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THE STEEL PLATE DENT TEST

W.L. Monson, et al

Maryland University
College Park, Maryland

August 1955

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August 31, 1955

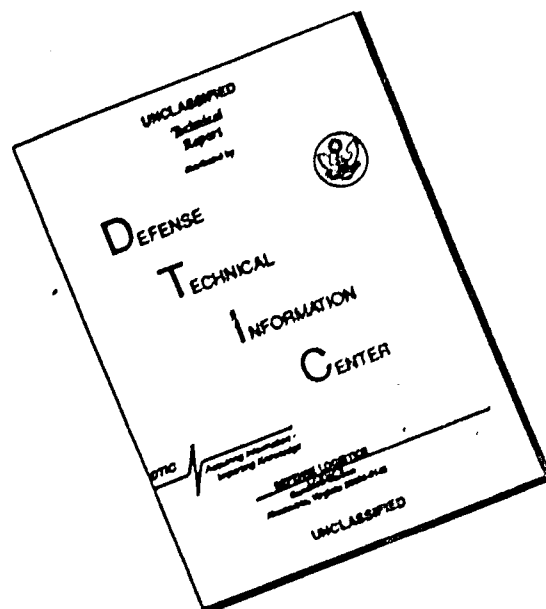
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FINAL REPORT
ON
THE STEEL PLATE DENT TEST

Contract No. N60921s-3179

Report by:

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August 31, 1955

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SUMMARY

This research consisted of a study of those factors which were relevant to the specification of a workable steel plate dent test.

A copy of the existing lead disc test machine was constructed. The anvil design and minimum size of test piece that could be used with no change to this machine was determined. The suitability of round and flat bar stock for use in fabricating test pieces was evaluated.

The sensitivity of the test for distinguishing between strong and weak detonators was investigated. Those factors such as test piece preparation and hardness which were found to influence the sensitivity of the test were evaluated as far as possible without a knowledge of the degree of correlation between the test and capacity of the detonator for initiation of explosives.

A flash detonator holder was designed and tested.

Recommendations were made as a result of these preliminary investigations which were intended to serve as a starting point for a more extensive evaluation of the steel plate dent test in practice.

CONCLUSIONS

1. An anvil, steel test piece (round or square), detonator holder, and firing pin can be simply centered in the existing MK-136-0 lead disc test machine.
2. The overall dimensions of the test pieces having a diameter or diagonal of 1.217 inches and thickness greater than $\frac{3}{8}$ " were not distorted when dented by MK-22-0 detonators.
3. In round stock, firing is parallel with the fiber while in flat bar stock firing is logically perpendicular to the fiber.
4. Neither round nor flat bar stock of C-1018 cold rolled steel holds any special advantages because of hardness uniformity. The most important factor to consider in the choice of a round or square test piece is the cost of manufacture of the piece.
5. The correlation between dent depth and hardness is much better when firing is parallel with the fiber at the center of the bar and center hardness of the bar is used as correlating variable than when firing is perpendicular to the fiber and either surface hardness or center hardness is used as the correlating variable.
6. Only dents produced by detonators having equal casing diameters can be compared in forming a rejection test based on use of the steel test piece.
7. For steel test pieces lying within the Rockwell B hardness range of 80 to 90 the rejection of all MK-22-0 detonators not producing a dent depth of 14.4 mils on a flat ground surface would result in rejection of around 5% of the detonators known to be at 100% full strength and around 95% of the detonators known to be at 50% of full charge.

8. The data and results indicate that the capacity of the steel plate dent test for distinguishing between MK-22-O detonators having 100% and those having 85% or 75% of tetryl present in a full charge, is poor when commercially available C-1018 cold rolled steel is used for the test piece without any specification of hardness range.
9. Based on the results of this investigation, the dent depths between the MK-22-O stab and flash detonators cannot be compared to form the basis of a rejection test. That is, the dent depth depends on the method of initiation and/or detonator holder.
10. The preparation of opposite test surfaces of the test pieces significantly affects the precision of measurements of dent depths. Failure to grind flat opposite surfaces reduces the precision to an extent that dents need be reported to the nearest mil instead of the nearest 0.1 mil as is the case when the surfaces are ground flat.

RECOMMENDATIONS

1. It is recommended that the test piece thickness be fixed at 0.625 (+ 0.000 - 0.100) inches.
2. It is recommended that the test surface of the piece and the opposite surface be ground smooth.
3. It is recommended that test pieces be cut from C-1018 cold drawn round stock having a maximum center hardness of 89 Rockwell B. After operation of the test with these test pieces, should it be found necessary to increase the sensitivity of the test, it is recommended that the tolerable hardness range in a test piece be reduced to 81 thru 85. This, however, will require rejection of many commercial bars of steel, or the use of special annealed steels.
4. Although it cannot be recommended at this time, experience may prove that it is possible to distinguish strong and weak detonators satisfactorily without preparing the test specimen by surface grinding. In such a case, test pieces of flat bar stock would be logically used. Such test pieces are readily adapted to the machine without any changes whatsoever.

Work would be required on correlating the capacity of a detonator to initiate explosives with the steel plate dent test when using an "as received" mill surface of the test piece before any conclusions or recommendations concerning such a test piece could be made.
5. For a one-shot rejection test, it is necessary to determine a value of dent depth which must be exceeded for acceptance for every type and size of detonator to be tested. This value could be obtained

by firing detonators having 100% and 50% of full charge on steels having hardness at each end of the tolerable hardness range. From these data a dent depth can be set which will reject both a certain percentage of 100% detonators and the desired percentage of 50% detonators. It would be expedient to choose a critical value of dent depth from only the firing of detonators known to have 100% of charge. The test would then be operated using a critical value of dent depth which is exceeded by 100%, 99% or 95% of the 100% detonators. In any case the correlation between the steel plate dent test and capacity of the detonator to initiate explosives must be determined.

6. The flash detonator holder shown in Figure 16 is recommended for use with the anvils described in Table VII in the testing of flash detonators.

I. INTRODUCTION

A. Objective

This research is a study of the factors leading to the engineering and packaging of a "Steel Plate Dent Test" that will be applicable to the production testing of Navy Service detonators.

B. Background

At present, Navy Service detonators are tested on the Mark 136 Detonator Test Set. The strength of the detonator is judged by the area of the hole blown in a thin disc of lead. This test is considered unsatisfactory because (a) the correlation between the area of the hole in the disc and the ability of the detonator to initiate a high explosive is not as good as desired and is also not sound from a theoretical point of view; and (b) it is not capable of testing a wide enough range of sizes of detonators. With large detonators, a hole is blown in the disc, while the smaller types of detonator may merely deform the disc without rupturing it. A thinner disc, on the other hand, might not discriminate satisfactorily between good and bad detonators of a larger size.

It was postulated by staff members of the Naval Ordnance Laboratory that because lead is soft and easily deformed, a detonation which exerted a (relatively) low pressure over a (relatively) long time interval could rupture a lead disc, yet the same detonation might not initiate a given high explosive, whereas a detonator exerting a higher average pressure for a shorter time might produce the same ruptured area in lead and also initiate the high explosive in question. This hypothesis could explain the poor correlation previously mentioned. It was believed, therefore, that a metal having a considerably higher yield stress than lead would show dents

in thick sections, the depth of which (a measure of the work of deformation), might correlate more closely with initiation ability than do lead disc rupture areas. Furthermore, such a test might be able to cover a wide range of sizes of detonators.

Subsequently, experimental results obtained at the Naval Ordnance Laboratory on the cold-rolled surface of flat steel bar stock confirmed the predictions of this hypothesis. A good correlation between depth of dent and initiation ability was shown to exist. An empirical equation which expressed the relationship of the dent depth and the steel hardness was also developed at NOL using a range of types of steel.

At the outset of this research program, the status of the "Steel Plate Dent Test" appeared to be as follows:

- (1) The test seemed superior to the lead disc test for the evaluation of detonator quality.
- (2) It was desired that a new test be designed which would be suitable for routine production testing of detonators by Naval Inspectors. In place of the measurement of the ruptured area of the lead disc there was to be substituted measurement of the depth of the dent produced in a steel test piece.
- (3) It was believed that SAE 1020 cold-finished steel had suitable physical properties for the purpose of the new test. This material is cheap, non-critical, and readily available.
- (4) At NOL dent tests had been carried out on the rolled surface of flat bar stock approximately 5/8 inch thick. What effect factors such as piece geometry (thickness, width or diameter) and method of fabrication might have, were not definitely known. Nor was it clear whether round stock would be more or less suitable than flat stock. The round shape is more directly adaptable to the existing M-13-0 test apparatus. Possible disadvantages would be inhomogeneity of round sections such as "piping", inclusions, trapped gas holes, hardness variations along the radius, etc. Because of the known effects of hardness on dent depth, the uniformity of the test surface is of greater importance than the type of fabrication or the shape of test specimens.

- (5) It was not certain what results would be obtained with the extremes in the range of strengths of detonators to be subjected to this test.

C. Experimental Program

In order to design a suitable production test for detonators, it is necessary to show that the proposed method (a) gives measurably different results with good and bad detonators, (b) is rapid and simple in operation and (c) is reproducible. The "Steel Plate Dent Test" as developed at NOL appeared to meet these requirements. It was decided however that experimental investigation was necessary to evaluate the following factors which would be important in the specification of a workable packaged test:

1. The range of sizes of detonators that could be evaluated by this test.
2. The suitability of round stock for fabrication of test pieces.
3. The size and shape and preparation of the test piece which would be used with minimum changes to the existing lead disc test machines.
4. The sensitivity of the test for distinguishing between good and bad detonators.
5. The design of plastic detonator holder for evaluation of flash detonators.

A test apparatus was constructed following the plan of the Mark 136 Model O test set but substituting a fixed-weight drop mechanism. Before construction of this apparatus was complete, the MK-56-0 stab detonator (the weakest stab detonator which was investigated) was fired on 5/8 inch thick SAE 1020 steel bar stock using the detonator test set in operation

at NOL. The results showed that these detonators gave dents nearly as deep as the MK-22-0 (one of the strongest), thus showing that the steel dent test responded to the necessary range.

The suitability of round stock was evaluated from studies on homogeneity of the stock and the effect of hardness on the dent test. The effect of geometry of the test piece was evaluated by firing a number of detonators on pieces of various thicknesses. The data from these tests were used to determine and evaluate relevant factors affecting the size, shape, uniformity and localization of the dent.

A plastic holder for flash detonators was designed and tested in order that flash detonators could be tested with the same apparatus. From the foregoing the specifications of the test piece, anvil and plastic holder could be derived.

The sensitivity of the test for distinguishing between good and bad detonators was determined by firing five groups of MK-22-0 type detonators, each group containing a different weight of tetryl. From these tests, the capacity of the steel plate dent test to distinguish between detonators of various strengths but having the same casing diameter was determined.

II. PROCEDURE

A. Test Machine

A test machine was constructed from drawings supplied by the Naval Ordnance Laboratory. The ball drop was fixed at 20 inches and ball weight at 2 ounces. All results reported in this report were obtained on this machine with the exception of tests on bar stock reported in Table IV which were made at the Naval Ordnance Laboratory.

B. Anvil

1. Anvils for Testing Stab Detonators

Special anvils were machined from a vanadium tool steel and hardened to 60 Rockwell C. One anvil was constructed so that the face on which the test piece is placed was recessed $1/16$ " into the anvil surface to provide a means for centering the piece. It was one solid piece of steel, having no holes as does the anvil used in the lead disc test. The other anvil had the dimensions specified for the lead disc test, but also without holes. A sketch of the cross section of the anvil with the recessed face for the steel dent test is shown in Figure 1.

The height of the anvil was so determined that when a $5/8$ " thick test piece was placed on the anvil, the surface of the steel test piece was at the same height relative to the machine as was the lead disc in the lead disc test. When test pieces of less than $5/8$ " in thickness were used, specially machined centering discs were placed beneath the anvil so that the height of the test piece was not changed relative to the machine.

