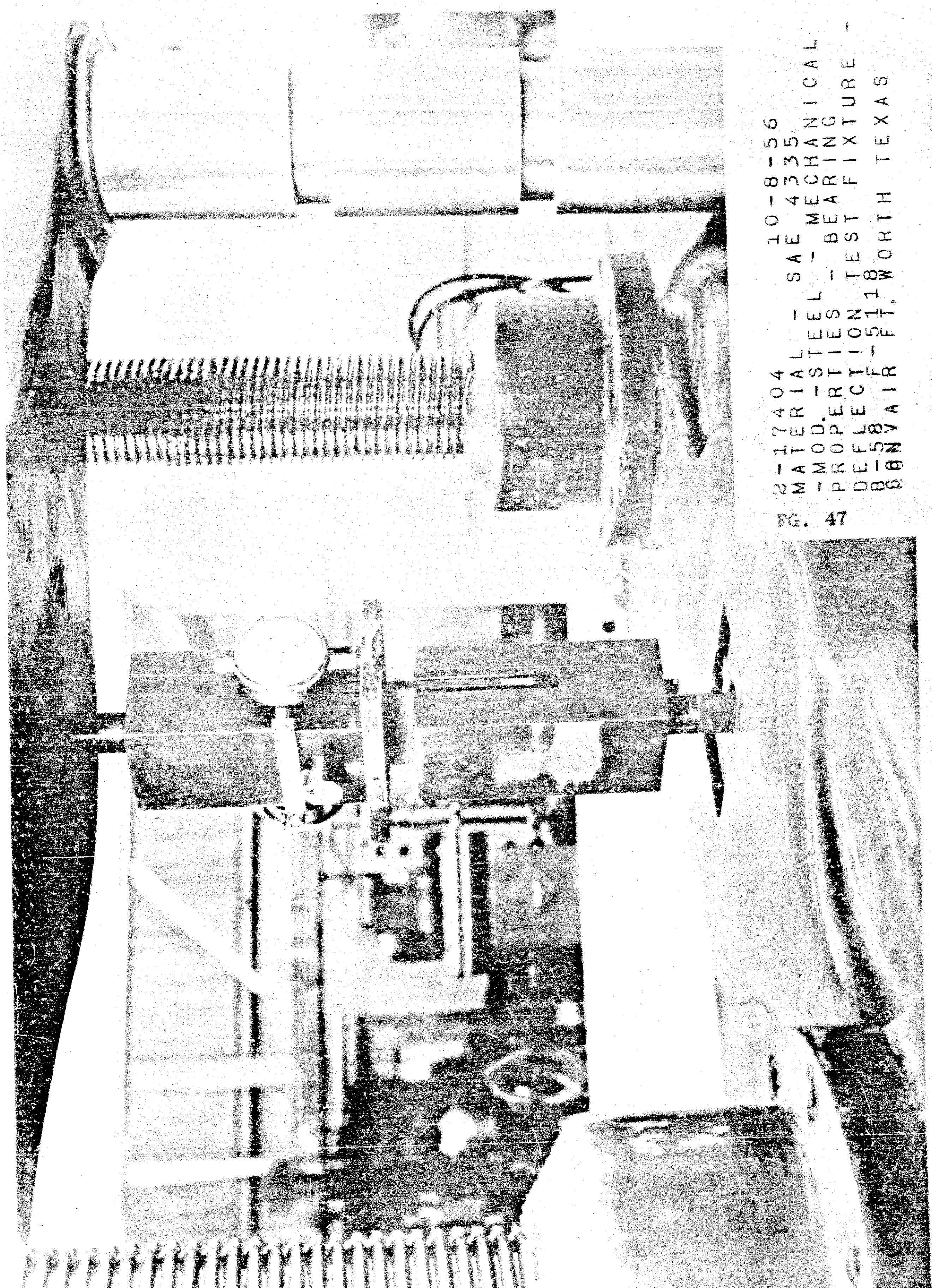

2-17920 1-29-57
MATERIAL - SAE4335 -MOD.-
STEEL - MECHANICAL PRO-
PERTIES - SHEAR TEST
FIXTURE - B-58 F-5118
CONVAIR FT. WORTH TEXAS

Figure 48


2-17404 10-8-56
MATERIAL - SAE 4335
-MOD. -STEEL - MECHANICAL
PROPERTIES - BEARING
DEFLECTION TEST FIXTURE -
B-58 F-5118
CONVAIR FT. WORTH TEXAS

