A
STUDY OF THE EFFECTS
OF
REPEATED TENSION IMPACT LOADS
UPON CERTAIN METALS USED
IN
AIRCRAFT CONSTRUCTION

Thesis

by

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SUMMARY

The repeated tension impact properties of a manganese bronze, used in aircraft landing gear fittings, are presented in this report.

The repeated tension impact test apparatus was adapted to take specimens in the form of sheet as well as specimens of the conventional bar type. With the modified apparatus, data on Alcoa 24 S-T and Dowmetal J-1H sheet specimens of varying thicknesses were obtained in order to present the aircraft designer with information directly applicable to the sheet materials currently in use.

An investigation was made of the effect of service operation on the repeated tension impact properties of three 25 S-T propeller blades. For this purpose, propeller blades were used with approximately 5, 314, and 788 hours of service operation.

A new machine, specifically designed for repeated tension impact testing, was placed in commission. With this machine, repeated tension impact test data on 24 S-T bar stock were extended to higher velocity ranges in an effort to determine the effect of velocity of impact.

INTRODUCTION

Impact testing has been carried out for many years. Until recently, these tests were of the single blow type and were recorded as the energy required to break the impact specimen in a single blow.

This method of testing did not necessarily set up a criterion of the impact properties of the material tested. In the usual case, a notch of specific dimensions was cut into the specimen, and the specimen was broken by a single blow at this notch. Such a test was more a measure of how susceptible the material was to rupture at a notch than it was a measure of the impact properties of the material.

Many different types of machines and shapes and sizes of specimens have been used in obtaining impact data. The result is that the data obtained are always a function of the particular type of test and in general are not comparable. There is a great need for the field of impact testing to be restricted to a few definite types of tests with standardized equipment. However, at this point, there is no established test or group of tests that is generally recognized as producing superior results for all applications.

In an effort to aid in finding a test criterion for impact properties, the California Institute of Technology began a series of investigations on repeated tension impact testing in 1938, of which this present work is the third of the series.

It is thought that this particular form of test offers valuable data to the designer because the test approximates fairly closely one type of impact that is being constantly experienced by any assembled structure, such as an airplane. During the course of its useful service life, the airplane is subjected to many different types of repeated stresses, and the ability to resist fatigue failure is an extremely important factor under routine service operation.

The repeated tension impact test combines an impact test in the form of a fatigue test. The results are evaluated as an "Impact Endurance Limit". If sufficient data of this kind could be obtained on a machine of a type generally recognized as a standard, it is felt that really valuable impact information, which is capable of numerical comparison, would become available to the designer for the first time.

In the repeated tension impact testing at this institution, three different types of machines have been used, no one of which is considered as being ideal for the purpose. However, each machine has incorporated certain advantages over those used previously.

In an appendix, the authors describe the difficulties and errors involved in the operation of the two types of machines used in this thesis and recommend modifications that should improve the range of their utility and their general accuracy. Confining the description of difficulties and precautions in the use of the two machines to an appendix will tend to simplify the discussion throughout the thesis. Also, many of the points of operating difficulty, which are only of interest to someone intending to continue the investigation, are kept out of the main report.

HISTORY OF REPEATED TENSION IMPACT TESTING

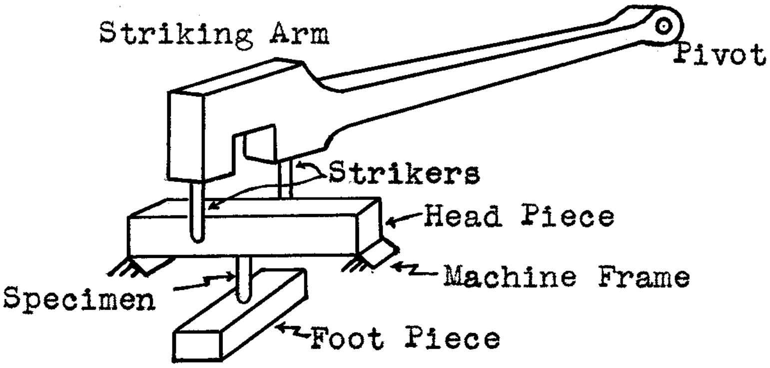
The first investigation of repeated tension impact properties was begun at the California Institute of Technology in 1938 as a research project assigned to Lieutenants G. F. Beardsley and L. D. Coates of the U. S. Navy (see reference a). This first investigation employed a Tinius-Olsen Izod impact testing machine. The machine was modified so that the pendulum struck a tup, screwed on the end of the specimen, producing a tension impact. The specimen, which had two threaded ends, had one end screwed into a heavy block known as the dynamometer. The other end was screwed into the tup. The tension impact was accomplished by the pendulum bob, which was split into two parts so as to allow it to pass across the length of the dynamometer and its specimen, striking the tup. This was repeated until the specimen finally broke. By carrying out this procedure at various energies per blow, a curve of energy per blow versus the number of blows to break was obtained.

Beardsley and Coates set up a criterion of impact properties which they called the, "Impact Endurance Limit", this they defined as the energy per blow in tensile impact loading below which the specimen will withstand an infinitely large number of blows without rupture. They determined this value for 24 S-T, 14 S-T, Dowmetal X, and Dowmetal Z-1, with and across the grain.

In the course of their work, Beardsley and Coates designed a falling carriage type of machine to be used for repeated tension impact testing. This machine has an advantage over pendulum types in that the striking velocity and striking energy can be made independent variables by controlling both height of drop and mass of attached blocks.

While this machine was being built, another pair of investigators at the California Institute of Technology, Lieutenant W. E. Gentner, U. S. Navy and Lieutenant J. O. Biglow, U. S. Navy, extended the investigation of repeated tension impact properties of aircraft materials to include: 17 S-T, 25 S-T, and Dowmetals J-1HT, X-1HT, and Z-1HT (see reference b).

This work was accomplished with a Matsumura Type Impact Endurance Testing Machine. The machine was modified by Gentner and Biglow so that it would impart a tension impact to the specimen as indicated schematically.



This machine was driven by a motor and had the advantage over the original pendulum type equipment, used by Coates and Beardsley, that it did not require continuous resetting and release of the pendulum by hand.

The present investigation makes use of both the Matsumura type machine, as modified by Gentner and Biglow, and the falling carriage type, as designed by Beardsley and Coates and slightly modified by the present authors. The Matsumura machine is shown in Figure I and the Falling Carriage machine in Figure II.

TESTING PROCEDURE

The Matsumura machine, shown in Figure I, delivers blows at the rate of 72 per minute and at energies which may be varied from 1.5 to 13.0 foot pounds. The variation in energy is accomplished by adding weights to or removing them from the striking arm or by adjusting the angle at which the arm is tripped. In conducting a series of tests on a given material, it is usually possible to obtain a sufficient energy range merely by adjusting the angle at which the striking arm trips, keeping the weights on the arm a constant. It has not been found practicable to use this machine at a constant tripping angle (i.e. constant velocity of impact) and to obtain a variation in the energy merely by adding weights to or subtracting weights from the striking arm.

In carrying out a test, the specimen (see Figure IX) is assembled tightly in the holders as shown in Figure III. The assembled specimen holders are then placed in the machine, as shown in Figure I. The strikers are then adjusted so that they hit the foot piece simultaneously, and the angle made by the arm when in the striking position is measured. The machine is then operated by hand to bring the striking arm to its tripping position and this angle is also measured. The difference between the two angles and the counter reading are recorded. The machine is started by plugging the motor into a three phase circuit; it is allowed to run until the specimen breaks. The counter is then read for the second time, and the difference between the two counter readings is recorded as the number of blows required to break the specimen.

A modified sheet specimen holder and a sheet specimen were designed by the authors for use with this machine in order to make the tension impact test directly applicable to aircraft materials in the form in which they are principally used, that is as sheet. This modification is shown in Figure IV, and the form of the specimen is shown in Figure X. The specimen is held in place by forcing the knurled surfaces of the specimen holders (see Figures VI and VIII) into the specimen. This is accomplished by setting the assembly bolts up tightly and by using a vice to squeeze the assembled parts together.

The test with the sheet specimen is carried out in the same manner as with the bar specimen.

The second machine used in this investigation is called, "The Falling Carriage Machine". It is shown in Figure II. It consists of a falling carriage which is guided by two vertical rails. Between the rails at the end of the run, there is a heavy block or anvil with a vertical hole bored directly below the center of the falling carriage. The specimen, which is shown in Figure IX, is screwed into the base of the carriage; on the other end of the specimen is screwed a weight of any desired amount. When the carriage is released, it drops and strikes the anvil; however, the specimen and its attached weight pass into the vertical opening in the anvil.

The weight on the end of the specimen, being suddenly brought to rest, exerts a tensile force on the specimen. By controlling the mass of the attached weights and the height of drop, the striking velocity and striking energy can be made independent variables.

At the present time, this machine has not been adapted to take sheet specimens, but this could be accomplished with a few modifications.

The machine requires a velocity of fall calibration before it can be used. A typical calibration is shown in Figure XII. This calibration was obtained by using a high speed camera. In general, it is not necessary to calibrate more often than once for each series of tests unless there has been work done on the machine, the machine has become dirty, has been reoiled, or there has been a marked change in temperature. A series of calibrations taken at one week intervals revealed no variation in the calibration.

As originally designed, this machine provided no means for stopping the carriage from bouncing upon hitting the anvil and from delivering a second blow. In a fall of sixty inches, the carriage was observed to bounce nine inches. This second blow represented considerable additional energy which was not being accounted for. To eliminate this bounce energy, the authors added two devices, Figure XI, which operate to catch the carriage and prevent its bouncing. These devices fit beside the top of the anvil block but are not shown in place in Figure II. When the falling carriage hits the toe of the arrester, the top of the arrester hooks over a portion of the falling carriage, checking it.

The carriage of this machine is lifted automatically by a vertical chain which carries several "pick-up" devices. These pick-up devices trip and drop the carriage at any desired height merely by setting two pick-up device operating guides in the proper place. The chain drive is operated by an electric motor which drives the chain through a reduction gear.

When running a test with this machine, the procedure is as follows:

(1) Select a velocity for the test.
(2) Enter calibration curve and select height at which to set pick-up device operating guides.
(3) Mount specimen in the machine with an appropriate weight.
(4) Record counter reading, height of drop and mass of weight.
(5) Start machine and allow to continue running until specimen breaks.
(6) Record counter reading.

The machine is fitted with an automatic cut-off which operates when the specimen breaks.

In testing with this machine, half the weight of the specimen should be added to the weight of the suspended mass.

DISCUSSION

Before proceeding with the testing program, it was decided to check data previously obtained on the Matsumura machine by Gentner and Biglow, reference (b). This check was made in order to develop operating technique and to see if consistent results were obtainable.

Figure XIII shows a plot of "E", the foot pounds energy per blow, versus "N", the number of blows to fracture, for 24 S-T bar stock. It is to be noted that the data obtained by the present investigators gives an impact endurance limit seven percent lower than that obtained previously. There are two explanations for this discrepancy: first, the properties of 24 S-T bar stock are not always consistent from lot to lot; second, the previous investigators used a lighter head and foot piece to hold the specimens. This difference was unintentional but resulted from the original head and foot being misplaced during a one year period when the machine was not in use.

This difference between the head and foot pieces can be seen by closely examining Figure I, which was taken from reference (b). The head and foot, shown assembled in place in Figure I, will be seen to differ from the head and foot used by the present investigators as shown in Figure III. It is thought that the heavier head and foot piece serve to provide a less elastic impact. This results in transferring more of the energy of impact to the specimen.

It is to be noted that the curves obtained by the present investigators have a much sharper break than those previously obtained. This effect may also be a result of a less elastic impact.

To carry the check with previous tests further, 17 S-T and 25 S-T specimens were used. The impact endurance limits obtained were found to be lower than the previous tests, and in each case the curves broke more sharply.

Before leaving Figure XIII, it should be explained that N/E vs N curves are derived from the E vs N curves so as to obtain a simple means of estimating the impact endurance limit. It can be seen that these curves plot very nearly as straight lines. This fact is taken advantage of in obtaining the impact endurance limit which is simply the inverse slope of these straight lines.

In order to obtain uniformity in plotting and results, the authors have consistently placed any point on the E vs N curves over 450 blows in the space between 450 and 460. In most cases this point was obtained at numbers of blows slightly in excess of 500 and lower than 600. This procedure is consistently followed in order to have a convenient scale for plotting and still be able to include data that is significant to the curve assumed.

The inability to check previous data, even though only a slight change was made in the testing machine, forcibly reveals the need for standardizing impact testing equipment to definite specifications. It was decided, however, to continue the investigation with the heavier head and foot piece since the data obtained proved to be consistent and roughly proportional to the data previously obtained.

The remainder of the discussion will be divided into the following subheads:

(a) Repeated Tension Impact Testing of 24 S-T and J-1H Sheet.
(b) Repeated Tension Impact Testing of Manganese Bronze Castings.
(c) Repeated Tension Impact Testing of Three 25 S-T Propeller Blades.
(d) Effect of Velocity of Impact on Impact Endurance Limit.
(e) Correlation of Impact Endurance Limit with Other Physical Properties of Materials.
(f) Conclusions.

(a) Repeated Tension Impact Testing of 24 S-T and J-1H Sheet:

The results of repeated tension impact tests of Alcoa 24 S-T and Dowmetal J-1H sheet specimens are presented in Figures XIV to XX. 24 S-T sheet is one of the standard coverings used, in this country, for skin stressed surfaces of modern aircraft. Recently, Dowmetal J-1H has received consideration as a skin stressed covering. If found acceptable and reliable, its low weight, permitting its use in thicker sections, would make it extremely desirable in aircraft. This Dowmetal is a modification of the alloy J-1, and it is also known by the American Society for Testing

Materials symbol, "A.S.T.M. 8x". It is essentially a magnesium alloy containing six percent aluminum, small amounts of manganese, zinc and silicon and less than 0.01 percent iron and nickel. The extremely low iron and nickel content makes it superior among magnesium alloys as regards corrosion resistance.

A summary of the data obtained is presented in the form of a table, page 27, and Figures XXI and XXII.

Figure XXI, a plot of impact endurance limit against sheet thickness for the four cases of 24 S-T and J-1H, with and across the grain, is obviously based on too few sheet thicknesses to draw any definite conclusions. It does, however, show the relative values obtained at a glance, and it does indicate that the thicker sheets are more efficient in impact than the thinner ones. In other words, doubling the sheet thickness more than doubles the impact endurance value in the ordinary range of thicknesses used in the aircraft industry. Above one-eighth inch in thickness, it appears that the impact endurance limit has a linear variation with thickness.

Before going further in this discussion, it should be pointed out that the 0.124 inch thickness of 24 S-T is Alclad. No weight is given to this fact in the analysis although its impact endurance limit value would have undoubtedly been higher if it had been available for test in the straight 24 S-T condition.

In order to compare 24 S-T and J-1H as to impact properties on a weight basis, the impact endurance limit has been divided by the weight of the respective cross sections and the values again plotted against sheet thickness. This effect is shown in Figure XXII. Here again, there are too few sheet thicknesses to indicate conclusive results and the need for more work along this line is indicated.

For purposes of this figure, weight of cross section is defined as the area of the cross section in square inches multiplied by a unit length and by the weight of a cubic inch of the material concerned. For 24 S-T, the weight of a cubic inch of material is taken as 0.10 pound and for J-1H, the value is 0.065 pound.

On a weight basis, it appears that the Dowmetal is better than 24 S-T in a certain range of thicknesses, but it is finally superseded by 24 S-T as the thickness becomes greater. The assumption, that the 24 S-T value exceeds the magnesium at a thickness of 0.180 inch, was indicated by the fact that it was possible to obtain one point on the 0.180 inch 24 S-T cross grain curve and by the fact that the 0.180 inch 24 S-T sheet with the grain was completely beyond the impact range of the testing machine. Accordingly, the 24 S-T curves have been extrapolated, as shown dotted, in Figure XXII.

It is regretted that availability of sheet sizes and time for investigation made obtaining the impact endurance limit values for other sheet sizes impracticable. These results should be checked and extended to determine definitely if the effect indicated by Figure XXII is a true one. Assuming the curves to be correct, 24 S-T is superior on a weight basis to J-1H in thicknesses of the order of 3/16 inch. On the other hand, in thicknesses of the order of 1/10 inch, J-1H is superior.