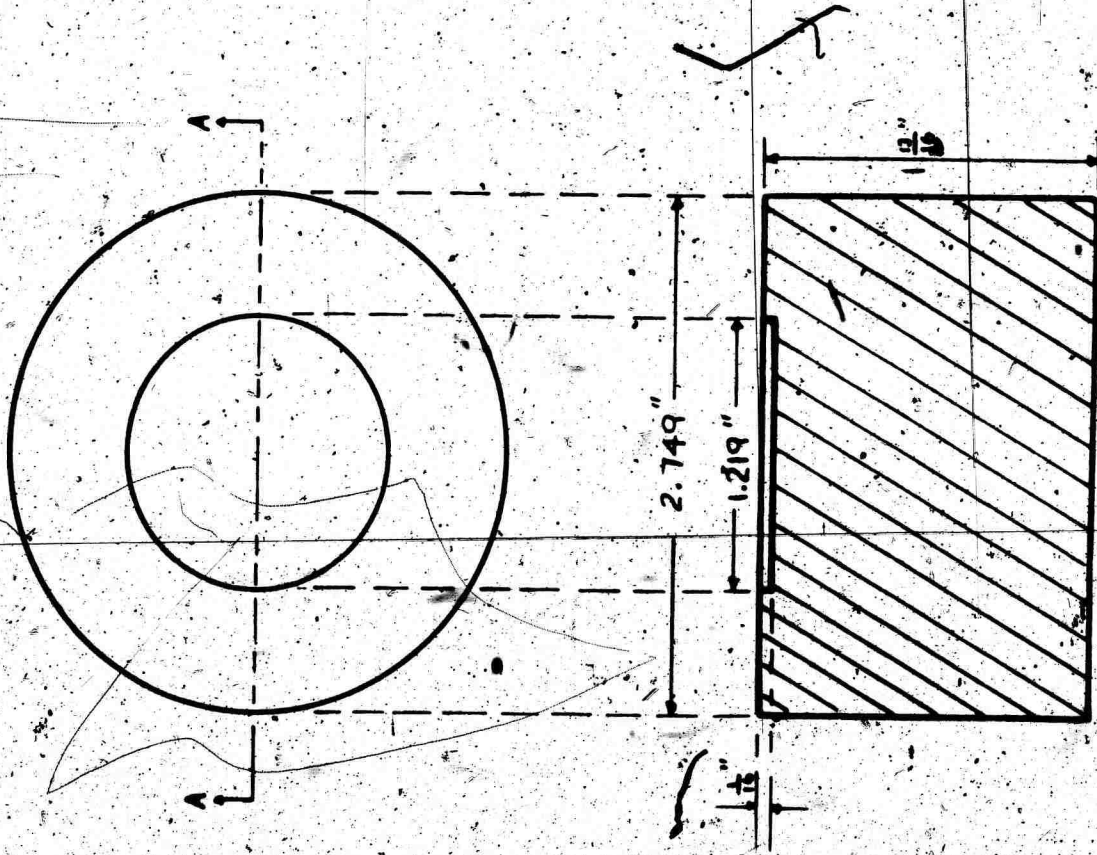
2. Anvils for Testing Flash Detonators

FIG. 1

ANVIL

PLAN VIEW

SCALE 4:1



SECTION A-A

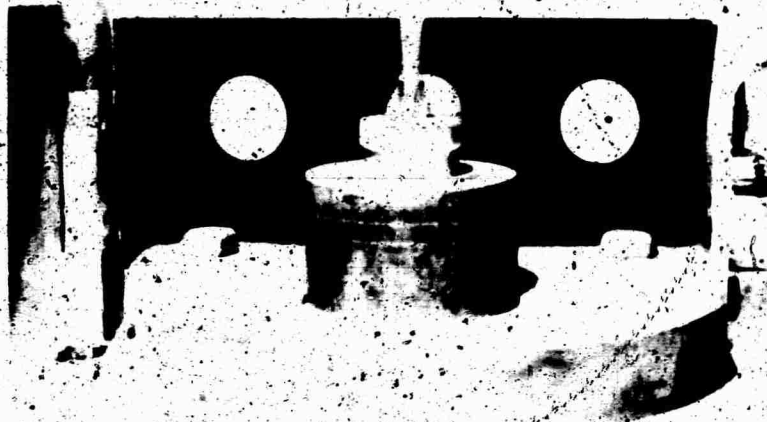


Figure 2

Anvil, test piece, plastic holder, and firing pin assembly for a round test piece.

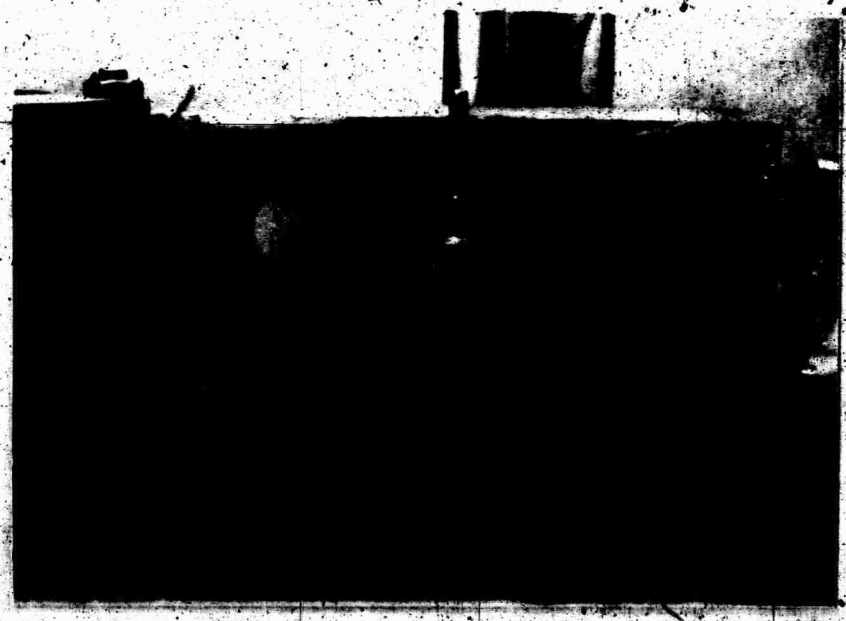


Figure 3

Anvil, test piece, plastic holder and firing pin assembly for a square test piece cut from flat bar stock.

Because the plastic detonator holder for flash detonators differs from that of stab detonators, it was necessary to machine a special anvil for flash detonators. This anvil differed from that shown in Fig. 1 for stab detonators only in the overall height dimension, which was $1-1/8$ instead of $1-13/16$ inches. The centering discs described above were used to adjust the height of the anvil when plastic detonator holders of different size were used. The height of the top of the holder was maintained constant. This is discussed in more detail in Section V.

C. Test Pieces

Test pieces were machined from either round or flat bar stock so that the piece would fit snugly into the recess in the anvil. The anvil, test piece, detonator holder and firing pin assembly are shown in Figures 2 and 3.

Round test pieces had a 1.217" diameter, whereas pieces cut from flat bar stock were squares with a diagonal of 1.217" and side of 0.862". The round pieces were ground smooth on opposite sides for ease in measuring dent depths. Some bar stock was ground and pieces which were ground are so specified in the data and results. Surface grinding is a variable which is discussed in Section IV.

Surface grinding was done with an 8" x $3/4$ " x $1-1/4$ ", 32A54-J5VBF Lundum wheel manufactured by the Norton Refractories Company.

D. Detonators

Detonators used in all tests were supplied by Naval Ordnance Laboratory.

E. Denting of the Test Piece

The procedure for denting the steel test piece is essentially that now used for testing detonators with the lead disc test. Briefly, the procedure

as follows:

- (1) Anvil is inserted into the machine.
- (2) A plastic detonator holder is sealed at the bottom with scotch tape and then fitted on to the test piece.
- (3) A detonator is inserted into the plastic holder.
- (4) The assembled test piece, plastic holder and detonator are placed on the recessed face of the anvil. The assembly at this point of the procedure is fixed due to the nature of construction of the machine anvil and test piece.
- (5) The door to the chamber containing the anvil is closed and a firing pin inserted into the plastic holder.
- (6) The ball is placed on the electromagnet 20 inches above the firing pin.
- (7) A safety door is closed and the ball is dropped.

Measurement of Dent Depth

The depth of a dent was measured to the nearest 0.1 mil with a depth gauge. A taper contact point* 3/16" diameter and having a contact radius of 0.031" was used in all depth measurements. The depth recorded was the largest found by a quick exploration of the dent with this probe.

Measurement of Hardness

Hardness was measured by means of a Rockwell hardness testing machine on samples of steel cut from the same bar as the test pieces. From these

* Manufactured by Federal Products Corp.

data the average center and surface hardness of the test piece were determined.

For round stock, the measurement of hardness at any point other than the center would have doubtful significance because of the wide variation of hardness readings over the cross sectional area. For samples cut from bar stock, hardness readings at points on the center line of the rolled surface were taken for each piece, and these averaged to give the piece hardness.

The hardness of pieces cut from the same bar were averaged to give a group hardness when a single value of hardness was used as a correlating variable.

III. THE STEEL TEST PIECE

A. General

The ultimate criterion for determining the suitability of a test piece in the steel plate dent test is the uniformity of the dent produced by a standard detonator on test pieces of a given hardness.

It would be expected that the reproducibility of dent depth would depend on similarity of the test pieces rather than uniformity of the steel throughout. For example, it would be expected that a round test piece that was harder at the center than at the edges would be just as suitable as a piece uniform throughout, so long as an identical piece was used each time. The dent depth for such a non-uniform piece must be correlated with capacity of the detonator to detonate explosives. In order that the test be meaningful the same type of correlation must also be presumed to exist and be determined for a piece having no change in properties with direction.

The difficulty in adapting to the test apparatus a piece having directional properties is that of procurement of large numbers of identical pieces.

A homogeneous piece has the special advantage in that the hardness of the steel around the area to be dented is obtained from a hardness measurement anywhere on the piece. Furthermore, the hardness distribution is not a variable.

Results of tests made with flat 5/8" bars Nos. 20 and 30 are given below. Both bars had a surface hardness of 82 but different center hardness. The effect of the different hardness gradients is apparent from the considerable difference in dent depth.

Table I

Bar No.	Effect of Hardness Gradient on Dent Depth		Dent Depth (average of over 20 shots)
	Surface Hardness	Center Hardness	
30	82	83	15.3
20	82	89	14.7

The detonators and preparation of both groups of test pieces were the same. The standard deviation of the detonators was 0.6 mils, making this difference in dent depths statistically significant at the 1% level by the statistical test.

Only if the depth of the dent produced were not very sensitive to the piece hardness would the non-uniformity of the piece with respect to hardness become insignificant. Otherwise a correction from hardness-dent depth correlations must be applied. Any lack of control over hardness or homogeneity effectively reduces the sensitivity of the test for distinguishing detonators of various strengths.

The above considerations indicated that the following items should be investigated in order to arrive at conclusions as to the suitability of round stock for the steel plate dent test:

- (1) Uniformity of round and bar stock over transverse cross section from piece to piece.
- (2) Effect of any non-uniform or directional properties on the uniformity of dent produced.
- (3) The effect of hardness on dent depth

B. Uniformity of Round Stock

- (1) Uniformity from bar to bar of round stock

The data obtained from hardness traverses of round stock are given in Table VII of the appendix. The hardness traverses for various round bars are plotted in Figure 4. This figure shows that for the round bars of 1018 cold rolled steel investigated the center hardness varied from 80 to 90 and the edge hardness from 82 to 92. Figure 5 shows hardness traverses for 3 bars of round stock 1-1/2 inches in diameter. Thus, even when the diameter of the round is the same, a considerable variation in

Figure 4

Hardness Traverse of Round Stock

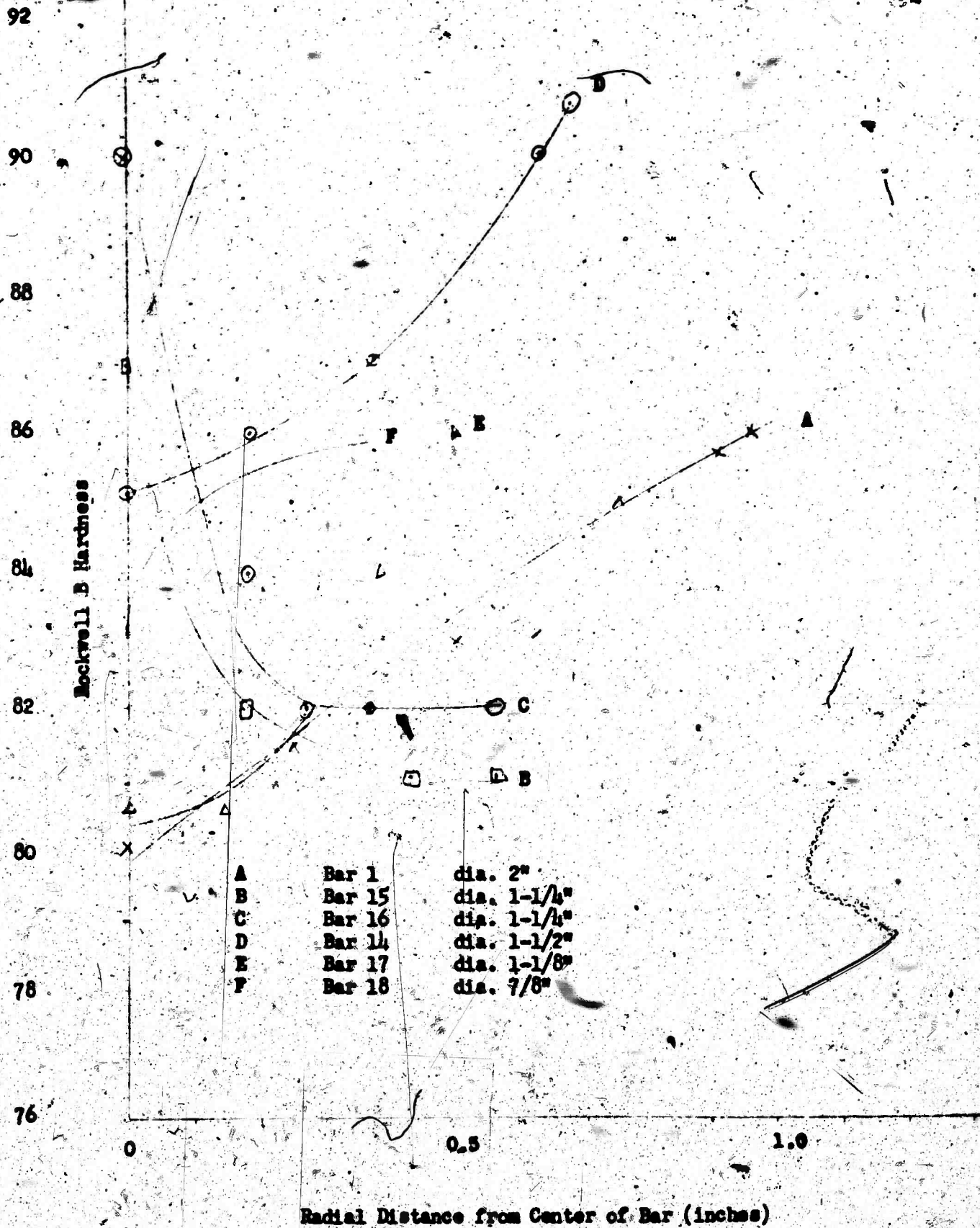
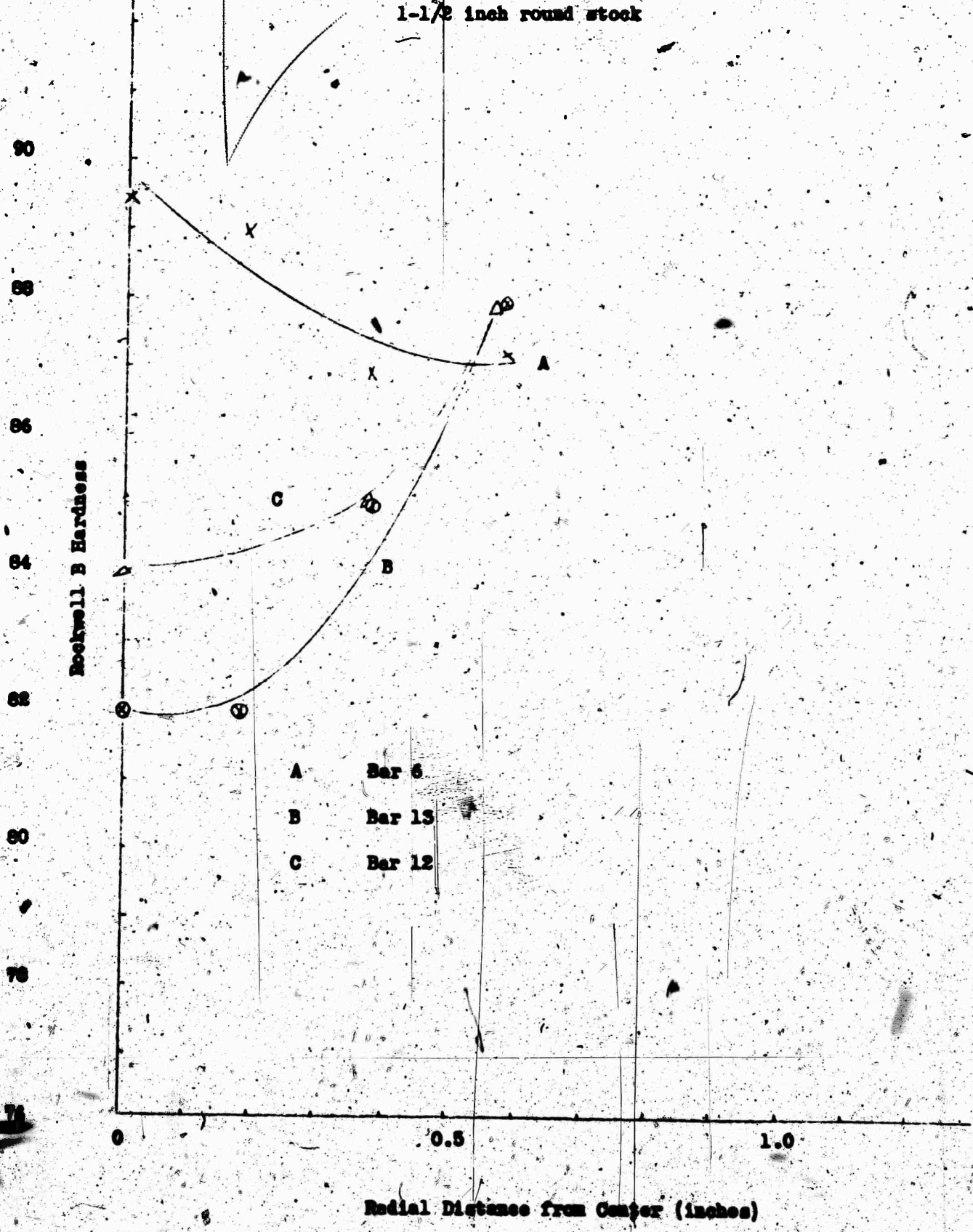