FG. 47

FIG 47

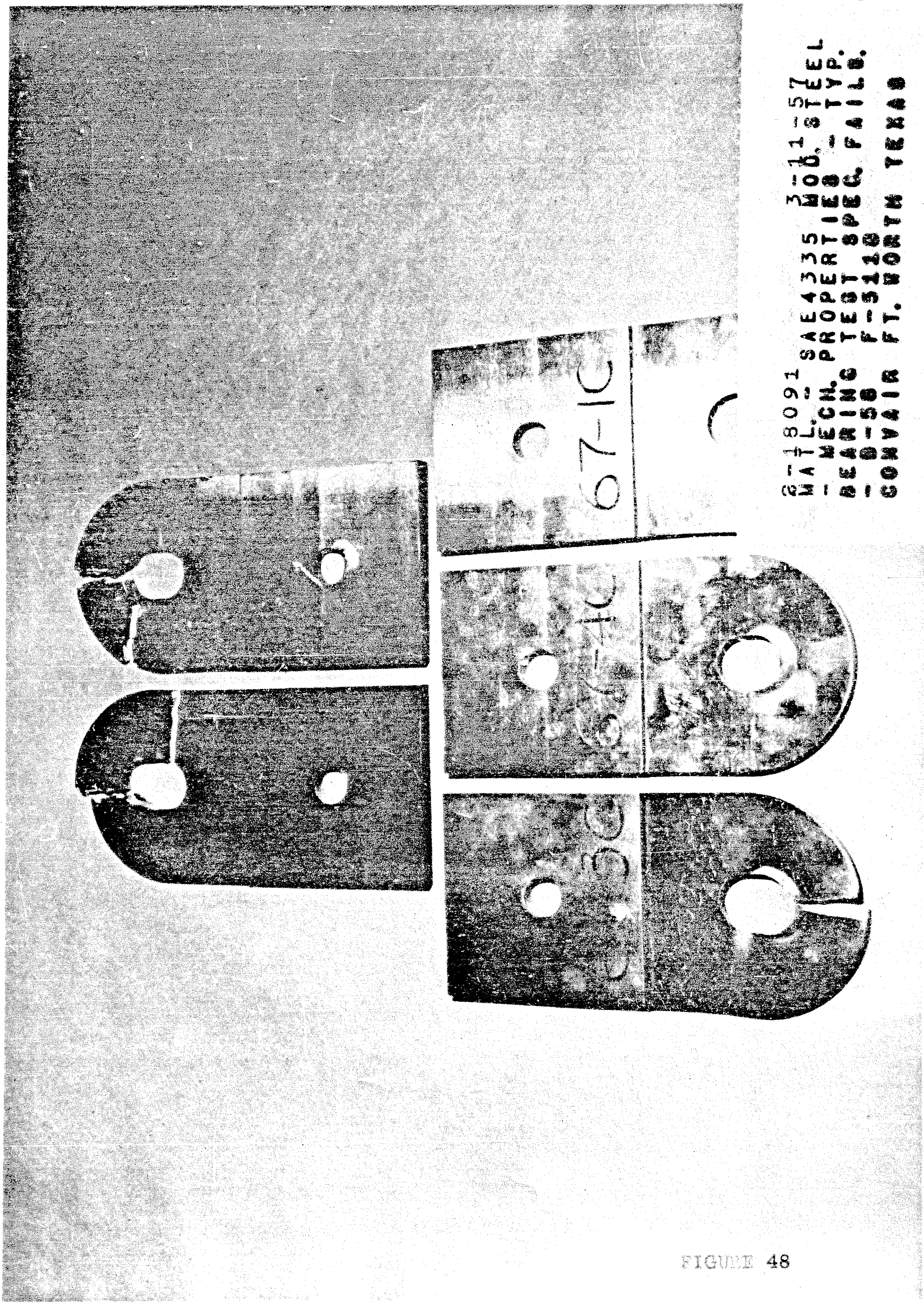


FIGURE 48

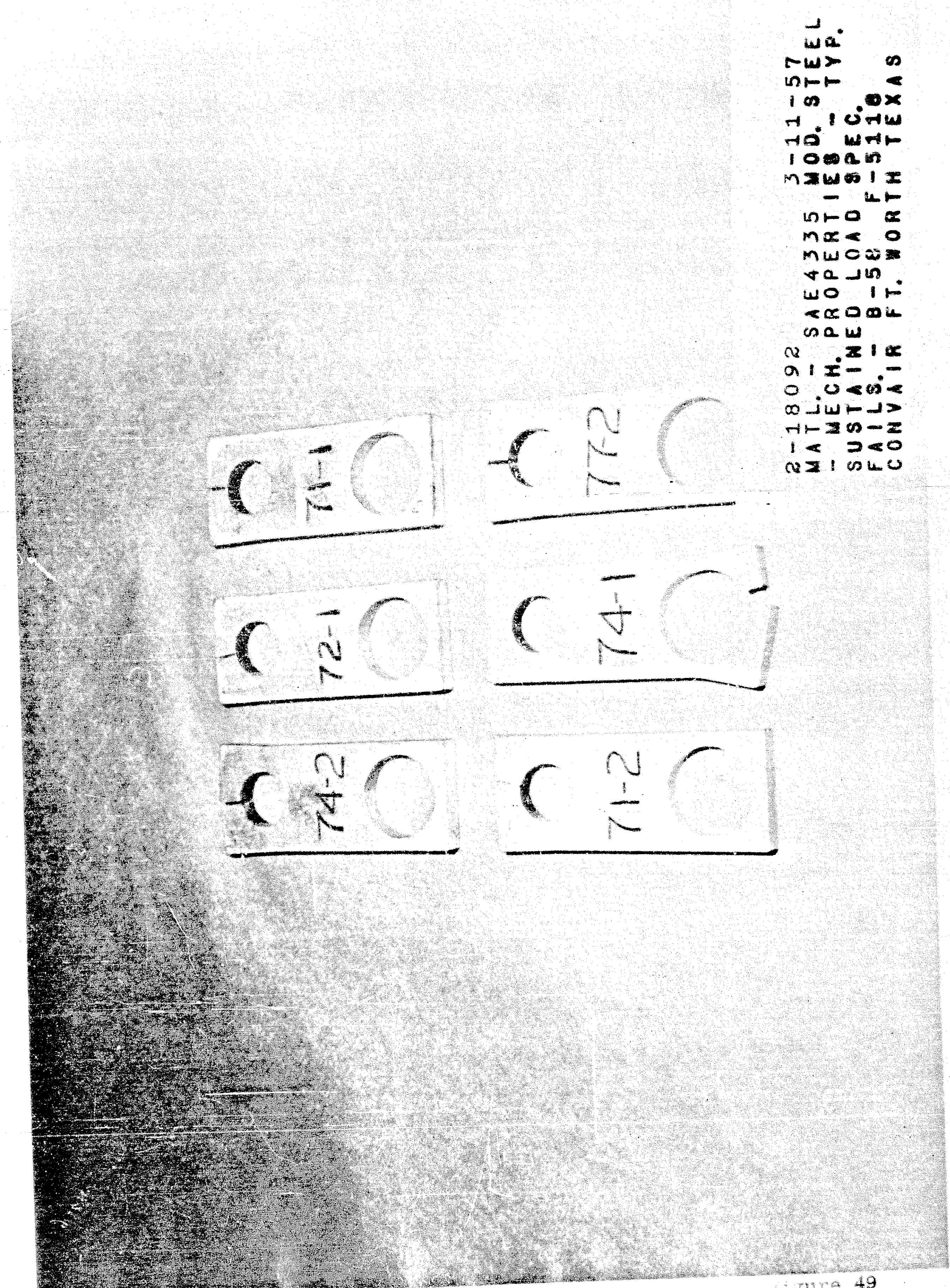
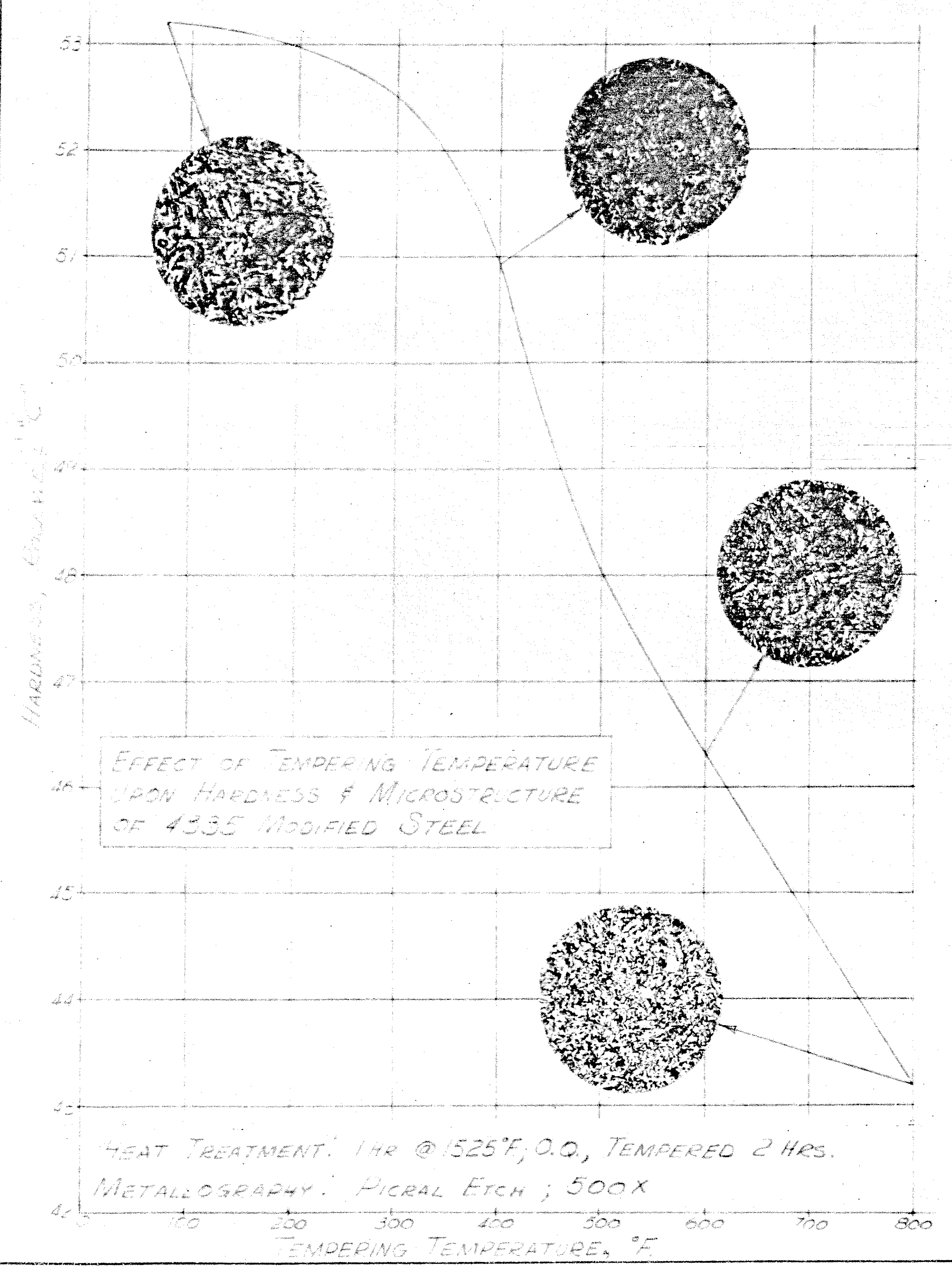
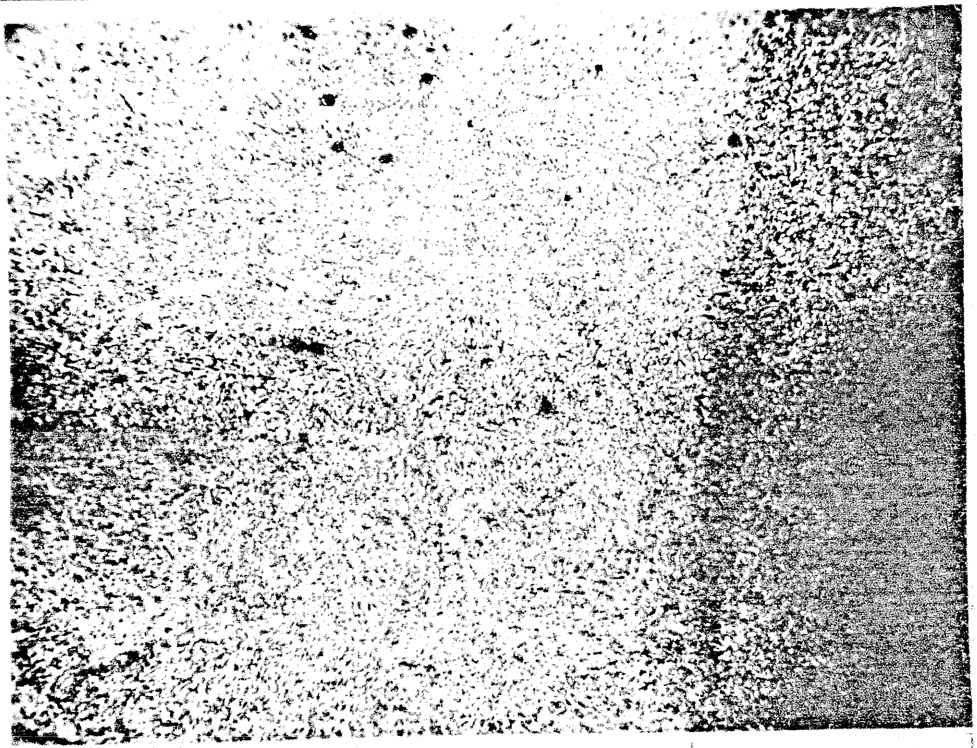

2-18092 3-11-57
MATL. - SAE4335 MOD. STEEL
- MECH. PROPERTIES - TYP.
SUSTAINED LOAD SPEC.
FAILS. - B-58 F-5118
CONVAIR FT. WORTH TEXAS
74-2
72-1
71-1
71-2
74-1
77-2

Figure 49



53
52
51
50
49
48
47
46
45
44
43
42
HARDNESS, ROCKWELL "C"
EFFECT OF TEMPERING TEMPERATURE
UPON HARDNESS & MICROSTRUCTURE
OF 4335 MODIFIED STEEL
HEAT TREATMENT: 1 HR @ 1525°F, O.Q., TEMPERED 2 HRS.
METALLOGRAPHY: PICRAL ETCH ; 500X
0
100
200
300
400
500
600
700
800
TEMPERING TEMPERATURE, °F

FIGURE 50



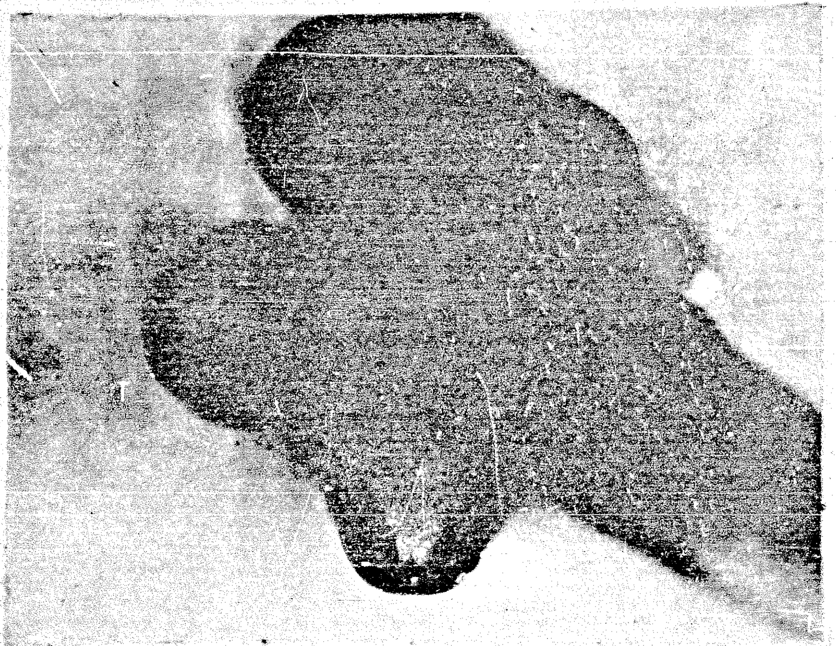
Weld Metal ⟷ Parent Metal

Typical weld junction of Arcos 5M (Special High Carbon) Electrodes and 4335 Mod. 250 X Mag. Picral Etch

Weld Metal ⟷ Parent Metal

Typical wled junction of P & H 21 electrodes and 4335 Mod. 250 X Mag. Picral Etch

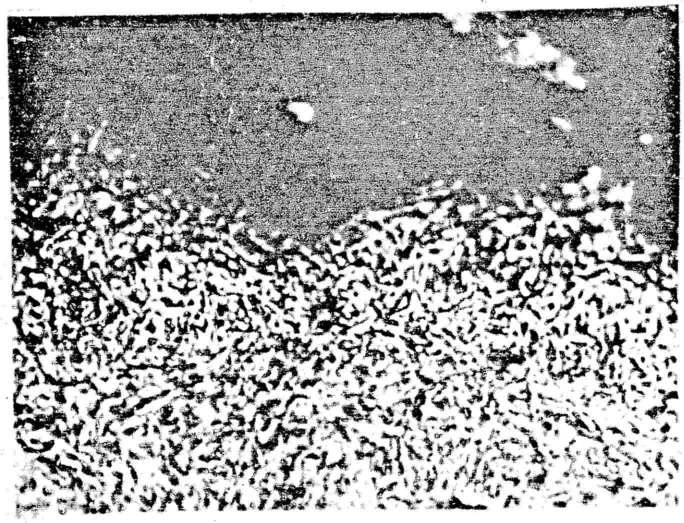
Figure 51



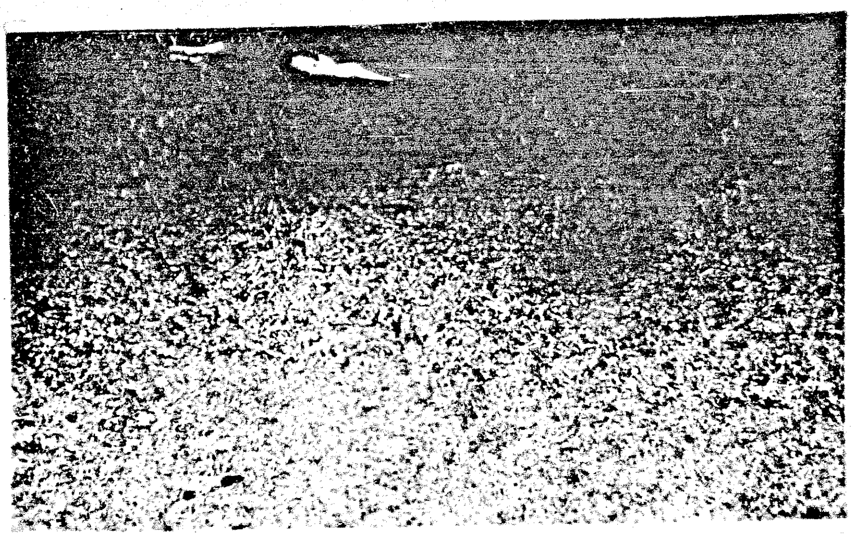
Examples of defects in fracture zone of arc welded 4335 Mod. tensile specimens. Note dark inclusions and shiny, spherical gas pockets.