Many of the magnesium alloys have been regarded as extremely notch sensitive. Being aware of this difficulty with magnesium alloys, precautions were taken to avoid scratches in the test sections, and in no instance where wild points were obtained, was premature failure definitely attributable to a notch or scratch.

J-1H, possessing a hexagonal lattice in common with magnesium alloys, shows markedly superior impact properties cross grain. As can be seen from Figures XVII to XX, this effect is consistent. It should also be noted that the with grain curves break more sharply than the cross grain, indicating that very few slight overloads of J-1H, with the grain in impact, will probably result in failure.

The cross grain superiority of J-1H is duplicated by the with grain superiority of 24 S-T which possesses the usual cubical lattice. In general, as indicated in Figures XIV to XX, the difference between the with and cross grain curves of 24 S-T is not as great as that of the J-1H sheet.

The type test specimen used is shown in Figure X while pictures of various broken specimens are shown in Figure VI. The dimensions of the test specimen were dictated by the space limitations of the testing machine. As can be seen from

Figure I, the Matsumura machine can take a specimen holder set of only one general kind and its dimensions must be kept within narrow limits.

In designing the holders for the sheet specimens, the idea of using knurled surfaces, to hold the ends of the specimen, was the most successful. As can be seen in Figure VI, these knurled surfaces bite deeply into the ends of the specimen and secure it rigidly.

It should also be noted that the exposed length cannot be made over 1 to 1 1/4 inches long without seriously interfering with the impact range of the machine. Another consideration, that operates in the design of the specimen, is the fact that a thin sheet offers little resistance to bending across the plane of the sheet and is, therefore, liable to violent vibration during impact. To avoid this vibration, it was necessary to make the width of the test section reasonably wide. The sum total of these deliberations plus considerable experimenting revealed that the specimen selected, Figure X, offered the most stability during impact, also, the greatest freedom from breaks in the fillet and from pulling out of the holders. Admittedly, the design of this specimen is very poor from the standpoint of obtaining the other physical properties of the material, a convenience very much to be desired.

The great majority of the fractures obtained in this testing were of the shear failure type. In many instances, the very nearly 45° break was sharp and clean as shown in

Figure VI.

(b) Repeated Tension Impact Testing of Manganese Bronze Castings:

The manganese bronze castings used in these tests conform to Federal specification QQ-B-726a and have a chemical analysis approximately as follows:

Copper - 56.91%
Tin - 0.17%
Lead - 0.15%
Zinc - 40.39%
Iron - 1.03%
Manganese - 0.42%
Aluminum - 0.93%

This bronze is extremely ductile and has been used in certain airplane landing gear fittings.

The results obtained, plotted in comparison with 24 S-T bar stock, are shown in Figure XXIII. As plotted, the impact endurance limit of the 24 S-T appears to be 8% higher than that of the bronze. This apparent advantage of the 24 S-T over the bronze is not quite true for the reason that the bronze elongated 1/4 inch more than the 24 S-T in a test length of one inch. The elongations of the two alloys are shown in the tensile tests, Figure XXVII.

The extreme elongation of the bronze permitted the Matsumura testing machine to make impacts of greater and greater energy as the test progressed. Since the elongation of the bronze exceeds that of the 24 S-T about 100%, this effect must be taken into account. A computation of the amount of the added energy produced by the extra 1/4 inch of elongation shows that about one foot pound of energy is unaccounted for.

Referring to the table, page 27, it can be seen that an additional foot pound added to the impact endurance limit of bronze will give it a value of 9.61 which exceeds the value of 24 S-T, listed as 9.32 foot pounds.

On a weight basis, the 24 S-T has a marked superiority over the manganese bronze. Dividing the impact endurance limit of each by the weight of a cubic inch of the materials concerned reveals that 24 S-T is to manganese bronze as 93.2 to 32.8.

The fact, that the bronze impact endurance limit properties are better than those of the 24 S-T, was again brought out in subsequent tests using the falling carriage machine. In these tests, the energy imparted was not a function of the elongation of the specimen. A discussion of the tests made using the falling carriage machine is made in part (d) of this discussion.

The type of fracture obtained is shown in Figure V. The break is a typical shear type. Note the evidence of cold working during elongation.

(c) Repeated Tension Impact Testing of Three 25 S-T Propeller Blades:

In order to check impact tests made on two 25 S-T propeller blades by Gentner and Biglow, reference (b), three damaged 25 S-T propeller blades were obtained from the U. S. Naval Air Station, San Diego, California. These blades had 5.5, 313.7, and 788.4 hours of operating time respectively. Specimens were cut from areas of the blades where little damage had occurred, and each specimen was so cut that its long dimension paralleled the length of the propeller blade.

The tests were made using the Matsumura machine, and the results are shown in Figure XXIV. The 313.7 and 788.4 hour propellers plotted identical curves which gave impact endurance limits 14% lower than the 5.5 hour propeller. These results seem reasonable and would indicate that the impact properties of 25 S-T gradually reduce with operating time until they reach a constant value. It is also indicated that this effect takes place somewhere between 5 and 313 hours. Such conclusions are based on too few tests, but the possibility of such an effect, which is worthy of further investigation, is indicated.

Any extension of this investigation should be made with propellers whose operating histories are comparable; that is, propellers that have been flown on one type plane with one type engine. For this purpose, airline propellers would probably be of greater value than ones obtained from the Navy. It is not known from what types of plane-engine combinations the propellers used in this investigation were taken.

An extensive impact testing program was carried out by the National Advisory Committee for Aeronautics in 1939 using the Charpy method and Luerssen-Greene torsion impact method. This report, reference (f), indicated that no effect was obtained regardless of the method and amount of fatigue stressing.

It should be pointed out that the results obtained by the N.A.C.A. are in no wise contrary to the results obtained in this present investigation. Many investigators, reference (c), have stated that the Charpy test, which involves measuring the energy required to break a specimen at a notch, is merely a measure of notch sensitivity. Notch sensitivity may be thought of as a function of crystal orientation, grain size and the basic molecular structure rather than as a function of fatigue stresses.

The torsion impact test is a satisfactory impact test of the single blow type. For certain applications, it is probably the best type of impact test that can be used. However, results obtained by this method have no known correlation with results obtained by the repeated tension impact method.

All the specimens had a shear type fracture of elliptical cross section. This was probably caused by the unequal directional strength induced by forging.

(d) Effect of Velocity of Impact on Impact Endurance Limit:

The tests to determine the effect of velocity of impact on the impact properties of a material were made using the falling carriage machine. Tests were run on 24 S-T bar stock at speeds of 6, 9, and 12 feet per second. The results are shown in Figure XXV. Of these curves, the authors feel that only the six feet per second curve is reliable. At this speed, the machine gave consistent results that were capable of duplication. At the higher speeds, the specimen was noted to bend in the middle of the test length, indicating an unbalance in the suspended weights or an uneven impact of the falling carriage on the anvil. Since bending occurred regardless of the weights used, it was concluded that the falling carriage was hitting the anvil in an uneven manner. On several occasions at 12 feet per second, this effect became so large that the suspended weight failed to pass through the hole in the anvil.

The results, as plotted in Figure XXV, indicate that the impact endurance limit is lowered by an increase in velocity. This represents the best guess after eliminating those tests in which the specimens were badly bent. More reliable results can undoubtedly be obtained with this machine if certain modifications in its design are carried out. These are discussed in an appendix.

The work of H. C. Mann, on the effect of velocity on impact, references (d), (e) and (g), indicates that he found velocity to have no effect at ordinary temperatures until velocities considerably in excess of 12 feet per second are reached. He reports that the critical velocity for different materials and alloys varies widely. This critical velocity is, however, for all materials tested by Mann, above the velocities attained in these tests.

The impact endurance limit obtained at 6 feet per second with the falling carriage machine was only 3.22 foot pounds.

This represents about 35% of the value obtained with the Matsumura machine. This large difference is explained by the difference in the elastic properties of the impacts of the two machines. In the case of the falling carriage machine, the carriage hits the heavy anvil solidly and without bounce. The bounce is eliminated by special arresters, Figure XI, previously described. In the case of the Matsumura machine, whose entire weight is probably less than the anvil of the falling carriage machine, the pendulum hits a small tup on the end of the specimen and then bounces clear. It is evident that the character of the impact in the two cases is very different and that it is much more nearly inelastic in the case of the falling carriage machine.

The six feet per second speed, being the maximum speed at which satisfactory data was obtainable, it was decided to run the manganese bronze castings at that speed in order to check the large drop in impact endurance limit with another material. The results of this test are combined with curves for 24 S-T at 6 feet per second in Figure XXVI. The bronze can be seen to exceed the 24 S-T as would have been expected from the previous comparison using the Matsumura machine. Here again, the less elastic impact has resulted in an impact endurance limit far below that previously obtained.

A study of the fractures obtained using the falling carriage machine at the higher speeds indicates a possible additional explanation of the excessive scatter in the data obtained. At high energies, where only a few blows to break were involved, the usual tension type of cup and cone fracture was obtained. At an intermediate energy range, the specimen would start to neck in the middle of the test length and then break in the fillet. At still a lower energy level, which involved a great number of blows, all breaks were obtained in the fillet. These varying types of breaks were not obtained at the six feet per second velocity nor were they obtained when using the Matsumura type machine.

(e) Correlation of Impact Endurance Limit with Other Physical Properties of Materials:

The physical properties of the materials used in this investigation have been determined by test and tabulated on page 27. In addition, typical handbook values have been listed on page 28. In each case the corresponding impact endurance limit has been included for ready comparison. These values of impact endurance limit, listed with the handbook physical properties, are based on the standard bar specimen. In the case of Alclad 24 S-T and J-1H, the listed values are best estimates since actual tests with these materials were made only with the sheet type specimen. The best estimates are based on a linear area relationship using the average of with grain and cross grain sheet impact endurance limit values.

Unfortunately, no well defined correlation of impact endurance limit with the other physical properties is apparent. 24 S-T, Alclad 24 S-T, and 25 S-T correlate fairly well, and it is probable that most of the series of wrought aluminum alloys will have impact endurance limits that vary approximately as their

PHYSICAL PROPERTIES DETERMINED BY TEST

MATERIAL	ULTIMATE	YIELD	ELONGATION	BRINELL	I.E.L.
.039 24ST Sheet WG	66,000	44,000	23%	104	1.60
.039 24ST Sheet CG	65,200	44,000	21%	104	1.50
.081 24ST Sheet WG	71,400	44,000	20%	109	4.48
.081 24ST Sheet CG	70,500	44,000	20%	109	3.84
.124 24ST*Sheet WG	66,600	45,000	19%	-	7.97
.124 24ST*Sheet CG	66,500	45,000	18%	-	7.30
				ROCKWELL	
.063 J-1H Sheet WG	43,600	33,000	9%	72.5 E	1.39
.063 J-1H Sheet CG	46,400	35,000	12%	72.5 E	1.63
.107 J-1H Sheet WG	46,800	35,000	8%	78.0 E	4.32
.107 J-1H Sheet CG	49,400	37,000	12%	78.0 E	4.87
.128 J-1H Sheet WG	47,500	36,000	6%	74.0 E	4.62
.128 J-1H Sheet CG	49,500	37,000	10%	74.0 E	5.98
.180 J-1H Sheet WG	44,500	37,000	4%	76.0 E	6.86
.180 J-1H Sheet CG	47,800	39,000	9%	76.0 E	8.15
.375 25ST Bar 5	57,000	35,000	19%	63.0 B	6.11
.375 25ST Bar 314	55,300	35,000	19%	63.0 B	5.26
.375 25ST Bar 788	56,100	35,000	19%	63.0 B	5.26
.375 24ST Bar M	70,000	50,000	19%	79.0 B	9.32
.375 24ST Bar FC	70,000	50,000	19%	79.0 B	3.22
.375 Mn. Bronze M	63,000	-	45%	71.0 B	8.61 9.61#
.375 Mn. Bronze FC	63,000	-	45%	71.0 B	3.70

* Alclad
\# Corrected for Elongation

WG - With Grain
CG - Cross Grain

M - Matsumura Machine
FC - Falling Carriage Machine

QUOTED PHYSICAL PROPERTIES					
	24 S-T	ALCLAD	25 S-T	J-1H	MN. BRONZE
Ultimate	68,000	62,000	57,000	45,000	65,000
Yield	45,000	41,000	35,000	35,000	30,000
Shear	41,000	40,000	35,000	21,000	41,000
Fatigue	18,000	-	15,000	17,000	-
Elongation	22%	20%	18%	8%	45%
Hardness	105 Br.	-	100 Br.	68 E	-
I.E.L.	9.32	9.15*	6.11	6.45*	9.61

* Best estimate.

ultimate, yield, and shear values. This conclusion is partially borne out by references (a) and (b) in which 14 S-T was the only exception. However, when a correlation including the bronze and the Dowmetal is attempted, the results are obviously inconsistent.

The conclusion is that impact endurance limit values cannot be correlated with the physical properties of materials of different crystalline arrangement and properties of elongation.

(f) Conclusions:

The following effects are listed as the conclusions indicated by this limited investigation:

(1) Manganese bronze castings have better impact properties than 24 S-T on a volume basis, but on a weight basis 24 S-T is almost three times better than manganese bronze.

(2) There is an optimum sheet thickness for 24 S-T and J-1H at which maximum impact endurance limit on a weight basis is obtained.

(3) On a weight basis, 24 S-T and J-1H have impact endurance limit values that are practically the same.

(4) Impact properties of 25 S-T propeller blades are lowered during the first few hundred hours of operation to a value which thereafter remains constant.

(5) With the Matsumura type testing machine, numerical impact endurance limit values for different materials are not directly comparable unless the elongations are approximately the same.

(6) Actual numerical values of impact endurance limit obtained from repeated tension impact testing machines of different types will be proportional to the elastic properties of the different machines.

(7) There is no evidence to indicate that impact endurance limit values are directly comparable to other physical properties.

TABLE OF REFERENCES

(a) Beardsley, G.F. and Coates, L.D.: A Study of Effect of Repeated Tension Impact Loads upon Certain Metals used in Aircraft Construction. Thesis for Degree of Master of Science in Aeronautical Engineering at California Institute of Technology, 1939.

(b) Gentner, W.E. and Biglow, J.O.: A Study of Effect of Repeated Tension Impact Loads upon Certain Metals used in Aircraft Construction. Thesis for Degree of Master of Science in Aeronautical Engineering at California Institute of Technology, 1940.

(c) Proceedings A.S.T.M., Vol. 38, Part II, 1938: Symposium on Impact Testing.

(d) Mann, H.C.: A Fundamental Study of the Design of Impact Test Specimens. Proceedings A.S.T.M., Vol. 37, Part II, 1937.

(e) Mann, H.C.: High Velocity Tension Impact Tests. Proceedings A.S.T.M., Vol. 36, Part II, 1936.

(f) Kies, J.A. and Quick, C.W.: Effect of Service Stresses on Impact Resistance. N.A.C.A. Technical Report No. 659, 1939.

(g) Mann, H.C.: Relation Between Tension Static and Dynamic Tests. Proceedings A.S.T.M., Vol. 35, Part II, 1935.

APPENDIX

This appendix is an enumeration of the difficulties encountered in using the two types of impact machines and offers suggestions for improving them in future designs.

(a) Matsumura Machine:

In operating this machine, great care must be exercised to see that the device, for preventing the hammer from chattering on the specimen tup after its main blow, is operating properly. Improper adjustment of this device will permit the hammer to deliver several partial blows in addition to the main blow before coming fully to rest, or it will result in the hammer being caught before delivery of the main blow. This latter condition is not easily recognized by either eye or ear until after some experience with the equipment. However, the chattering condition is easily recognized.

A careful inspection of this machine will reveal that the pivot point for the pendulum catcher is attached to the cement supporting block independently of the main frame. Accordingly, the main frame must be bolted in such relation to this pivot point that the catcher can function properly. During a long period of operation, the main frame securing bolts tend to work loose and to permit the main frame to move relative to the catcher pivot point. Keeping the main frame securely bolted to the cement supporting block in the proper place is essential to consistent test results.

It is recommended that a routine check of the machine be made before each day's operations. This check should include a thorough oiling of all working parts and tightening of all bolts.

Before entering on an extensive testing program, this machine should be given an overhaul. At the present time, it would be desirable to replace the pendulum catcher shaft and set screws and the pendulum bearings.

This machine has several advantages in operation which make it superior to the falling carriage machine. These are:

(1) Testing may be carried out in an expeditious manner. The machine delivers 72 blows per minute and little time is required to service the machine between tests.

(2) Calibration is simple and permanent.