Figure 5

Hardness Traverse
1-1/2 inch round stock



A Bar 6
B Bar 13
C Bar 12

center hardness from bar to bar was found. These results indicate that in order for round stock to be suitable for the test piece, the effect of hardness variation over the range of 80-90 Rockwell B must prove to be negligible or that lack of control over hardness in this range can be tolerated.

(2) Uniformity of hardness in lengthwise direction in round bar

Inspection of the hardness traverses given in Table VII of the appendix shows that the hardness did not change appreciably for pieces cut from the same bar. The hardness gradient across the cross section as well as the hardness was found to vary from bar to bar. This indicates that it will be difficult to purchase commercial steel which will yield identical test pieces from bar to bar. The bars reported in this table were 12 inches long with the exception of Bar 16, which was three feet long.

(3) The effect of hardness is discussed in Paragraph F of this section.

C. Directional Properties of Round Stock

Any piping present in any of the round stock examined was not detectable by inspection of macroetched pieces, and if present at all must have capillary dimensions which are small in comparison with the size of hardness test dent and detonator dent. Piping does not seem to be a consideration in the evaluation of round stock.

On macroetching pieces of both flat and round bar stock there is observed the fibrous structure of the rolled steel. These fibers are oriented in the longitudinal direction in the bar. Test pieces oriented from round bars, therefore, are fired on in a direction parallel to that of the fibers, while a flat bar stock is logically cut into test pieces which are fired on transversely. Macroetching with

concentrated hydrochloric acid brings out lines of work hardening in cold rolled steel. Sample D in Figure 6 shows the fibers in a sectioned sample of round stock that was etched with concentrated HCl. Sample E in this figure is a corresponding section of flat bar stock. The firing of a detonator on a piece does not affect these lines. This is shown by the dented and undented piece in Figure 7.

D. Uniformity of Bar Stock

Data on hardness of bar stock across the cut cross sectional area are given in Tables XIII and XIV of the appendix. The hardness gradient in a given bar of cold rolled stock does not seem to be quite as great as in round stock, being 6 points for flat bar stock in contrast to 8 points for round stock on the Rockwell B scale for the samples examined. Bar number 28 which was an annealed tool steel, was quite uniform over the cut cross section and was the nearest thing to a homogeneous steel found. The variation in hardness from bar to bar of such steel was not investigated. This suggests, however, that annealing is one way in which a more homogeneous test piece can be obtained. Test pieces cut from such stock would involve the higher cost of annealed alloy steel which is around 9¢ per 5/8" thick test piece in contrast to under 2¢ for the same piece cut from 1018 cold rolled steel.

The investigation of the uniformity of hardness over the cross sectional surface of 1018 cold rolled round and bar stock indicated no special advantages of bar stock because of homogeneity.

E. Geometry of the Test Piece

(1) Thickness of test piece

The steel plate dent test could be most easily adapted to the

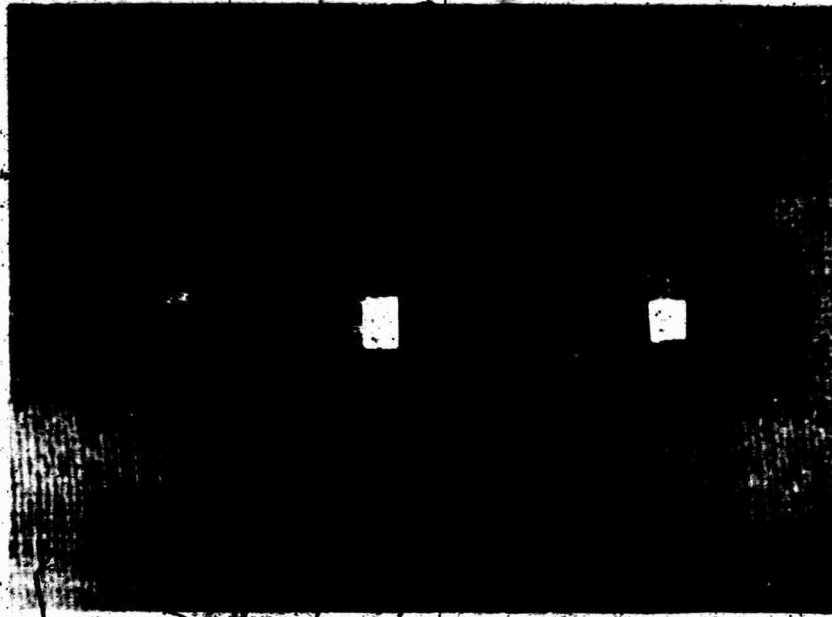


Figure 6

Crosssection of round (D) and bar (E) stock showing profile of dent made by MK-22 detonator.

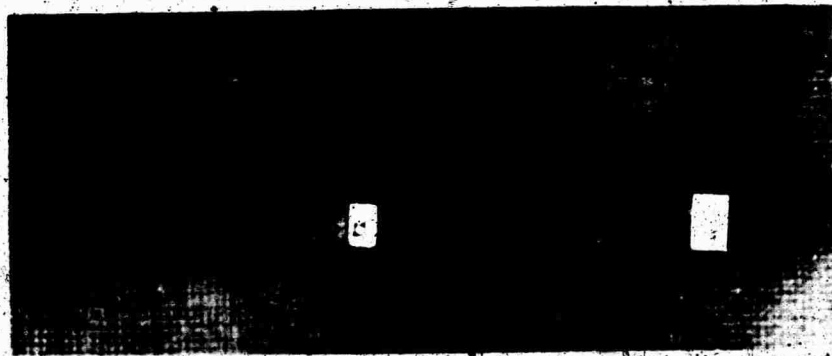


Figure 7

One dented (B) and one undented (G) piece of round stock 3/8 inches thick.

existing apparatus if the steel plate were as nearly the same size and shape as the original lead disc test piece as possible. This suggested an investigation of the smallest steel test piece that could be used.

Other factors being equal, the ultimate criterion as to whether a given size and shape of test piece is suitable is the correlation of the dent produced with the capacity of the detonator to set off explosives, regardless of whether or not the overall dimensions of the test piece are distorted in the dent test. Since such a correlation was beyond the scope of this research, and also because the measurement of dent depth is more precise when the overall dimensions of the piece are not affected by the firing of a detonator, the concept used in choosing the size of the smallest suitable piece was that of the infinitely large piece. That is, as long as the piece was not distorted, and the dent depth was the same as it would be in a large block, the size and shape of the piece was said to be satisfactory. Actually the largest piece tested was 1.219" diameter and 5/8" thick. The strongest stab detonator (MK22) did not distort this piece. Any piece smaller than this and which was fabricated from the same steel, that gave the same dent depth and no distortion of the piece was said to be satisfactory.

The data for dent tests on pieces of round stock 5/8", 3/8", 1/4" and 1/8" thick, and flat bar stock, 5/8", 3/8", 5/16", 3/16" and 1/8" are given in Tables IX, X and XI of the appendix. The results of the tests are summarized in Table II.

These results indicate that a piece 3/8" thick is sufficiently thick for use in the dent test for use with detonators no stronger than the MK-22-0. A piece 5/8" in thickness is well over this minimum thickness and is recommended as the piece thickness for the steel plate dent test.

* Table II

Dent Produced in 1018 Steel Test Pieces by Detonator MK-22-0

Piece Thickness	Dia. or edge of square	Steel	No. of Tests	Av. Hardness, Rockwell B	Av. dent depth (mils)	Mean Deviation	Gross Distortion of Piece
Round Stock							
5/8"	1.219" dia.	1018 cold rolled	24	90	14.3	0.25	None
3/8"	"	"	24	90	14.3	0.20	None
1/4"	"	"	25	90	14.3	0.33	1-1/2 mils bulge on bottom
1/8"	"	"	24	90	13.4	0.40	2-1/2 mils bulge on bottom
Flat Bar Stock							
5/8"	0.352" edge	1018 cold rolled	22	82	14.7	0.4	None
3/8"	"	"	21	87	14.6	0.3	None
5/16"	"	"	23	87	14.8	0.5	None
3/16"	"	"	9	84	14.6	0.9	Bulge on bottom
1/8"	"	"	5	94	13.2	0.5	Bulge on bottom

The mean deviation of the dents produced in bar stock was found to be higher than for round stock. The round test piece (diameter 1.219") is larger than the square test piece (diagonal 1.219"). Around the dent a ripple in the surface of around 0.1 mil is produced which extends somewhat further out from the dent on the square test piece. It was found that measurement of height of the original surface was somewhat easier in the case of the round test piece because of less ripple in the dented surface. The difference in mean deviation of dent depths for round and square test pieces is attributed to this rippling in the original surface. The lower deviation in dent depth measurements on round stock is one advantage in the use of round stock as a test piece.

Figure 8 shows sections of round test pieces on which MK-22 detonators have been fired. Figure 9 shows sections of square pieces on which detonators from the same batch were fired. Sample G of Figure 7 shows a piece before denting. The samples were macroetched with concentrated HCl in order to bring out the work hardened areas. The hardness in the bottom of the dent was found to be 8 to 10 points higher than the original piece hardness. Two short lines below the dent in pieces A and B of Figure 8 indicate work hardening near the base of the piece. These pieces were distorted by the detonation. These lines were absent, however, in pieces C and D (Figure 8) which were not distorted by the detonator.

Magnification of the affected area in Piece A of Figure 8 is shown in Figure 10. The dark area represents metal under stress that etched more rapidly than the surrounding area. The profile of a dent of an MK 56 magnified 20x is shown in Figure 11. Every dent is a little different; some contain a low spot as in Figure 11. Some have a flat bottom and some are quite irregular and unsymmetrical.