Unetched 1.6X Mag.

Figure 52



Example of notch produced on surface of 4335 Mod. fatigue specimen which was machined to 250 rms finish. Picral Etch 2000X Mag.



Shot peened surface of 4335 Mod. fatigue specimen. Note compressed impressions resulting from impact of shot. Nital Etch 500X Mag.

Figure 53

CONVAIR — Fort Worth

TABULATION SHEET

Dept. 6 — FWP 1660A-5-54

TABLE I

JOMINY HARDENABILITY RESULTS

SPECIMEN LOCATION →	6" DIAMETER BAR — CENTER	SURFACE	½ RADIUS	½ RADIUS	½ RADIUS	½ RADIUS	1¼" DIAMETER BAR — No. 1	No. 2	No. 3	No. 4
AUSTENITIZING TEMP. °F →	1600	1600	1550	1600	1650	1700	1550	1600	1650	1700
DISTANCE FROM QUENCHED END IN SIXTEENTHS OF INCH										
1	53.5	56.0	56.0	55.5	55.5	54.0	54.0	56.0	55.5	54.5
2	53.5	56.0	56.0	55.0	55.0	54.0	54.0	55.0	55.0	54.5
3	53.0	55.5	55.5	54.5	55.0	54.0	54.0	55.0	54.0	54.0
4	53.0	55.0	55.0	54.5	55.0	53.5	54.0	54.0	54.0	54.0
5	53.0	55.0	55.0	54.0	55.0	53.5	54.0	54.0	54.0	54.0
6	53.0	55.0	55.0	54.0	55.0	53.5	54.0	54.0	54.0	54.0
7	53.0	55.0	54.5	54.0	55.0	53.5	54.0	54.0	54.0	54.0
8	53.0	54.5	54.5	54.0	55.0	53.5	54.0	54.0	54.0	54.0
9	52.5	54.5	54.0	54.0	55.0	53.5	54.0	54.0	54.0	54.0
10	52.5	54.5	54.0	53.0	55.0	53.5	54.0	54.0	54.0	54.0
11	52.0	54.5	53.5	53.5	54.5	53.0	54.0	54.0	54.0	54.0
12	52.0	54.0	53.0	53.5	54.5	53.0	54.0	54.0	54.0	54.0
13	51.5	54.0	52.5	53.0	54.5	53.0	53.0	54.0	54.0	54.0
14	51.5	54.0	51.0	53.0	54.0	53.0	53.0	54.0	54.0	54.0
15	51.0	54.0	50.0	53.0	54.0	52.5	53.0	54.0	54.0	54.0
16	51.0	54.0	50.0	53.0	54.5	53.0	53.0	54.0	54.0	54.0
18	51.0	54.0	49.5	53.0	54.5	52.0	53.0	54.0	54.0	53.0
20	51.0	54.0	49.0	53.5	54.5	52.0	53.0	54.0	54.0	53.0
24	47.0	54.0	48.5	52.0	54.0	52.5	53.0	54.0	53.0	52.0
32	46.0	53.0	46.0	51.5	54.0	48.5	50.0	51.0	51.0	50.0
40	42.5	50.5	45.0	48.0	52.0	46.0	47.0	48.0	48.0	48.5

NOTE: ALL SPECIMENS NORMALIZED AT 1650°F - 1 HOUR AT TEMPERATURE, BEFORE MACHINING.
ALL SPECIMENS HELD AT AUSTENITIZING TEMPERATURE ½ HOUR, BEFORE QUENCH

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TABLE II PHASE I PART A
TENSILE PROPERTIES AT VARIOUS AUSTENITIZING TEMPERATURES AND HOLDING TIMES

SPECIMEN NUMBER	AUSTENITIZING TEMP °F	TIME AT TEMP. HOURS	SPECIMEN DIAMETER INCHES	SPECIMEN AREA-SQ. INCHES	YIELD STRENGTH POUNDS	YIELD STRENGTH PSI	ULTIMATE STRENGTH POUNDS	ULTIMATE STRENGTH PSI	PERCENT ELONG.	PERCENT REDUCTION IN AREA	Y.S./U.T.S. RATIO	HARDNESS ROCKWELL "C"
1	1500	1	.496	.1932	43,500	225,200	51,000	264,000	11	40.3	.853	51.5
2		2	.496	.1932	43,800	226,700	51,600	267,100	13	45.2	.849	52.0
3		4	.497	.1940	42,700	220,100	50,500	260,300	12	43.4	.846	51.5
4	1550	1	.505	.2003	44,500	222,200	53,400	266,600	13	45.5	.833	51.5
5		2	.505	.2003	44,200	220,700	52,000	259,600	13	45.1	.850	51.0
6		4	.505	.2003	43,200	215,700	51,700	258,100	12	43.4	.836	51.0
7	1600	1	.499	.1956	43,300	221,400	51,500	263,300	13	43.8	.841	51.5
8		2	.496	.1932	41,200	213,300	49,800	257,800	12	44.9	.827	51.0
9		4	.5015	.1975	42,200	213,700	51,100	258,700	12	41.9	.826	50.5
94	1650	1	.502	.1979	42,400	214,200	52,100	263,300	12	45.6	.814	51.0
95		2	.498	.1948	41,200	211,500	49,900	256,200	12	44.0	.826	51.0
96		4	.496	.1932	40,600	210,100	49,700	257,200	12	43.7	.817	51.5

NOTE: HARDNESS READINGS - AVERAGE OF 5 READINGS PER SPECIMEN

ALL SPECIMENS OIL QUENCHED FROM AUSTENITIZING TEMPERATURE AND THEN TEMPERED AT 450°F FOR 2 HOURS.

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TABLE III PHASE I PART B
TENSILE PROPERTIES AT VARIOUS TEMPERING TEMPERATURES AND HOLDING TIMES

SPECIMEN NUMBER	TEMPERED AT °F	HOLDING TIME AT TEMP.-HRS	SPECIMEN DIAMETER INCHES	SPECIMEN AREA SQ INCHES	YIELD STRENGTH POUNDS	YIELD STRENGTH PSI	ULTIMATE STRENGTH POUNDS	ULTIMATE STRENGTH PSI	PERCENT ELONG.	PERCENT REDUCTION IN AREA	Y.S./U.T.S. RATIO	HARDNESS ROCKWELL "C"
10	400	2	.505	.2003	44,000	219,700	54,100	270,100	12.0	42.2	.813	52.0
11		4	.505	.2003	46,500	232,200	55,400	276,600	* 9.5	41.3	.839	53.5
12		8	.505	.2003	44,600	222,700	53,200	265,600	12.0	42.8	.838	51.6
13		12	.505	.2003	43,800	218,700	53,100	265,100	12.0	43.4	.825	51.3
14		16	.505	.2003	45,600	227,700	53,400	266,600	*10.0	41.0	.854	51.5
15		24	.505	.2003	46,400	231,700	54,000	269,600	*10.0	44.5	.859	51.8
16	425	2	.505	.2003	45,300	221,200	54,500	272,100	12.0	44.5	.831	51.9
17		4	.505	.2003	43,500	217,200	52,400	261,600	12.0	42.2	.830	50.7
18		8	.505	.2003	44,700	223,200	52,400	261,600	12.0	43.4	.853	51.3
19		12	.504	.1995	45,300	227,100	53,100	266,200	11.0	42.5	.853	50.5
20		16	.504	.1995	44,600	223,600	52,800	264,700	13.0	46.0	.845	49.2
21		24	.505	.2003	43,500	217,200	51,600	257,600	*10.0	44.0	.843	50.1
22	450	2	.504	.1995	43,600	218,500	52,300	262,200	11.0	44.4	.833	51.2
23		4	.5045	.1999	45,800	229,100	52,600	263,100	12.0	45.1	.871	50.0
24		8	.505	.2003	46,900	234,100	53,400	266,600	12.0	45.1	.875	51.1
25		12	.505	.2003	45,400	226,700	51,700	258,100	11.0	41.5	.878	49.5
26		16	.5055	.2007	46,500	231,700	52,600	262,100	12.0	46.0	.884	50.8
27		24	.504	.1995	45,300	227,100	51,300	257,100	11.0	42.0	.883	49.9
28	475	2	.504	.1995	48,700	244,100	54,200	271,700	11.0	40.7	.898	51.8
29		4	.505	.2003	48,600	242,600	53,600	267,[illegible]	11.0	42.8	.907	51.5
30		8	.504	.1995	47,400	237,600	52,100	261,200	10.0	40.5	.910	50.9
31		12	.505	.2003	48,800	243,600	53,200	265,600	11.0	42.2	.917	51.6
32		16	.5055	.2007	48,300	240,700	53,200	265,100	12.0	45.4	.908	51.2
33		24	.5045	.1999	48,200	241,100	52,500	262,600	12.0	45.1	.918	50.9
34	500	2	.5035	.1991	46,500	233,600	51,400	258,200	12.0	44.7	.905	50.1
35		4	.504	.1995	46,800	234,600	52,000	260,700	12.0	46.5	.900	50.4
36		8	.504	.1995	47,700	239,100	52,300	262,200	10.0	44.6	.912	50.8
37		12	.504	.1995	45,600	228,600	51,600	258,600	11.0	40.0	.884	50.1
38		16	.504	.1995	47,100	236,100	52,100	261,200	12.0	44.7	.904	50.3
39		24	.504	.1995	43,500	218,000	51,200	256,600	12.0	43.4	.850	50.5

* SPECIMENS FAILED NEAR GAGE MARKS

NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F – 1 HOUR AT TEMPERATURE, OIL QUENCHED, THEN TEMPERED AS INDICATED.
HARDNESS READINGS – AVERAGE OF 5 READINGS PER SPECIMEN

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TABLE IV PHASE I PART B SHEET 1 OF 2
NOTCH TENSILE PROPERTIES AT VARIOUS TEMPERING TEMPERATURES AND HOLDING TIMES