(3) The pendulum is prevented from chattering on the specimen tup by a simple and efficient means.

(4) This machine does not require a great number of weights in order to vary the energy per blow.

The disadvantages of this machine are:

(1) The energy delivered per blow is a function of the elongation of the material. Therefore, results obtained for different materials are not directly comparable unless their elongations are approximately the same.

(2) The energy range is limited between 1.5 and 13 foot pounds.

(3) It is not practical to make velocity of impact and energy of impact independent variables.

If a similar machine, incorporating the same principles, were to be manufactured, the following points are suggested:

(1) Increase the energy range by increasing the length of the pendulum arm. It would be desirable to have a maximum energy capacity of 25 to 30 foot pounds.

(2) Provide a calibrated pendulum throw device that is easily and quickly adjusted. The calibration should be in degrees of elevation at the tripping point.

(3) Provide a variable speed drive calibrated in blows per second.

(b) The Falling Carriage Machine:

This machine is in process of development and was used for test purposes for the first time by the authors.

As previously stated, this machine operated satisfactorily at speeds up to six feet per second but failed to deliver results that are considered entirely reliable above that speed. This failure, above six feet per second, is thought to result from the carriage falling unevenly in the plane of its guides. The carriage, hitting the anvil in an uneven manner, applies a couple in the plane of the guides to the specimen. Under this couple, the specimen usually bends to the left as seen by an observer facing the machine.

This problem is difficult to solve with the present system since the falling carriage must have ample clearances on the guides to permit a free fall. In addition, accurate mass balancing of the carriage, its specimen and attached weight appears to be impractical.

It is also possible that the carriage arresters are introducing stresses into the specimen of a variable nature. As previously explained, the carriage hits the toe of this catcher and rotates it to a position over a portion of the carriage. The surface of contact between the arrester and the carriage is padded with leather to reduce arresting stresses. In order that the arrester may move into position to catch the carriage a small amount of clearance between these two surfaces must be provided. Consequently, the stress cycle imposed on the specimen must be something like the following:

(1) A tension impact.

(2) A compression impact as the carriage bounces about 1/16 inch to come into contact with the arrester.

(3) A second tension impact when the carriage is thrown against the anvil for a second time.

In addition to the above there may be some sort of vibratory stresses applied to the specimen.

When the arresters are in proper adjustment, the carriage appears to hit the anvil with an absolutely dead beat blow. The fact that a good energy transfer is accomplished is evidenced by the fact that impact endurance limit values obtained with this machine are about one-third of those obtained with the Matsumura machine.

As a piece of test equipment, criticized from the operating view point, this machine has the following advantages:

(1) Velocity of impact and energy of impact are independent variables.

(2) Impact properties obtained are not a function of the elongation of the material.

(3) For practical purposes, the energy range is unlimited.

(4) This machine is easy to reset, reload, and operate.

From the operating view point, its disadvantages are:

(1) This machine operates at a rate of about 2½ blows per minute. This means it will take over three hours to complete a single test of 500 blows. These figures are based on the machine being equipped with three pick-up devices. Faster operation of the chain drive cannot be permitted because of the danger of applying a slight tension impact load to the specimen as the carriage is picked up.

(2) To properly vary the energy per blow, an excessive number of weights ranging from 1/4 to 25 pounds are required.

(3) The machine requires a velocity of fall calibration. This calibration requires considerable time to complete but experience to date reveals that one calibration will suffice for any given testing program.

(4) This machine makes an excessive amount of noise.

(5) With the present design of carriage, the bolts holding the bearing brasses shear after a few hours of operation at velocities as high as 12 feet per second. This introduces considerable inconvenience and will require redesign

of the carriage.

This machine will require considerable development in order to make a thoroughly reliable piece of test equipment. The following are the best ideas of the authors on possible modifications:

(1) In order to permit faster operation, attach the specimen to the anvil. This will allow faster pick up of the carriage without imposing loads on the specimen.

(2) Accomplish impact by strikers on the carriage which hit a tup on the end of the specimen. This will be an arrangement very similar to that used on the Matsumura machine.

(3) Arrange the strikers in a plane perpendicular to the plane of the guides so that the effect of the uneven blow in bending the specimen will be eliminated.

(4) Vary the energy of the blow by carrying different amounts of weight on the carriage. This will eliminate the need for so many individual weights in that weight combinations can be used.

These suggestions for improving the falling carriage machine include no method of arresting the carriage after it delivers its main blow to the specimen. To date, no simple method of accomplishing this has suggested itself.

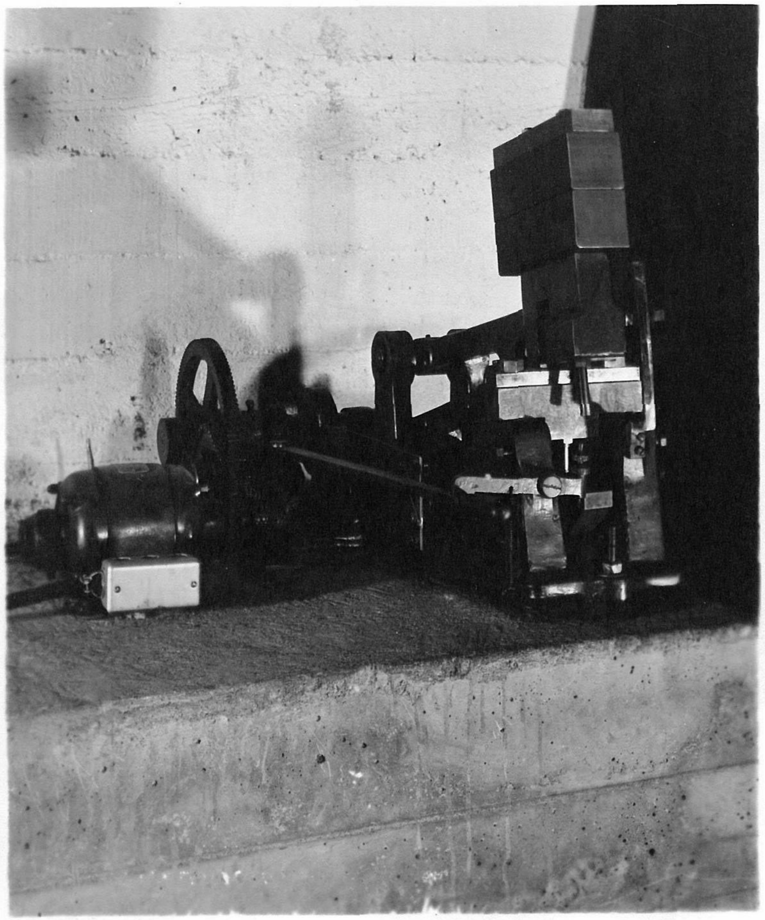


Figure I - Matsumura Machine

Figure II - Falling Carriage Machine

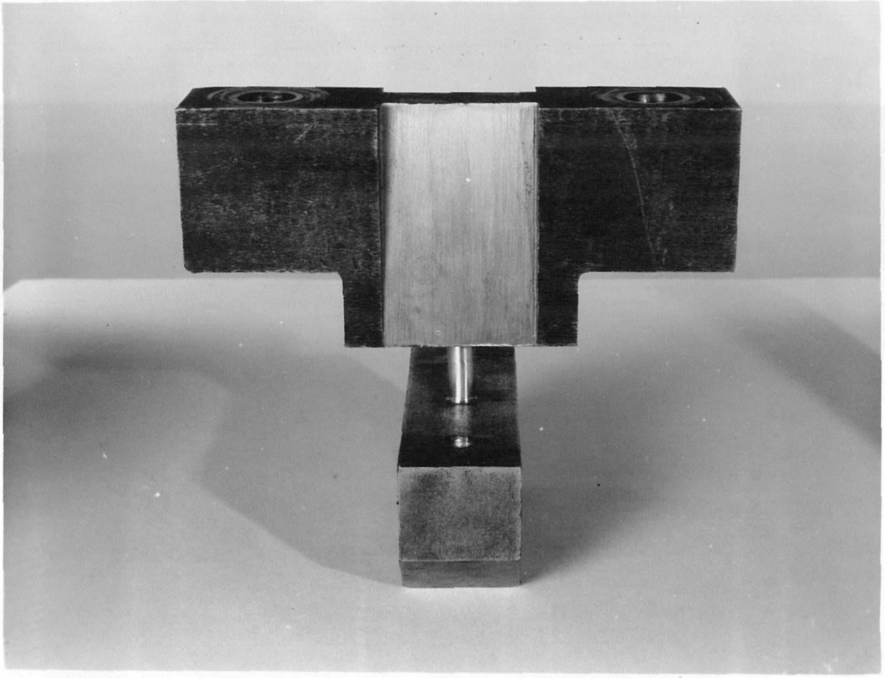


Figure III - Bar Specimen Holders.

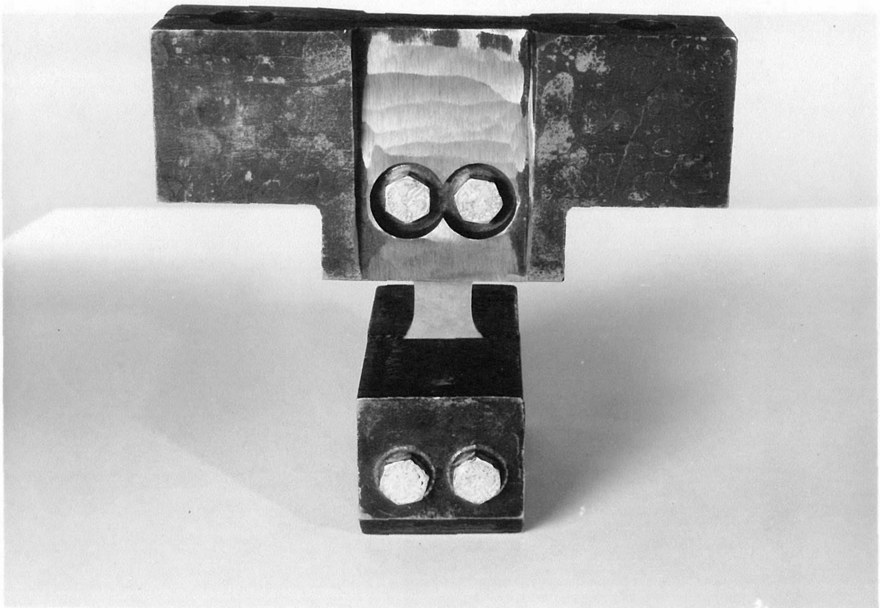
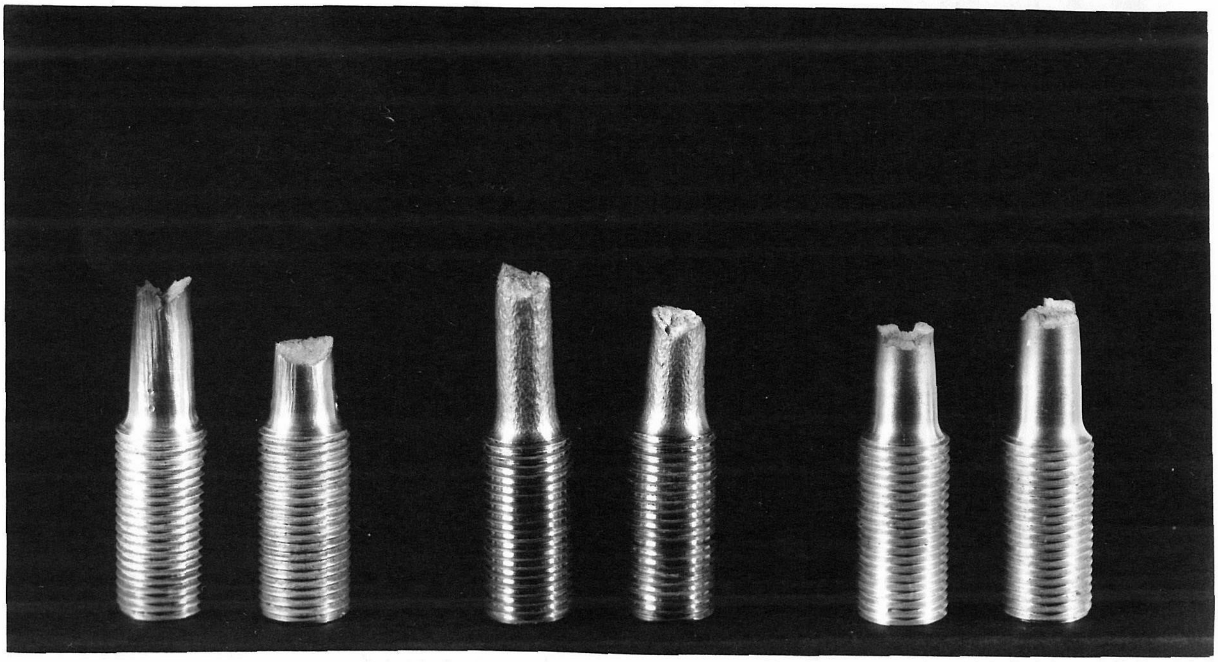
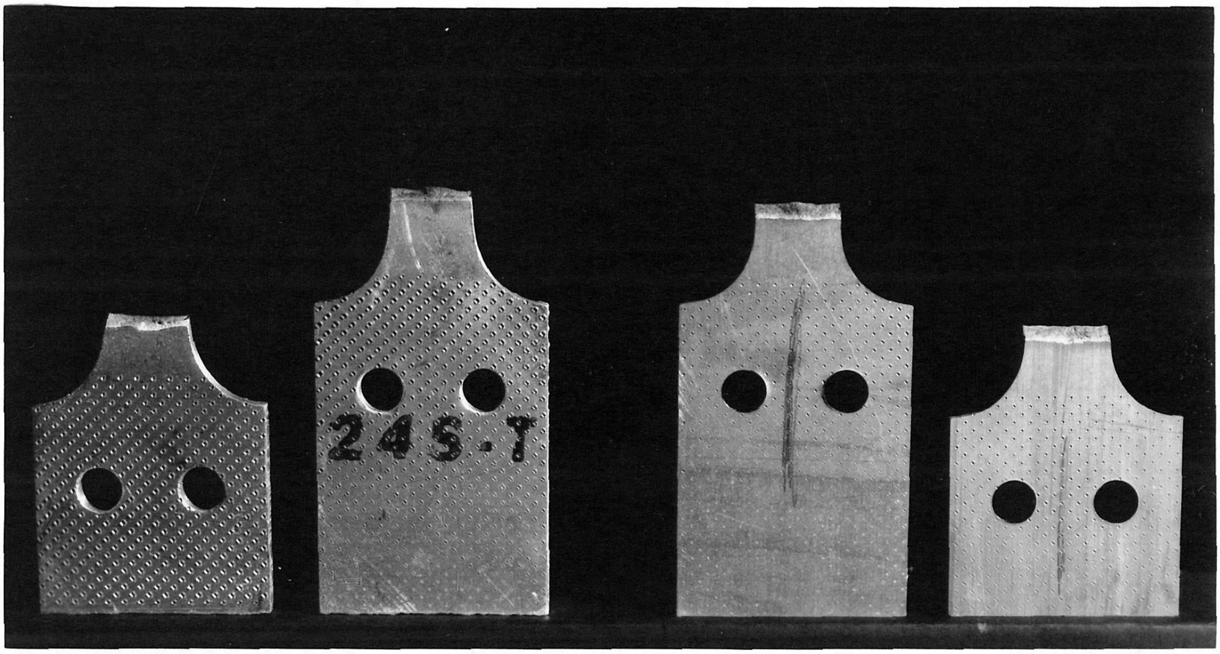


Figure IV - Sheet Specimen Holders.



25 S-T Mn. Bronze 24 S-T

Figure V.



Alclad 24 S-T J-1H

Figure VI.

