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O T T A W A November 7th, 1942.

R E P O R T

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1321.

Correlation between Metallurgical Tests and Ballistic Limit on Dominion Foundries and Steel 60 mm. Armour Plate.

(This is Report No. 8 of the Canadian Bureau of Mines 1942 Armour Plate Statistics Series.)

(Copy No. 43.)

BUREAU OF MINES
DIVISION OF METALLIC MINERALS
ORE DRESSING AND
METALLURGICAL LABORATORIES

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

OTTAWA November 7th, 1942.

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Introduction.

The policy of Ordnance Inspection originally was merely to test war material and decide whether or not it passed a specification. Thus, a manufacturer's inspector and an ordnance inspector were engaged in the same work. Industry must maintain an inspection program which will

* Ballistic limit in this report refers to the speed at which a 2-pdr. shot must travel to defeat the plate.

(Introduction, cont'd) -

guide its processes and determine the quality level of the materials produced. To what extent should Ordnance Inspection duplicate the work of manufacturer's inspection?

Following are comments from Britain and the United States War Department on this subject:

> "We have no intention of allowing the ordnance inspector to become a sieve for weeding out defectives from the product of a low-quality manufacturer. That is the manufacturer's job. But we will help him to get the quality of his product under control at a satisfactory level by advising with him and by making constantly available to him all information as to levels and trends in his quality which may be evidenced by ordnance inspection results on his product."

The above was contained in "Quality Control Procedures in Ordnance Inspection," by G. D. Edwards, War Department, Washington, D.C., published in MECHANICAL ENGINEERING, September 1942.

> "The inspection department of the Ministry of Aircraft Production is henceforward prepared to judge the quality of a manufacturer's product on the evidence provided by the control chart and, if that evidence is satisfactory, to leave inspection to the manufacturer. It is to be hoped that the inspection departments of the other Production Ministries will follow this timely lead in the direction of economizing in governmental inspection effort and man-power."

The above statement of policy was made by the Chief Inspector of the A.I.D. and is reported in the April 24, 1942, issue of THE ENGINEER (London).

From the above it would appear that inspection involves more than accepting or rejecting individual products. It also involves accepting or rejecting a manufacturing process. Processes are accepted or rejected on the basis of

(Introduction, cont'd)

the quality level of their product as shown by the control chart.

The principle that a systematic program must be adopted in order to study and control industrial output is inferred in the above quotations. The best system of studying the manufactured product is the quality control chart method.

The present report, and others in this series, attempts to supply some of the parts of the background required for a Quality Control program on armour plate. Those charged with the responsibility of examining armour plate require answers to the following questions:

1. What are the factors that affect armour quality in order of importance?
2. What is the ideal range for each factor?
3. How closely can this factor be controlled?
4. What proof is required that the factor is in control?

The answers to the above are at present dogmatic rather than scientific. It is expected that scientific answers will be obtained by statistical analysis of operating data. Unfortunately, at present only a few of the many operating variables are recorded. This report was written to show how the ideal range for test values can be arrived at.

PURPOSE OF WORK:

Armour plate is made for the purpose of resisting projectiles. The best proof of acceptability of armour is an actual test of its resistance to projectiles. Unfortunately, such a test destroys the material. It is desirable to have some non-destructive test which will serve as an indicator of armour quality. To date no single test has been found which will serve to indicate the quality of armour. Some tests, such as the through-plate tensile specimen and the notched bend test, have a more definite relationship to ballistic properties than have others such as sulphur and silicon.

In the manufacture of armour plate there are factors which are integral parts of the process. Carbon content, Brinell hardness, etc., are properties which can be measured and which are always there. Rate of cooling from 1300° to 1000° F. on quenching, pouring time, and pouring temperature are more difficult to measure and record; nevertheless, they are always present. For each of these factors there may or may not be an ideal range, within which the optimum effect of the factor is reached. Production of the highest possible quality of industrial output depends upon lining up all of the important factors to their optimum point. This might be compared to tuning an old-fashioned radio which requires that each of several dials be adjusted to an exact point before perfect reception is achieved. Unfortunately, metallurgical variables are not all easily measured and unknown factors may have a greater influence than those that are at present recorded.

The test data recorded herein cover only a fraction of the production variables. The main purpose is to show how

(Purpose of Work, cont'd) -

ideal conditions can be arrived at by a study of industrial data.

EXAMPLE:

Page 6 shows the Grossman Hardenability and ballistic results as reported by D.F. & S. for 134 heats of 60 mm. armour. The data is arbitrarily divided into three groups:

A - 2-5-9 inches diameter (Grossman Hardenability).
B - 6-9-9 " " " "
C - 10-21 " " " "

A line drawn through 1,930 feet per second cuts each group in two. Then we find that in Group A, 30 per cent of the results are above 1,930 ft./sec.; in Group B, 56 per cent; and in Group C, 35 per cent.

The relationship is shown graphically on Page 7. Note that the width of each oblong denotes the range of hardenability included in the group. Height of each oblong indicates the percentage of results in that group above 1,930 ft./sec. Also, the number included in the group is recorded in the oblong.

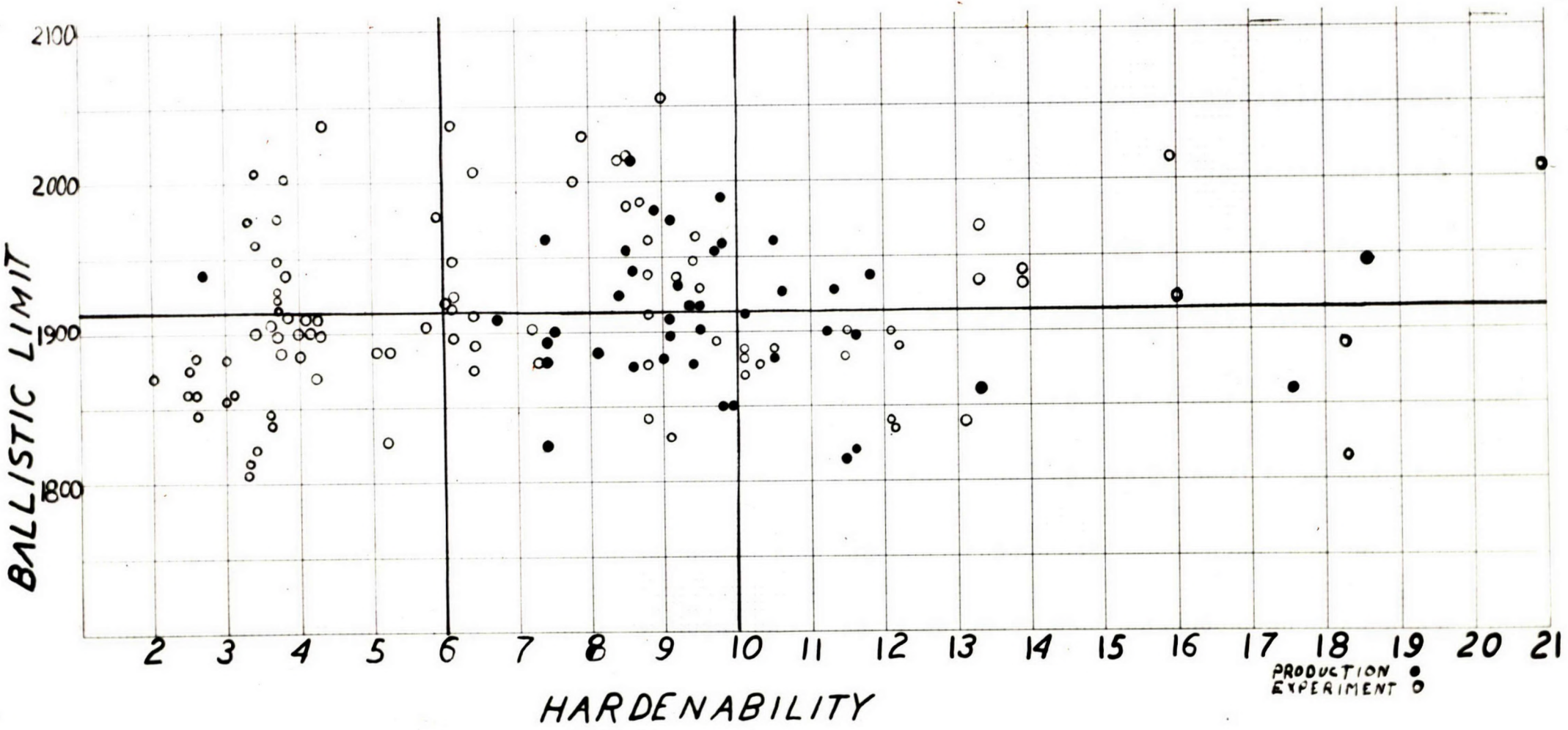
Reliability:

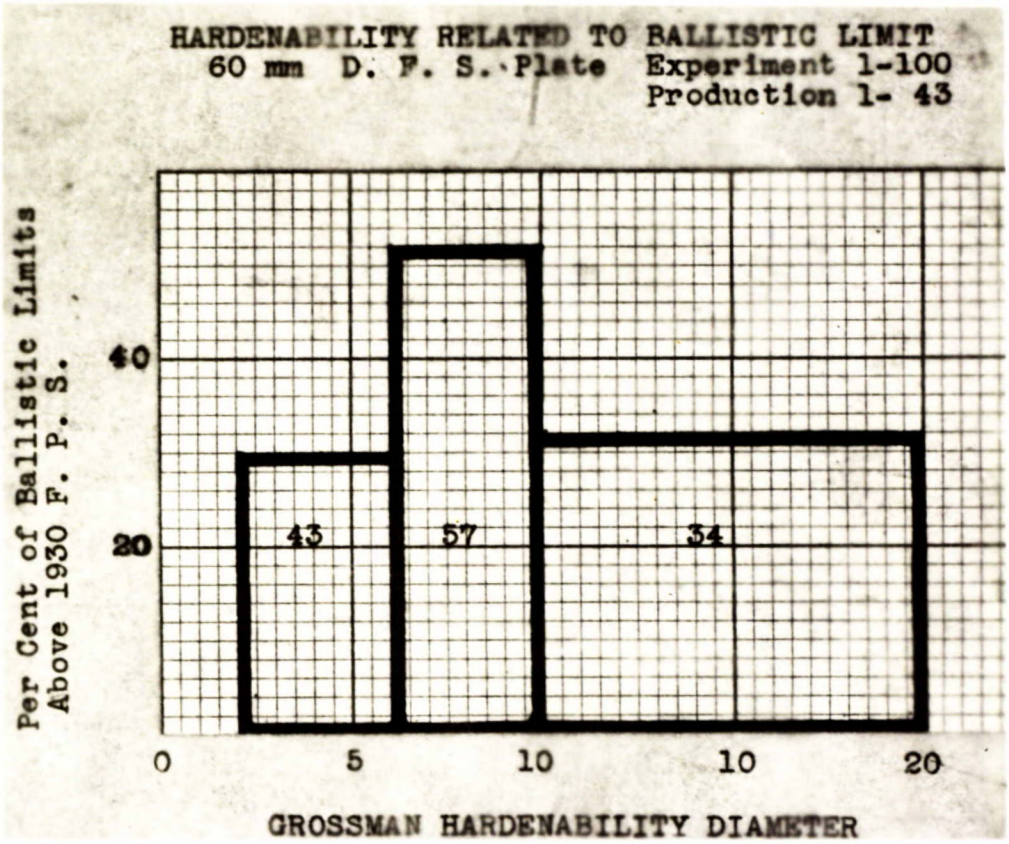
The chart on Page 6 indicates a relationship between hardenability and ballistic limit. How reliable is this indication?

The odds that chance alone would produce a scattering of dots as shown on Page 6 are 104 to 10,000, or about one chance in a hundred. The methods of calculating this type of probability are explained in standard statistical texts.

(Pages 6 and 7 are photostats.)

(Text resumed on Page 8)


2100
2000
1900
1800
BALLISTIC LIMIT
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
HARDENABILITY
PRODUCTION ●
EXPERIMENT ○


HARDENABILITY RELATED TO BALLISTIC LIMIT
60 mm D. F. S. Plate Experiment 1-100
Production 1- 43
Per Cent of Ballistic Limits
Above 1930 F. P. S.
40
20
43
57
34
0
5
10
10
20
GROSSMAN HARDENABILITY DIAMETER

(Reliability, cont'd) -

There is a possibility that this relationship holds only for a certain process and a change in the process might alter the relationship. There is also the possibility that this relationship is a transient condition.

A practical proof of reliability is given with time. Consider the chart on Page 9. In Period No. 1 the ballistic limits of heats containing manganese 0.62 - 0.75 per cent were greater than those containing manganese 0.34 - 0.61 per cent.

Q. Is this a reliable guide?

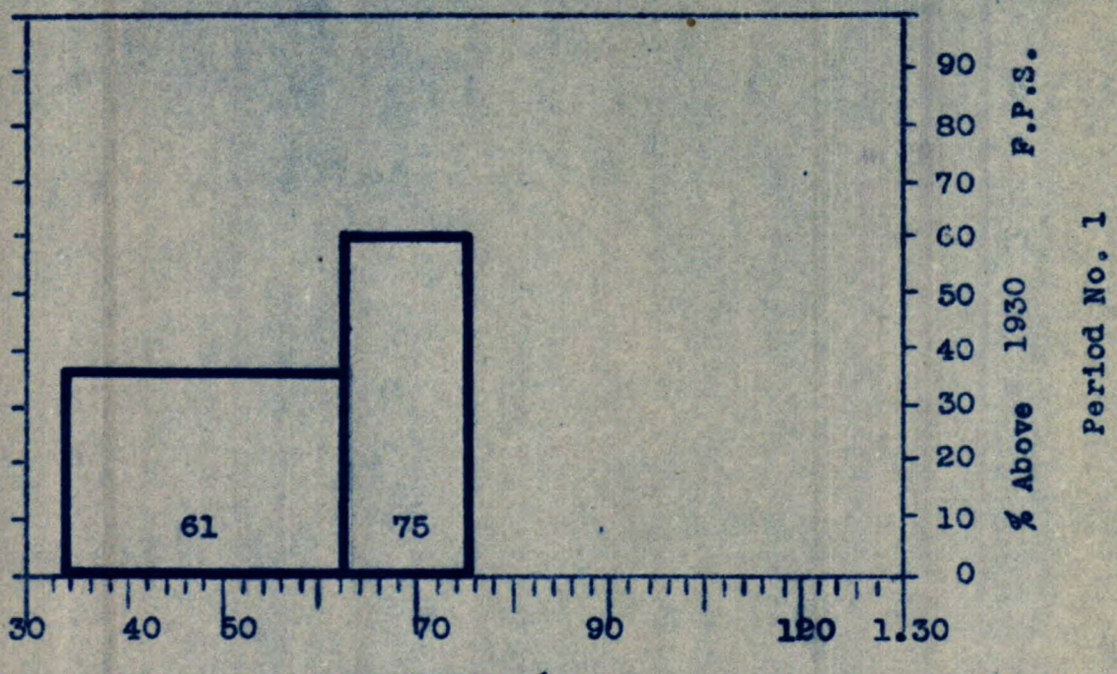
A. In Period No. 2 on Page 9, the relationship of No. 1 is reversed. In Period No. 3, only slight effect due to manganese is indicated. The indication of relationship shown in Period No. 1, therefore, did not prove to be reliable and was probably produced by chance or by transient conditions.

On Page 10 the relationship between hardness and ballistic limit is shown. Note that in Period No. 1 as hardness increased the ballistic limit increased also. This result might have been accidental. However, in Period No. 2 the same trend is evident. In Period No. 3 the same trend is still shown. Could these results be due to chance or accident?