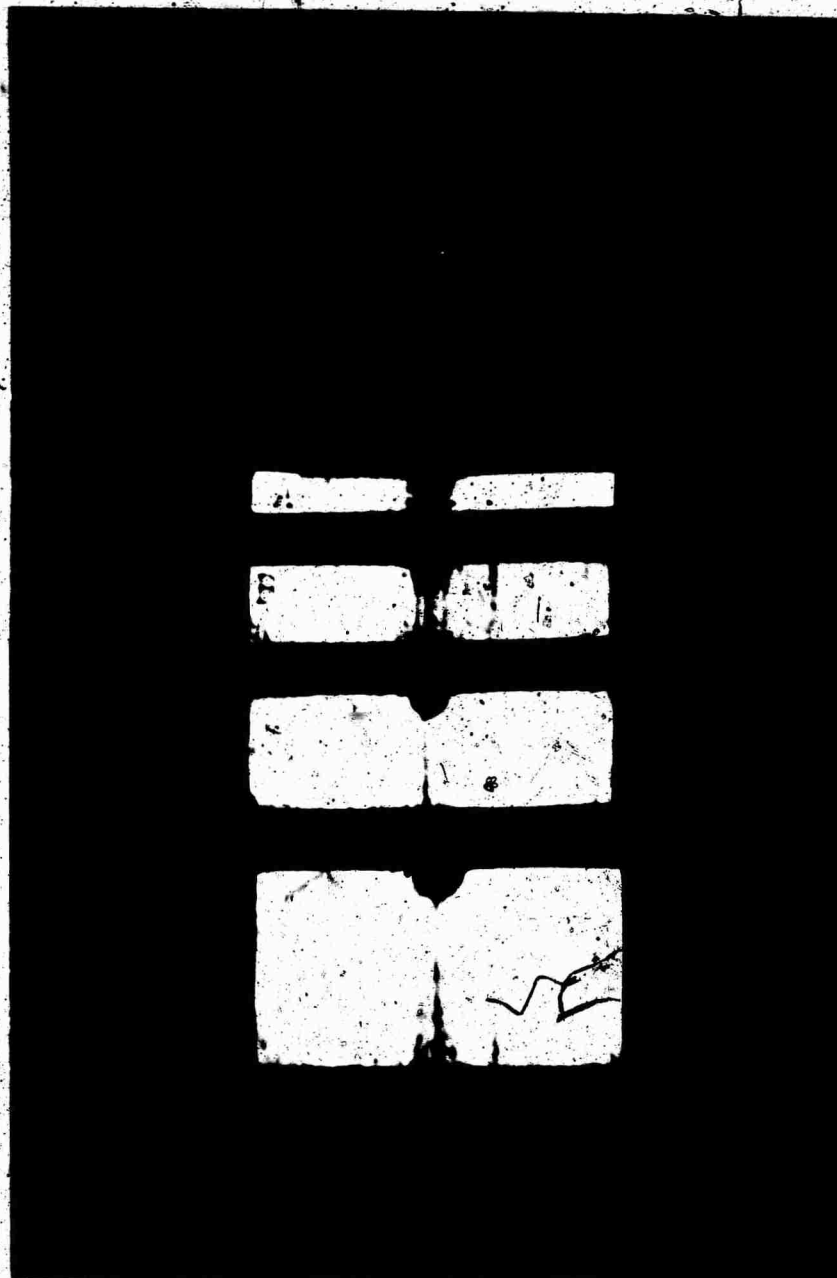


Figure 8

Pieces of round stock dented by the 17-⁰⁰ detonator.
A, 1/8 inches thick; B, 1/4 inches thick; C, 3/8 inches
thick; D, 5/8 inches thick.



Figure 9

Pieces of flat bar stock, dented by MK-22-0 detonator

L, 1/8 inches thick; M, 3/16 inches thick;

N, 5/16 inches thick; O, 3/8 inches thick;

P, 5/8 inches thick.



Figure 10

Enlargement of macroetched section of sample A in figure 6.



Figure 11

Photograph of profile dent made by detonator MK-56
enlarged 20X.

(2) Assembly of Anvil and Test Piece in the Machine

As shown in Figures 2 and 3, either a $5/8$ " thick round test piece (1.217" diameter) or a $5/8$ " thick square test piece (0.862" side, 1.217" diagonal) can easily be centered in the machine on the anvil sketched in Figure 1. The plastic holder may then be centered on the square or round test piece. There seems to be no problem alignment of the anvil, square or round test piece, plastic holder, firing pin and ball drop mechanism. This assembly is shown in Figures 2 and 3.

F. Effect of Hardness

There are two ways in which a test piece can be machined from bar stock. The detonator may be fired on the mill surface or the cut cross section of the square bar stock may be ground and the detonator fired on this surface. Firing on this latter surface is similar to firing on a test piece cut from round stock in that the direction of firing is parallel to the direction of the fiber.

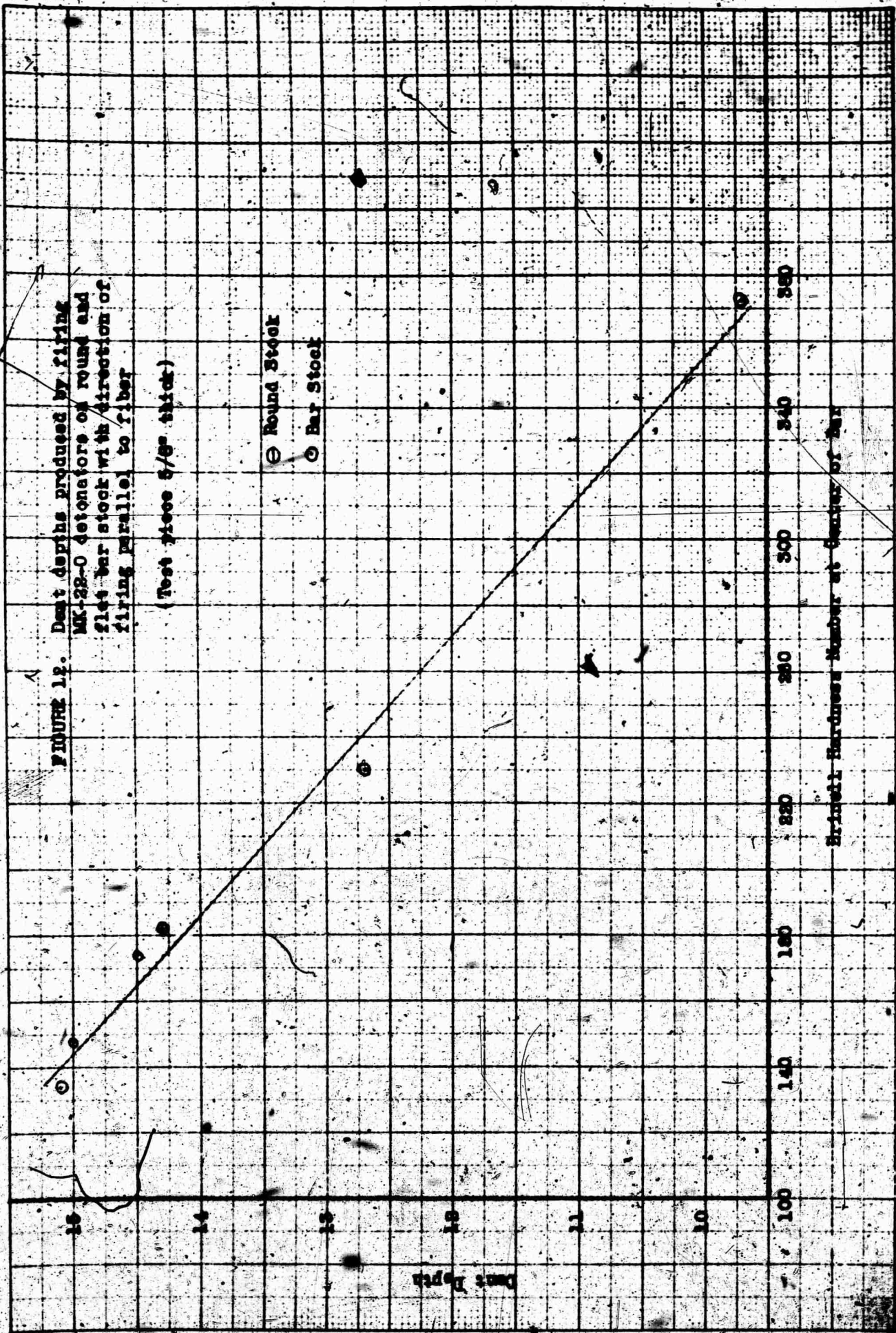
The center hardness throughout a given bar of round or square stock was found to be rather uniform in hardness as shown in Tables XIII and XIV of the appendix. This arrangement means that the center of the dent will be located in steel having the same original hardness regardless of the depth of the dent. This is not so when a detonator is fired on the mill surface since the hardness is changing in the direction of the dent.

Figures 12 and 13 show that a reasonable correlation between hardness and dent depth existed when MK 22-0 detonators were fired at the center of a ground cross sectional surface. When the detonators were fired on the mill surface, also prepared by surface grinding, as shown in Figure 13, the correlation of either surface or center hardness with dent depth was poor. As shown in paragraph A of this section, the center hardness of the

FIGURE 12. Dent depths produced by firing
 MK-22-O detonators on round and
 flat bar stock with direction of
 firing parallel to fiber

(Test piece 5/16" thick)

○ Round Stock
 ⊙ Bar Stock

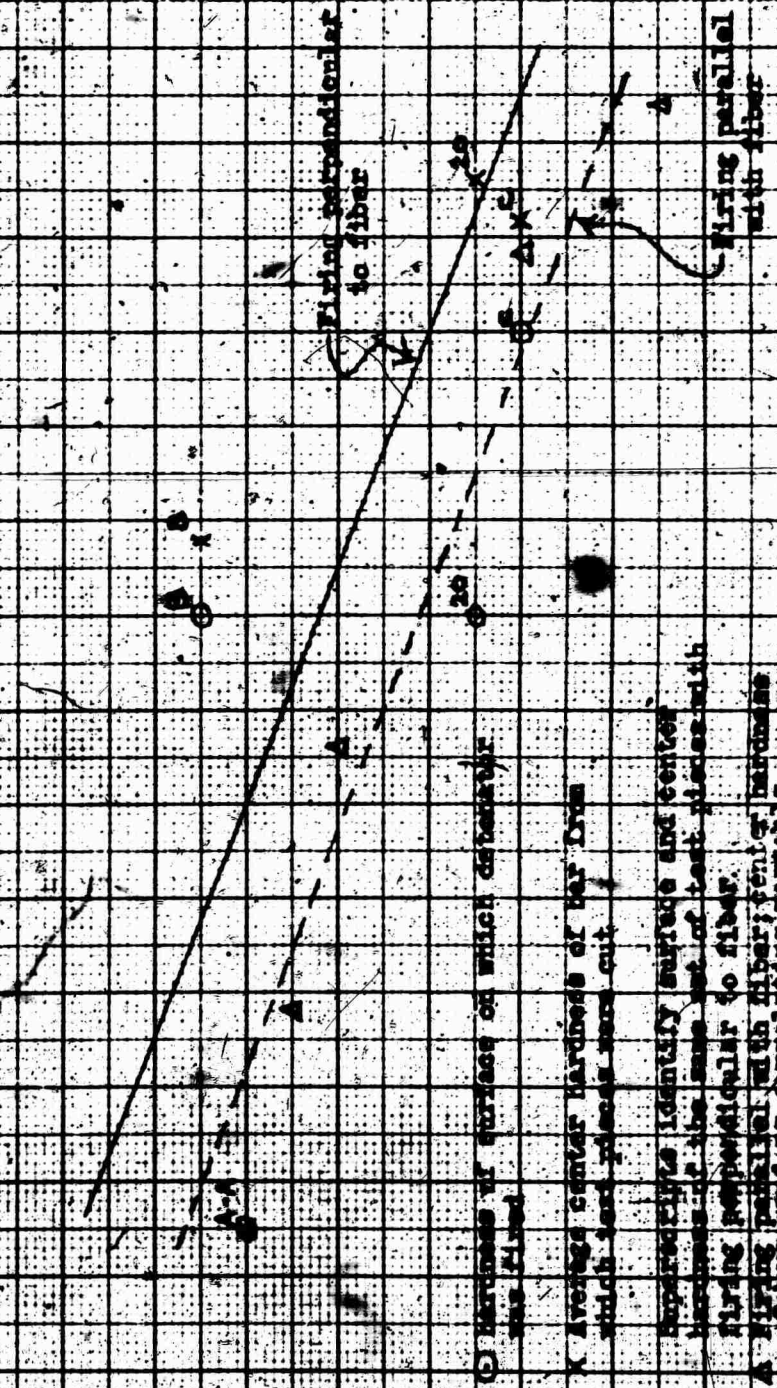


Brinell Hardness Number at Center of Bar

Dent Depth

Figure 15. Test depths produced by MS-22-0 by firing on
 a prepared III surface perpendicular to the
 fiber direction and on cross sectional surface
 parallel to fiber direction.

(Test pieces 5/8" thick)



○ Hardness of surface on which deflection
 was filed

X Average center hardness of bar from
 which test pieces were cut

Superficially identify surface and center
 hardness of the same set of test pieces with
 firing perpendicular to fiber.

▲ Firing parallel with fiber; center hardness
 of bar used is correlating variable

Brinell Hardness Number

bar seems to exert considerable influence on the dent depth even when the detonator is fired on the mill surface.

G. Preparation of Surface of the Test Piece

A test piece cut from round stock is logically ground to smoothness with a surface grinder to provide a flat surface for denting. One of the possible advantages in use of flat bar stock for the test piece lies in the possible use of the flat surface with only a minor cleaning operation. It was found that the flat surface of a piece of flat bar stock $7/8"$ x $5/8"$ and $7/8"$ x $7/8"$ varied in height up to 1.5 mils. These pieces would rock slightly during the measurement of dent depth and add to the uncertainty of the measurement. Cleaning by light sanding was found not to affect the regularity or irregularity of the surface.