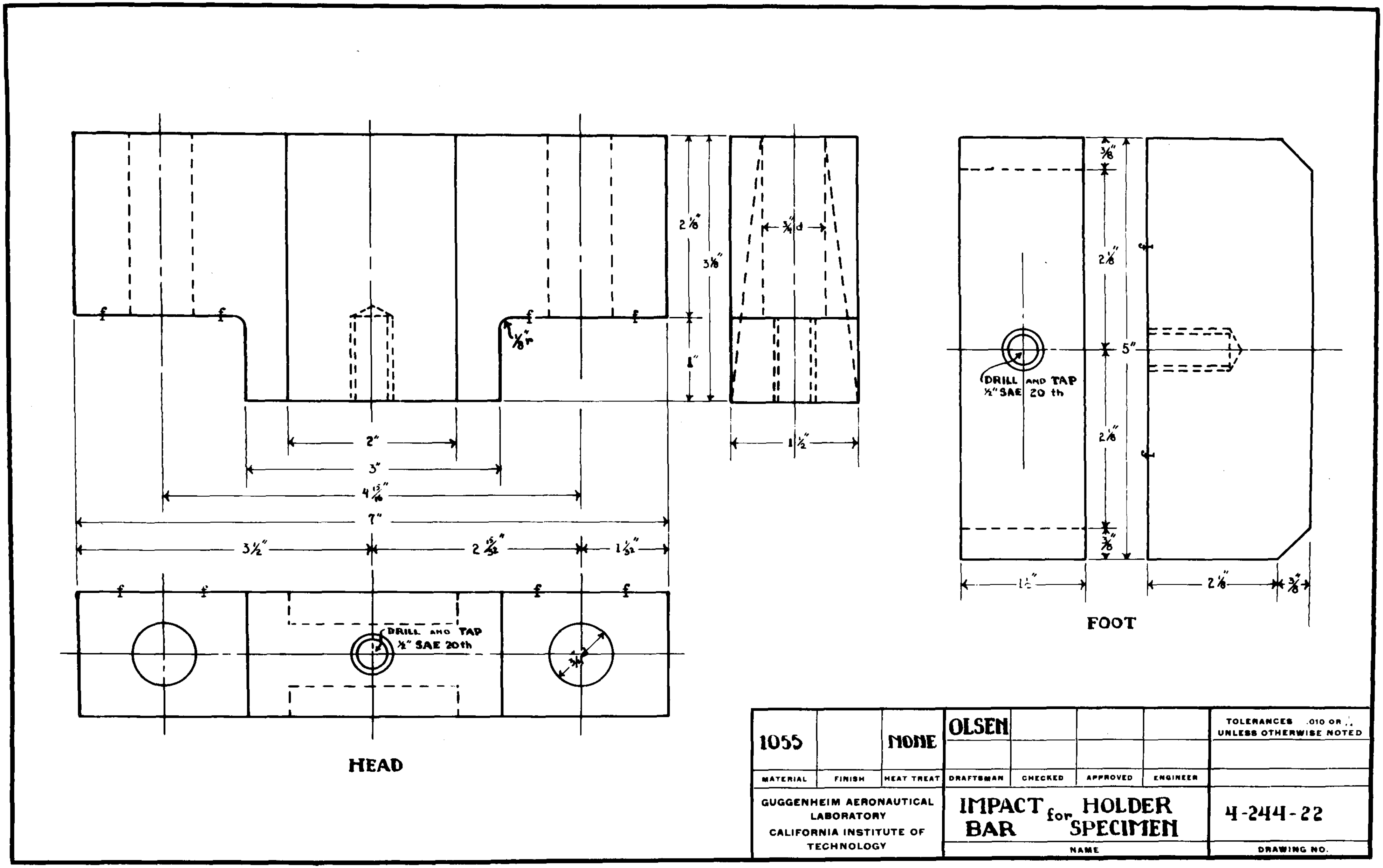

2⅛"
3⅛"
1"
¾ d
1½"
⅛ r
f
2"
3"
4 13/16"
7"
3½"
2 15/32"
1 1/32"
DRILL AND TAP ½" SAE 20th
¾
HEAD
⅜"
2⅛"
5"
2⅛"
⅜"
DRILL AND TAP ½" SAE 20 th
1½"
2⅛"
⅜"
FOOT
1055
NONE
OLSEN
MATERIAL
FINISH
HEAT TREAT
DRAFTSMAN
CHECKED
APPROVED
ENGINEER
TOLERANCES .010 OR ¹⁄₆₄ UNLESS OTHERWISE NOTED
GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
IMPACT BAR for HOLDER SPECIMEN
NAME
4-244-22
DRAWING NO.

Figure VII.

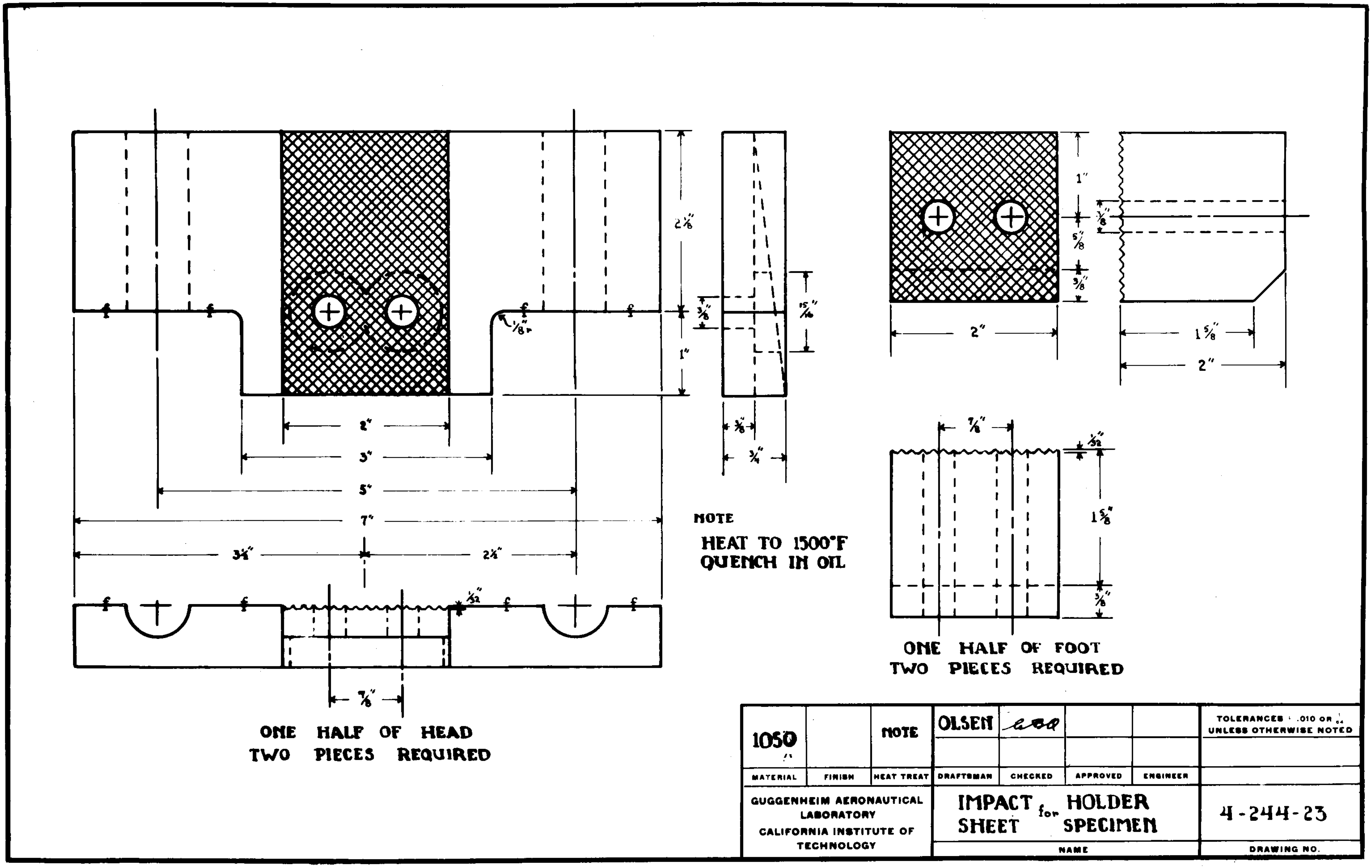
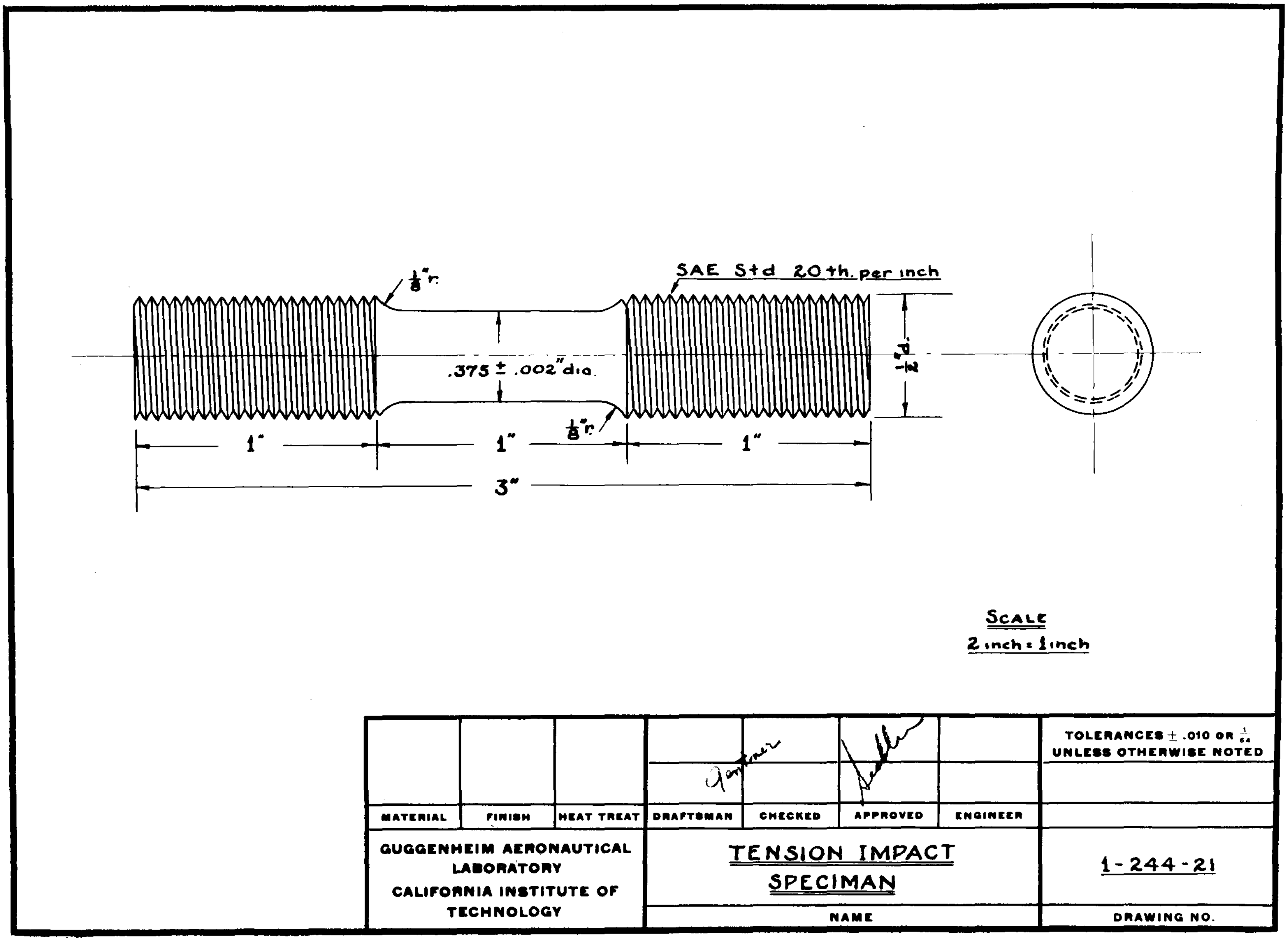
2⅝"
1"
⅜"
15/16"
¾"
2"
3"
5"
7"
3¼"
2¼"
⅛R
1/32"
⅞"
ONE HALF OF HEAD
TWO PIECES REQUIRED
NOTE
HEAT TO 1500°F
QUENCH IN OIL
1"
⅝"
⅜"
2"
1⅝"
2"
⅞"
1/32"
1⅝"
⅜"
ONE HALF OF FOOT
TWO PIECES REQUIRED
1050
MATERIAL
FINISH
NOTE
HEAT TREAT
OLSEN
DRAFTSMAN
CHECKED
APPROVED
ENGINEER
TOLERANCES ± .010 OR 1/64 UNLESS OTHERWISE NOTED
GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
IMPACT SHEET for HOLDER SPECIMEN
NAME
4-244-23
DRAWING NO.

Figure VIII.



SAE Std 20 th. per inch
$\frac{1}{8}$" r.
$\frac{1}{8}$" r.
.375 ± .002" dia.
$\frac{1}{2}$" D.
1"
1"
1"
3"
SCALE
2 inch = 1 inch
MATERIAL
FINISH
HEAT TREAT
DRAFTSMAN
CHECKED
APPROVED
ENGINEER
TOLERANCES ± .010 OR $\frac{1}{64}$
UNLESS OTHERWISE NOTED
GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
TENSION IMPACT SPECIMAN
NAME
1-244-21
DRAWING NO.

Figure IX.