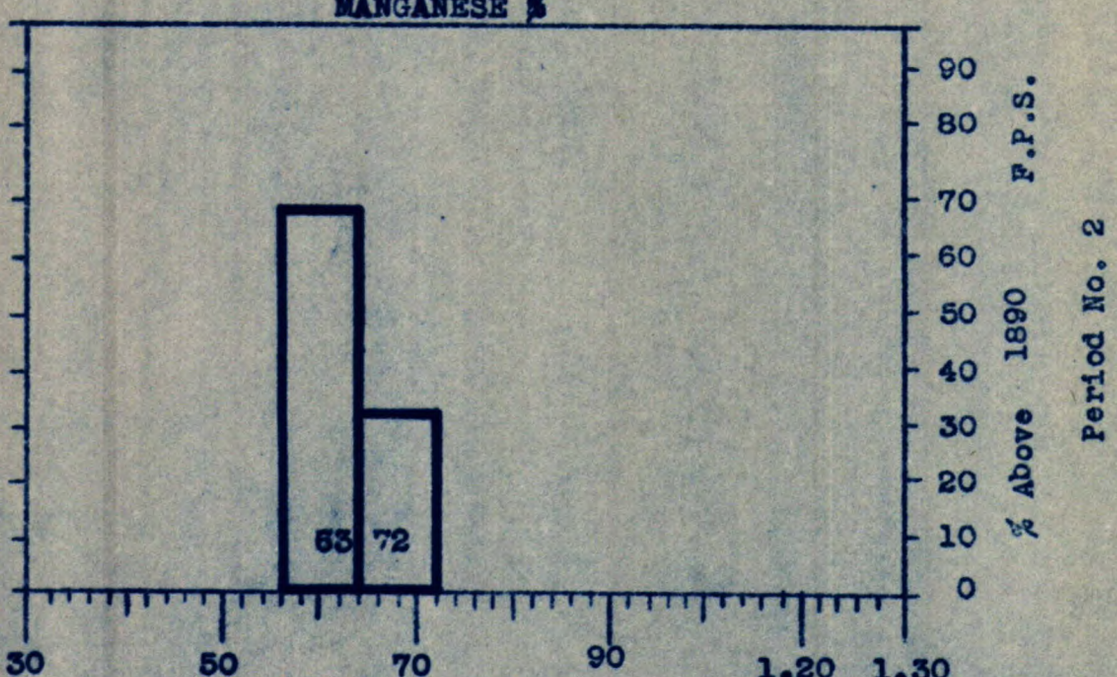
(Pages 9 and 10 are photostats.)

(Text resumed on Page 11)

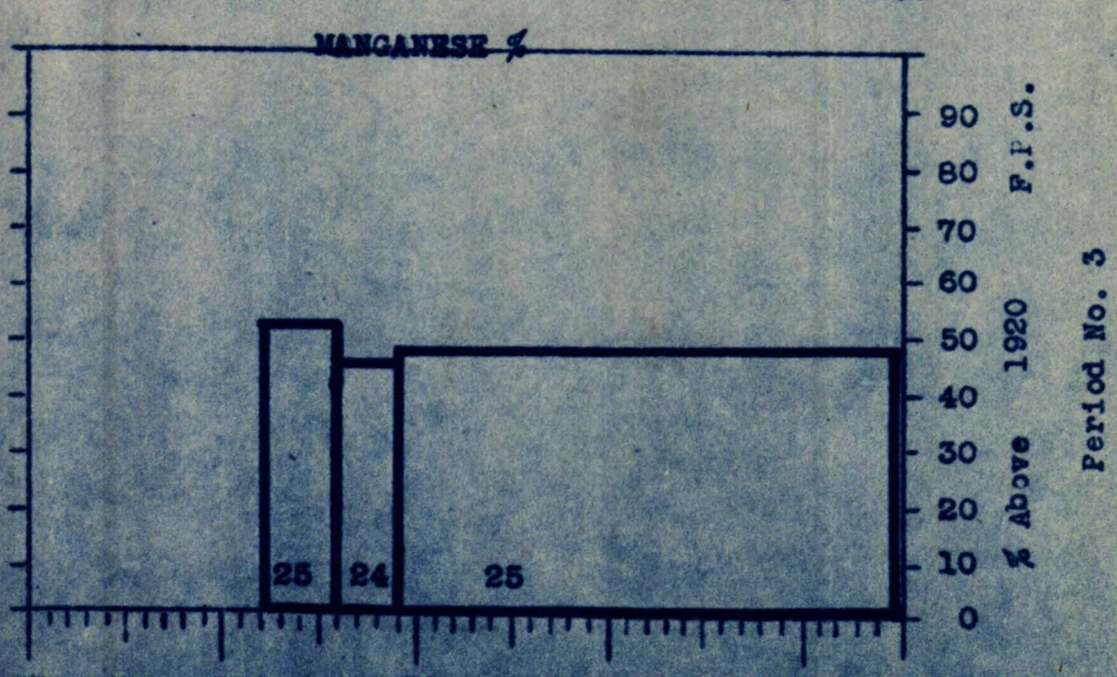
CORRELATION BETWEEN MANGAN. AND BALLISTIC LIMIT
HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO. OF RESULTS