This loss of precision is reflected in the standard deviation of the detonators. Some pertinent data showing dent depth and standard deviations for test pieces cut from flat bar stock are as follows:

Table III

Effect of Test Piece Preparation on Precision of Measurement

Surface Preparation	Detonator	No. of Shots	Dent Depth	Standard Deviation
Flat surface as received with cleaning by light sanding Surface hardness 82	MK-56-0	22	12.4	1.0
	MK-22-0	9	15.7	1.5
Ground flat on surface grinder Surface hardness 82	MK-22-0	22	14.7	0.4

In order to evaluate during this research the inherent capacity of the test for evaluation of detonators, maximum precision was achieved by surface grinding all samples. Whether or not test pieces must undergo a surface

grinding operation for a production test is then dependent on the precision desired.

When the cross sectional surface of bar stock is to be used as the test piece the situation is similar to round stock where the cut surface must be ground flat and smooth.

2. Summary and Comparison of Possible Test Pieces

The relative advantages and disadvantages in use of three types of test pieces are compared in Table IV

Comparison of Test Pieces Cut from Round and Bar Stock

Round Stock

Flat Bar Stock

Flat Bar Stock

with cross sectional surface used for test surface

with one of the flat mill surfaces used for the test surface

Preparation of Test Surface
Requires a surface grinding operation for preparation of a flat smooth surface.

Surface does not have to be ground but poor precision unless surface is flattened by surface grinding.

Cutting piece to size

1. Can be turned to correct diameter on lathe and easily cut off

1. 7/8" square stock must be ground on at least 2 sides to produce a piece having diagonals of 1.219" for use with existing anvil and plastic holder.

1. 7/8"x5/8" bar may be cut and pieces ground to either a square or rectangle having diagonals of 1.219".

2. Anvil and plastic detonator holder can be changed to take commercially available diameter of round stock.

2. Diameter of depression in anvil and plastic detonator holder must be increased to 1.239" to accommodate piece sliced from 7/8" square bar stock.

2. The diameter of the anvil depression and plastic holder may be increased to take 7/8" square test piece cut from 7/8"x5/8" stock.

3. The corners of the piece cut from 7/8" square stock may be ground slightly to reduce the piece diagonal to 1.219".

3. The corners of the piece cut from 7/8" square stock may be ground slightly to reduce the piece diagonal to 1.219".

3. The corners of the piece cut from 7/8" square stock may be ground slightly to reduce the piece diagonal to 1.219".

Centering

Pieces may be easily centered in the test assembly.

Pieces may be easily centered in the test assembly.

Pieces may be easily centered in the test assembly.

Measurement of dent depth

Readings are least affected by ripple around dent.

Readings more affected by ripple in surface around dent but are satisfactory.

Readings affected by ripple in surface around dent but are satisfactory.

Table IV (Contd.)

	Round Stock	Flat Bar Stock with gross sectional surface used for test surface	Flat Bar Stock with one of the flat mill surfaces used for the test surface
--	-------------	---	---

Homogeneity of cold rolled stock by hardness testing.	max. variation of hardness 10 points bar to bar; 8 points within a single bar.	Max. variation of hardness 10 points bar to bar; 8 points within a single bar.	max. variation of hardness 10 points bar to bar; 8 points within a single bar.
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Hardness	Reasonable correlation between center hardness of bar and dent depth.	Reasonable correlation between center hardness of bar and dent depth.	No apparent correlation between surface hardness and dent depth. Hardness gradient appears to be variable.
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Examination of a single flat bar indicated that an annealed tool steel was especially uniform in hardness.

IV. SENSITIVITY OF STEEL PLATE DENT TEST FOR EVALUATION OF DETONATORS

A. Criterion for Acceptance or Rejection of a Detonator

It would be desirable if a dent depth could be set which if not exceeded would be the basis of rejection of a single detonator or group of detonators. The setting of any such depth is complicated by its dependence on the hardness of the test piece, and a large standard deviation for a lot of detonators.

An investigation was undertaken to determine the feasibility of specifying such a rejection test for detonators. The results, which are discussed in the following sections, indicate that the sensitivity of the test for distinguishing detonators of various strengths is low but can be made reasonably sensitive by rather strict specifications.

B. Effect of Type of Detonator on Dent Depth

During the course of these investigations, three types of detonators were used. These are listed below along with the dents produced in steel having a Rockwell B hardness of 82.

MK-22-0	Stab	14.7	(22 shots)
MK-56-0	Stab	12.4	(22 shots)
MK-58-0	Flash	4.2	(22 shots)

The strongest stab detonator which was to be investigated was the MK-22-0, the weakest stab detonator the MK-56-0. The dent depths differed by 2.3 mils from the weakest to the strongest. The volume of the dents and thus the work output of these two detonators, however, were considerably different since the diameter of the dent was approximately that of the diameter of the detonator casing. This is 0.160" for the MK-22-0 and 0.1115" for the MK-56-0. This shows that for evaluation of detonators, the dent depth should be compared only for detonators of the same diameter.

The weakest detonator tested was the MK-58-O flash detonator. This detonator produced a measurable dent of 4.2 mils with a standard deviation of 0.3 mils.

C. Sensitivity of Test for Distinguishing Detonators of Various Strengths

The following MK-22-O type detonators were supplied by NOL. Throughout this report these detonators are referred to by the per cent tetryl based on 160 mg of tetryl being 100% of full charge.

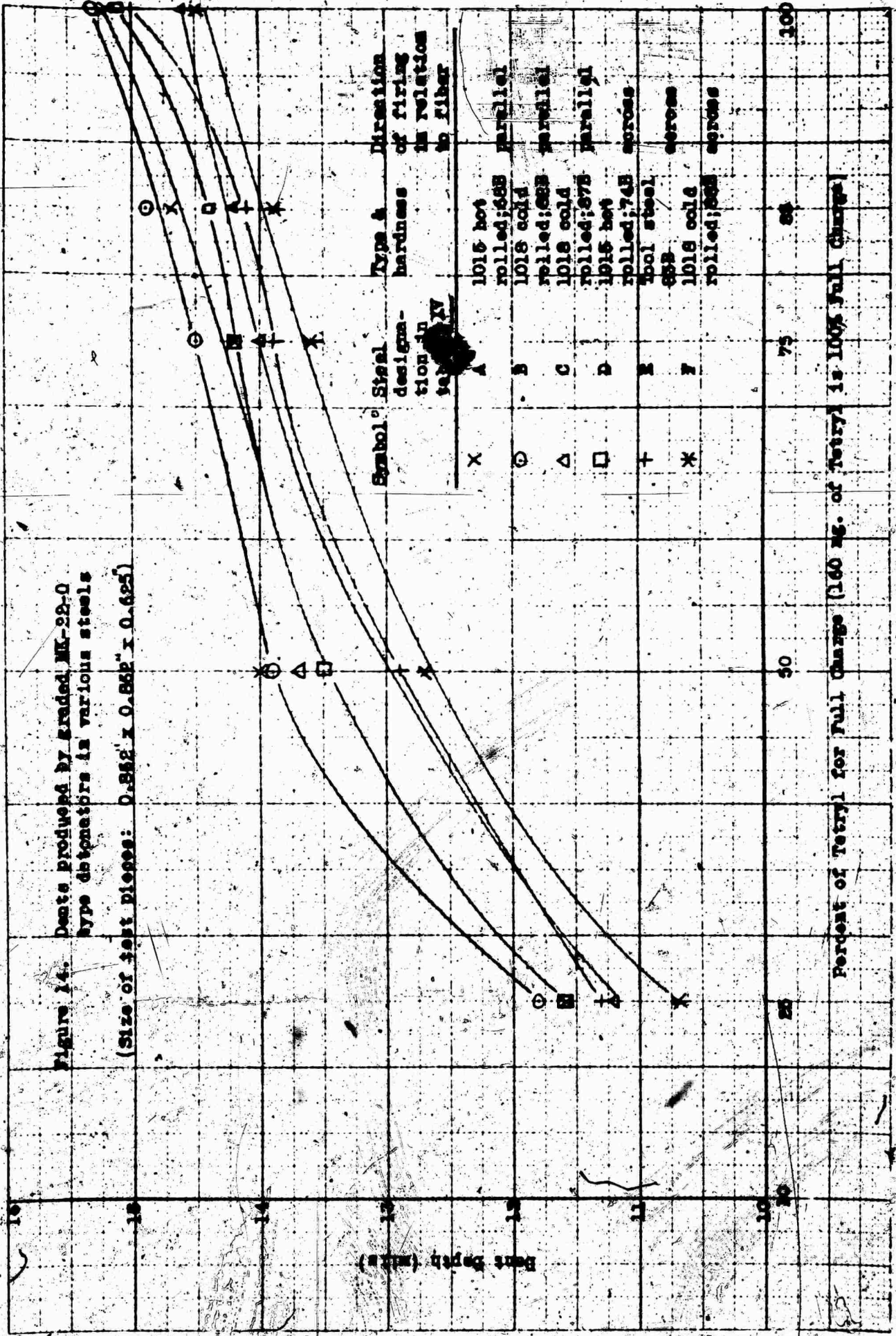
% of full charge	100%	85%	75%	50%	25%
PbN ₆ Priming Mix	52	52	52	52	52
PbN ₆	118	118	118	118	118
Tetryl	80	68	60	40	20
Tetryl	80	68	60	40	20

The total quantity of tetryl is the sum of the two values for tetryl in the above table. The two values are reported to indicate pressing in two stages.

These detonators were fired on eight different types of steels. These data are given in Table XV of the appendix. The average dent depths are given in Table XVII in the appendix with the number of shots on which the average was based in parenthesis. The averages in Table XVII include data from Table XVI of the appendix which represents another lot of 100% detonators.

After 4 detonators of each per cent group had been fired on steels A to F, 3 on steel G and 2 on Steel H, the remainder were fired on steel B in order to increase the significance of the mean for one of the steels. The results given in Table XVII of the appendix are plotted in Figure 14 on the following page. A separate curve is drawn for each of the different steels.

Figure 14. Dents produced by graded MK-22-0 type detonators in various steels
 (Size of test pieces: 0.862" x 0.862" x 0.625")



Percent of Tetryl for Full Charge (160 mg. of Tetryl is 100% Full Charge)

The effect of hardness of steel on the dent produced by the 100% NE-22-0 detonator is shown in Figure 12.

The low sensitivity of the test for detonators containing over 50% of full charge is apparent from Figure 14. The points in this figure are all averages of at least 4 shots. The line for Steel B is based on averages of 6 to 20 shots. An examination of the single shots reported in Table XV of the appendix shows that the greatest depth for 50% detonator was 14.5 in the hardness range 80 to 90. This was for one shot out of 22. The shallowest dent for a 100% detonator in the same hardness range was 14.4 which is for one shot out of 20. Thus by setting the acceptable dent depth at 14.4, one out of twenty 50% detonators would be accepted as 100% detonators.

In the case of the 75% detonators, 4 out of 18 exceed a depth of 14.4 mils and would be accepted as 100% detonators.

In the case of the 85% detonators, 11 out of 22 detonators would have exceeded a depth of 14.4 mils and been accepted as 100% detonators.

Had a dent depth of 14.4 been chosen with a specification that steel hardness may vary from 80 to 90, then on the basis of a number of 100% detonators greater than 20 it is statistically probable that several 100% detonators would fail to produce dent of 14.4 mils and therefore would be rejected. The data show it is possible to select a dent depth such as 14.4 mils which will accept over 95% of the 100% detonators but reject 95% of the 50% detonators.

Whether or not this constitutes a satisfactory rejection test depends on correlation of the test operated in this manner with the capacity of the detonator to initiate explosives. Such an investigation is beyond the scope of this research.

-3-

The effect of raising the required dent depth standard from 14.4 mils is to increase the number of 100% detonators rejected as well as the number of 85% and 75% detonators rejected. The data indicate that the test when based on rejection of a detonator by a single shot has poor capacity to reject detonators having a strength of 75% full charge and over.

The fact that a 75% detonator can produce a dent greater than some 100% detonators seems to be at least in part due to the geometry of the dent. Low dents are smooth and take the probe well. Some dents have been observed to be irregular so that the probe would not fit into the lower part of the dent. Difference in dent shape, therefore, may explain the overlap in dent depths from 100%, 85% and 75% detonators. The volume of the dent, which unfortunately cannot be measured practically, should prove to be a more reliable criterion of detonator strength.

There are two ways in which the test can be made more sensitive and one way in which it is made less sensitive.

By narrowing the acceptable hardness range or distinguishing between averages of groups of detonators the test may be made more sensitive. In contrast to this, anything that acts to increase the standard deviation such as not grinding flat the surface of the samples, or too hastily probing for maximum dent depth, would have the effect of increasing the acceptance rate of low power detonators as equivalent 100% full charge, and rejecting detonators equivalent to 100% full charge.

The hardness range could be narrowed by purchasing from a supplier only those bars of steel which met certain hardness requirements. The hardness throughout many bars of 1018 and 1020 cold rolled steel falls between 81 and 85. Harder 1018 and 1020 steels can be annealed to yield hardness in this range. Annealed alloy tool steel can be purchased at a steel cost of around 9¢ per test piece.

D. Standard Deviation of the Detonators

The standard deviation of detonators fired on 5/8" test pieces was calculated and tabulated in Table XIX of the appendix. These standard deviations were calculated from results obtained by two operators. The standard deviations for two lots of 100⁺ detonators were pooled. Furthermore, the standard deviations were calculated from tests in which the surface of all test pieces were ground flat.

These standard deviations, therefore, will probably be different than those calculated when operators, lots of detonators, preparation of test piece, and dent depth measuring apparatus are completely randomized. The standard deviations obtained in this research serve to evaluate maximum sensitivity of the dent test.

The estimate of the standard deviation for the 100% detonators based on 22 degrees of freedom was 0.6 mils. The estimate based on 103 shots 0.5 mils. These standard deviations take into account the precision in measuring dent depth. Following are tables of the least highly significant difference in means based on the Student t Tables* at the 1% level.