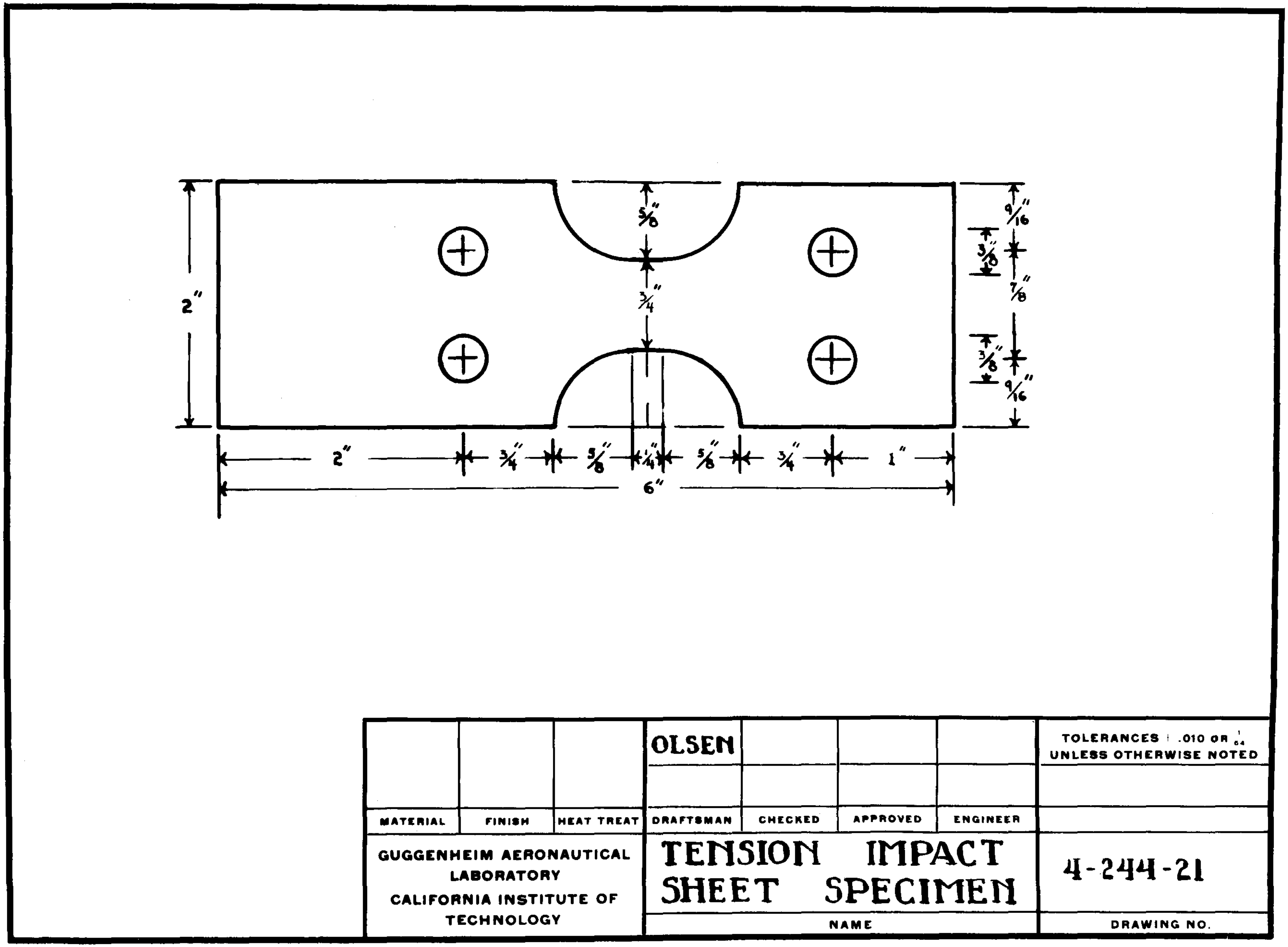
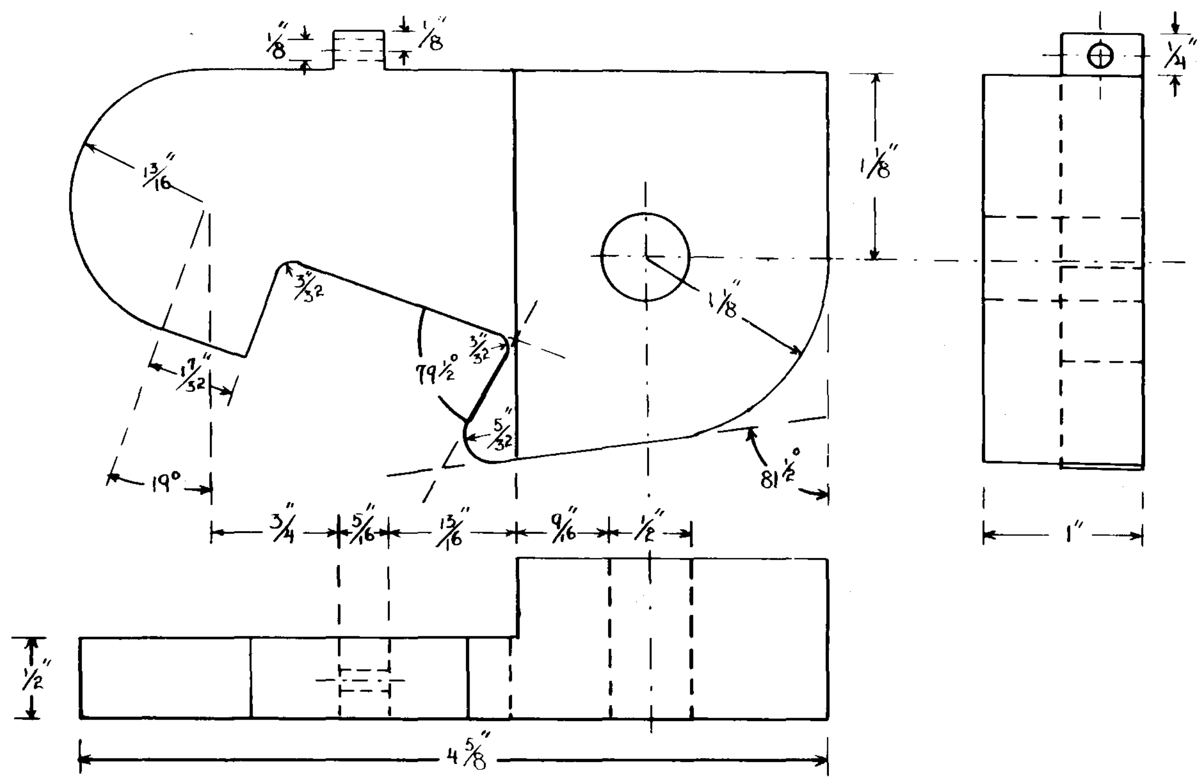
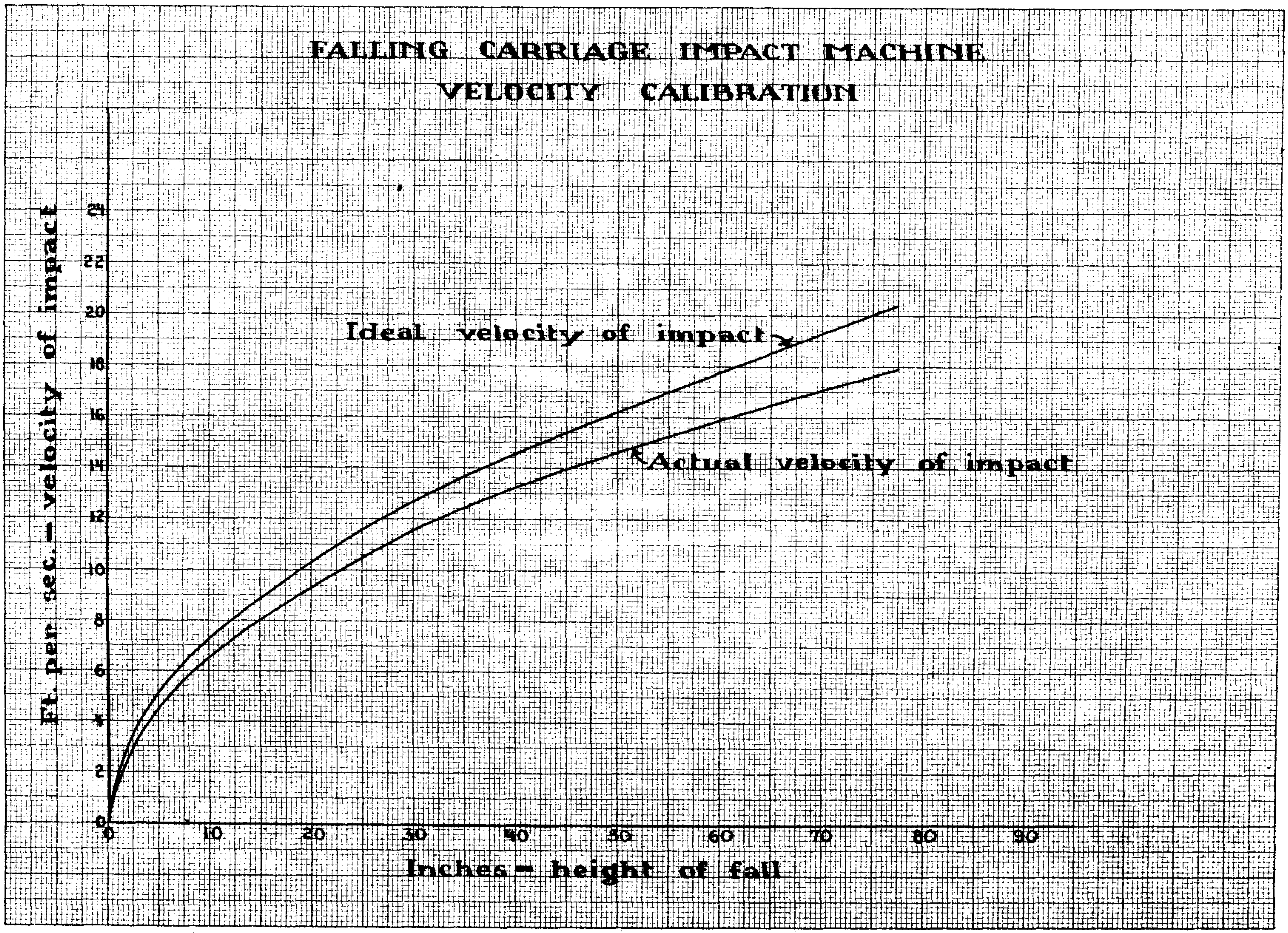

2"
5/8"
3/4"
9/16"
3/8"
7/8"
3/8"
9/16"
2"
3/4"
5/8"
1/4"
5/8"
3/4"
1"
6"
MATERIAL
FINISH
HEAT TREAT
OLSEN
DRAFTSMAN
CHECKED
APPROVED
ENGINEER
TOLERANCES ± .010 OR 1/64 UNLESS OTHERWISE NOTED
GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
TENSION IMPACT SHEET SPECIMEN
NAME
4-244-21
DRAWING NO.

Figure X.



1020	ROUGH	NONE	BROWN				TOLERANCES .010 OR [illegible] UNLESS OTHERWISE NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			CARRIAGE ARRESTER				4-244-20
			NAME				DRAWING NO.

Figure XI.



FALLING CARRIAGE IMPACT MACHINE
VELOCITY CALIBRATION

Figure XII

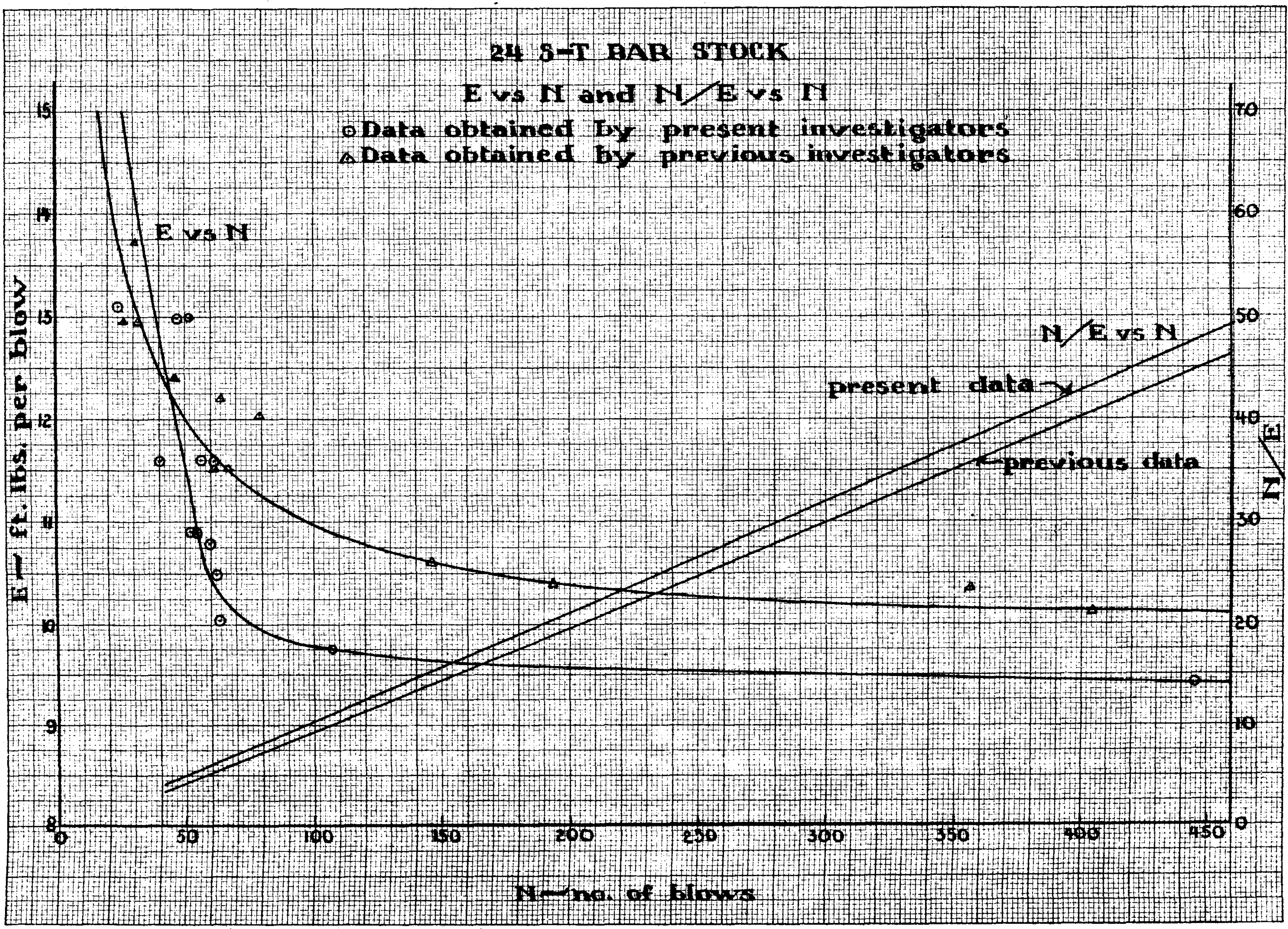

24 S-T BAR STOCK
E vs N and N/E vs N
⊙ Data obtained by present investigators
△ Data obtained by previous investigators
E vs N
N/E vs N
present data
previous data
E — ft. lbs. per blow
N/E
N — no. of blows
8
9
10
11
12
13
14
15
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
400
450

Figure XIII

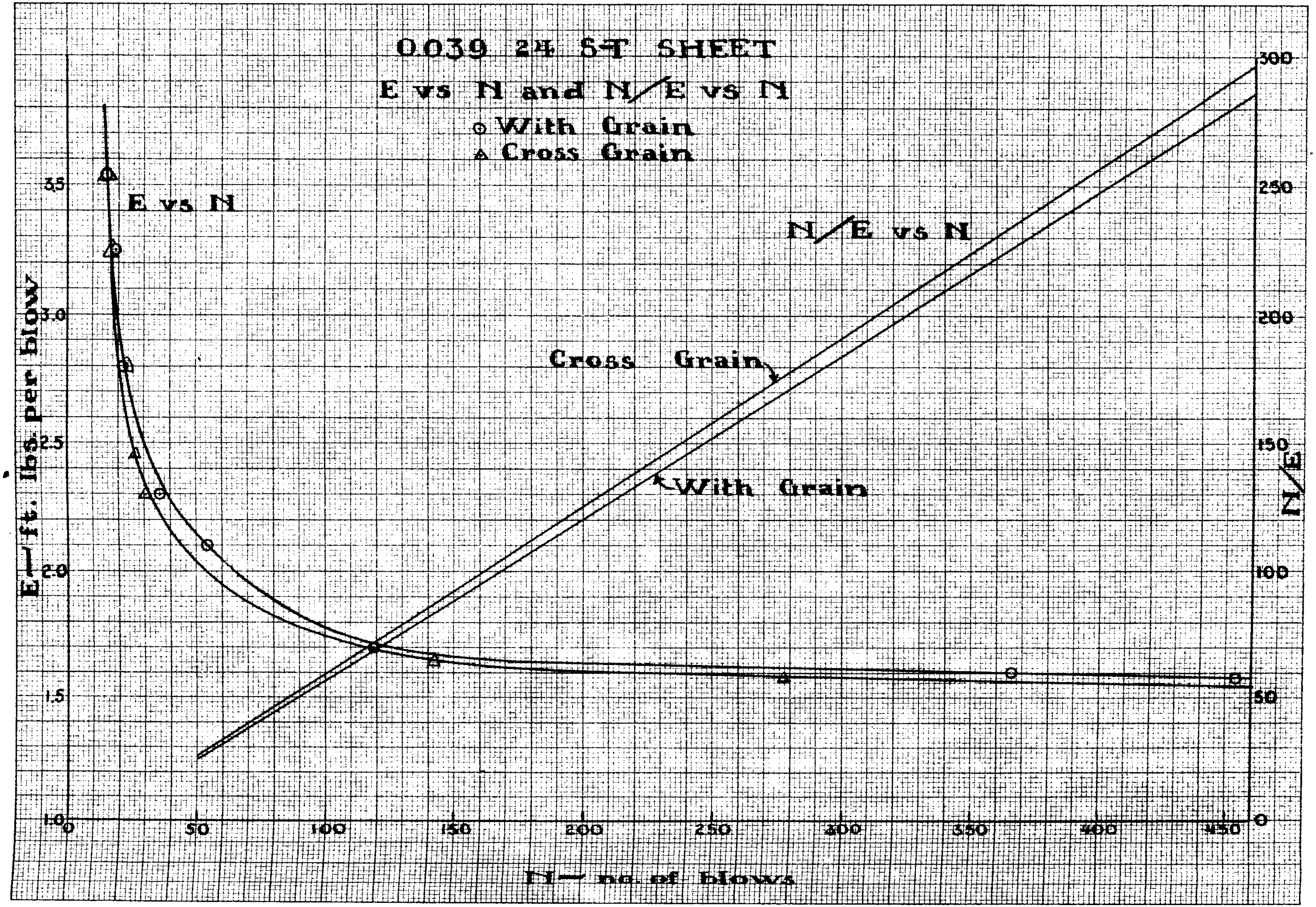

0.039 24 S-T SHEET
E vs N and N/E vs N
○ With Grain
△ Cross Grain
E vs N
N/E vs N
Cross Grain
With Grain
E — ft. lbs. per blow
3.5
3.0
2.5
2.0
1.5
1.0
N/E
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
450
N — no. of blows