Period No. 1



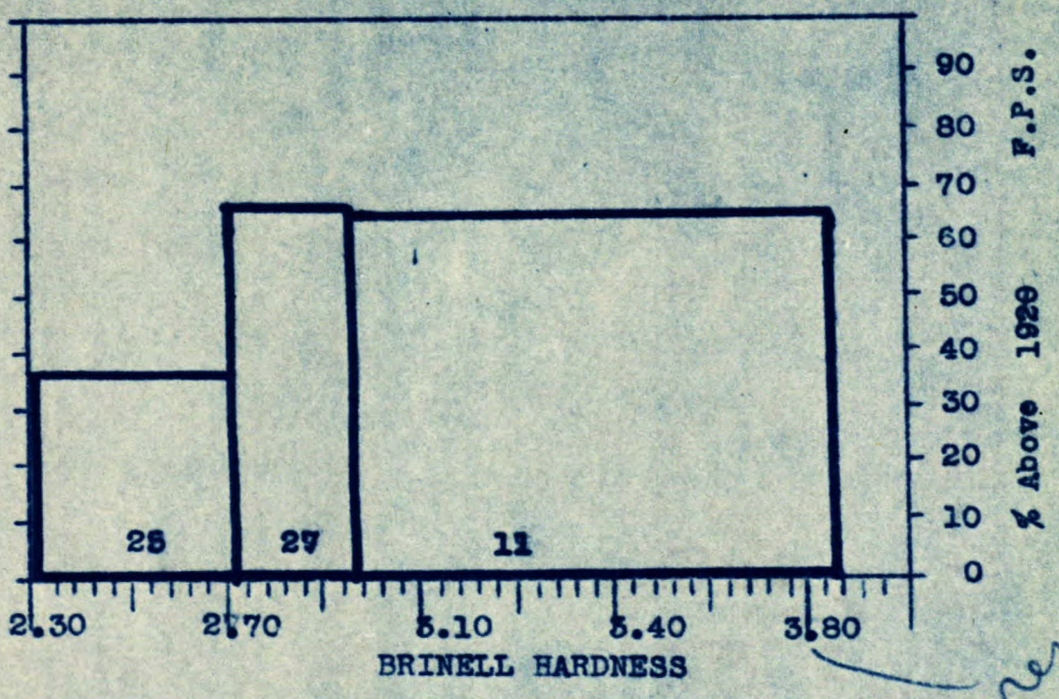
Period No. 2



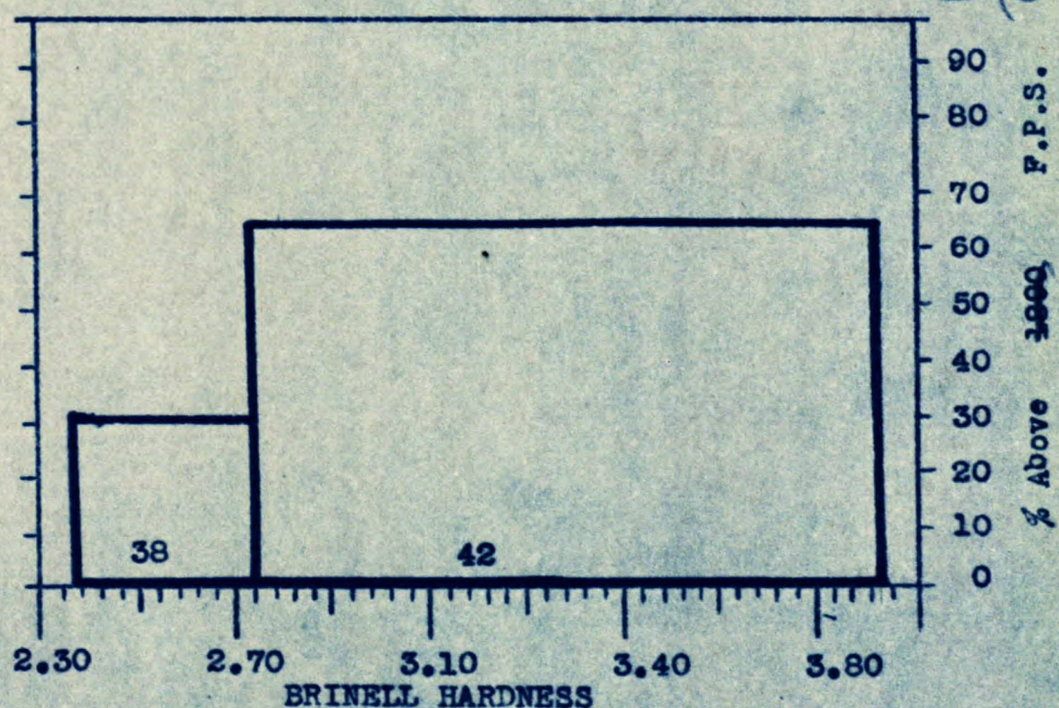
Period No. 3

CORRELATION BETWEEN BRINELL AND BALLISTIC LIMIT

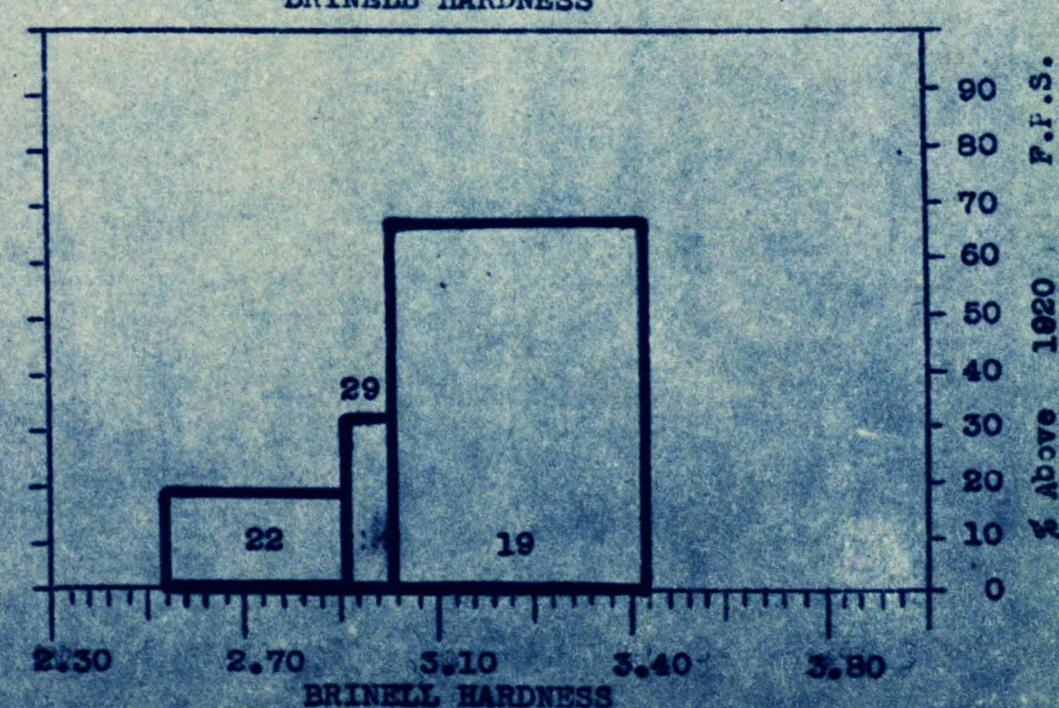
HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO. OF RESULTS



Period No. 1



Period No. 2



Period No. 3

(Reliability, cont'd) -

Three similar results in this case are almost sufficient to rule out any possibility of chance producing the result. The relationship between hardness and ballistic limit is therefore assumed to be as shown.

Reliability of trend depends upon the amount of supporting evidence and the length of time over which the trend existed.

CORRELATION:

The factors studied have been placed in two groups, as follows:

DEFINITELY CONNECTED WITH ARMOUR QUALITY	NO DEFINITE CONNECTION WITH ARMOUR QUALITY
Hardenability	Nickel
Phosphorus	Elongation
Yield	Sulphur
Molybdenum	Reduction of area
Carbon	Silicon
Izod	Manganese
Tensile	
Brinell	
Chromium	

In order to prevent undue optimism, it is necessary to point out that lining up all the factors known to correlate with armour quality will not necessarily produce high-quality armour. This is because the unknown factors may be more effective than the known, and their influence may produce wide variations.

More information through production research on armour plate could be obtained if testing and recording of

(Correlation, cont'd) -

now intangible factors were undertaken. Some factors which might be studied are:

Grain size.
Inclusion ratings.
Notched bend test.
Through-plate tensile test.
Details of heat history,
- charge make-up
- melt-down time
- additions
- slag fluidity
- pouring temperature.

Details of rolling history.
Temperature-time curve on quenching.
Hardness after quenching.
Amount of decarburization.

In the everlasting struggle towards perfection, everything which might have some bearing on the armour quality should be measured and recorded for comparison with ballistics, not once or twice, but a sufficient number of times so that true relationship, if any, can be seen.

FACTORS DEFINITELY CONNECTED WITH ARMOUR QUALITY:

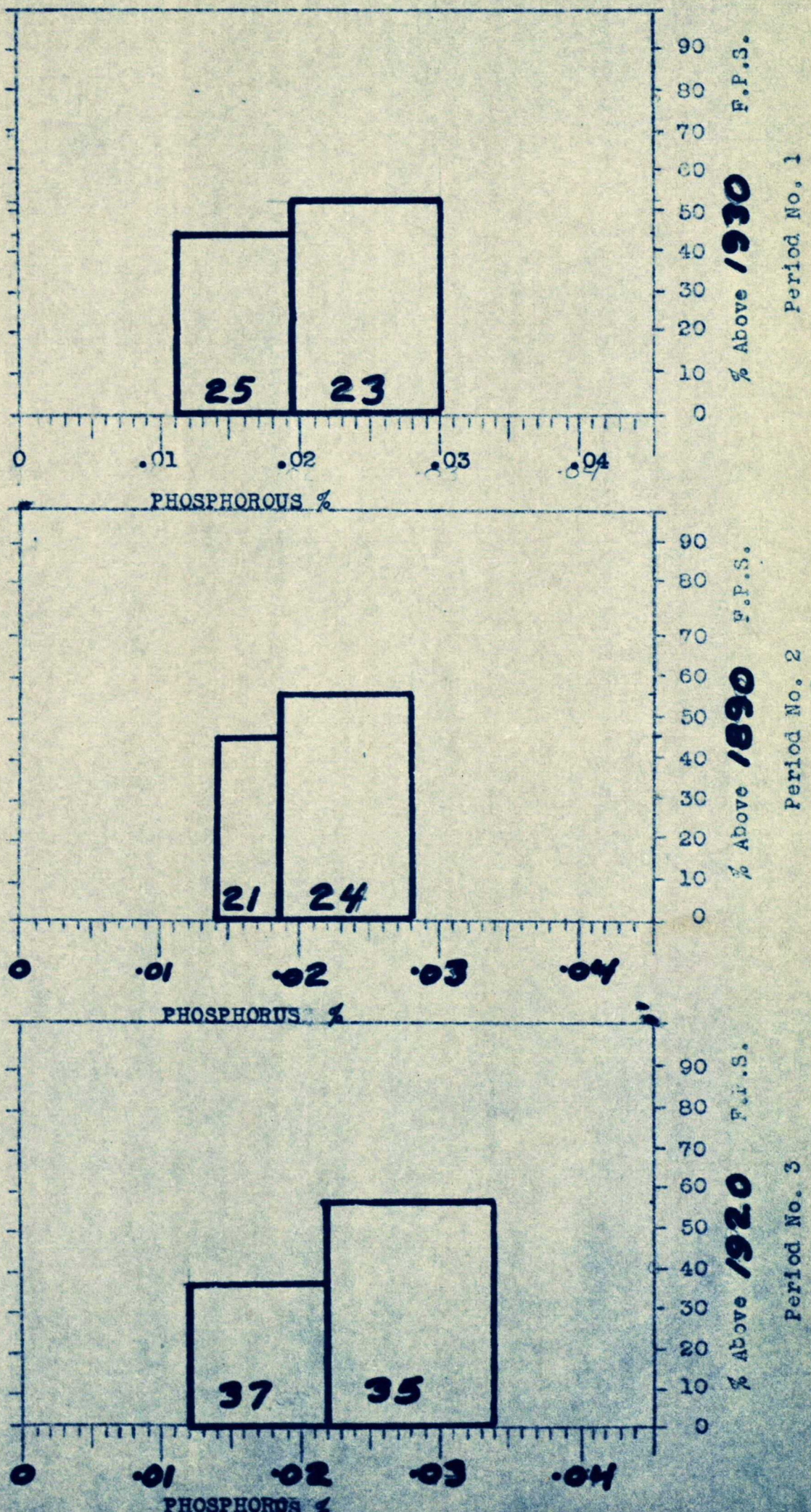
Pages 13 to 19 show the results of comparing test values with ballistic limits over three 6-month periods. The results, of course, apply only to the source and should not be taken to be of general application. These trends hold true for a wide variety of analysis and conditions.