Table V

Least Significant Difference in means of Dent Depths

No. of shots per lot of detonators	15					25				
Degrees of Freedom	15 + 15 - 2 = 28					48				
Standard Deviation (mils)	1.5	1.0	0.6	0.5	0.3	1.5	1.0	0.6	0.5	0.3
Least Highly Significant Difference in means	1.5	1.0	0.6	0.5	0.3	1.1	0.8	0.5	0.4	0.3

* Villars, D.S., "Statistical Design and Analysis of Experiments for Development Research", p.378, Mac C. Brown Co., (1951)

The standard deviation of 0.5 mils for the 100 detonators indicates that the steel used for the test piece is highly significant since the difference in means varies from 14.6 to 15.2 in samples A, B and C and from 14.5 to 15.1 with samples D, E and F.

Statistical analysis of steels A through F of Table XV of the appendix and all groups of detonators in this table is summarized below. Only the first four readings in a column for each subclass were used in order to make the table symmetrical.

Table VI

Results of Variance Analysis of Detonators and Steels A, B, C, D, E, & F, from Table XV of Appendix

	Degrees of Freedom	Sum of Squares	Variability	Variance	F from tests	Critical value of F at 1% level from test tables
(Grand Total of 120 readings) ²						
120		22424.268				
Total Dent Tests (120)	119	22806.360	382.092	3.21		
Subclasses (30)	29	22690.600	256.330			
Between Detonators (5)	4	22625.910	201.642	5.03	3.6	3.5
Between Steels (6)	5	22436.604	12.336	2.47	1.8	3.2
Interaction	20		42,352	2.11	1.5	2.0
Within Subclasses	90		125.66	1.40		

Sample calculations showing how this table was formed are given on page 1 of the appendix.

This analysis indicates qualitatively that the difference in detonators is considerably greater than the difference in steels. Since F for the

detonators exceeds the critical value of 3.5, the difference in detonators is highly significant but any difference in steel is not conclusive by examination by the F. test at the 1% probability level since the experimental F does not exceed the critical value. As the result of a different analysis, it was mentioned on page 37 that the t test does detect an effect of the steel.

The interaction effect is not relevant to this evaluation since any relation between groups other than addition and subtraction of the same constant will show interaction. The correlation of Figure 12 indicates dents are inversely proportioned to hardness and such a relation would show interaction in a statistical analysis of data.

V. TESTING OF FLASH DETONATORS

A. The Flash Detonator Holder

As a result of investigation of stab detonators, it had been found that a test piece of $5/8$ " thick and 1.219 " in diameter or diagonal could be used for the steel plate dent test. An experimental flash detonator holder was designed. For investigative purposes only the part shown in Figure 15 was machined at NOB. One group of 50 was machined for the X-22-C detonator and another group of 50 was machined for the MK-58-0 detonator. A standard plastic holder for the 102 primer was fitted on top of the machined detonator holder to form the complete flash detonator and primer plastic holder assembly. In practice this complete detonator and primer holder would be injection molded as one piece, having a wall thickness of $0.5" \pm 0.01"$.

B. Anvil for Testing Flash Detonators

Since the height dimension of the plastic holders will be different by as much as 0.45 " it will be necessary to use different anvils for holders of different heights. The overall anvil height of the anvil shown in Figure 1 when used with flash detonator holders shown in Figure 15 is given in the table below. This height puts the top of the plastic holder at the same height as the top of the holder for the stab detonator.

Table VII

Anvil Dimensions for Flash Detonators

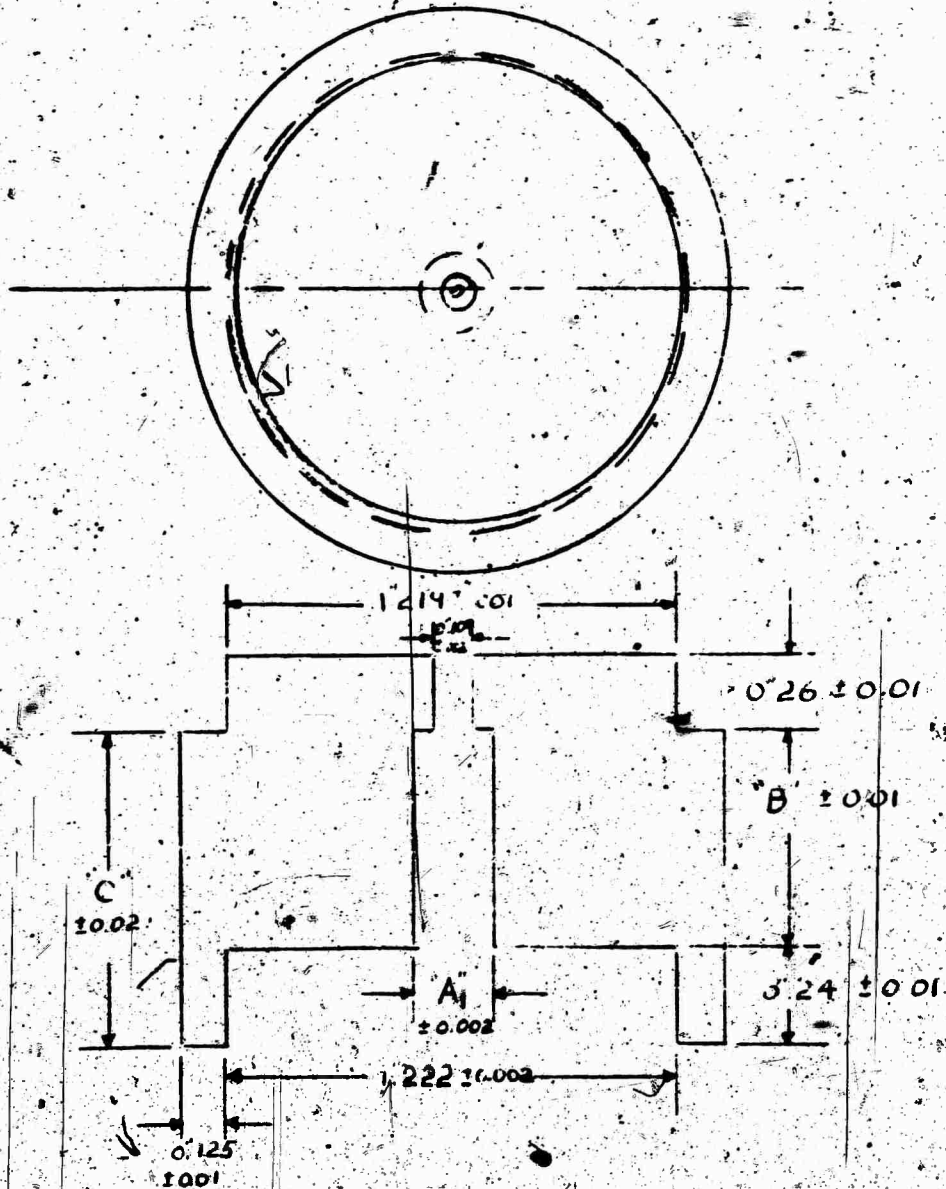
Detonator	Primer	Overall height of anvil shown in Fig. 1 for test piece thickness of $5/8$ "
X-22-0	102	$1-1/8$ "
MK-58-0	102	$1-9/16$ "

An alternative assembly for the flash detonator test is that which was actually used in this research. One anvil is machined and hardened having a height $1-1/8$ " and centering spacers up to $1/2$ " in thickness are

Figure 15

Base Piece for Flash Detonator Holder

(Flash detonator holder is formed by mounting Firing pin and Detonator Holder for MK102 primer (Drawing No. 398475, Naval Ordnance Laboratory) on top of this piece.)



Material: Polystyrene or Equivalent

Used with Detonator MK:	Dimensions		
	"A"	"B"	"C"
22	0.196	0.570	0.820
56	0.128	0.135	0.385

added beneath the anvil to bring the anvil to the desired height.

C. Results from Firing Flash Detonators

Twenty-two MK-22-0 detonators and twenty-three MK-58-0 were fired by stabbing the 102 primer located 0.2" above the detonator in the plastic holder assembly. The data are given in Table VIII in the appendix. Test pieces were all ground flat. The dent depth and standard deviations of MK-22-0 flash and stab detonators are given below for a test piece hardness of #2.

Table VIII

Comparison of MK-22-0 Flash and Stab Detonators

	No. of shots	Dent Depth (mils)	Estimated Standard Deviation (mils)
MK-22-0 Flash	22	14.1	0.5
MK-22-0 Stab	22	14.7	0.5

Test Piece Hardness - 82B; all pieces cut from same bar.

The difference in these averages is statistically significant at the 1% probability level. The difference may be due to holder design and method of initiating the detonator. Investigations as to the cause of this difference were not carried out. This means that the rejection of detonators must be based on a criterion which will be different for flash and stab detonators. The value of the dent depth which must be exceeded must be picked from experience since the relation between the steel plate dent test and performance of the detonator must be known or studied simultaneously with operation of the test.

D. Recommended Flash Detonator Holder

Testing of flash detonators with the holder described in Figure 15 suggested that the holder sketched in Figure 16 should prove to be

suitable for testing of flash detonators. Anvils having the dimensions given in Table VII must be used with this detonator holder.

Si

APPENDIX

TABLE 7X

DENT TEST DATA

Piece No.	Steel	Shape	Detonator	Confinement	Hardness	Depth Mils.
1	1020	5/8" bar	56-0	Plastic	Class hardness of samples 1 through 34; 82.9 Rockwell B scale	12.0
2	"	"	22-0	"		13.8
3	"	"	22-0	"		14.2
4	"	"	56-0	"		12.0
5	"	"	56-0	"		11.4
6	"	"	56-0	"		12.8
7	"	"	56-0	Brass sleeve		17.4
8	"	"	56-0	Counterbored plastic		14.0
9	"	"	56-0	Plastic		13.5
10	"	"	56-0	"		14.0
11	"	"	56-0	"	11.4	
12	"	"	56-0	"	11.8	
13	"	"	56-0	"	14.2	
14	"	"	56-0	"	12.0	
15	"	"	56-0	"	11.6	
16	"	"	56-0	"	11.8	
17	"	"	22-0	Steel block	25.5	
18	"	"	56-0	Plastic	11.9	
19	"	"	56-0	"	13.6	
20	"	"	56-0	"	12.3	
21	"	"	56-0	"	11.9	
22	"	"	56-0	"	14.0	
23	"	"	56-0	"	11.2	
24	"	"	56-0	"	11.7	
25	"	"	56-0	"	11.4	
26	"	"	56-0	"	11.6	
27	"	"	56-0	"	14.4	
28	"	"	22-0	"	17.0	
29	"	"	22-0	"	18.7	
30	"	"	22-0	"	16.7	
31	"	"	22-0	"	16.4	
32	"	"	22-0	"	14.6	
33	"	"	22-0	"	15.6	
34	"	"	22-0	"	14.2	
35	1013	1.219" dia x 5/8" rd.	22-0	"	Av. center hardness, samples 35 through 132, 90.2 Rockwell B scale	14.6
36	"	"	22-0	"		14.8
37	"	"	22-0	"		14.0
38	"	"	22-0	"		14.2
39	"	"	22-0	"		14.4
40	"	"	22-0	"		14.3
41	"	"	22-0	"		14.1
42	"	"	22-0	"		13.9
43	"	"	22-0	"		14.3
44	"	"	22-0	"		14.2
45	"	"	22-0	"		14.3
46	"	"	22-0	"		14.0

TABLE IV (Contd.)

DETT TEST DATA

Piece No.	Steel	Shape	Detonator	Confinement	Hardness	Depth, in.
47	1018	1.219" dia. x 5/8" rd.	22-0	Plastic		14.8
48	"	"	22-0	"		15.4
49	"	"	22-0	"		14.2
50	"	"	22-0	"		14.5
51	"	"	22-0	"		13.7
52	"	"	22-0	"		14.5
53	"	"	22-0	"		14.4
54	"	"	22-0	"		14.2
55	"	"	22-0	"		14.2
56	"	"	22-0	"		14.1
57	"	"	22-0	"		14.2
58	"	"	22-0	"		14.1
59	"	"	22-0	"		14.2
60	1018	1.219" dia. x 3/8" round	22-0	"		14.5
61	"	"	22-0	"		14.2
62	"	"	22-0	"		14.4
63	"	"	22-0	"		14.0
64	"	"	22-0	"		14.6
65	"	"	22-0	"		14.0
66	"	"	22-0	"		14.4
67	"	"	22-0	"		14.2
68	"	"	22-0	"		14.2
69	"	"	22-0	"		14.3
70	"	"	22-0	"		14.2
71	"	"	22-0	"		14.7
73	"	"	22-0	"		14.1
74	"	"	22-0	"		13.9
75	"	"	22-0	"		14.1
76	"	"	22-0	"		14.4
77	"	"	22-0	"		14.5
78	"	"	22-0	"		14.3
79	"	"	22-0	"		13.8
80	"	"	22-0	"		13.8
81	"	"	22-0	"		14.6
82	"	"	22-0	"		14.4
83	"	"	22-0	"		14.5
84	1018	1.219" dia. x 1/4" round	22-0	"		14.6
85	"	"	22-0	"		14.3
86	"	"	22-0	"		13.4
87	"	"	22-0	"		14.3
88	"	"	22-0	"		14.5
89	"	"	22-0	"		14.4
90	"	"	22-0	"		14.4
91	"	"	22-0	"		14.9
92	"	"	22-0	"		14.3
93	"	"	22-0	"		14.5
94	"	"	22-0	"		13.8

TABLE IX (Contd.)