Figure XIV

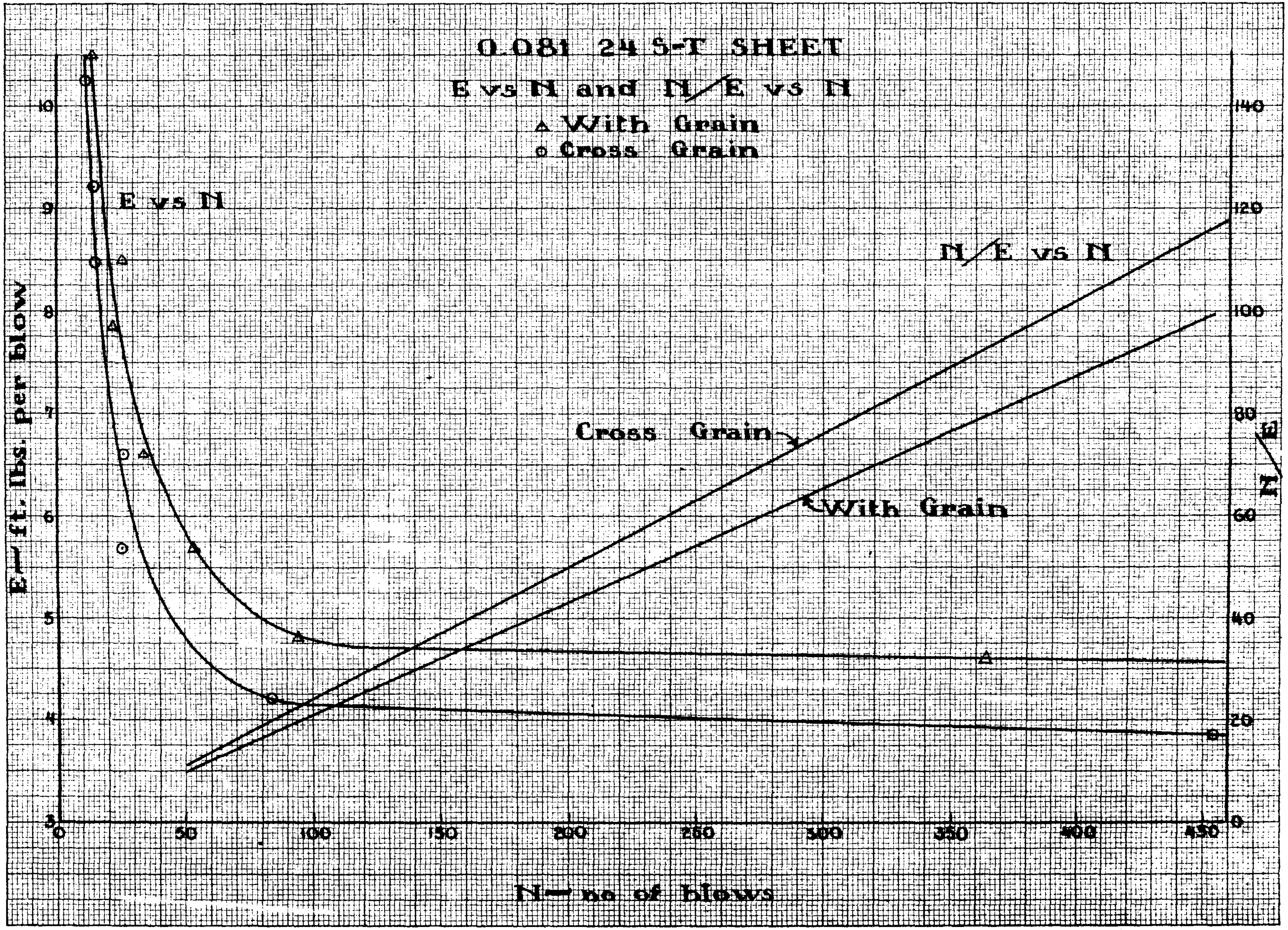

0.081 24 S-T SHEET
E vs N and N/E vs N
△ With Grain
○ Cross Grain
E vs N
N/E vs N
Cross Grain
With Grain
E— ft. lbs. per blow
N— no. of blows
N/E
3
4
5
6
7
8
9
10
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450

Figure XV

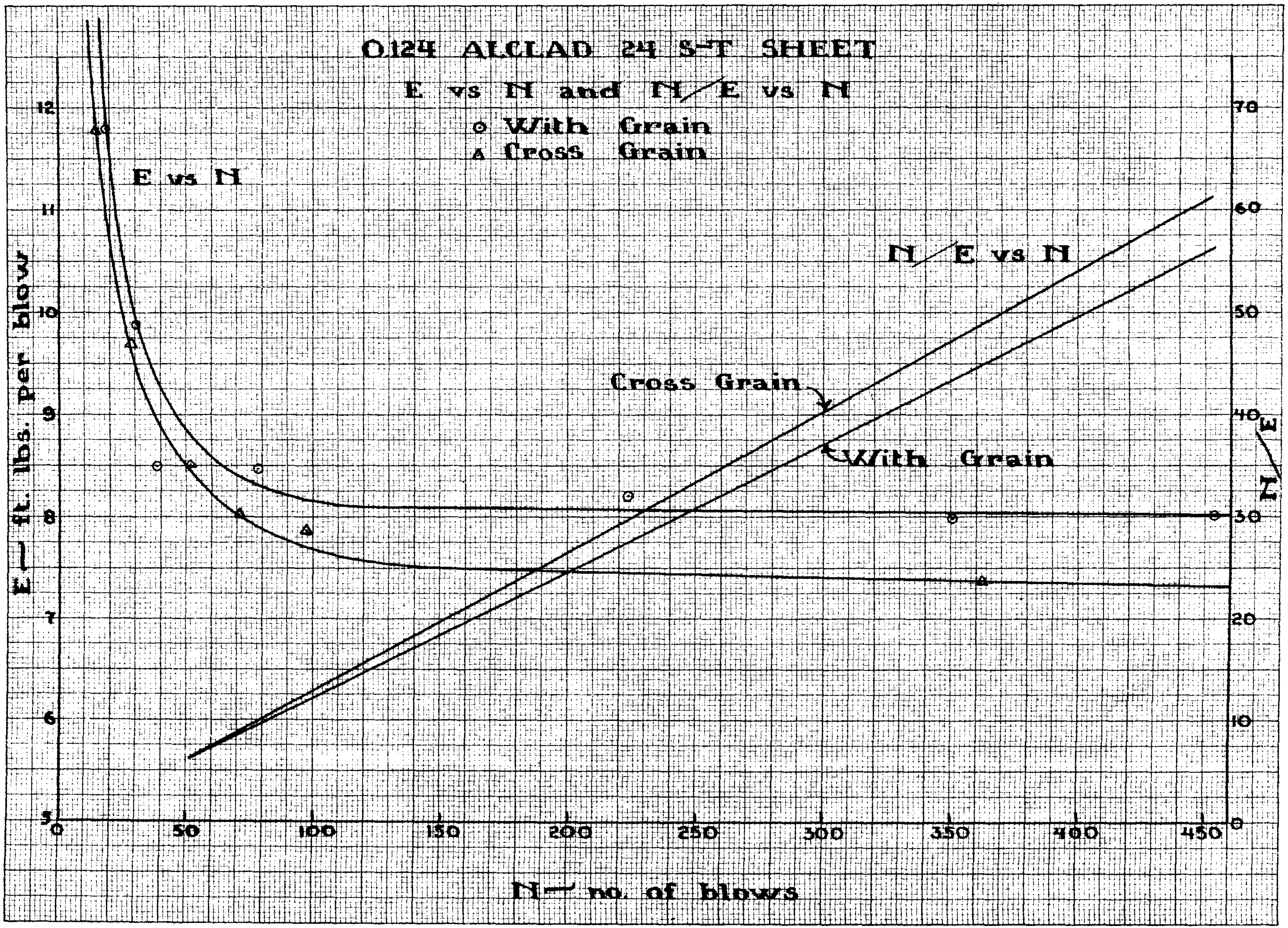

O124 ALCLAD 24 S-T SHEET
E vs N and N/E vs N
⊙ With Grain
△ Cross Grain
E vs N
N/E vs N
Cross Grain
With Grain
E — ft. lbs. per blow
N/E
N — no. of blows
5
6
7
8
9
10
11
12
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
400
450

Figure XVI

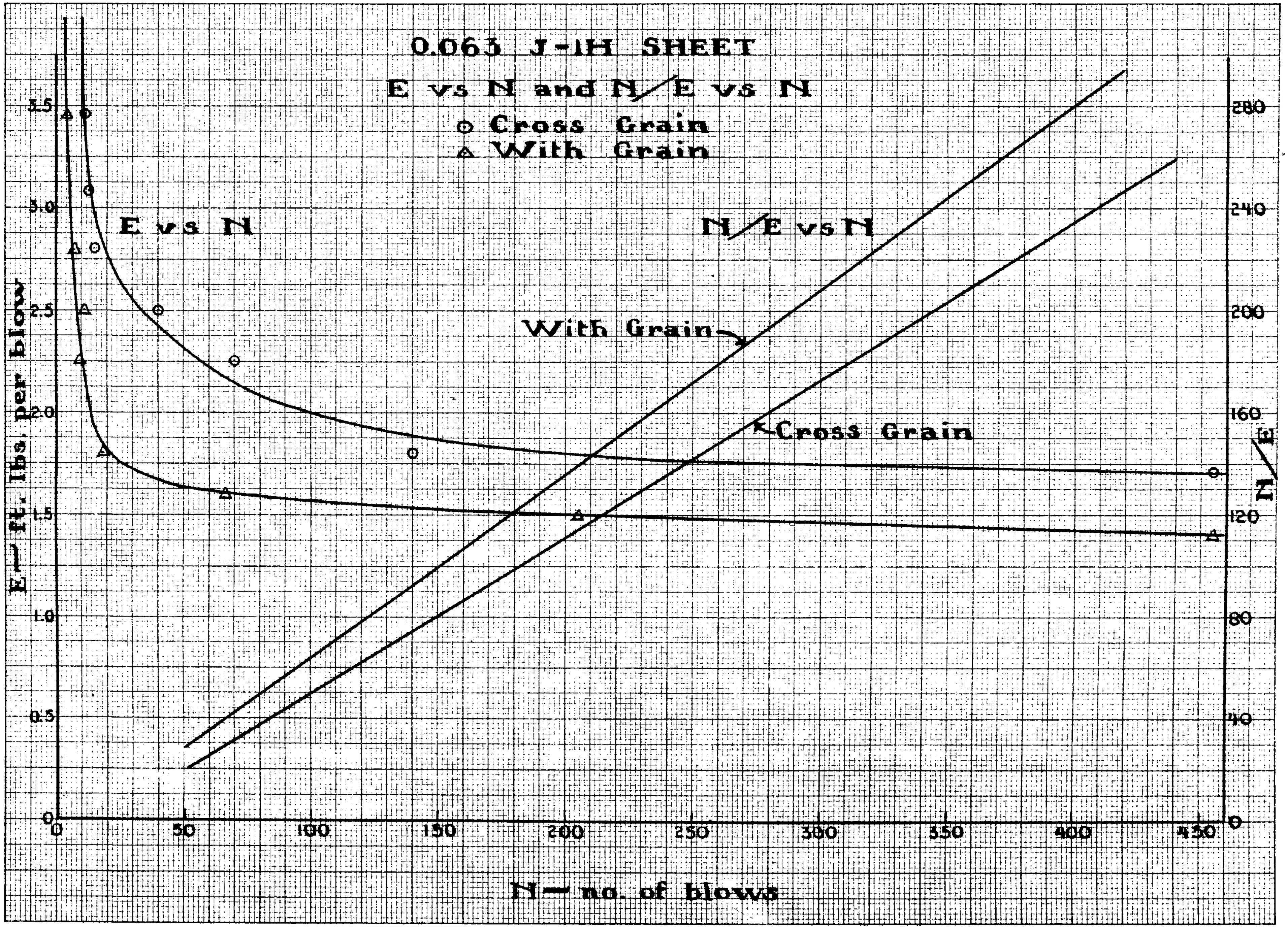

0.063 J-1H SHEET
E vs N and N/E vs N
○ Cross Grain
△ With Grain
E vs N
N/E vs N
With Grain
Cross Grain
E — ft. lbs. per blow
N/E
N — no. of blows
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
50
100
150
200
250
300
350
400
450
0
40
80
120
160
200
240
280