(Pages 13 to 19 are photostats.)

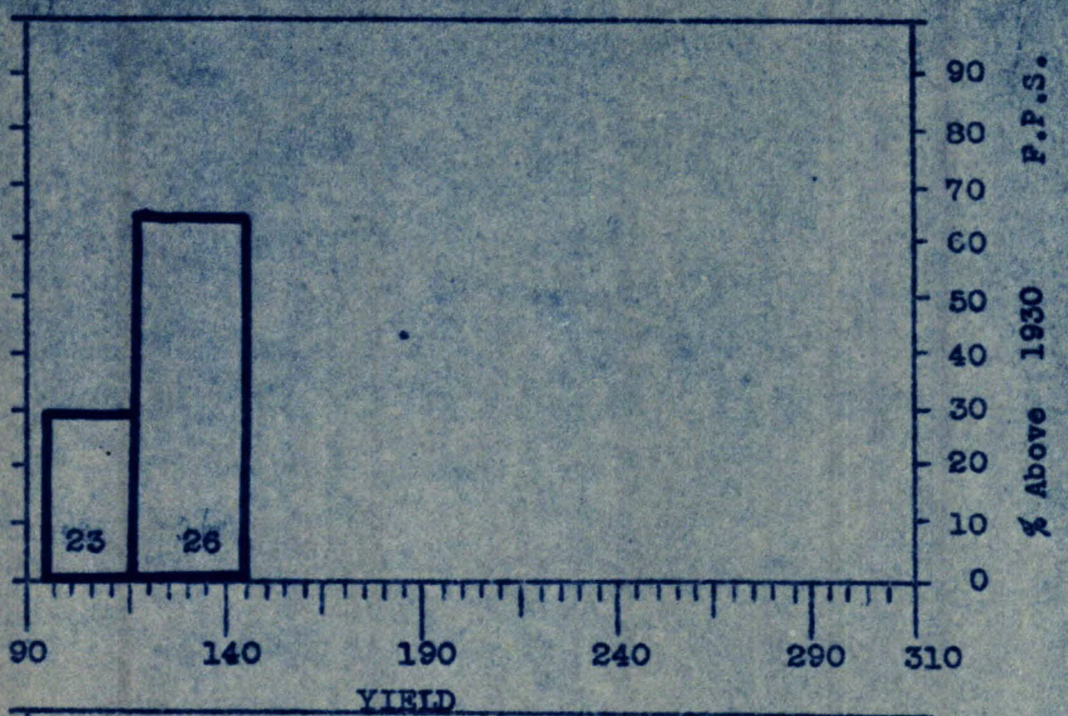
(Text resumed on Page 20)

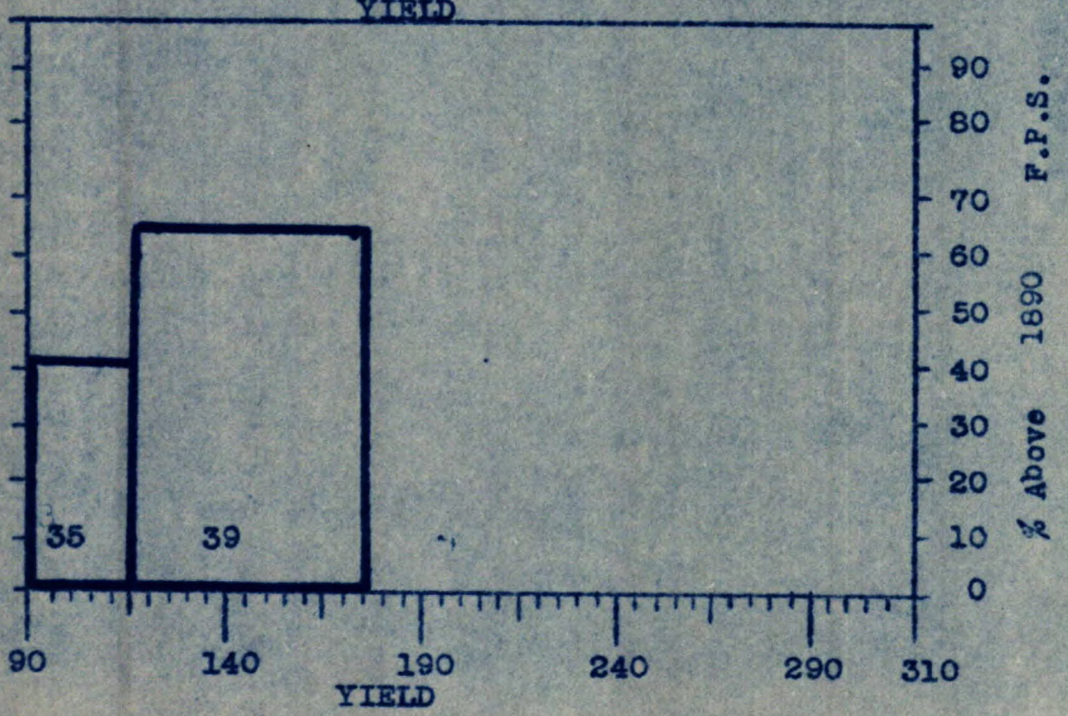
CORRELATION BETWEEN PHOS. AND BALLISTIC LIMIT

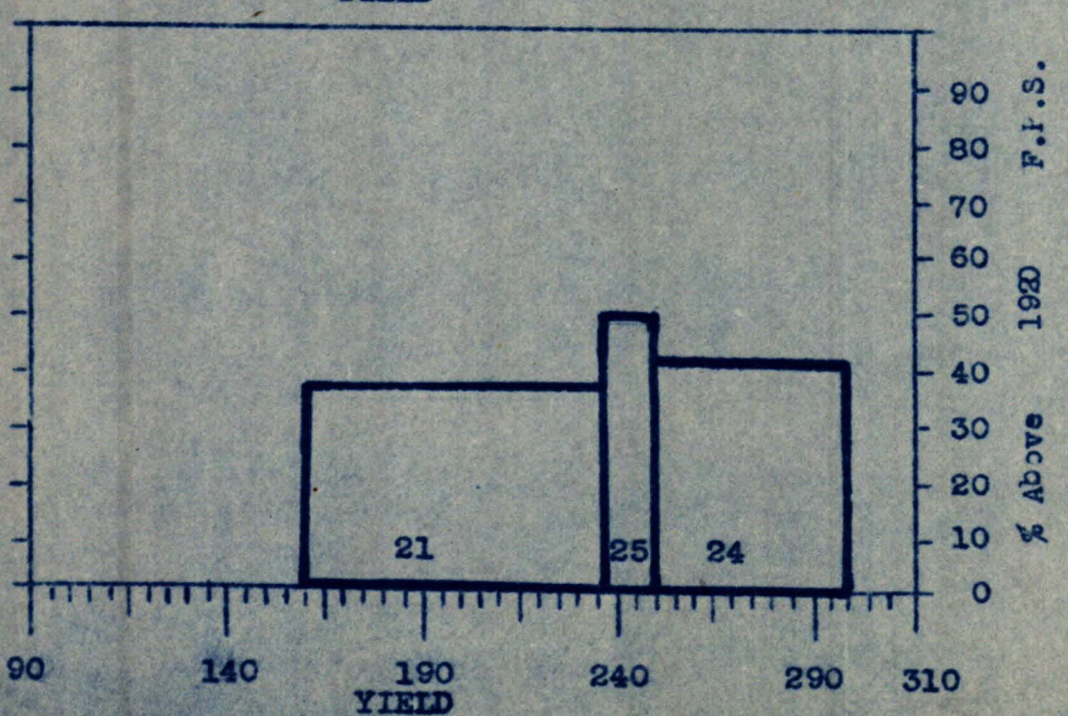
HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO. OF RESULTS