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DENT TEST DATA

Piece No.	Steel	Shape	Detonator	Confinement	Hardness	Depth, mils.
95	1018	1.219" dia. x 1/4", round	22-0	Plastic		14.7
96	"	"	22-0	"		14.1
97	"	"	22-0	"		14.1
98	"	"	22-0	"		14.0
99	"	"	22-0	"		13.6
100	"	"	22-0	"		13.9
101	"	"	22-0	"		13.3
102	"	"	22-0	"		14.2
103	"	"	22-0	"		13.8
104	"	"	22-0	"		14.6
105	"	"	22-0	"		14.6
106	"	"	22-0	"		14.7
107	"	"	22-0	"		14.3
108	"	"	22-0	"		15.1
109	1018	1.219" dia. x 1/8", round	22-0	"		13.3
110	"	"	22-0	"		13.6
111	"	"	22-0	"		13.3
112	"	"	22-0	"		14.2
113	"	"	22-0	"		13.7
114	"	"	22-0	"		14.7
115	"	"	22-0	"		12.8
116	"	"	22-0	"		13.8
117	"	"	22-0	"		13.1
118	"	"	22-0	"		13.4
119	"	"	22-0	"		13.8
120	"	"	22-0	"		12.5
121	"	"	22-0	"		13.3
122	"	"	22-0	"		13.4
123	"	"	22-0	"		14.4
124	"	"	22-0	"		13.0
125	"	"	22-0	"		13.5
126	"	"	22-0	"		13.5
127	"	"	22-0	"		13.8
128	"	"	22-0	"		14.2
129	"	"	22-0	"		13.0
130	"	"	22-0	"		13.1
131	"	"	22-0	"		13.1
132	"	"	22-0	"		12.3

Table X

DENT TEST DATA FOR TEST PIECES CUT FROM
FLAT BAR STOCK

Detonator MK-22-0
Confinement - Plastic Holder

Piece No.	Steel	Shape	Rockwell Hardness	Depth (mils)
150	1018 cold rolled bar stock 7/8" x 5/8" Bar No. 20	Square; side 0.862" thickness 5/8"	Av. 82B	14.7
151	"	"	"	13.8
152	"	"	"	11.5
153	"	"	"	13.8
154	"	"	"	14.9
155	"	"	"	15.2
156	"	"	"	14.3
157	"	"	"	14.5
158	"	"	"	15.2
159	"	"	"	14.7
160	"	"	"	14.8
161	"	"	"	14.8
162	"	"	"	13.8
163	"	"	"	15.2
164	"	"	"	14.7
165	"	"	"	15.6
166	"	"	"	14.1
167	"	"	"	13.8
168	"	"	"	15.7
169	"	"	"	14.7
170	"	"	"	15.0
171	"	"	"	15.3
172	Bar No. 20, 7/8" x 3/8" thickness 3/8"	"	87B	15.0
173	"	"	"	15.5
174	"	"	"	14.2
175	"	"	"	15.4
176	"	"	"	15.2
177	"	"	"	14.6
178	"	"	"	14.1
179	"	"	"	14.3
180	"	"	"	14.5
181	"	"	"	14.9
182	"	"	"	14.0
183	"	"	"	14.4
184	"	"	"	14.0
185	"	"	"	14.7
186	"	"	"	15.0
187	"	"	"	14.6
188	"	"	"	14.5
189	"	"	"	13.8
190	"	"	"	14.6
191	"	"	"	14.3
192	"	"	"	14.1

Table X (Contd.)

Piece No.	Steel	Shape	Rockwell Hardness	Depth (mils)
194	1018 cold rolled bar stock 7/8" x 5/8" Bar No. 22	Square; side 0.862" thickness 5/16"	87B	14.5
195	"	"	"	15.5
196	"	"	"	14.7
197	"	"	"	15.5
198	"	"	"	14.6
199	"	"	"	15.0
200	"	"	"	14.0
201	"	"	"	15.8
202	"	"	"	14.7
203	"	"	"	15.3
204	"	"	"	15.3
205	"	"	"	14.4
206	"	"	"	13.9
207	"	"	"	15.2
208	"	"	"	14.7
209	"	"	"	15.0
210	"	"	"	15.2
211	"	"	"	14.5
212	"	"	"	14.8
213	"	"	"	14.0
214	"	"	"	15.1
215	"	"	"	15.0
216	"	"	"	15.2
218	Bar No. 23, 7/8" x 3/16"	Thickness 3/16"	84B	13.5
219	"	"	"	14.2
220	"	"	"	15.2
221	"	"	"	14.9
222	"	"	"	14.1
223	"	"	"	17.5
224	"	"	"	13.8
225	"	"	"	15.2
226	"	"	"	13.4
230	7/8" x 1/8" Bar No. 24	Thickness 1/8"	94B	14.1
231	"	"	"	13.1
232	"	"	"	12.5
233	"	"	"	13.0
234	"	"	"	13.3

Results of Firings of MK-22-0, MK-56-0 and MK-50-0 Stab-an

Detonator	Test Piece Shape and Thickness	Type of Steel and No. of bar from Tables II and IV	Preparation of Surface	Rockwell Hardness	Number of Tests
Stab MK-56-0	Square side 0.862" 5/8" thick	1020 bar stock cold rolled Supplied by NOL	As received	Av. 83B	22
Stab MK-22-0	Square side 0.862" 5/8" thick	1020 bar stock cold rolled Supplied by NOL	As received	Av. 83B	9
Stab MK-22-0	Round Dia. 1.219" 5/8" thick	1018 round stock cold rolled Bar No. 16	Ground flat with surface grinder	90B center hardness	24
"	Same as above but 3/8" thick	Bar No. 16	"	"	24
"	Same as above but 1/4" thick	Bar No. 16	"	"	25
"	Same as above but 1/8" thick	Bar No. 16	"	"	24
Stab MK-22-0	Square Side 0.862" 5/8" thick	1018 bar stock cold rolled Bar No. 20	ground flat with surface grinder	82B	22
"	Same as above but 3/8" thick	Bar No. 21	"	87B	21
"	Same as above but 5/16" thick	Bar No. 22	"	87B	23
"	Same as above but 3/16" thick	Bar No. 23	"	84B	9
"	Same as above but 1/8" thick	Bar No. 24	"	94B	5
Flush MK-22-0 and 102 primer	Square Side 0.862" 5/8" thick	1018 bar stock cold rolled Bar No. 20	ground flat	82	22
Flush MK-56-0 and 102 primer		Bar No. 20	ground flat	82	23

* A pooled estimate based on 103 shots gives 0.5.

Table I: Flash Detonators on Various Test Pieces

Serial No.	Avg. cent depth mils	Mean Deviation mils	Standard Deviation mils	Remarks	Table containing original data
	12.4	-	1.		Table I, pieces 1 thru 27, excluding 7 & 8 where M-21-U used.
	14.7	1.27	1.5	No gross distortion of test piece	Table I, piece Nos. 2, 3, and 27.
	14.3	0.25	0.3	No gross distortion of test piece	Table I
	14.5	0.20		No gross distortion of test piece	Table I
	14.3	0.33		18 mils bulge on bottom	Table I
	15.4	0.40		25 mils bulge on bottom	Table I
	14.7	0.40	0.6	No gross distortion of test piece	Table III
	14.6	0.34		No gross distortion of test piece	Table III
	14.6	0.40		No gross distortion of test piece	Table III
	14.6	0.93		Bulge on bottom	Table III
	13.2	0.40		Bulge on bottom	Table III
	14.1		0.5		Table XVII
	14.2		0.3		Table XVII

TABLE XII
 Hardness Traverses for Round Stock
 (Rockwell C Hardness)

Bar	Dia.	Piece No.	% of radial distance from center to edge												
			Center	10	25	30	40	50	60	75	80	90	95		
1	2(1m)	1	79.5	81.5		82.5	83.2	84.8	85.5	85.0	85.5	85.2	85.2		
		2						83.0					85.8		
		3						83.0					85.3		
		4						82.3					85.0		
		5		80		80.8		82.0		85.0			85.5		
		6		80		82.5		84.2		85.1			85.1		
		7		80		81.5		82.8		85.3			85.2		
		8		80		82.0		84.8		85.2			85.0		
		9		79.5									86.0		
		10		79.5		82.1									
		11						81.2							
		12						81.7							
		13			79.0						84.2				
		14			80.5								84.0		
		15			81.0		81.0		82.7		85.0		85.0		
2	1 11/16	1	82		84			85		86					
		2	82		83			84		84					
3	1 11/16	1	81		81			83		85					
		2	85					88				90			
4	1 11/16	1	81					84					88		
		2	82					84					89		
5	1 11/16	1	83					86					87		
		2	83					86					87		
6	1 1/2	1	89		88			85		86					
		2	90		90			91		91					
7	1 1/2	1	82		82			85		88					
		2	82		82			85		87					
9	1 1/2	1	85		86			86		86			87		
		2	85					85					88		
10	1 1/2	1	86		84			85		86			88		
		2	86					85					88		
11	1 1/2	1	82					85					87		
		2	83					85					88		
12	1 1/2	1	81					85					88		
		2	82					85					88		
13	1 1/2	1	85					86					88		
		2	84					85					88		

TABLE XII (Contd.)

Hardness Traverses for Round Stock

Dia.	Piece No.	% of radial distance from center to edge								
		Center	10	25	50	75	90	95		
1 1/4	1	85		85		87.5		89.3		91.5
	2	85.5								93.5
	3	85.2								
	4	85.0		85						
	5	85.5						90.0		
	6							90.5		
	7	85.5				87.0				
	8			86.0						92.2
	9	85.5		86.3		87.0		90.5		93.0
1 1/4	1	87.0		83.0		80.0		81.0		
	2	87.2				81.0				82.5
	3	87.0		81.2				81.5		83.0
	4	87.3		81.5		81.0		82.6		79.5
	5	86.5				81.2				77.5
1 1/4	1	87.0		85.7		81.0		83.0		82.5
	2							81.5		82.0
	3	89.5		82.5		81.0		83.5		79.5
	4	90.0		82.8		81.3		82.5		82.0
	5	89.3				81.5				
	6	92.0				84.0				
	7	90.4				82.2				
	8	91.0		86.2		82.2		83.8		
	9	92.5		86.2		83.3		83.4		83.0
1 1/8	1	81.5		81.0		82.5		84.0		86.0
	2	80.0		80.0		81.0		83.5		84.5
1 1/8	1	83.0		86.0		85.0		85.5		
	2	83.0				85.0				

Traverse on Bar 16 across diameter

points equally spaced across diameter of 1.219

Piece No.	Rockwell B Hardness	Point No.	Rockwell B Hardness	Point No.	Rockwell B Hardness
	85	9	89	18	83.5
	84.5	10	91.5	19	83.5
	84	11	93	20	87.5
	83.5	13	93.5	21	84
	83	14	91	22	84
	82.5	15	88.5	23	84.5
	83	16	85		
	85.5	17	84		

Table XIII

Results of Hardness Traverse Measurements of Flat Bar Stock

Bar No.	Steel	Size	Range in Hardness						
			Center of Bar	Surface 1 (center line)	Surface 2 (center line)	Edge 1 (cut)	Edge 2 (cut)	Edge 3 (mill edge)	Edge 4 (mill edge)
20	1018 cold rolled steel	7/8"x5/8"	88.0 - 89.0	83.0 - 86.0	83.8 - 87.0	87.3 - 89.0	86.6 - 89		82.2 - 84.6
			v. hardness for bar, 82.3	mean dev. 0.6	No. of readings, 25				
21		7/8"x3/8"	85.1 - 87.5	86.8 - 87.2		85.1 - 85.7	87.3 - 89.5	84.2-86.5	89.0 - 90.7
			v. for bar	mean dev. 0.4	No. of readings, 25				
22		7/8"x5/16"		85.4 - 88.1					
			v. hardness of bar	mean deviation 0.5	No. of readings, 25				
23		7/8"x3/16"		Average 83.9					
			mean dev. 0.5	No. of readings, 10					
24		7/8"x1/8"		Average 94.4					
			mean dev. 0.4	No. of readings, 5					
25		7/8"x7/8"	86 - 86.5					86 - 91.5	
26		7/8"x5/8"	81.3 - 83.5					74 - 84.5	

Table XIV

Hardness Traverse of Cross Section of Flat Bar Stock

(Readings equally spaced along center line through center hardness readings. Six equal divisions of line give five readings)

Bar No.	Steel	Size		Rockwell B readings							
				Center							
25	1018 cold rolled square	7/8"x7/8"		87.9	85.7	86.0	86.1	88.5			
				89.4	86.5	86.5	87.0	86.5			
				90.4	91.7	86.0	87.4	90.0			
				89.0	90.8	86.0	86.5	89.3			
				90.4	87.0	86.5	86.5	89.0			
				88.3	86.4	86.0	86.0	83.7			
	101 cold rolled	7/8"x5/8" traverse of center line of shortest length	other	82.5	80.8	82.6	82.6	83.0			
			center	83.5	83.3	83.5	83.0	81.7			
			line	81.0	80.6	81.3	81.8	83.1			
			average	69.5	72.5	74.0	69.2	68.2			
			surface	69.0	70.5	73.0	70.0	67.0			
			hardness	67.8	76.5	74.5	68.9	68.0			
27	101 hot rolled	7/8" sq.	68	67.9	73.4	73.0	70.6	67.2			
				68.3	70.8	74.0	71.4	63.9			
				66.8	71.5	75.0	71.5	67.4			
				68.8	68.8	74.0	68.9	71.5			
				69.0	71.3	73.0	69.0	72.0			
				69.3	72.2	74.5	69.5	73.2			
				68.0	73.2	73.0	69.1	71.4			
				69.2	74.7	74.0	68.5	75.0			
				66.7	70.0	75.0	68.0	70.6			
			28	Anderson extra annealed tool steel	7/8" sq.	average	84.0	83.4	83.4	84.0	83.5
						hardness of	84.0	84.3	84.6	84.0	85.0
						pairs of	84.3	83.4	83.4	83.6	85.4
						opposite	83.7	83.6	84.6	85.6	84.5
						surfaces	83.0	82.5	82.4	82.8	84.4
84, 86.5	83.0	82.5				82.4	82.8	84.3			
84, 86.5	84.0	81.3				82.4	82.0	83.4			
	82.1	81.0				81.4	81.2	83.4			
	84.4	83.4				82.8	82.9	85.8			
	83.0	82.9				82.5	83.8	84.9			
	81.4	82.6				82.8	83.1	84.1			
	83.2	83.1				82.5	82.5	84.0			

Table XIV (Contd.)