Figure XVII

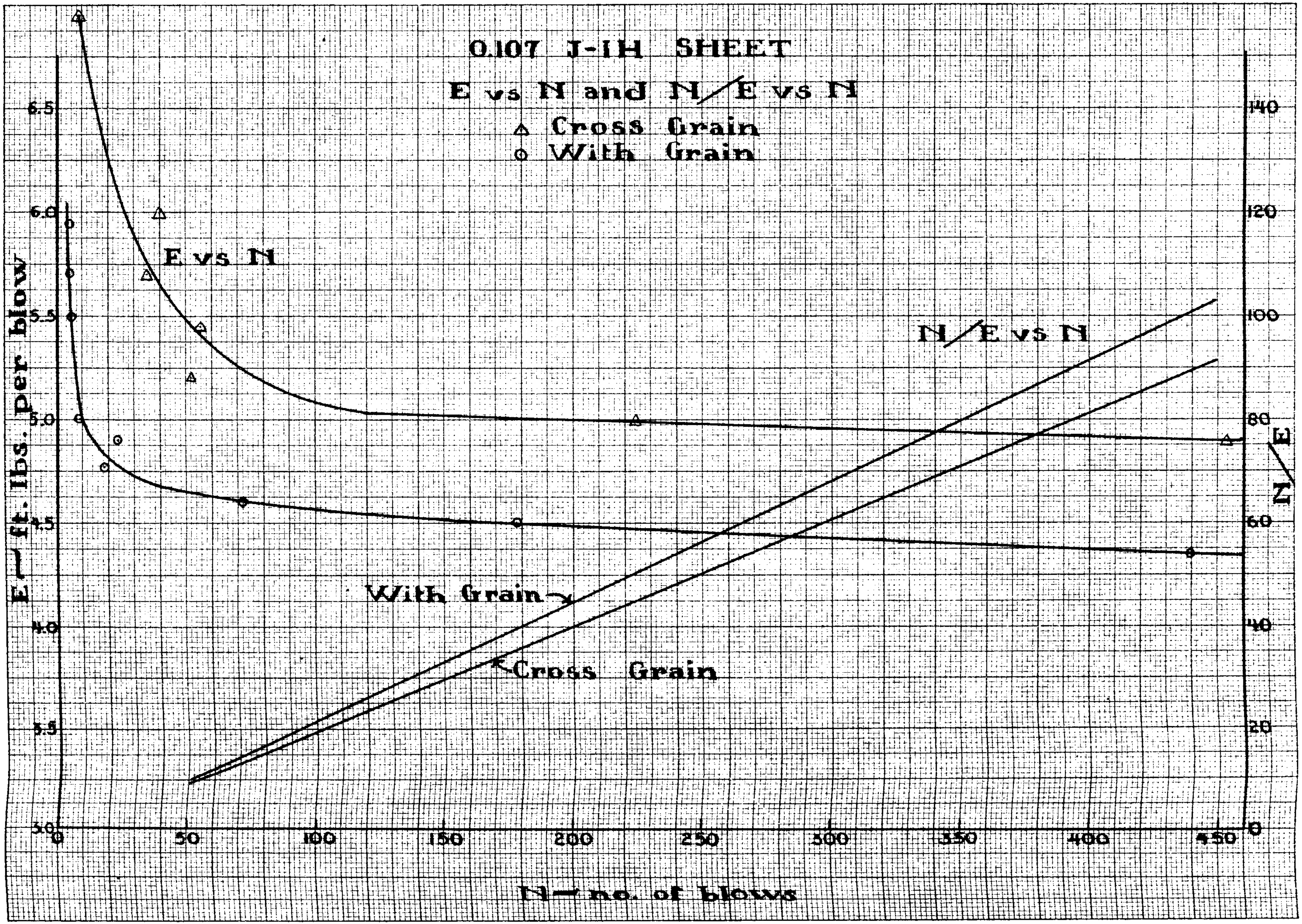


Figure XVIII

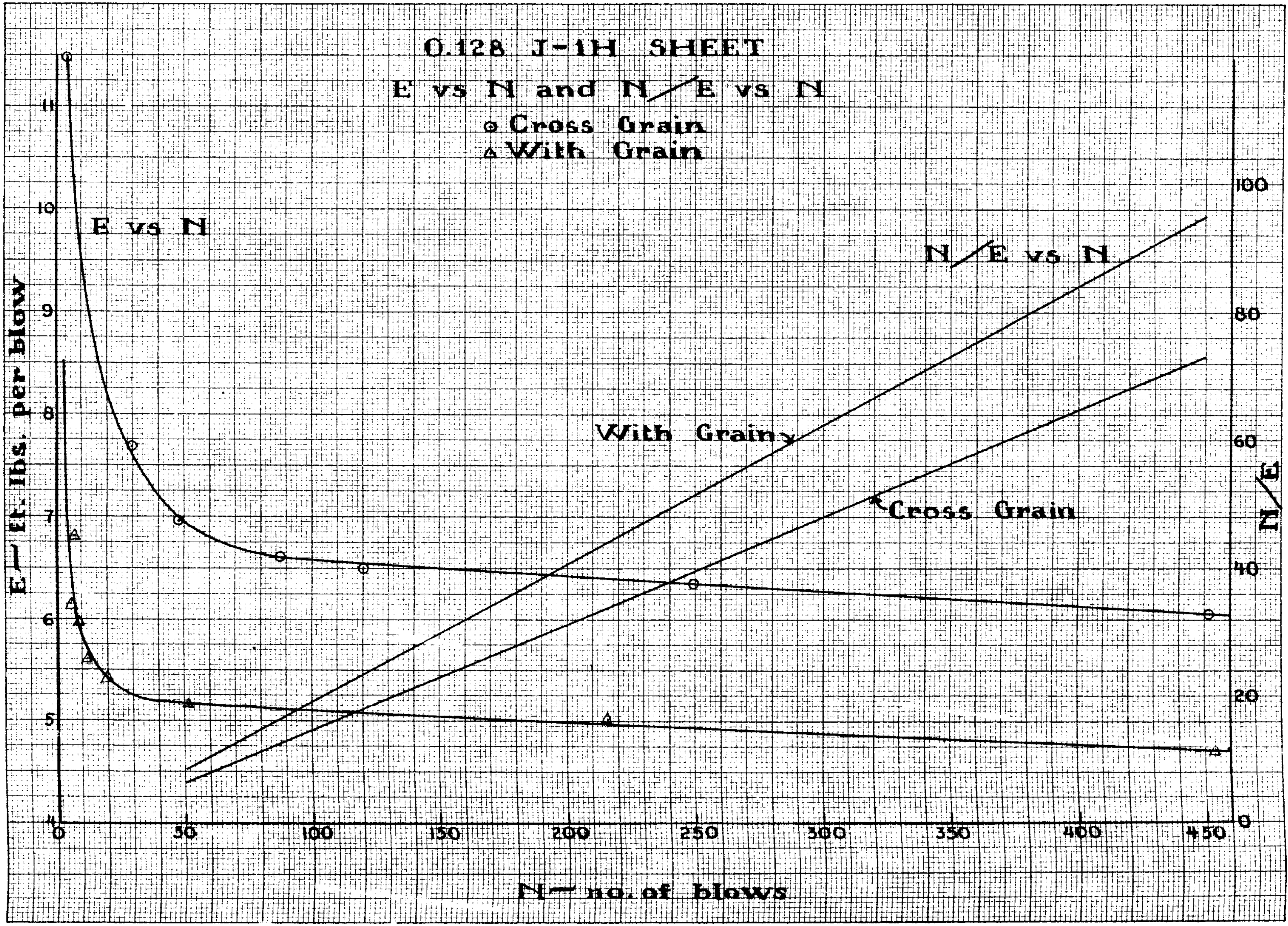

0.128 J-1H SHEET
E vs N and N/E vs N
⊙ Cross Grain
△ With Grain
E vs N
N/E vs N
With Grain
Cross Grain
E — ft. lbs. per blow
N/E
N — no. of blows
4
5
6
7
8
9
10
11
0
20
40
60
80
100
0
50
100
150
200
250
300
350
400
450

Figure XIX

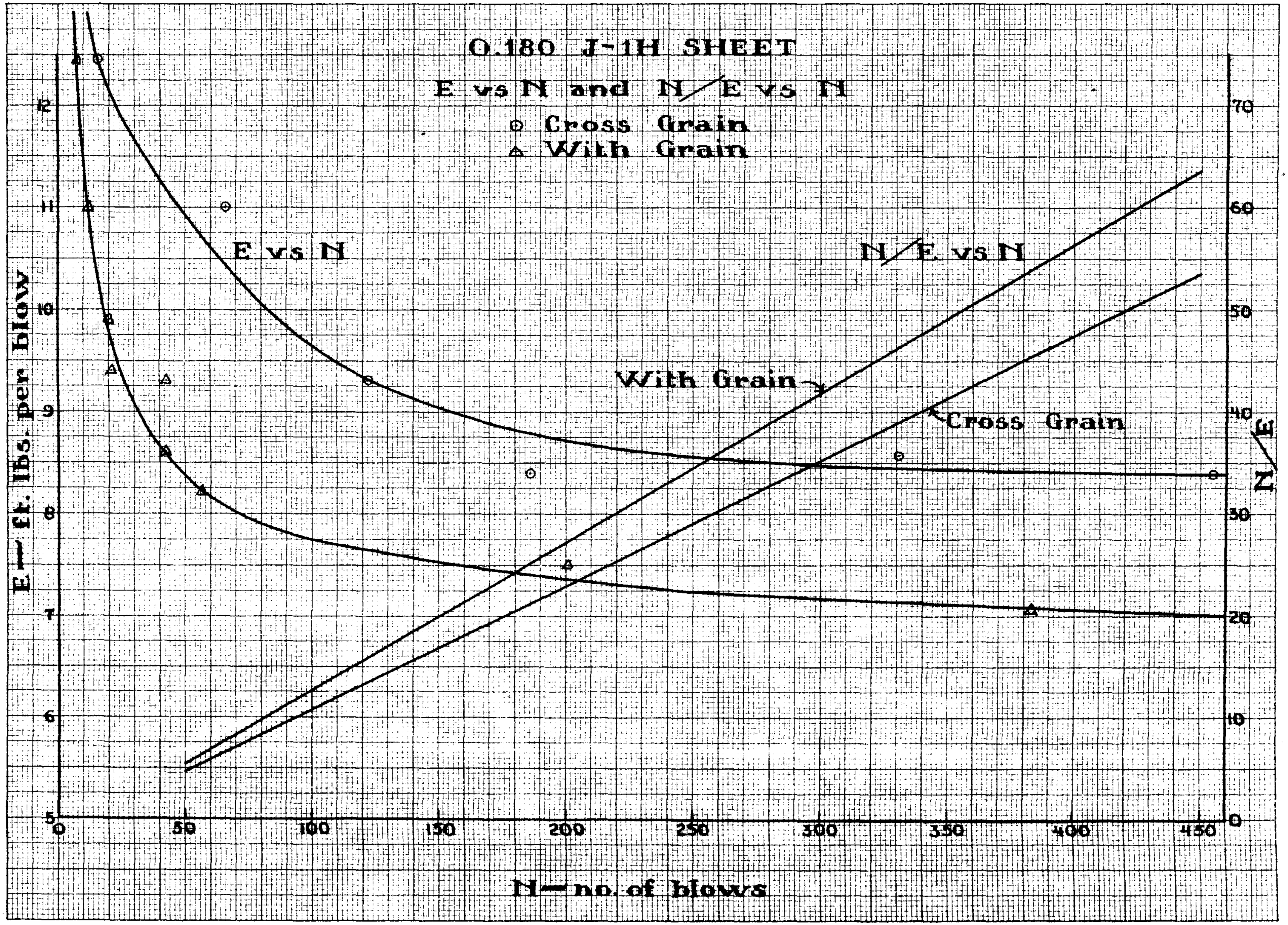

0.180 J-1H SHEET
E vs N and N/E vs N
⊙ Cross Grain
△ With Grain
E vs N
N/E vs N
With Grain
Cross Grain
E — ft. lbs. per blow
5
6
7
8
9
10
11
12
N/E
0
10
20
30
40
50
60
70
N — no. of blows
0
50
100
150
200
250
300
350
400
450

Figure XX

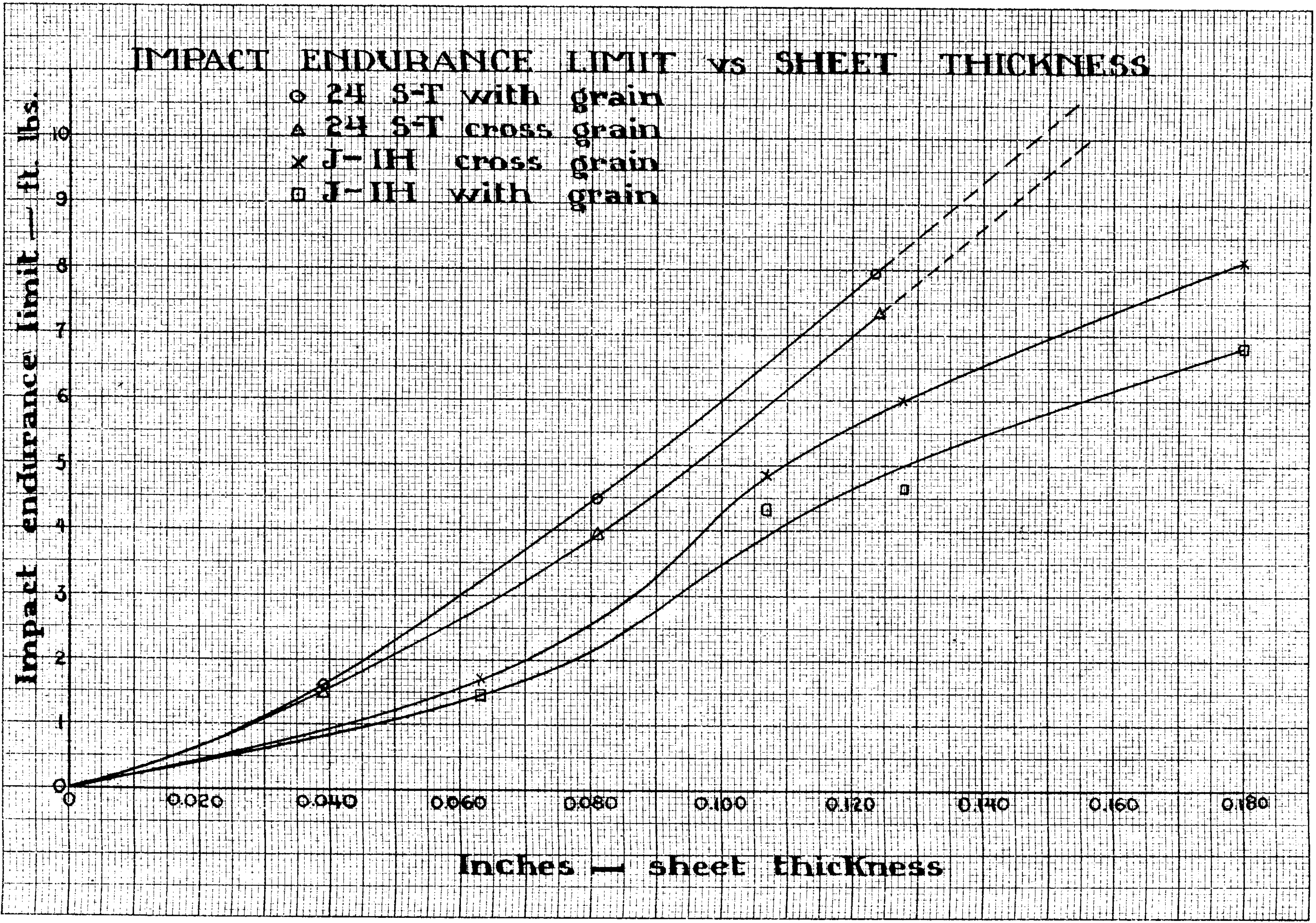

IMPACT ENDURANCE LIMIT vs SHEET THICKNESS
○ 24 S-T with grain
△ 24 S-T cross grain
× J-1H cross grain
□ J-1H with grain
Impact endurance limit — ft. lbs.
0
1
2
3
4
5
6
7
8
9
10
0
0.020
0.040
0.060
0.080
0.100
0.120
0.140
0.160
0.180
Inches — sheet thickness

Figure XXI

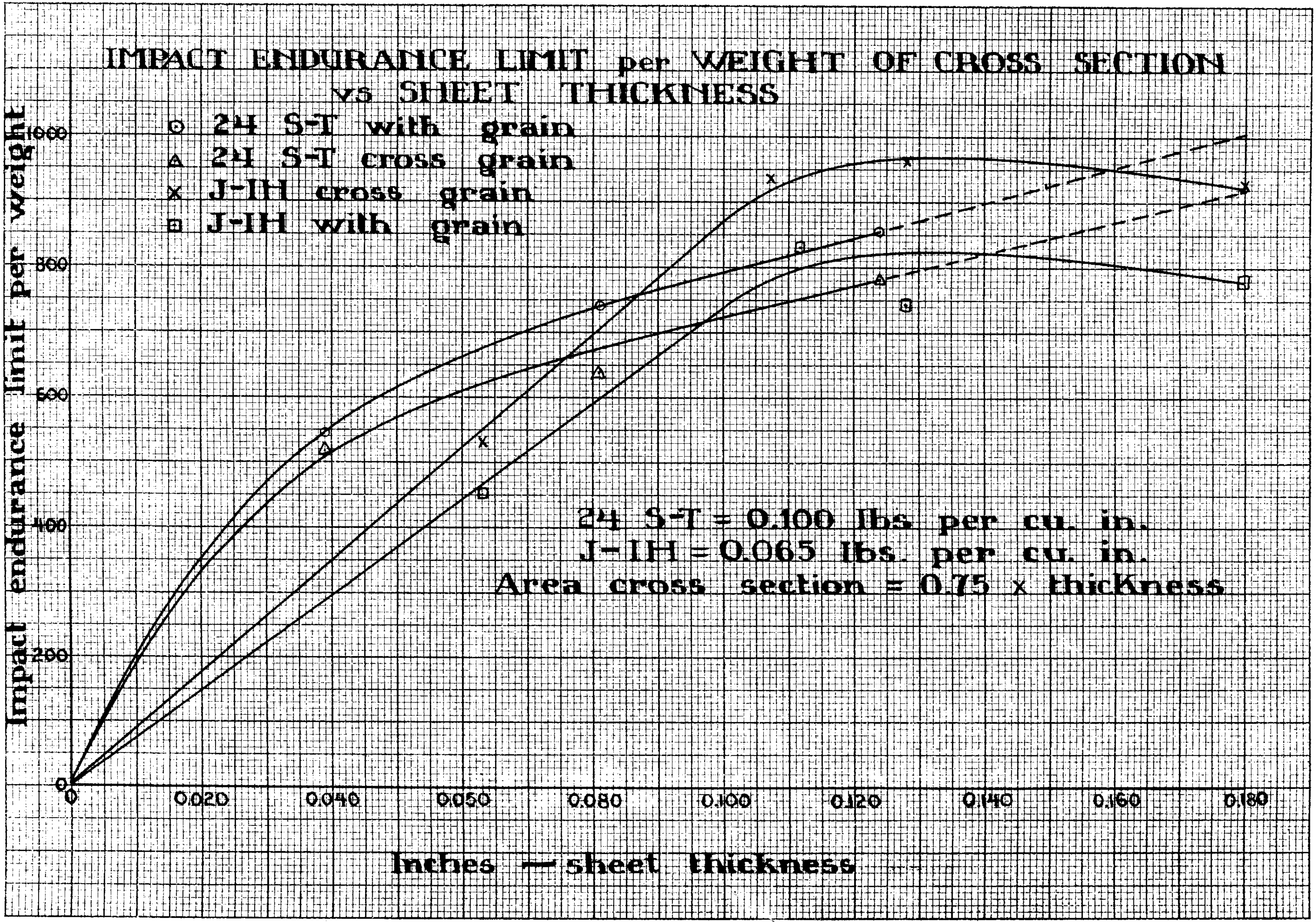

IMPACT ENDURANCE LIMIT per WEIGHT OF CROSS SECTION
vs SHEET THICKNESS
○ 24 S-T with grain
△ 24 S-T cross grain
× J-1H cross grain
□ J-1H with grain
24 S-T = 0.100 lbs per cu. in.
J-1H = 0.065 lbs. per cu. in.
Area cross section = 0.75 × thickness
Impact endurance limit per weight
1000
800
600
400
200
0
0
0.020
0.040
0.050
0.080
0.100
0.120
0.140
0.160
0.180
Inches — sheet thickness