CORRELATION BETWEEN YIELD AND BALLISTIC LIMIT
HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO. OF RESULTS







CORRELATION BETWEEN MOLYBD. AND BALLISTIC LIMIT

HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
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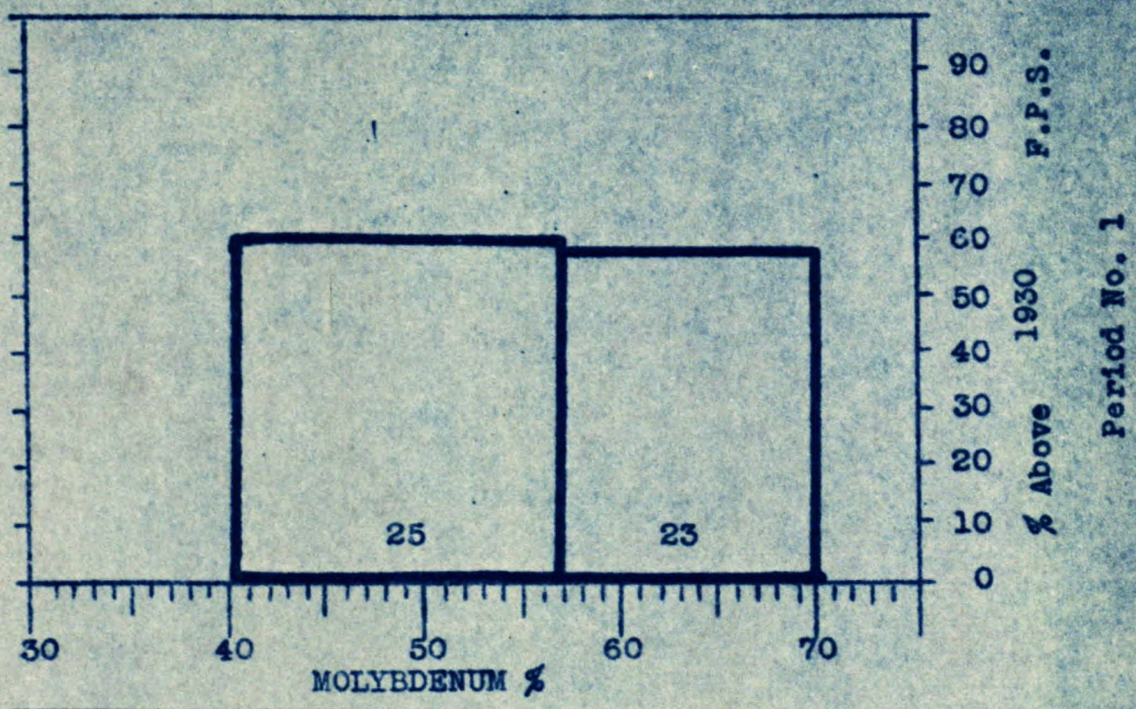
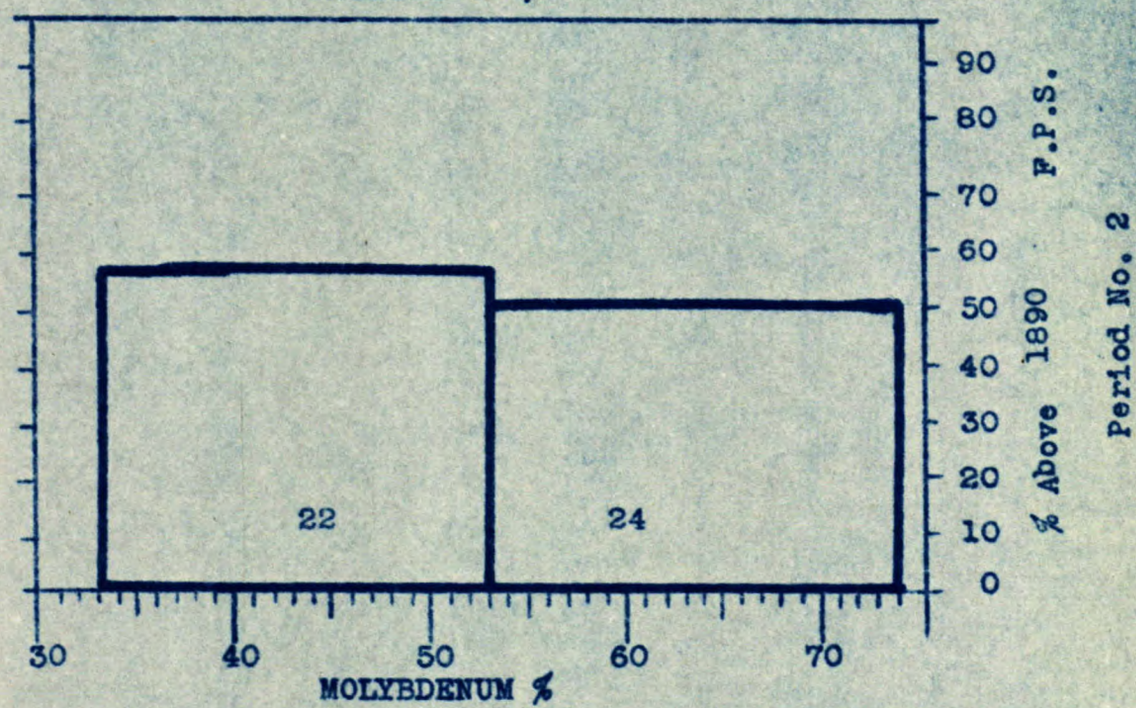
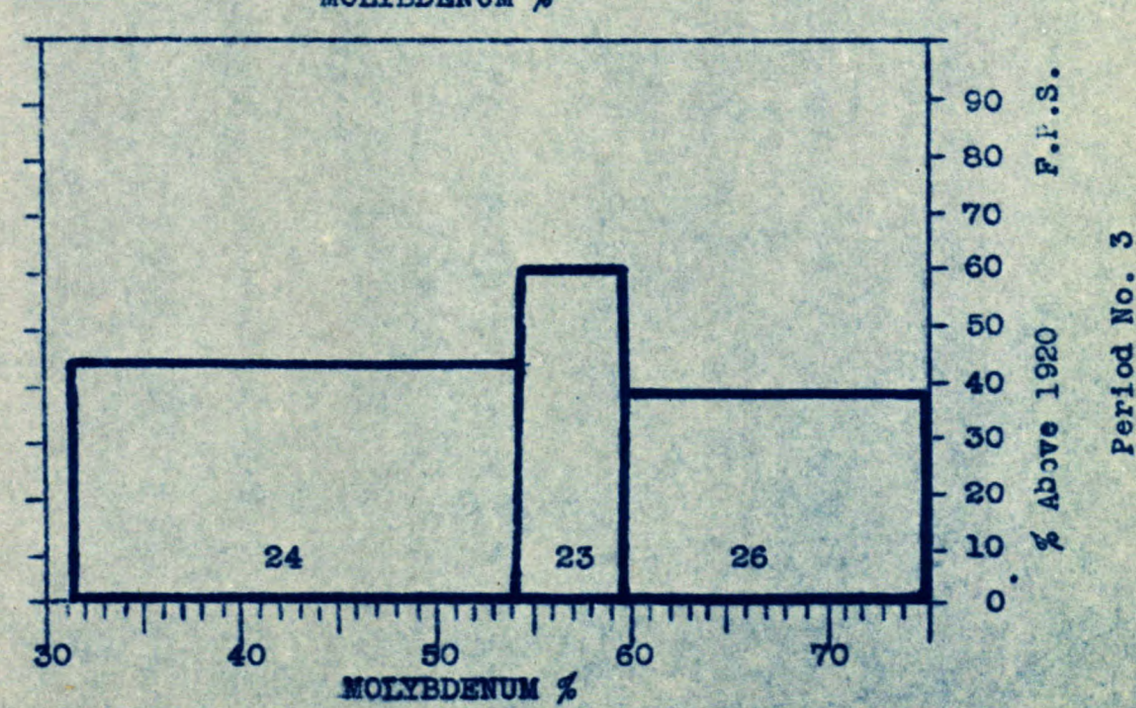
NUMBER IN " " NO. OF RESULTS