SPECIMEN NUMBER	TEMPERED AT °F	HOLDING TIME AT TEMP.-HRS	SPECIMEN DIAMETER INCHES	SPECIMEN NOTCH RADIUS INCHES	SPECIMEN AREA SQ. INCHES	ULTIMATE POUNDS	STRENGTH PSI	AVERAGE ULTIMATE STR. - PSI	NS/UTS RATIO	AVERAGE NS/UTS RATIO	HARDNESS ROCKWELL "C"	AVERAGE HARDNESS ROCKWELL C
10	400	2	.5061	.0020	.2012	50,000	248,500		.92		52.4	
10 A		2	.5059	.0030	.2010	48,600	241,800	245,150	.90	.91	52.8	52.6
11		4	.5062	.0035	.2012	51,400	255,500		.92		52.0	
11 A		4	.5037	.0030	.1993	50,000	250,900	253,200	.91	.915	53.0	52.5
12		8	.5047	.0035	.2001	52,300	261,400		.98		51.5	
12 A		8	.5053	.0035	.2005	50,700	252,900	257,150	.95	.965	52.2	51.85
13		12	.5046	.0040	.2000	50,000	250,000		.94		52.2	
13 A		12	.5059	.0045	.2010	53,800	267,700	258,850	1.01	.975	52.2	52.2
14		16	.5063	.0035	.2013	53,700	266,800		1.00		51.8	
14 A		16	.4995	.0035	.1960	53,200	271,400	269,100	1.02	1.01	51.4	51.6
15		24	.5037	.0045	.1993	48,800	244,900		.91		51.3	
15 A		24	.5004	.0040	.1969	52,500	266,900	255,900	.99	.95	51.1	51.15
16	425	2	.5052	.0025	.2005	51,200	255,400		.94		52.1	
16 A		2	.5043	.0035	.1997	55,000	275,400	265,400	1.01	.975	52.0	52.05
17		4	.5039	.0025	.1994	51,800	259,800		.99		51.8	
17 A		4	.5051	.0025	.2004	50,600	252,500	256,150	.97	.98	51.4	51.6
18		8	.5050	.0050	.2003	49,800	248,600		.95		52.1	
18 A		8	.5065	.0040	.2014	54,300	269,600	259,100	1.03	.99	50.9	51.5
19		12	.5032	.0040	.1989	49,800	250,400		.94		51.4	
19 A		12	.5054	.0045	.2006	54,000	269,200	261,600	1.01	.975	51.4	51.4
20		16	.5037	.0030	.1993	48,000	240,800		.91		51.4	
20 A		16	.5034	.0045	.1990	52,500	263,800	252,300	1.00	.955	51.5	51.45
21		24	.5019	.0015	.1978	51,500	260,400		1.01		51.0	
21 A		24	.5052	.0040	.2005	49,300	245,900	253,150	.95	.98	51.3	51.15
22	450	2	.5054	.0045	.2006	53,500	266,700		1.02		52.1	
22 A		2	.5060	.0023	.2011	52,400	260,600	263,650	.99	1.015	51.5	52.3
23		4	.5050	.0040	.2003	49,600	247,600		.94		51.2	
23 A		4	.5079	.0055	.2026	54,700	270,000	258,800	1.03	.985	51.7	51.45
24		8	.5058	.0025	.2009	47,200	234,900		.88		50.8	
24 A		8	.5068	.0025	.2017	46,000	228,100	231,500	.86	.87	51.0	50.9

NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F - 1 HOUR AT TEMPERATURE, OIL QUENCHED THEN TEMPERED AS INDICATED.
HARDNESS READINGS - AVERAGE OF 5 READINGS PER SPECIMEN.

TABLE IV PHASE I PART B SHEET 2 OF 2
NOTCH TENSILE PROPERTIES AT VARIOUS TEMPERING TEMPERATURES AND HOLDING TIMES

SPECIMEN NUMBER	TEMPERED AT °F	HOLDING TIME AT TEMP-HRS	SPECIMEN DIAMETER INCHES	SPECIMEN NOTCH RADIUS INCHES	SPECIMEN AREA SQ. INCHES	ULTIMATE POUNDS	STRENGTH PSI	AVERAGE ULTIMATE STR - PSI	NS/UTS RATIO	AVERAGE NS/UTS RATIO	HARDNESS ROCKWELL "C"	AVERAGE HARDNESS ROCKWELL "C"
25	450	12	.5066	.0043	.2016	50,700	251,500	253,950	.97	.98	51.2	51.1
25 A		12	.5081	.0040	.2028	52,000	256,400		.99		51.0	
26		16	.5056	.0040	.2009	50,700	252,400	246,100	.96	.935	49.9	50.45
26 A		16	.5018	.0025	.1977	47,400	239,800		.91		51.0	
27		24	.5074	.0020	.2022	44,100	218,100	240,850	.85	.94	51.4	51.25
27 A		24	.5069	.0030	.2018	53,200	263,600		1.03		51.1	
28	475	2	.5079	.0025	.2026	46,600	230,000	238650	.85	.88	51.6	51.6
28 A		2	.5049	.0040	.2002	49,500	247,300		.91		51.6	
29		4	.5088	.0055	.2033	52,900	260,200	258,250	.97	.965	51.1	51.2
29 A		4	.5131	.0040	.2068	53,000	256,300		.96		51.3	
30		8	.5027	.0030	.1985	47,400	238,800	243,100	.91	.93	51.8	51.45
30 A		8	.5042	.0035	.1997	49,400	247,400		.95		51.1	
31		12	.5032	.0035	.1989	46,300	232,800	235,250	.88	.885	51.9	51.45
31 A		12	.5028	.0042	.1986	47,200	237,700		.89		50.9	
32		16	.5050	.0025	.2003	47,800	238,400	250,900	.90	.945	51.6	51.25
32 A		16	.5080	.0050	.2027	53,400	263,400		.99		50.9	
33		24	.5075	.0025	.2023	49,300	243,700	238550	.93	.91	51.0	51.05
33 A		24	.5090	.0030	.2035	47,500	233,400		.89		51.1	
34	500	2	.5039	.0020	.1994	50,200	251,800	246,750	.98	.96	50.8	50.9
34 A		2	.5044	.0035	.1998	48,300	241,700		.94		51.0	
35		4	.5059	.0045	.2010	48,900	243,300	244,100	.93	.935	50.3	49.95
35 A		4	.5053	.0030	.2005	49,100	244,900		.94		49.6	
36		8	.5060	.0030	.2011	49,200	244,700	254,150	.93	.97	50.7	51.1
36 A		8	.5045	.0037	.1999	52,700	263,600		1.01		51.5	
37		12	.5055	.0025	.2007	47,800	238,200	250,750	.92	.97	50.3	50.25
37 A		12	.5062	.0060	.2013	53,000	263,300		1.02		50.2	
38		16	.5058	.0040	.2009	47,200	234,900	239,000	.90	.915	50.5	50.7
38 A		16	.5055	.0030	.2007	48,800	243,100		.93		50.9	
39		24	.5059	.0030	.2009	49,200	244,900	244,900	.95	.95	50.0	49.95
39 A		24	.5077	.0022	.2025	49,600	244,900		.95		49.9	

NOTE ALL SPECIMENS AUSTENITIZED AT 1525 °F - 1 HOUR AT TEMPERATURE, OIL QUENCHED, THEN TEMPERED AS INDICATED
HARDNESS READINGS - AVERAGE OF 5 READINGS PER SPECIMEN

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TABLE V PHASE I PART B
IZOD IMPACT STRENGTH AT VARIOUS TEMPERING TEMPERATURES AND HOLDING TIMES SHEET 1 OF 2

	SPECIMEN NUMBER	TEMPERED AT °F	HOLDING TIME AT TEMP. HRS	IMPACT STRENGTH FOOT-LBS	HARDNESS ROCKWELL "C"	SPECIMEN NUMBER	TEMPERED AT °F	HOLDING TIME AT TEMP. HRS	IMPACT STRENGTH FOOT-LBS	HARDNESS ROCKWELL "C"	SPECIMEN NUMBER	TEMPERED AT °F	HOLDING TIME AT TEMP. HRS	IMPACT STRENGTH FOOT-LBS	HARDNESS ROCKWELL "C"	
	10-1	400	2	16.5	52.6	18-1	425	8	17.5	51.4	26-1	450	16	14.5	51.3	
	-2		2	17.0	52.8	-2		8	15.5	51.7	-2		16	13.5	51.1	
	-3		2	17.0	52.8	-3		8	17.0	51.0	-3		16	12.5	51.0	
AVERAGE				16.8	52.7				16.6	51.4				13.5	51.1	AVERAGE
	11-1		4	17.5	51.9	19-1		12	16.5	51.1	27-1		24	13.5	50.6	
	-2		4	18.0	52.0	-2		12	14.5	51.7	-2		24	13.0	51.1	
	-3		4	16.0	52.7	-3		12	16.0	51.1	-3		24	12.5	50.8	
AVERAGE				17.1	52.2				15.6	51.3				13.0	50.8	AVERAGE
	12-1		8	15.0	52.0	20-1		16	13.5	51.7	28-1	475	2	14.5	52.0	
	-2		8	17.5	51.7	-2		16	17.5	52.0	-2		2	16.0	51.9	
	-3		8	18.5	52.1	-3		16	16.5	51.7	-3		2	17.5	51.9	
AVERAGE				17.0	51.9				15.8	51.8				16.0	51.9	AVERAGE
	13-1		12	17.5	51.5	21-1		24	17.5	51.2	29-1		4	14.5	51.9	
	-2		12	17.0	51.9	-2		24	11.5	51.1	-2		4	16.5	49.8	
	-3		12	14.0	51.7	-3		24	14.0	51.6	-3		4	15.5	51.7	
AVERAGE				16.1	51.7				14.3	51.3				15.5	51.1	AVERAGE
	14-1		16	18.0	52.3	22-1	450	2	19.0	52.4	30-1		8	13.5	51.2	
	-2		16	16.5	52.1	-2		2	19.0	51.9	-2		8	14.5	51.9	
	-3		16	16.0	52.2	-3		2	20.0	51.9	-3		8	13.5	51.2	
AVERAGE				16.8	52.2				19.3	52.1				13.8	51.4	AVERAGE
	15-1		24	14.0	51.5	23-1		4	16.5	51.3	31-1		12	11.5	51.3	
	-2		24	14.5	52.3	-2		4	15.0	51.9	-2		12	16.5	51.5	
	-3		24	15.0	51.6	-3		4	19.0	51.7	-3		12	16.0	50.9	
AVERAGE				14.5	51.8				16.8	51.6				14.6	51.6	AVERAGE
	16-1	425	2	16.5	52.2	24-1		8	16.5	51.1	32-1		16	15.0	50.5	
	-2		2	17.5	52.3	-2		8	16.0	51.1	-2		16	14.0	51.0	
	-3		2	20.0	51.9	-3		8	13.0	51.1	-3		16	11.0	51.6	
AVERAGE				18.0	52.1				15.1	51.1				13.3	51.0	AVERAGE
	17-1		4	15.0	51.5	25-1		12	13.5	51.4	33-1		24	15.5	50.8	
	-2		4	17.0	51.7	-2		12	13.5	50.9	-2		24	15.5	50.3	
	-3		4	16.0	51.6	-3		12	14.0	51.5	-3		24	14.0	51.1	
AVERAGE				16.0	51.6				13.6	51.8				15.0	50.7	AVERAGE

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TABLE V PHASE I PART B
IZOD IMPACT STRENGTH AT VARIOUS TEMPERING TEMPERATURES AND HOLDING TIMES SHEET 2 OF 2