Figure XXII

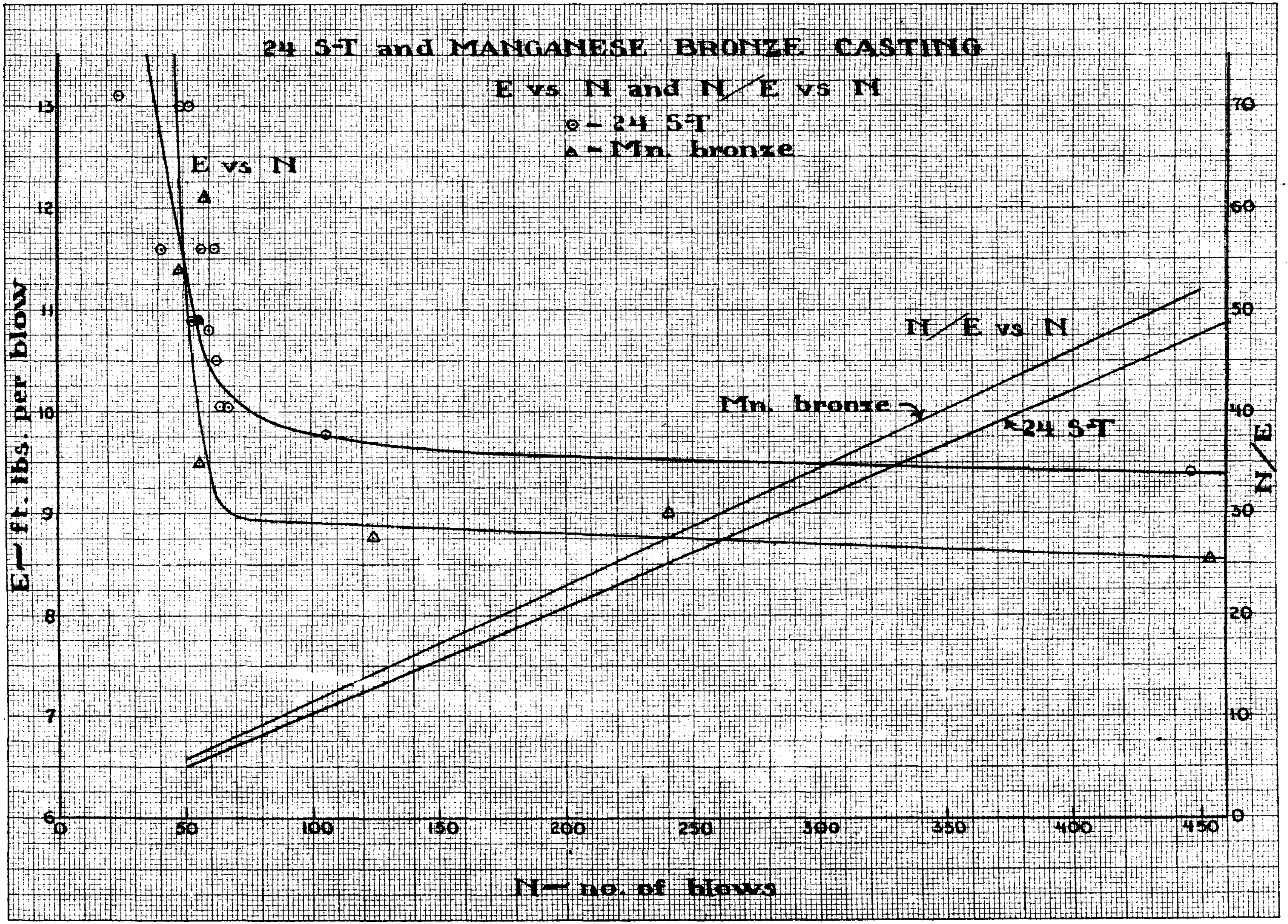


Figure XXIII

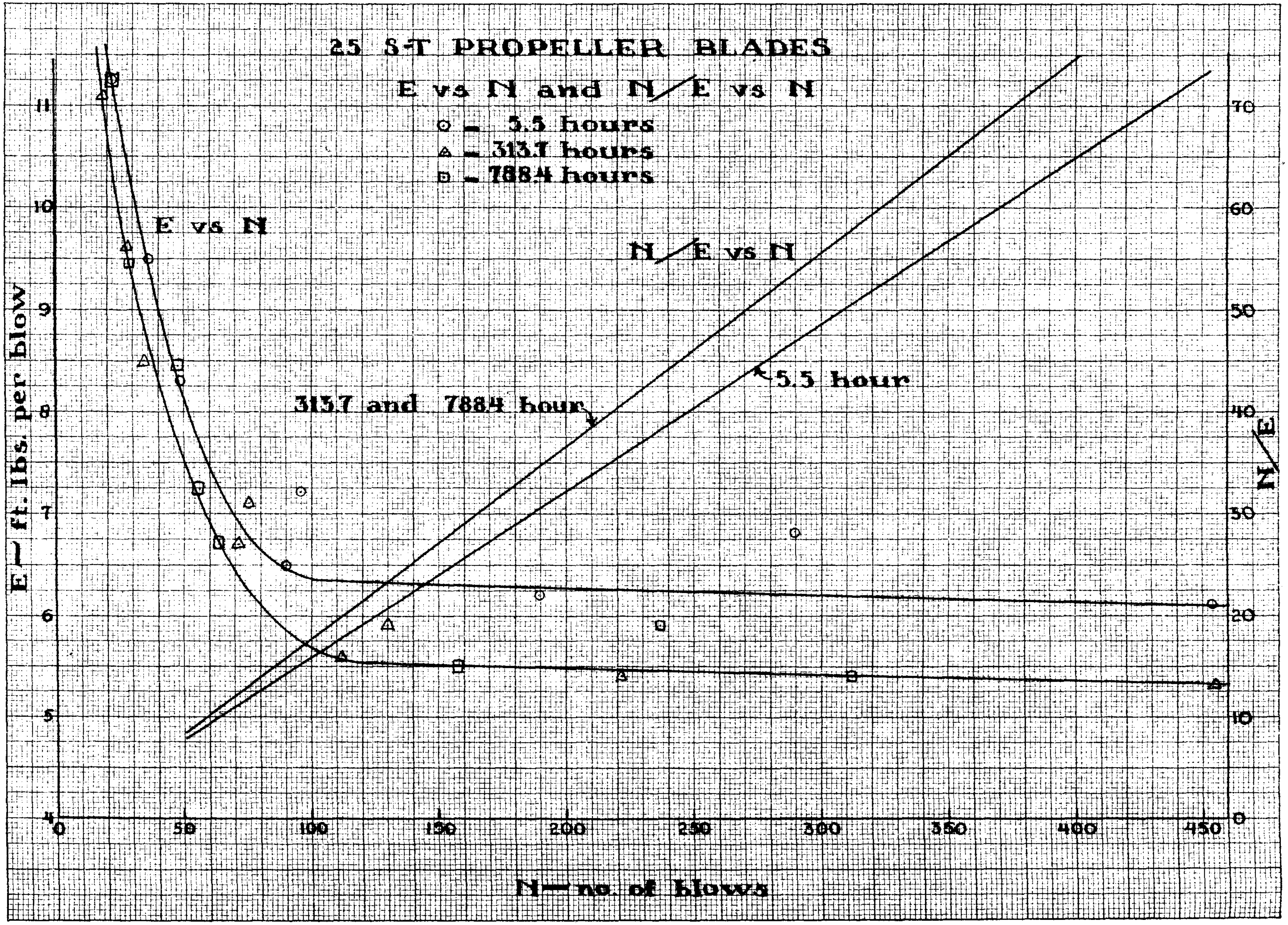

25 S-T PROPELLER BLADES
E vs N and N/E vs N
○ – 5.5 hours
△ – 313.7 hours
□ – 788.4 hours
E vs N
N/E vs N
313.7 and 788.4 hour
5.5 hour
E — ft. lbs. per blow
N/E
N — no. of blows
4
5
6
7
8
9
10
11
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
400
450

Figure XXIV

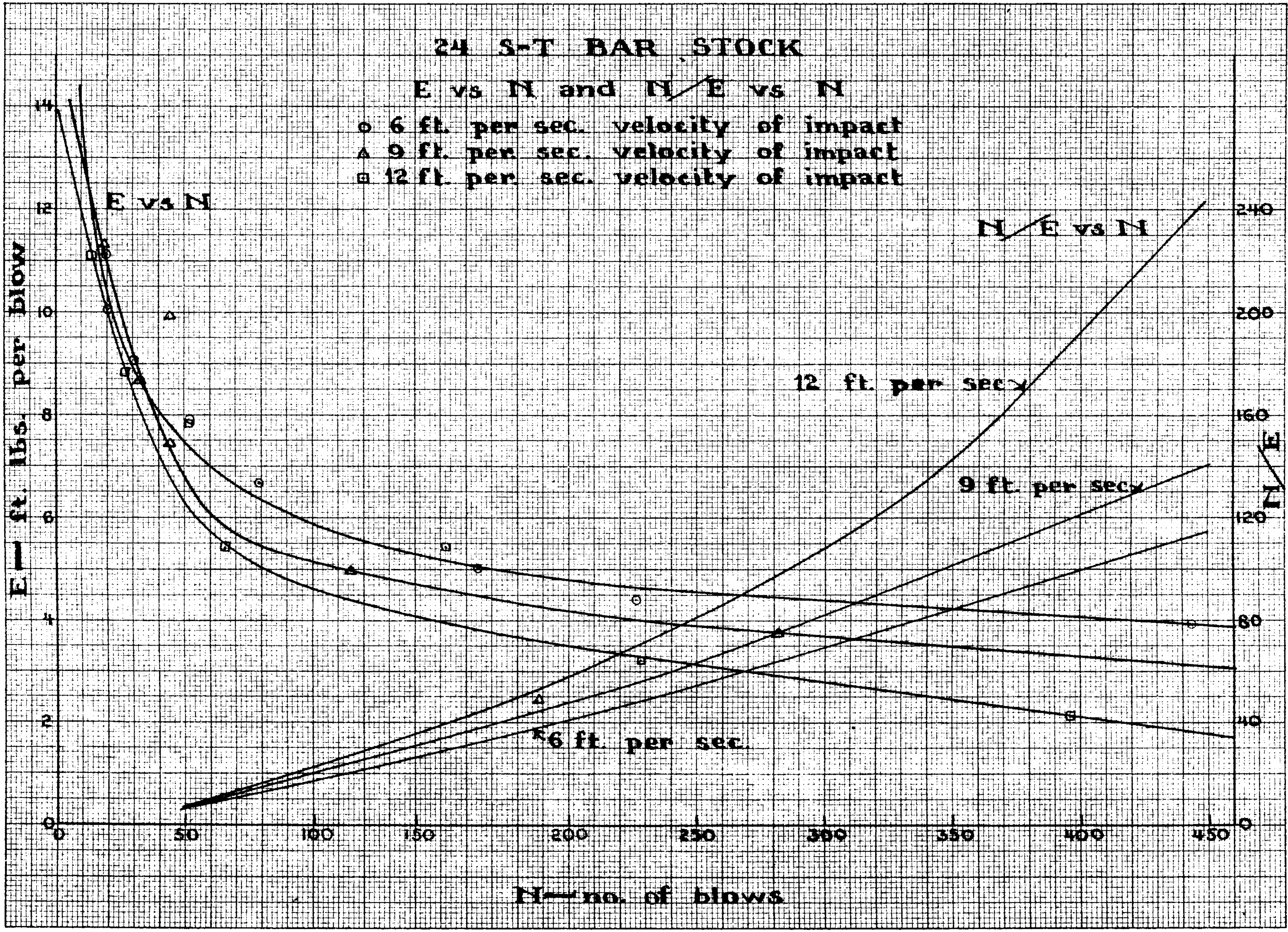

24 S-T BAR STOCK
E vs N and N/E vs N
○ 6 ft. per sec. velocity of impact
△ 9 ft. per sec. velocity of impact
□ 12 ft. per sec. velocity of impact
E vs N
N/E vs N
12 ft. per sec.
9 ft. per sec.
6 ft. per sec.
E — ft. lbs. per blow
N/E
N — no. of blows
0
2
4
6
8
10
12
14
0
50
100
150
200
250
300
350
400
450
0
40
80
120
160
200
240

Figure XXV

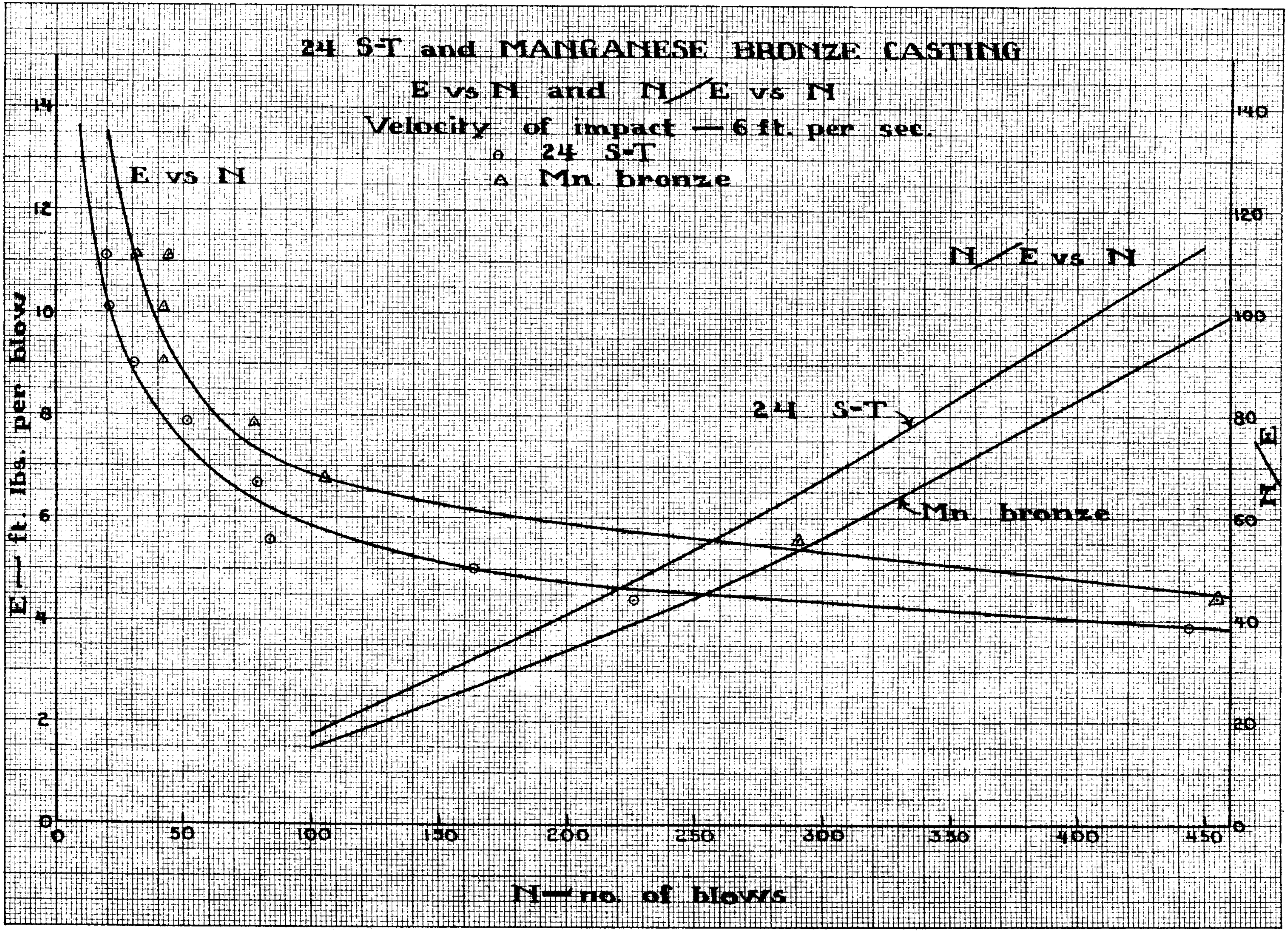

24 S-T and MANGANESE BRONZE CASTING
E vs N and N/E vs N
Velocity of impact — 6 ft. per sec.
○ 24 S-T
△ Mn. bronze
E vs N
N/E vs N
24 S-T
Mn. bronze
E — ft. lbs. per blow
N — no. of blows
N/E
0
2
4
6
8
10
12
14
0
50
100
150
200
250
300
350
400
450
0
20
40
60
80
100
120
140

Figure XXVI

TENSILE TEST

STANDARD IMPACT BAR SPECIMEN

Figure XXVII