Bar No.	Steel	Size		Rockwell B Readings		
					Center	
29	1018 cold rolled	7/8" square	Av. sur-	88.8	88.3	88.1
			Face hard-	88.5	88.2	91.1
			ness 88	86.2	88.3	87.0
				88.2	87.2	88.9
				89.8	88.2	90.0
				89.4	88.5	89.0
				90.0	88.2	90.0
				90.7	88.5	90.0
				90.0	90.2	89.3
				87.5	87.5	86.8
				88.9	90.2	90.0
				88.0	87.5	88.9
			30	1018 cold rolled	7/8" x 5/8"	traverse
of short	82.0	81.8				85.2
center	85.7	84.2				84.5
line	83.1	82.1				84.5
	85.3	84.0				84.3
	83.2	83.2				83.5

Av. surface hardness 82

av. center of bar hardness 83

Table XV

Depth of Dent Sets for the Determination of Set
for Evaluation of Det

Material type W-22-0
Test piece size: $\frac{17}{32} \times \frac{27}{32} \times \frac{1}{4}$

Type of test pieces were test	Rockwell Hardness of Surface	Surface used for Test	100%		85%	
			(160 mg tetrag)	(160 mg tetrag)	(160 mg tetrag)	(160 mg tetrag)
A. Hot rolled steel flat bar size 7/8 square Bar No. 27	88H	mill surface	15.2	14.8	15.0	14.5
		smoothed by surface grinding	14.5	14.0	14.0	13.5
		mill surface	15.0	14.5	14.0	13.5
		smoothed by surface grinding	14.0	13.5	13.0	12.5
B. Hot rolled steel flat bar size 7/8 square Bar No. 27	88H	mill surface	15.2	14.7	14.2	13.7
		smoothed by surface grinding	14.5	14.0	13.5	13.0
		mill surface	15.0	14.5	14.0	13.5
		smoothed by surface grinding	14.0	13.5	13.0	12.5
C. Hot rolled steel flat bar size 7/8 square Bar No. 27	88H	mill surface	15.2	14.7	14.2	13.7
		smoothed by surface grinding	14.5	14.0	13.5	13.0
		mill surface	15.0	14.5	14.0	13.5
		smoothed by surface grinding	14.0	13.5	13.0	12.5
D. Same as C Bar No. 27	74R (center hard- ness of bar)	mill surface	15.4	14.9	14.5	14.0
		smoothed by surface grinding	15.2	14.7	14.2	13.7
		mill surface	15.1	14.6	14.1	13.6
		smoothed by surface grinding	14.7	14.2	13.7	13.2
E. Anderson ex- tra Tool Steel 7/8 square W.P. Crucible Steel Co. Bar No. 28	83B	mill surface	15.1	14.6	14.1	13.6
		smoothed by surface grinding	15.5	15.0	14.5	14.0
		mill surface	15.7	15.2	14.7	14.2
		smoothed by surface grinding	14.7	14.2	13.7	13.2
F. Same as C Bar No. 29	88H (center hard- ness of bar)	mill surface	14.6	14.1	13.6	13.1
		smoothed by surface grinding	14.7	14.2	13.7	13.2
		mill surface	14.4	13.9	13.4	12.9
		smoothed by surface grinding	15.7	15.2	14.7	14.2
G. Same as E but quenched and tempered Bar No. 28	20C	mill surface	12.7	12.2	11.7	11.2
		smoothed by surface grinding	12.2	11.7	11.2	10.7
		mill surface	13.0	12.5	12.0	11.5
H. Same as G but tempered to high- er hardness Bar No. 28	40C	mill surface	10.5	10.0	9.5	9.0
		smoothed by surface grinding	8.7	8.2	7.7	7.2

Table XV

the Determination of Sensitivity of Steel Plate Bent Test
for Evaluation of Detonators

Per cent of Tetryl in Detonator based on 160 mg of Tetryl as 100%

No.	85% (160 mg tetryl)			75% (120 mg tetryl)			50% (80 mg tetryl)			25% (40 mg tetryl)		
	mils			mils			mils			mils		
1	14.0			14.0			14.1			11.5		
2	13.0			13.5			13.9			12.7		
3	15.0			14.3			14.9			10.0		
4	14.0			14.4			13.2			12.0		
5	14.2	15.4	15.1	14.1	14.1		14.5	14.0	14.6	12.7	12.0	
6	14.0	15.1	15.1	14.7	14.7		14.2	13.6	13.9	11.7	12.0	
7	14.3	14.5		14.1			13.0	13.7		11.2	11.9	
8	14.3	14.3		13.5			14.0	13.9		11.5	11.7	
9	14.2			13.7			14.0			11.4		
10	14.0			14.1			12.3			10.4		
11	14.0			14.3			13.0			11.4		
12	13.5			13.7			14.2			11.5		
13	14.5			14.3			12.5			12.1		
14	14.1			14.5			13.8			10.6		
15	14.2			14.2			13.7			12.4		
16	14.5			13.8			13.8			11.2		
17	14.1			13.7			12.7			11.5		
18	14.1			14.1			12.7			11.0		
19	14.2			13.5			13.0			11.1		
20	13.9			14.3			13.1			11.4		
21	14.5			14.2			12.8			10.7		
22	13.9			13.3			12.5			10.0		
23	13.9			13.8			12.3			10.0		
24	13.4			13.2			13.4			12.1		
25	10.8			11.9			11.7			8.0		
26	11.3			10.8			10.4			9.0		
27	11.5			11.3			12.6			9.0		
28	7.9			8.1			7.9					
29	9.6			8.2			8.9					

Table XVI

Additional Dent Depth Data from Firing MK-22-0 (100% Charge)

Detonator on the Various Steels Described in Table V

(Dent depth in mils)

Steel	A	B	C	D	E	F
	15.3	15.0	14.4	15.4	15.2	14.0
	15.0	14.8	14.0	14.4	15.5	14.7
	14.7	14.7	13.9	14.9	14.6	13.7
	15.2	15.4	14.4	15.2	14.6	14.2
	14.7	15.4	14.8	15.2	14.8	14.5
	15.3	16.2	13.5	14.9	15.0	14.4
	15.3	15.2	14.6	15.6	14.9	14.2
		15.2	14.8	15.0	14.7	14.0
		15.3	15.2	15.6	15.0	15.2
		15.3	14.3	15.0		14.3
		14.9	15.0	15.1		14.4
			14.3			14.5

14.1

15.2

14.0

Table XV

Average Dent Depths Obtained on Firing M-27-30 Tra
 (Number in parenthesis is the number of shots)

Steel Description given in Table XV	Direction of firing relative to fiber direction	Rockwell Hardness of Surface	Per Cent of Tetryl			
			1.0%	65%	75%	90%
A	Perpendicular	68H	15.2 (11)	14.7 (4)	14.2 (4)	14.0 (4)
B	Perpendicular	32H	15.3 (20)	14.9 (10)	14.5 (6)	13.7 (10)
C	Perpendicular	37H	14.6 (12)	14.2 (4)	14.0 (4)	13.7 (4)
D	Parallel	74H Center of bar	15.1 (15)	14.4 (4)	14.2 (4)	13.5 (4)
E	Parallel	53H	15.0 (13)	14.1 (4)	13.9 (4)	12.9 (4)
F	Parallel	8H Center of bar	14.5 (19)	13.7 (4)	13.0 (4)	12.7 (4)
G	Parallel	20H	12.7 (3)	11.2 (3)	11.3 (3)	11.0 (3)
H	Parallel	40H	9.7 (2)	8.7 (2)	8.1 (2)	8.4 (2)

Table XVII

Deaths Obtained on Firing M-22-0 Graded Detonators on Various Grades of TNT
 in parenthesis is the number of shots from which the mean was calculated

	per Cent of Tetryl in Detonator based on lot no. of Tetryl				
Lot	65%	75%	50%	25%	Range
2 (11)	14.7 (4)	14.2 (4)	14.0 (4)	11.5 (3)	XV and XVI
3 (20)	14.9 (10)	11.5 (6)	13.3 (10)	11.8 (4)	XV and XVI
5 (1c)	14.2 (4)	14.0 (4)	13.7 (4)	11.2 (4)	XV and XVI
1 (15)	14.4 (4)	14.2 (4)	13.8 (4)	11.5 (3)	XV and XVI
6 (13)	14.1 (4)	13.9 (4)	12.9 (4)	11.4 (1)	XV and XVI
5 (19)	13.9 (4)	13.0 (4)	12.7 (4)	10.7 (4)	XV and XVI
7 (3)	11.2 (3)	11.3 (3)	11.0 (3)	8.2 (3)	XV and XVI
7 (2)	8.7 (2)	8.1 (2)	8.4 (2)		XV and XVI

Table VIII

Dent Depth Data from Firing of Flash Detonators

MK-58 and MK-22-0 with the 102 Primer

Test Piece Size: 27/32" x 27/32" x 5/8"

Av. Hardness of Test Piece - 82

Pieces cut from Bar No. 20

Dent Depth in mils

MK-58

3.8
4.4
3.9
4.8
4.3
4.8
4.2
4.4
4.1
4.5
3.7
3.8
4.6
4.0
3.8
4.0
3.8
3.9
4.4
4.7
3.9
4.2
3.7

Mean 4.2

MK-22-0

14.2
13.9
14.2
14.1
13.6
14.0
14.3
14.3
14.3
13.6
13.5
15.0
14.3
14.1
14.3
14.1
13.7
15.0
14.1
13.5
13.8
13.7
Mean 14.1

Table IX

Standard Deviation for Detonators Fired on
5/8" Thick Steel Test Pieces

Detonator	No. of Shots	Table of Data	Number of degrees of freedom avail. for calculating stand.dev.	Standard Deviation (mils)	Remarks
<u>Stub Detonators</u>					
K-56-0	22	I	21	1.05	Lot 1, bar stock as received
K-22-0*	9	I	8	1.5	Lot 1, bar stock as rec.
160 mg. tetryl	24	I	23	0.3	Lot 2, ground surface
(100% charge)	22	III	21	0.6	Lot 2, bar stock ground
	28	VI	22	0.5	Lot 1 " " "
	65	VII	59	0.5	Lot 2 " " "
K-22-0	30	VI	24	0.6	surface prepared by grinding
136 mg tetryl (25% charge)					
K-22-0	26	VI	20	0.5	"
120 mg tetryl (75% charge)					
K-22-0	30	VI	24	0.7	"
80 mg tetryl (50% charge)					
MK-22-0	28	VI	22	0.8	"
40 mg tetryl (25% charge)					
<u>Flash Detonators (Flashed by Stabbing 102 Primer)</u>					
K-22-0	22	VIII	21	0.5	Surface prepared by grinding
K-58-0	23	VIII	22	0.3	"

* Pooled Standard Deviation from Data of Table III, VI, VII with
59 + 21 + 22 + 1 = 103 degree of freedom = 0.5

Sample Calculations showing the Formation of

Table VI

(1) Source of data is Table V for steels A, B, C, D, E, and F. First four measurements of the first column in each subdivision were used, making the total number of measurements to be used for calculation 120.

(2)
$$\frac{(\text{Grand Total of 120 readings})^2}{120} = 224242.268$$

(3) Variability =
$$\frac{(\text{grand total})^2}{120} - \text{sum of squares}$$

(4) Variance = variability + degrees of freedom

(5) Total Dent Tests

The measurements of 120 dent tests were each squared and then summed. (sum of squares = 22806.306. The difference between item (2) and item (3) when divided by the degrees of freedom for estimating deviation from the mean gives the variance of 3.21.

(6) Subclasses.

The mean of each subclass was summed and squared. The difference between items (2) and (4) gave variability of 256.330 which is used below to estimate the error.

(7) Between Detonators

The numbers in columns of subdivisions were totaled and the totals squared. Following are the totals squared for the five columns:

100%	132860.25
85%	118198.44
75%	114176.41
50%	103748.41
25%	74038.41

These figures were summed and divided by the number of items per total (=24), giving a sum of squares equal to 22625.9100. The variance of 5.03 was obtained by dividing the variability by the degrees of freedom.

(8) Between Steels

The numbers in rows of subdivisions were totaled and the totals squared. Following are the totals squared for the five rows:

A	77841.00
B	80089.00
C	73441.00
D	75405.16
E	72576.36
F	69379.56

Sample calculations (contd.)

The total of these numbers divided by the no. of measurements per total (=20) is the sum of squares for steels. The difference between item (2) and the sum of squares on division by the degrees of freedom (5) gives a variance of 2.47. (D)

9. Interaction

The variability for interaction was obtained by subtracting variability of "between steels" and between detonators from the variability of subclasses. Variance was obtained by dividing variability by degrees of freedom.

10. Within subclasses

Variance in this category represents deviation due to error. It is used in the denominator of the variance ratios for calculation of F. It is calculated from the relation

$$\text{Total variability} = \text{variability of subclass} + \text{variability within subclass}$$

$$\text{Variability within subclass} = 382.092 - 256.33 = 123.66$$

11. Ratio of Variances, F.

F is the ratio variance for steel, detonator, and interaction to the variance for the estimated error.