	SPECIMEN NUMBER	TEMPERED AT °F	HOLDING TIME AT TEMP-HRS	IMPACT STRENGTH FOOT-LBS	HARDNESS ROCKWELL "C"	SPECIMEN NUMBER	TEMPERED AT °F	HOLDING TIME AT TEMP-HRS	IMPACT STRENGTH FOOT-LBS	HARDNESS ROCKWELL "C"	SPECIMEN NUMBER	TEMPERED AT °F	HOLDING TIME AT TEMP-HRS	IMPACT STRENGTH FOOT-LBS	HARDNESS ROCKWELL "C"	
	34-1	500	2	12.5	50.7	36-1	500	8	14.5	50.2	38-1	500	16	11.5	50.3	
	-2	↓	2	15.5	50.8	-2	↓	8	13.5	50.9	-2	↓	16	15.0	51.0	
	-3		2	16.0	50.7	-3		8	14.5	50.7	-3		16	14.5	50.4	
AVERAGE				14.6	50.7				14.1	50.5				13.6	50.6	AVERAGE
	35-1		4	14.0	50.5	37-1		12	14.0	50.4	39-1		24	16.5	50.0	
	-2		4	14.5	51.1	-2		12	15.0	50.2	-2		24	14.0	51.5	
	-3		4	13.5	50.6	-3		12	15.0	50.4	-3		24	13.5	50.6	
AVERAGE				14.0	50.7				15.0	50.3				14.6	50.7	AVERAGE

NOTE: ALL SPECIMENS AUSTENITIZED AT 1525°F – 1 HOUR AT TEMPERATURE, OIL QUENCHED, THEN TEMPERED AS INDICATED

HARDNESS READINGS – AVERAGE OF 5 READINGS PER SPECIMEN

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TABLE VI PHASE I PART C
TENSILE PROPERTIES AT VARIOUS QUENCH TEMPERATURES, HOLDING TIMES, COOLING CYCLES, AND TEMPERING TEMPERATURES

SPECIMEN NUMBER	QUENCH TEMP °F HELD - HRS	COOLING CYCLE °F HELD - HRS	TEMPERING CYCLE °F HELD - HRS	COOLING CYCLE °F HELD - HRS	TEMPERING CYCLE °F HELD - HRS	COOLING CYCLE °F HELD - HRS	SPECIMEN AREA SQ. INCHES	YIELD POUNDS	STRENGTH PSI	ULTIMATE POUNDS	STRENGTH PSI	PERCENT ELONGATION	PERCENT REDUCTION IN AREA	YS/UTS RATIO	HARDNESS ROCKWELL "C"
40	550-2	AIR COOL TO ROOM TEMP	NONE				.2009	40,000	199,100	48,200	239,900	14	51.3	.829	49.4
41	500-4						.2003	44,600	222,700	52,600	262,600	12	43.1	.848	51.3
42	450-2						.2005	42,800	213,500	55,100	274,800	12	42.0	.777	53.5
43	400-2						.2003	40,200	200,700	54,600	272,600	13	42.8	.736	53.8
44	350-2						.1997	34000	170,300	57,600	288400	14	37.8	.590	55.0
45	300-2						.2002	33,400	166,800	59,700	298,200	12	37.3	.559	54.7
46	250-2						.1989	35,600	179,000	58,200	292,600	12	35.3	.612	55.8
47	550-2	-120-2	550-2	AIR COOL TO ROOM TEMP			.1990	42,300	212,600	49,100	246,700	11	46.9	.862	49.1
48	500-4		500-2				.2011	44,500	221,300	52,100	259,100	13	50.0	.854	51.4
49	450-2		450-2				.2003	45,200	225,700	54,800	273,800	12	43.4	.824	52.9
50	400-2		400-2				.2014	39,900	198,100	53,800	267,100	14	41.4	.742	53.5
51	350-2		350-2				.2009	36,100	179,700	56,300	280,200	13	39.1	.641	53.7
52	300-2		300-2				.1989	36,400	183,000	56,700	285,100	12	37.2	.642	54.1
53	250-2		250-2				.1999	38,700	193,600	60,000	300,100	12	36.2	.645	56.0
54	550-2		550-2	-120-2	550-2	AIR COOL TO ROOM TEMP	.1999	41,500	207,600	48,200	241,100	11	48.6	.861	49.3
55	500-4		500-2		500-2		.1970	43,500	220,800	50,800	257,900	12	46.0	.856	50.7
56	450-2		450-2		450-2		.2011	44,600	221,800	55,300	275,000	12	42.5	.807	52.9
57	400-2		400-2		400-2		.1915	40,100	209,400	52,100	272,100	12	39.9	.770	53.1
58	350-2		350-2		350-2		.1952	36,500	187,000	55,200	282,800	12	37.6	.661	54.2
59	300-2		300-2		300-2		.2013	37,700	187,300	58,100	288,600	12	34.1	.649	54.6
60	250-2		250-2		250-2		.1993	40,200	201,700	59,700	299,950	12	36.0	.673	55.9

ALL SPECIMENS AUSTENITIZED AT 1525°F - 1 HOUR AT TEMPERATURE OIL QUENCHED, TEMPERED, COOLED, ETC. AS INDICATED
HARDNESS READINGS - AVERAGE OF 5 READINGS PER SPECIMEN.

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TABLE VII PHASE I PART C SHEET 1 OF 2

NOTCH TENSILE PROPERTIES AT VARIOUS QUENCH TEMPERATURES, HOLDING TIMES, COOLING CYCLES, AND TEMPERING TEMPERATURES

	SPECIMEN NUMBER	QUENCH TEMP °F HELD-HRS	COOLING CYCLE °F HELD-HRS	TEMPERING CYCLE °F HELD-HRS	COOLING CYCLE °F HELD-HRS	TEMPERING CYCLE °F HELD-HRS	COOLING CYCLE °F HELD-HRS	SPECIMEN NOTCH RADIUS INCHES	SPECIMEN DIAMETER INCHES	SPECIMEN AREA SQ INCHES	ULTIMATE POUNDS	STRENGTH PSI	NS/UTS RATIO	HARDNESS ROCKWELL "C"
	40	550-2	AIR COOL TO ROOM TEMP	NONE				.0025	.4819	.1823	52,800	289,600	1.21	49.0
	40A	550-2						.0040	.5074	.2022	60,200	297,700	1.24	48.1
AVERAGE												293,700	1.225	48.6
	41	500-4						.0025	.4868	.1861	51,000	274,000	1.04	51.6
	41A	500-4						.0025	.4827	.1830	48,300	263,900	1.01	50.8
AVERAGE												269,000	1.025	51.2
	42	450-2						.0015	.4966	.1937	44,700	230,800	.840	53.0
	42A	450-2						.0010	.4779	.1794	41,600	231,900	.844	52.9
AVERAGE												231,400	.842	52.95
	43	400-2						.0025	.4884	.1873	46,600	248,800	.913	52.6
	43A	400-2						.0030	.4639	.1690	44,400	262,700	.964	52.6
AVERAGE												255,800	.939	52.6
	44	350-2						.0035	.5193	.2118	48,300	228,100	.791	53.3
	44A	350-2						.0035	.4886	.1875	49,000	213,300	.740	52.9
AVERAGE												229700	.766	53.1
	45	300-2						.0025	.5060	.2011	44,200	219,800	.737	54.0
	45A	300-2						.0020	.5146	.2080	34,000	163,500	.548	54.0
AVERAGE												191,700	.643	54.0
	46	250-2						.0015	.4771	.1788	25,700	143,700	.491	54.5
	46A	250-2						.0020	.4787	.1800	36,300	201,700	.689	53.7
AVERAGE												172,700	.590	54.1
	47	550-2	-120-2	550-2	AIR COOL TO ROOM TEMP			.0040	.4870	.1863	56,200	301,700	1.220	47.2
	47A	550-2		550-2				.0010	.4736	.1762	51,300	291,100	1.18	47.0
AVERAGE												296,400	1.20	47.1
	48	500-4		500-2				.0040	.4913	.1895	55,900	295,000	1.14	50.0
	48A	500-4		500-2				.0020	.5012	.1973	54,800	277,700	1.07	50.4
AVERAGE												286,400	1.105	50.2
	49	450-2		450-2				.0025	.5057	.2009	52,600	261,800	.956	52.0
	49A	450-2		450-2				.0040	.4894	.1881	56,900	302,500	1.105	52.2
AVERAGE												282,200	1.03	52.1
	50	400-2		400-2				.0040	.4899	.1885	52,500	278,500	1.06	52.9
	50A	400-2		400-2				.0030	.4740	.1765	43,600	247,000	.944	53.0
AVERAGE												262,750	1.00	52.95

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TABLE VII PHASE I PART C SHEET 2 OF 2

NOTCH TENSILE PROPERTIES AT VARIOUS QUENCH TEMPERATURES, HOLDING TIMES, COOLING CYCLES, AND TEMPERING TEMPERATURES

	Specimen Number	Quench Temp °F Held-Hrs	Cooling Cycle °F Held-Hrs	Tempering Cycle °F Held-Hrs	Cooling Cycle °F Held-Hrs	Tempering Cycle °F Held-Hrs	Cooling Cycle °F Held-Hrs	Specimen Notch Radius Inches	Specimen Diameter Inches	Specimen Area Sq Inches	Ultimate Strength Pounds	Ultimate Strength PSI	NS/UTS Ratio	Hardness Rockwell "C"
	51	350-2	-120-2	350-2	Air cool to room temp			.0030	.4654	.1701	37,700	221,600	.791	53.0
	51A	350-2		350-2				.0040	.4847	.1845	46,900	254,200	.907	52.9
AVERAGE												237,900	.850	52.95
	52	300-2		300-2				.0030	.4705	.1739	38,000	218,500	.766	54.0
	52A	300-2		300-2				.0015	.5047	.2001	43,000	214,900	.754	53.9
AVERAGE												216,700	.760	53.95
	53	250-2		250-2				.0025	.5119	.2058	39,100	190,000	.633	54 5
	53A	250-2		250-2				.0040	.5070	.2019	42,600	211,000	.703	54.0
AVERAGE												200,500	.668	54.25
	54	550-2		550-2	-120-2	550-2	Air cool to room temp	.0035	.4648	.1697	51,500	303,500	1.26	48.0
	54A	550-2		550-2		550-2		.0035	.4830	.1832	53,800	293,700	1.22	47.5
AVERAGE												298,600	1.24	47.75
	55	500-4		500-2		500-2		.0035	.4851	.1848	56,400	305,200	1.18	50.8
	55A	500-4		500-2		500-2		.0022	.4839	.1839	51,300	279,000	1.08	51.0
AVERAGE												292,100	1.13	50.9
	56	450-2		450-2		450-2		.0035	.4738	.1763	50,100	284,200	1.03	52.0
	56A	450-2		450-2		450-2		.0030	.5046	.2000	50,800	254,000	.924	52.9
AVERAGE												269,100	.977	52.45
	57	400-2		400-2		400-2		.0035	.4905	.1890	53,000	289,400	1.03	52.5
	57A	400-2		400-2		400-2		.0045	.4816	.1822	47,100	258,500	.95	52.5
AVERAGE												269,500	.99	52.5
	58	350-2		350-2		350-2		.0040	.4921	.1902	49,200	258,700	.915	53.0
	58A	350-2		350-2		350-2		.0040	.5077	.2025	51,300	253,300	.896	53.0
AVERAGE												256,000	.906	53.0
	59	300-2		300-2		300-2		.0025	.4936	.1914	49,600	212,100	.735	54.1
	59A	300-2		300-2		300-2		.0040	.5107	.2049	48,400	236,200	.818	53.8
AVERAGE												224,200	.777	53.95
	60	250-2		250-2		250-2		.0040	.5061	.2012	47,800	237,600	.793	54.6
	60A	250-2		250-2		250-2		.0025	.5059	.2009	43,300	215,500	.720	54.6
AVERAGE												226,600	.757	54.6

ALL SPECIMENS AUSTENITIZED AT 1525°F – 1 HOUR AT TEMPERATURE, OIL QUENCHED, TEMPERED, COOLED ETC. AS INDICATED.