CORRELATION BETWEEN CARBON AND BALLISTIC LIMIT
HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
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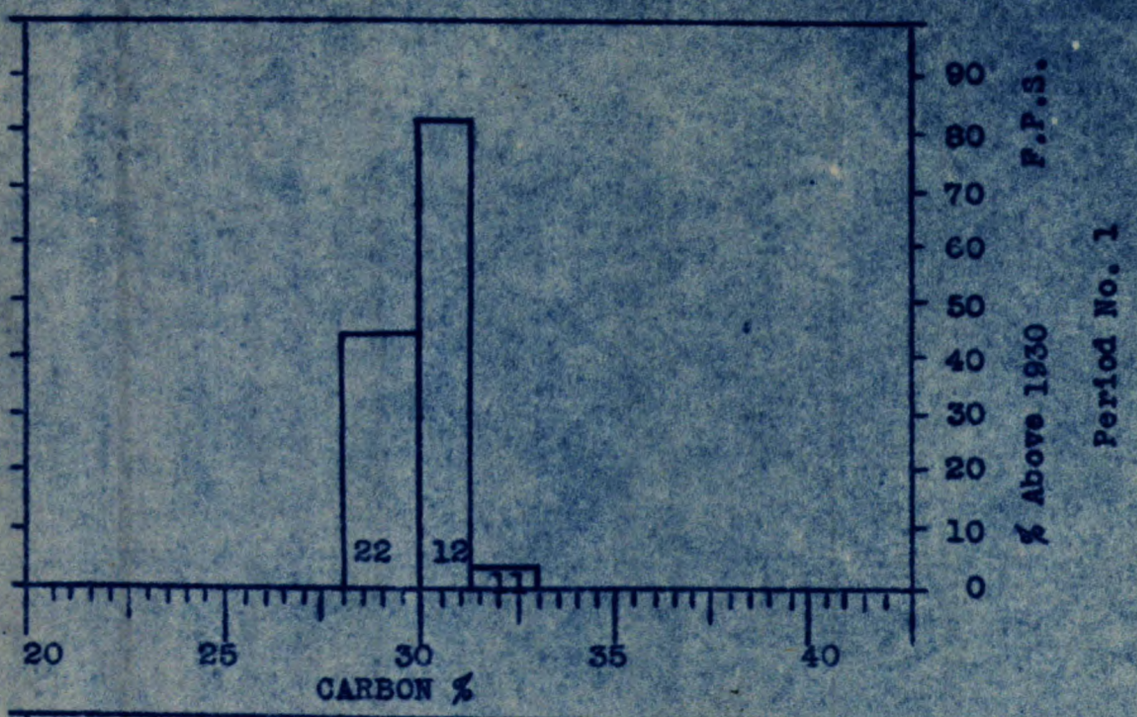
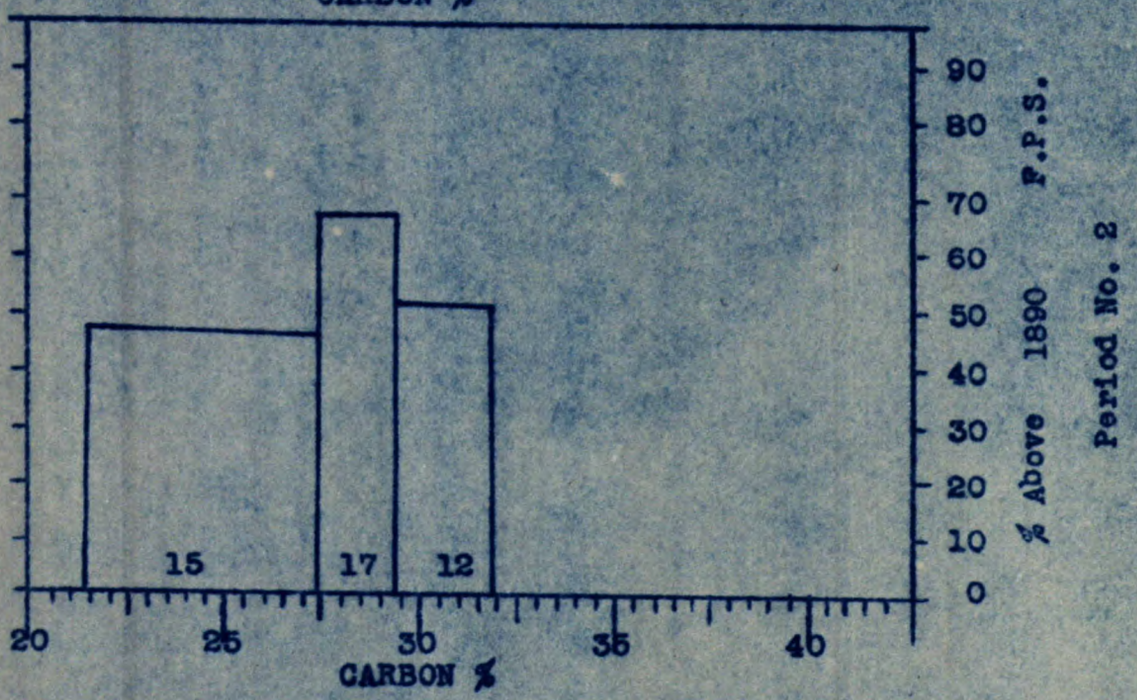
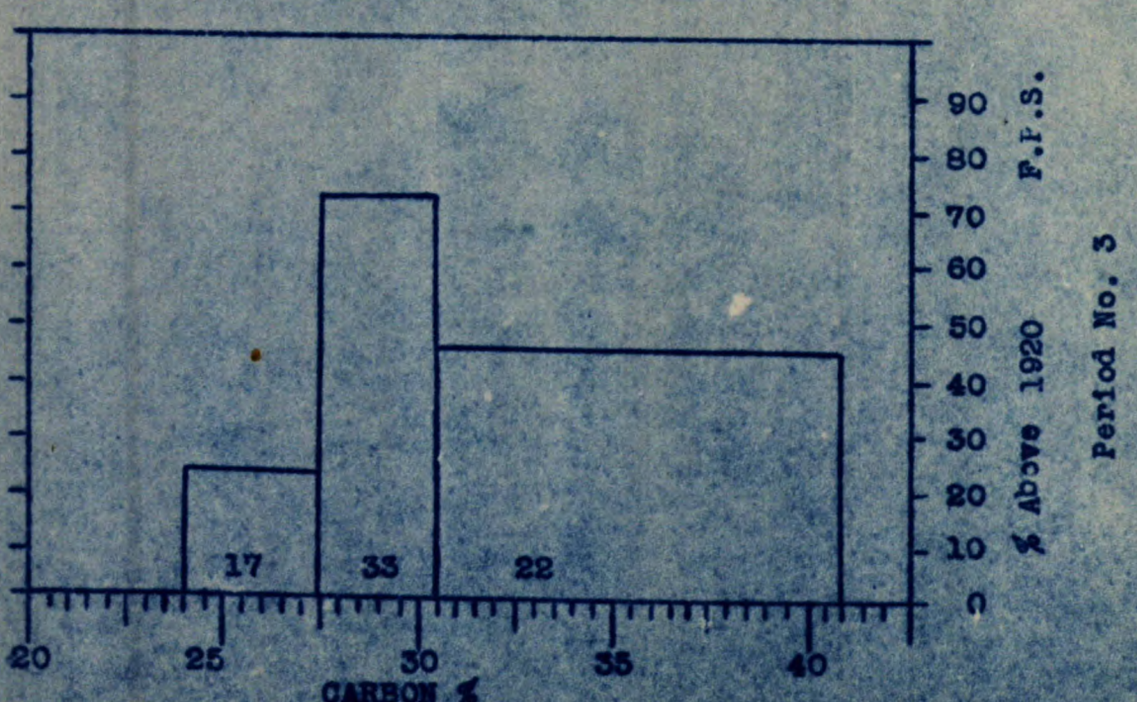
NUMBER IN " " NO. OF RESULTS