HARDNESS READINGS – AVERAGE OF 5 READINGS PER SPECIMEN

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TABLE VIII PHASE I PART C SHEET 1 OF 2
IZOD IMPACT STRENGTH AT VARIOUS QUENCH TEMPERATURES, HOLDING TIMES, COOLING CYCLES, AND TEMPERING TEMPERATURES

Specimen Number	Quench Temp °F Held-Hrs	Cooling Cycle °F Held-Hrs	Tempering Cycle °F Held-Hrs	Cooling Cycle °F Held-Hrs	Impact Strength Foot-Lbs	Hardness Rockwell "C"	Specimen Number	Quench Temp °F Held-Hrs	Cooling Cycle °F Held-Hrs	Tempering Cycle Held-Hrs	Cooling Cycle °F Held-Hrs	Tempering Cycle °F Held-Hrs	Cooling Cycle °F Held-Hrs	Impact Strength Foot-Lbs	Hardness Rockwell "C"
40-1	550-2	Air cool to room temp	None		19.5	50.9	48-1	500-4	-120-2	500-2	Air cool to room temp			15.0	51.0
-2	550-2	↓	↓		17.5	50.4	-2	500-4	↓	500-2	↓			16.5	51.4
-3	550-2	↓	↓		19.5	50.3	-3	500-2	↓	500-2	↓			16.5	51.7
AVERAGE		↓	↓		18.8	50.5	AVERAGE		↓		↓			16.0	51.4
41-1	500-4	↓	↓		14.5	51.5	49-1	450-2	↓	450-2	↓			15.0	51.7
-2	500-4	↓	↓		16.5	50.0	-2	450-2	↓	450-2	↓			17.5	51.7
-3	500-4	↓	↓		16.5	51.8	-3	450-2	↓	450-2	↓			17.5	52.0
AVERAGE		↓	↓		15.8	51.1	AVERAGE		↓		↓			16.7	51.8
42-1	450-2	↓	↓		17.5	51.6	50-1	400-2	↓	400-2	↓			16.5	52.0
-2	450-2	↓	↓		19.0	52.3	-2	400-2	↓	400-2	↓			18.5	52.2
-3	450-2	↓	↓		16.0	51.8	-3	400-2	↓	400-2	↓			16.5	51.3
AVERAGE		↓	↓		17.5	51.9	AVERAGE		↓		↓			17.2	51.8
43-1	400-2	↓	↓		20.5	52.1	51-1	350-2	↓	350-2	↓			18.5	52.8
-2	400-2	↓	↓		17.5	51.7	-2	350-2	↓	350-2	↓			17.5	52.9
-3	400-2	↓	↓		18.0	52.0	-3	350-2	↓	350-2	↓			16.0	53.2
AVERAGE		↓	↓		18.7	51.9	AVERAGE		↓		↓			17.3	53.0
44-1	350-2	↓	↓		18.5	52.9	52-1	300-2	↓	300-2	↓			16.5	54.4
-2	350-2	↓	↓		18.5	52.5	-2	300-2	↓	300-2	↓			18.5	54.0
-3	350-2	↓	↓		18.0	52.9	-3	300-2	↓	300-2	↓			16.0	54.9
AVERAGE		↓	↓		18.3	52.8	AVERAGE		↓		↓			17.0	54.4
45-1	300-2	↓	↓		18.5	53.3	53-1	250-2	↓	250-2	↓			17.5	54.1
-2	300-2	↓	↓		16.5	53.3	-2	250-2	↓	250-2	↓			16.5	54.0
-3	300-2	↓	↓		16.5	53.8	-3	250-2	↓	250-2	↓			15.5	54.4
AVERAGE		↓	↓		17.2	53.5	AVERAGE		↓		↓			16.5	54.2
46-1	250-2	↓	↓		15.0	54.0	54-1	550-2	↓	550-2	-120-2	550-2	Air cool to room temp	18.0	50.0
-2	250-2	↓	↓		16.0	54.2	-2	550-2	↓	550-2	↓	550-2	↓	17.5	49.3
-3	250-2	↓	↓		14.5	53.9	-3	550-2	↓	550-2	↓	550-2	↓	17.5	50.2
AVERAGE					15.2	54.0	AVERAGE		↓		↓		↓	17.7	49.8
47-1	550-2	-120-2	550-2	Air cool to room temp	18.5	50.2	55-1	500-4	↓	500-2	↓	500-2	↓	17.5	51.5
-2	550-2	↓	550-2	↓	17.0	49.2	-2	500-4	↓	500-2	↓	500-2	↓	17.5	51.5
-3	550-2	↓	550-2	↓	18.0	48.7	-3	500-4	↓	500-2	↓	500-2	↓	16.5	51.3
AVERAGE					17.8	49.4	AVERAGE							17.2	51.4

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TABLE VIII PHASE I PART C SHEET 2 OF 2

IZOD IMPACT STRENGTH AT VARIOUS QUENCH TEMPERATURES HOLDING TIMES, COOLING CYCLES, AND TEMPERING TEMPERATURES

SPECIMEN NUMBER	QUENCH TEMP °F HELD – HRS	COOLING CYCLE °F HELD – HRS	TEMPERING CYCLE °F HELD – HRS	COOLING CYCLE °F HELD – HRS	TEMPERING CYCLE °F HELD – HRS	COOLING CYCLE °F HELD – HRS	IMPACT STRENGTH FOOT-LBS	HARDNESS ROCKWELL "C"
56-1	450-2	-120-2	450-2	-120-2	450-2	AIR COOL TO ROOM TEMP	16.0	52.0
-2	450-2		450-2		450-2		14.0	52.4
-3	450-2		450-2		450-2		14.0	51.9
AVERAGE							14.7	52.1
57-1	400-2		400-2		400-2		17.0	51.8
-2	400-2		400-2		400-2		17.5	51.9
-3	400-2		400-2		400-2		20.0	52.0
AVERAGE							18.2	51.9
58-1	350-2		350-2		350-2		19.5	52.5
-2	350-2		350-2		350-2		18.0	52.7
-3	350-2		350-2		350-2		19.0	52.4
AVERAGE							18.8	52.5
59-1	300-2		300-2		300-2		17.5	54.1
-2	300-2		300-2		300-2		16.5	53.8
-3	300-2		300-2		300-2		16.5	53.9
AVERAGE							16.8	53.9
60-1	250-2		250-2		250-2		17.5	54.9
-2	250-2		250-2		250-2		15.5	55.0
-3	250-2	↓	250-2	↓	250-2	↓	16.5	54.5
AVERAGE							16.5	54.8

ALL SPECIMENS AUSTENITIZED AT 1525°F – 1 HOUR AT TEMPERATURE, OIL QUENCHED, TEMPERED COOLED, ETC. AS INDICATED

HARDNESS READINGS – AVERAGE OF 5 READINGS PER SPECIMEN.

TABLE IX PHASE I
DATA SUMMARY SHEET SHOWING THE BEST PROCESSING METHODS

TYPE OF PROCESSING TREATMENT	YIELD STRENGTH PSI	ULTIMATE TENSILE STR. PSI	YS/UTS RATIO	NS/UTS RATIO	PERCENT REDUCTION IN AREA	PERCENT ELONG-ATION	IZOD IMPACT STR. FT-LBS
1. AUSTENITIZE 1525°F, OIL QUENCH TEMPERED AT 450°F - 2 HOURS	218,500	262,200	.833	1.015	44.4	11.0	19.3
2. AUSTENITIZE 1525°F, OIL QUENCH TEMPERED AT 450°F - 4 HOURS	229,100	263,100	.871	.985	45.1	12.0	16.8
3. AUSTENITIZE 1525°F, OIL QUENCH TEMPERED AT 475°F - 2 HOURS	244,100	271,700	.898	.880	40.7	11.0	16.0
4. AUSTENITIZE 1525°F OIL QUENCH TEMPERED AT 475°F - 4 HOURS	242,600	267,600	.907	.965	42.8	11.0	15.5
5. AUSTENITIZE 1525°F OIL QUENCH TEMPERED AT 500°F - 2 HOURS	233,600	258,200	.905	.960	44.7	12.0	14.6
6. AUSTENITIZE 1525°F OIL QUENCH TEMPERED AT 500°F - 4 HOURS	234,600	260,700	.900	.935	46.3	12.0	14.0
7. AUSTENITIZE 1525°F - QUENCH 450°F COOL TO ROOM TEMPERATURE	213,500	274,800	.777	.842	42.0	12.0	17.5
8. AUSTENITIZE 1525°F QUENCH 450°F COOL TO -120°F TEMPER 450°F COOL R.T.	225,700	273,800	.824	1.030	43.4	12.0	16.7
9. AUSTENITIZE 1525°F - QUENCH 450°F COOL TO -120°F, TEMPER 450°F COOL TO -120°F, TEMPER 450°F COOL TO ROOM TEMPERATURE	221,800	275,000	.807	.977	42.5	12.0	14.7
10. AUSTENITIZE 1525°F QUENCH 500°F COOL TO ROOM TEMPERATURE	222,700	262,600	.848	1.025	43.1	12.0	15.8
11. AUSTENITIZE 1525°F QUENCH 500°F COOL TO -120°F TEMPER 500°F COOL TO R.T.	221,300	259,100	.854	1.105	50.0	13.0	16.0
12. AUSTENITIZE 1525°F QUENCH 500°F COOL TO -120°F TEMPER 500°F COOL TO -120°F TEMPER 500°F COOL TO ROOM TEMPERATURE	220,800	257,900	.856	1.130	46.0	12.0	17.2
4340 STEEL HEAT TREATED TO 260-280000 PSI (1" BAR)							
4340 STEEL AUSTENITIZED 1575°F OIL QUENCH DOUBLE TEMPER 475°F	234,450	271,700	.866	.955	27.6	6.5	13.2

CONVAIR — FORT WORTH

TABULATION SHEET

TABLE X. PHASE I QUENCH CRACK TEST DATA FOR MODIFIED SAE 4335

SPECIMEN NO.	NOTCH DIMENSIONS				CRACKED	NOT CRACKED
	INSIDE RADIUS	OUTSIDE RADIUS	INSIDE DEPTH	OUTSIDE DEPTH		
1	.003	.003	.014	.015		X
2	.003	.002	.013	.013		X
3	.003	.002	.015	.015		X
4	.002	.003	.023	.017		X
5	.003	.002	.015	.018		X
6	.004	.004	.013	.015		X
7	.004	.004	.015	.013		X
8	.004	.004	.016	.016		X
9	.004	.003	.013	.012		X
10	.003	.002	.014	.013		X
11	.001	.001	.015	.014		X

ALL SPECIMENS AUSTENIZED AT 1525°F FOR 1 HR. AND QUENCHED IN OIL AT 82°F.

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TABLE XI PHASE I. RECHECK OF IZOD IMPACT STRENGTH

Specimen No.	Temper Temp °F	Hours at Temp.	Test 1 Izod Str. Ft-lbs.	Test 1 Hardness R_c	Test 2 Izod Str.	Test 2 Hardness
22-1	450	2	19.0	52.4	18.5	52.0
-2	↓	↓	19.0	51.9	17.0	50.4
-3	↓	↓	20.0	51.9	16.5	51.5
-4	↓	↓	—	—	17.0	51.6
-5	↓	↓	—	—	16.0	51.6
Average			19.3	52.1	17.0	51.4
23-1	450	4	16.5	51.3	14.5	51.2
-2	↓	↓	15.0	51.9	15.5	51.7
-3	↓	↓	19.0	51.7	17.0	50.6
-4	↓	↓	—	—	16.0	50.3
Average			16.8	51.6	16.2	50.7
28-1	475	2	14.5	52.0	14.0	50.8
-2	↓	↓	16.0	51.9	16.5	51.8
-3	↓	↓	17.5	51.9	15.5	51.0
-4	↓	↓	—	—	17.0	51.2
Average			16.0	51.9	15.6	51.1
29-1	475	4	14.5	51.9	14.5	50.9
-2	↓	↓	16.5	49.8	14.0	51.8
-3	↓	↓	15.5	51.7	16.0	50.7
-4	↓	↓	—	—	15.0	49.8
Average			15.5	51.1	14.1	50.8

TEST 1 CONDUCTED BY S. D. TANNENBAUM
TEST 2 CONDUCTED BY J. S. FURMAN

ALL SPECIMENS BAKED 4 HRS. @ 375°F AFTER GRINDING

CONVAIR—FORT WORTH

TABULATION SHEET

TABLE XII LONGITUDINAL & TRANSVERSE TENSILE DATA FOR MODIFIED 4335

Spec No.	Type	Initial Diameter	Area	Yield Lbs.	Ultimate Lbs.	Yield Stress PSI	Ultimate Stress PSI	Elastic Modulus PSI x 10⁶	Elongation %	Final Diameter	Area Reduction %	Hardness Rc	Hardness BHN
62 -1	Longitudinal	.5043	.1997	45,150	52,900	225,839	264,897	28.332	11.0	.383	42.4	50.3	495
-2		.5030	.1987	45,550	52,400	229,240	263,740	28.758	11.0	.382	42.5	50.9	503
-3		.4995	.1960	45,190	52,400	230,608	267,402	29.053	11.0	.375	43.7	51.0	506
-4		.5053	.2005	45,100	52,400	224,938	261,347	30.072	10.3	.385	42.0	50.1	477
-5		.5044	.1998	46,000	53,000	230,230	265,265	29.613	10.5	.380	43.2	50.6	495
-6		.5046	.2000	45,000	52,200	225,000	261,000	29.310	10.0	.387	41.4	50.5	492
-7		.5038	.1993	46,000	53,200	230,808	267,934	31.842	10.0	.380	43.1	51.4	515
Avg.						228,075	264,512	29.569	10.5		42.6	50.7	4976
63 -1	Transverse	.5036	.1992	43,650	50,500	219,127	253,514	29.266	4.0	.480	9.1	50.4	491
-2		.5066	.2016	43,800	50,600	217,262	250,992	31.445	2.3	.494	4.9	50.1	480
-3		.5062	.2012	44,000	51,000	218,688	253,479	33.005	3.8	.488	7.1	50.1	486
-4		.5062	.2012	45,600	51,000	226,640	253,479	Results Invalid	5.0*	.486	7.8	50.6	503
-5		.5038	.1993	44,000	50,600	220,773	253,889	30.039	5.0*	.482	8.4	50.0	477
-6		.5033	.1989	44,200	50,200	222,222	252,388	Results Invalid	3.0	.487	6.3	50.3	490
Avg.						220,785	252,957	30.936	3.9		7.3	50.3	488.3

* Approximate

CONVAIR—FORT WORTH

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TABLE XIII COMPRESSION PROPERTIES FOR MODIFIED 4335

SPEC. No.	DIA.	AREA SQ. INCH	YIELD LBS.	YIELD PSI	MODULUS PSI X 10^6	HARDNESS R_c
64-1	.7990	.5014	114800	228959	32.323	51.0
-2	7989	.5013	111700	222821	31.408	50.4
-3	.7989	.5013	114000	227409	32.189	50.5
-4	.7990	.5014	115500	230355	31.816	50.1
-5	.7989	.5013	113500	226411	31.282	50.4
AVG.				227191	31.804	50.5

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TABLE XIV DOUBLE SHEAR DATA FOR MODIFIED 4335 PINS

SPEC. NO.	TYPE PIN	PIN DIAMETER	HOLE DIAMETER	TOTAL AREA	DIAMETER-THICKNESS RATIO	ULTIMATE SHEAR LBS.	SHEAR STRESS PSI	HARDNESS R_c
66 -1	HOLLOW	.9985	.313	1.4122	3	225,800	159,892	50.6
-2	"	.9983	.312	1.4125	3	226,500	160,354	50.3
AVG.							160,123	50.5
-4	HOLLOW	.9988	.6000	1.0010	5	147,800	147,652	50.3
-5	"	.9989	.6001	1.0012	5	149,200	149,021	50.9
AVG.							148,337	50.6
-7	HOLLOW	.9987	.7139	.7689	7	107,800	140,200	50.5
-8	"	.9989	.7132	.7680	7	108,100	140,755	51.0
AVG.							140,478	50.8
-10	HOLLOW	.9987	.7770	.6180	9	84,600	136,893	51.0
-11	"	.9987	.7771	.6180	9	81,800	132,362	50.3
AVG.							134,627	50.7
-13	HOLLOW	.9989	.8161	.5212	11	67,200	128,933	49.0
-14	"	.9988	.8167	.5193	11	67,700	130,368	50.1
-15	"	.9989	.8165	.5201	11	68,200	131,129	50.0
AVG.							130,143	49.7
65 -1	SOLID	.9984	———	1.5658	1	260,500	166,369	50.8
-2	"	.9980	———	1.5656	1	258,000	164,793	50.9
-4	"	.9986	———	1.5656	1	260,500	166,390	50.9
-5	"	.9975	———	1.5622	1	259,000	165,792	51.1
AVG.							165,836	50.9

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TABLE XIV BEARING DATA FOR MODIFIED 4335

Spec. No.		Hole Diameter	Thickness	Area	Edge-Distance Ratio	Ultimate Bearing LBS.	Bearing Stress PSI	Hardness Rc	Remarks
67	-1A	1.0007	.2485	.2487	1.0	53,200	213,912	50.6	
	-2A	1.0002	.2485	.2485	↓	52,800	212,475	50.3	
	-3A	1.0003	.2487	.2488	↓	52,600	211,415	50.1	
	Avg.						212,601	50.3	
	-1B	1.0003	.2492	.2493	1.5	88,100	353,389	50.2	
	-2B	1.0004	.2491	.2492	↓	85,200	———	50.4	Bearing Failure in Smaller Hole
	-3B	1.0004	.2490	.2491	↓	88,600	355,680	50.6	
	-4B	1.0003	.2493	.2493	↓	87,400	350,582	50.7	
	Avg.						353,217	50.5	
	-1C	.9994	.2487	.2486	2.0	92,100	370,475	50.4	Results Invalid - Spec. Improperly Finished
	-2C	.9986	.2479	.2476	↓	105,200	424,879	50.3	
	-3C	.9992	.2482	.2480	↓	111,200	448,387	50.4	
	-4C	.9992	.2478	.2476	↓	120,500	486,672	50.4	No Failure - Test Machine Maximum Capacity
	-5C	.9995	.2491	.2490	↓	119,100	478,313	50.3	
	Avg.						459,563	50.4	

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Table XVI Sustained Load Data of Modified 4335

Spec. No.	Condition	Thickness	Side Width	Opp. Side Width	Hardness R_c	Estimated Ultimate	Test - % Ultimate	Total Area	Load Lbs.	Hrs. to Failure	Remarks
68 -1	Bare	.4015	.2492	.2491	50.1	262,500	80	.2000	42,000	1440	No Failure
-2		.4013	.2492	.2497	50.2	263,000	80	.2002	42,100	1440	" "
69 -1		.4010	.2495	.2502	50.3	263,500	70	.2004	37,000	1440	" "
-2		.4012	.2499	.2497	49.8	261,000	70	.2005	36,600	1440	" "
70 -1		.4016	.2495	.2500	50.2	263,000	90	.2006	47,500	1440	" "
-2		.4014	.2483	.2512	50.5	265,000	90	.2005	47,800	1440	" "
71 -1	Cd Plate	.4010	.2495	.2470	50.4	264,000	80	.1991	42,000	86.4	Failed in Smaller Hole
-2		.4015	.2491	.2490	50.0	262,000	80	.2000	41,900	110.4	Failed in Smaller Hole
72 -1		.4009	.2495	.2472	50.6	265,500	70	.1991	37,000	49.1	" " " "
-2		.4012	.2482	.2473	50.6	265,500	70	.1988	36,900	7.6	" " " "
73 -1		.4010	.2499	.2492	50.2	263,000	60	.2001	31,600	1440	No Failure
-2		.4015	.2494	.2490	49.9	261,500	60	.2001	31,400	1440	" "
74 -1		.4012	.2490	.2496	51.0	267,500	90	.2001	48,200	469	Correct Failure
-2		.4010	.2491	.2494	50.4	264,000	90	.1999	47,500	6.2	Failed in Smaller Hole
75 -1	Shot Peen	.4014	.2479	.2501	50.3	263,500	80	.1999	42,100	1440	No Failure
-2	Cr Plate	.4016	.2490	.2491	50.5	265,000	80	.2000	42,400	1440	" "
76 -1	Bake	.4013	.2489	.2497	50.5	265,000	90	.2001	47,700	1440	" "
-2	*	.4016	.2489	.2492	50.2	263,000	80	.2001	41,700	1440	" "
77 -1		.4010	.2490	.2502	50.7	266,000	70	.2001	37300	1440	" "
-2	*	.4010	.2489	.2494	50.3	263,500	90	.1998	47,400	633.6	Failed in Smaller Hole
78 -1		.4012	.2502	.2499	50.7	266,000	90	.2007	48,000	1440	No Failure
-2		.4010	.2501	.2498	50.5	265,000	70	.2004	37,200	1440	" "
79 -1	Cr Plate	.4009	.2505	.2493	50.2	263,000	70	.2004	36,900	1440	No Failure
-2	Bake	.4012	.2500	.2497	50.8	266,500	70	.2005	37,400	1440	No Failure

*Specimens Mistakenly Cadmium Plated

CONVAIR — FORT WORTH

TABULATION SHEET TABLE XVII LONGITUDINAL TENSILE DATA FOR CONVAIR ARC WELDED MODIFIED 4335

SPEC. NO.	TYPE WELD	DIAMETER	AREA	YIELD LBS.	ULTIMATE LBS.	YIELD STRESS PSI	ULTIMATE STRESS PSI	ELONGATION %	FINAL DIA.	AREA REDUCTION %	ELASTIC MODULUS PSI X 10⁶	HARDNESS - R_c PARENT METAL	HEAT AFFECTED ZONE	WELD AREA	
80-1	B	.5004	.1967	35400	39650	179,969	201,576	7.5	.402	35.6	29.505	50.5	50.0	41.3	W
-2	↓	.5051	.2004	37,300	40,750	186,123	203,343	9.0	.397	38.1	29.252	51.0	50.0	41.1	W
-8	↓	.5024	.1982	34,800	39,200	175,580	197,780	3.0*	.486	6.4	32.716	50.7	50.0	42.5	WJ
-9	↓	.5035	.1991	35,750	40,000	179,558	200,904	3.5*	.484	8.2	28.538	51.2	49.7	42.7	W
-10	↓	.5045	.1999	37,750	41,350	188,844	206,853	6.0	.472	12.7	30.372	50.6	50.3	41.6	WJ
AVG.						182,016	202,091	5.8		28.8‡	30.077	50.8	50.0	41.8	
80-3	F	.5031	.1988	36300	39,750	182,596	199,950	4.0*	.445	21.8	29.552	50.8	49.8	41.9	WJ
-4	↓	.5000	.1964	37000	41,100	188,391	209,267	5.0*	.468	12.4	27.495	50.4	49.8	41.4	WJ
-5	↓	.5055	.2007	37,350	41,650	186,087	207,524	5.0*	.462	16.7	28.650	50.4	49.7	40.6	W
-6	↓	.5043	.1997	36,900	41,200	184,777	206,309	3.0*	.469	13.5	29.509	50.2	50.0	40.8	W
-7	↓	.5064	.2014	38,750	41,550	192,403	206,306	5.0	.473	12.8	26.340	50.6	49.0	41.6	WJ
AVG.						186,851	205,871	4.4		15.4	28.309	50.5	49.7	41.3	

* WELD POROSITY IN FRACTURE

B - ARCOS 5M ELECTRODES, 25 VOLTS, 125 AMPS, ELECTRO POSITIVE

F - P & H 21 ELECTRODES, 25 VOLTS, 125 AMPS, ELECTRO POSITIVE

‡ - AVE. DOES NOT INCLUDE LOW READINGS RESULTING FROM POROSITY FAILURES

W - WELD FAILURE

WJ - WELD JUNCTION FAILURE

CONVAIR — FORT WORTH

TABULATION SHEET TABLE XVIII LONGITUDINAL TENSILE DATA FOR MENASCO FLASH WELDED 4335 M.

Spec. No.	Outer Diameter	Inner Diameter	Area	Yield LBS.	Ultimate LBS.	Yield Stress PSI	Ultimate Stress PSI	Elongation %	Final Area	Area Reduction %	Elastic Modulus PSI×10⁶	Hardness Rc Parent Metal	Hardness Rc Heat Affected Zone *
81 -1	1.4990	1.2995	.4385	None	89,400	None	203,877	None	.435	0.8	28.9	49.5	48.0
-2	1.4981	↓	.4379	↓	94,100	↓	214,889	↓	.430	1.8	33.4	50.5	48.0
-3	1.4996	↓	.4397	↓	86,400	↓	196,498	↓	.432	1.8	30.6	50.5	49.5
-4	1.4975	↓	.4346	↓	91,000	↓	209,388	↓	.431	2.0	30.0	49.5	48.5
-5	1.4978	↓	.4354	↓	82,050	↓	188,447	↓	.433	0.6	Results Invalid	49.3	45.0
-6	1.5019	↓	.4451	↓	90,500	↓	203,325	↓	.434	2.5	32.4	49.5	48.5
-7	1.4989	↓	.4380	↓	95,100	↓	217,123	↓	.433	1.1	34.4	50.1	48.0
Avg.							204,792			1.5	31.6	49.8	47.9

* Rockwell "C" Numbers Converted From Knoop Measurements

TABLE XIX FATIGUE DATA OF MODIFIED 4335 – ROTATING BEAM TEST – UNNOTCHED

SPECIMEN No.	SURFACE CONDITION	DIAMETER INCHES	FACTOR	STRESS PSI x 10^3	LOAD LBS.	CYCLES x 10^3 TO FAILURE	HARDNESS R_c
87-2	MACHINE TO 100 RMS	.2013	.4034	160	54.5	22	49.3
-4	CD PLATE, BAKE @ 375°F.	.1952	.3650	220	70.3	2	49.8
-5	↓	.2027	.4088	120	39.1	2,079	49.5
-6	↓	.1960	.3696	120	34.4	2,539	50.0
-7	↓	.2021	.4052	160	54.8	33	49.4
-8	↓	.1972	.3765	140	42.7	32	49.0
-9	↓	.2018	.4034	140	46.5	50	50.0
-10	↓	.1960	.3696	115	32.5	10,320→	48.6
90-1	MACHINE TO 40 RMS,	.2010	.3986	120	37.8	60*	50.7
-2	SHOT PEEN, CD PLATE,	.1960	.3696	120	34.4	32*	50.9
-3	GRIND TO .002" PLATE -	.2017	.4028	160	54.4	28	51.0
-4	16 RMS, BAKE @ 375°F.	.1996	.3904	160	52.5	84	51.2
-5	↓	.1997	.3910	120	36.9	10165→	50.6
-6	↓	.2003	.3945	130	41.3	5025	51.0
-7	↓	.1999	.3922	140	44.9	84	51.4
-8	↓	.2026	.4082	140	47.1	505	48.9
-9	↓	.1994	.3892	140	44.5	162	50.7
-10	↓	.2010	.3986	130	41.8	3699	51.1
	* RESULTS INVALID – PLATING INADVERTENTLY REMOVED DURING GRINDING						
84-1	MACHINE TO 100 RMS	.2019	.4040	220	78.9	2	51.1
-2	SHOT PEEN	.1971	.3759	160	50.1	90	51.2
-3	↓	.1964	.3719	160	49.5	73	50.6
-4	↓	.2015	.4016	120	38.2	10,032→	50.6
-5	↓	.1978	.3799	120	35.6	10,615→	49.0
-6	↓	.1976	.3787	140	43.0	718	49.5
-7	↓	.1973	.3770	140	42.8	294	50.5
-8	↓	.1982	.3822	130	39.7	3529	51.2
-9	↓	.1990	.3868	130	40.3	3,083	50.4
-10	↓	.1960	.3696	125	36.2	5,968	50.7

→ TEST DISCONTINUED

TABLE XIX FATIGUE DATA CON'T.

Specimen No.	Surface Condition	Diameter Inches	Factor	Stress PSI × 10^3	Load LBS.	Cycles × 10^3 To Failure	Hardness R_c
91 -1	Grind to 16 RMS,	.2024	.4070	220	79.9	2	48.4
-2	Bake @ 375°F.	.2022	.4058	220	79.3	2	49.3
-3	↓	.2010	.3986	160	53.8	23	48.3
-4	↓	.2005	.3957	160	53.3	34	48.0
-5	↓	.2023	.4064	120	38.8	560	49.0
-7	↓	.2024	.4070	120	38.8	2,017	50.6
-8	↓	.2023	.4064	140	46.9	99	49.1
-9	↓	.2024	.4070	140	47.0	67	49.0
-10	↓	.2024	.4070	115	36.8	10,014 →	49.8
92 -1	Machine to 40 RMS,	.2011	.3992	80	21.9	66	47.0
-2	Cr Plate, Grind to	.2009	.3980	120	37.8	17	51.1
-3	.002" Plate - 16 RMS,	.2022	.4118	120	39.4	31	49.9
-4	Bake @ 375°F.	.1982	.3822	160	51.2	6	48.9
-5	↓	.2016	.4025	160	54.4	15	50.4
-6	↓	.2025	.4076	220	79.7	2	50.1
93 -3	Finished Per AIA-	.2014	.4002	160	54.0	50	49.1
-4	ARTC-W76,	.2001	.3933	160	52.9	52	49.5
-5	(Longitudinally	.2013	.3998	220	78.0	2	48.6
-6	Polished)	.2009	.3980	140	45.7	105	50.0
-7	↓	.1997	.3909	140	44.7	63	48.9
-8	↓	.1993	.3886	115	34.7	11,573 →	50.6
-9	↓	.1985	.3839	120	36.1	5,630	50.1

→ Test Discontinued

TABLE XIX FATIGUE DATA CON'T.

SPECIMEN No.	SURFACE	CONDITION	DIAMETER INCHES	FACTOR	STRESS PSI $\times 10^3$	LOAD LBS.	CYCLES $\times 10^3$ TO FAILURE	HARDNESS R_c
94 - 1	MACHINE	TO 250 RMS	.2003	.3945	220	76.8	2.5	48.2
-2			.1984	.3833	160	51.3	25	49.0
-3			.1990	.3868	160	51.9	20	49.0
-4			.2017	.4028	120	38.3	9,132	49.1
-5			.1987	.3851	120	36.2	216	48.5
-6			.2016	.4022	120	38.3	448	49.5
-7			.2014	.4002	140	46.0	163	51.3
-8			.2032	.4118	115	37.4	160	50.9
-9			.1988	.3856	140	44.0	41	51.0
-10			.2022	.4058	115	36.7	10,025 →	51.0

→ TEST DISCONTINUED

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TABLE XX BAR STOCK SIZES USED FOR TEST SPECIMENS

TYPE SPECIMEN	ROD SIZE	HEAT NO.
TENSILE — LONG.	3/4"	75680
TENSILE — TRANS.	6"	75679
NOTCH TENSILE	3/4"	75680
IZOD IMPACT	3/4"	"
COMPRESSION	1 1/4"	"
SOLID & HOLLOW SHEAR	1 1/4"	"
BEARING	6"	75679
SUSTAINED LOAD	6"	"
MENASCO FLASH WELD	2 3/4"	75680
MENASCO UNIWELD	6"	75679
FATIGUE — AXIAL	3/4"	75680
FATIGUE — R.R. MOORE	3/4"	"

MILL CHEMICAL ANALYSIS

HEAT NO.	%C	%Mn	%Si	%Cr	%Ni	%Mo	%V	%S	%P	SUPPLIER
75679	.35	.75	.27	.76	1.77	.42	.12	.018	.016	EARL JORGENSEN CO.
75680	.35	.72	.30	.76	1.82	.43	.14	.010	.012	" " "

TABLE XXI

COMPARISON OF MECHANICAL PROPERTIES OF SAE 4335 MODIFIED & SAE 4340

HEAT TREATED TO 260,000 - 280,000 PSI

PROPERTY-LONGITUDINAL	4335 Mod.	4340 * Lockheed)	4340 ** (Convair)
Ult. tensile stress, psi	265,000	260,000	271,700
Yield tensile stress, psi	228,000	208,000	234,400
Yield/Ult. ratio	.86	.80	.86
Compression yield, psi	227,000	208,000	
Elongation, percent	10.5		6.5
Reduction of area percent	42.6		27.6
Ult. Shear stress, psi	166,000	152,000	
Ult. bearing stress, e/d = 1.5	353,000	366,000	
Ult. bearing stress, e/d = 2.0	460,000	462,000	
Notch/Ult. tensile stress R = .003	.88-1.02		.96
Rm. Temp. Izod Str., ft-lb.	16 - 17		13.2
Fatigue str. at 160 ksi	2.8×10^4 cycles		2.8×10^4 cycles
R. R. Moore at 140 ksi	8.3×10^4		6.8×10^4
at 120 ksi	1.3×10^6		5.5×10^5
at 110 ksi	Below endurance limit		4.5×10^7

* Melcon, M. A., "Ultra High Strength Steel for Aircraft Structures", Product Engineering, October 1953, page 129.

** Batteiger, J. C. and Clark, J. M., "Convair, Ft. Worth Report No. MR 52-8, November 1954.