CORRELATION BETWEEN **IZOD** AND BALLISTIC LIMIT

HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
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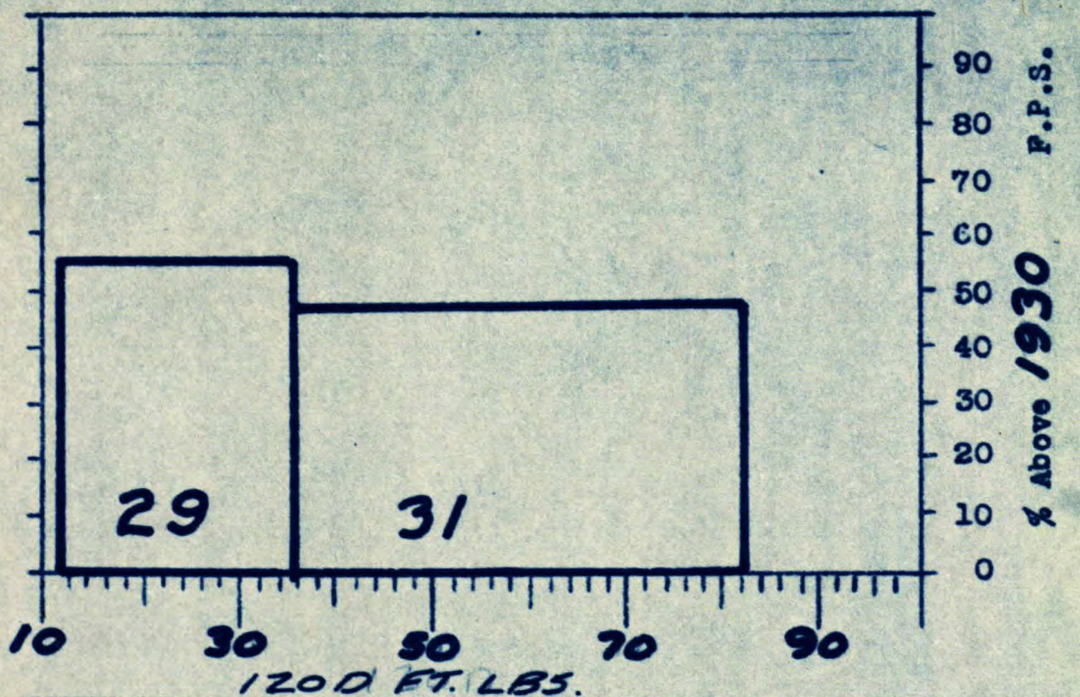
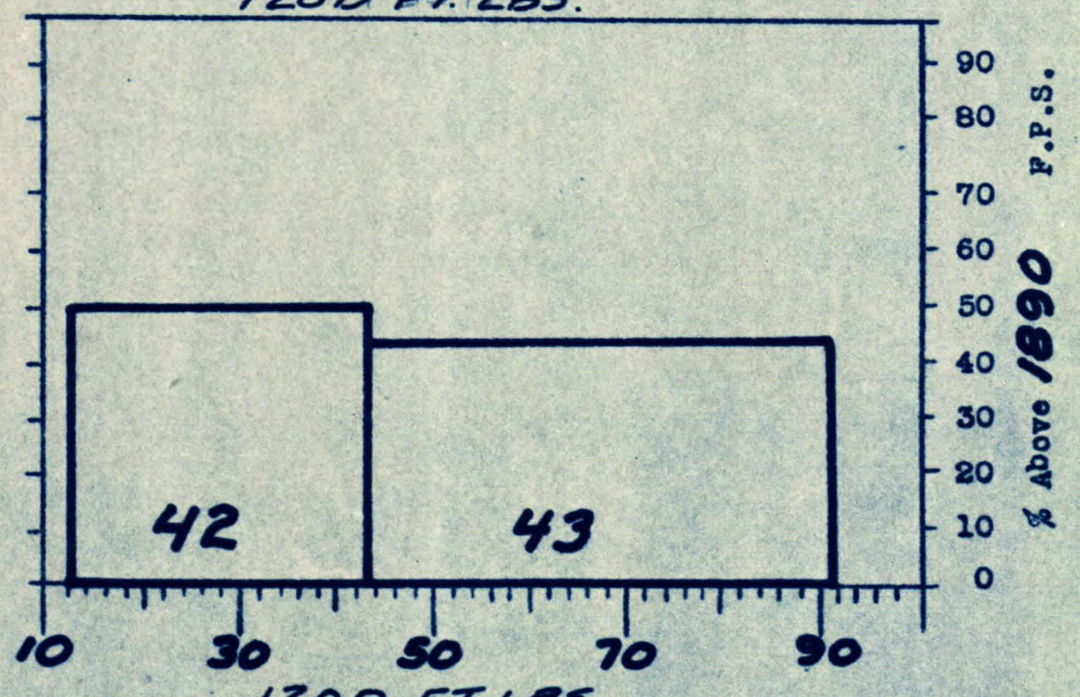
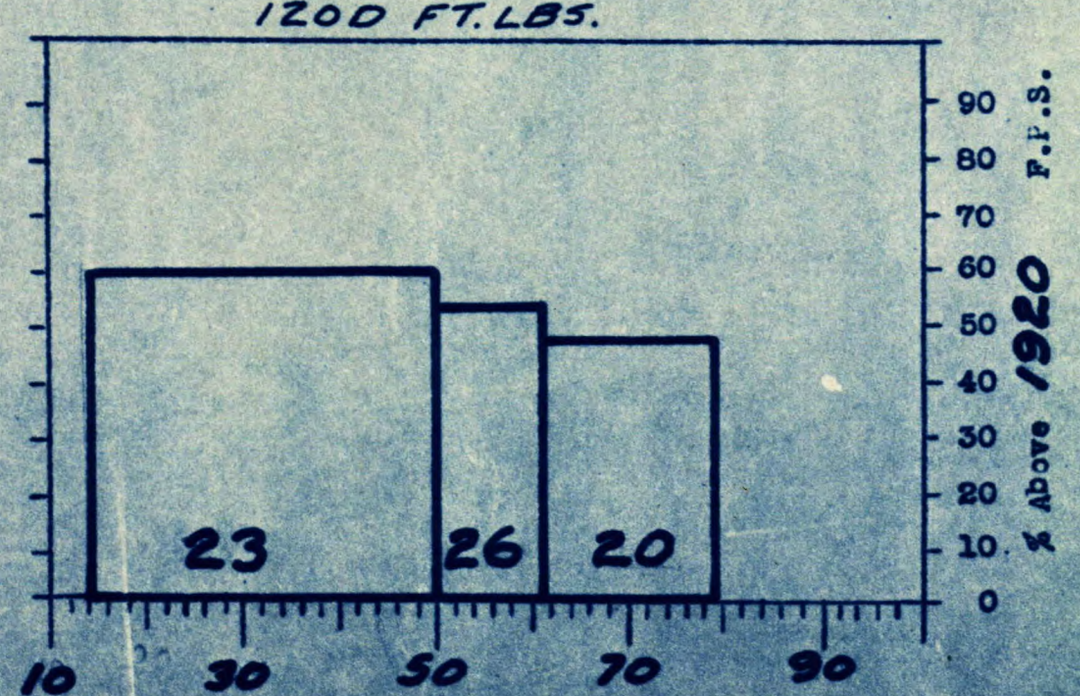
NUMBER IN " " NO. OF RESULTS







CORRELATION BETWEEN TENSILE AND BALLISTIC LIMIT
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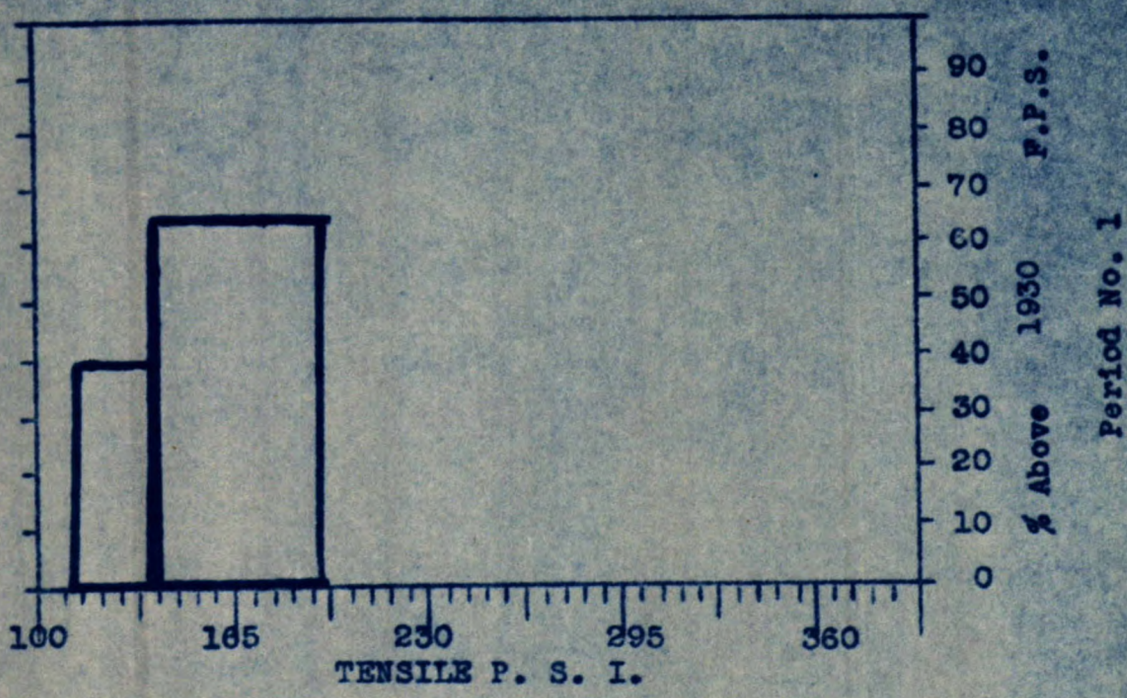
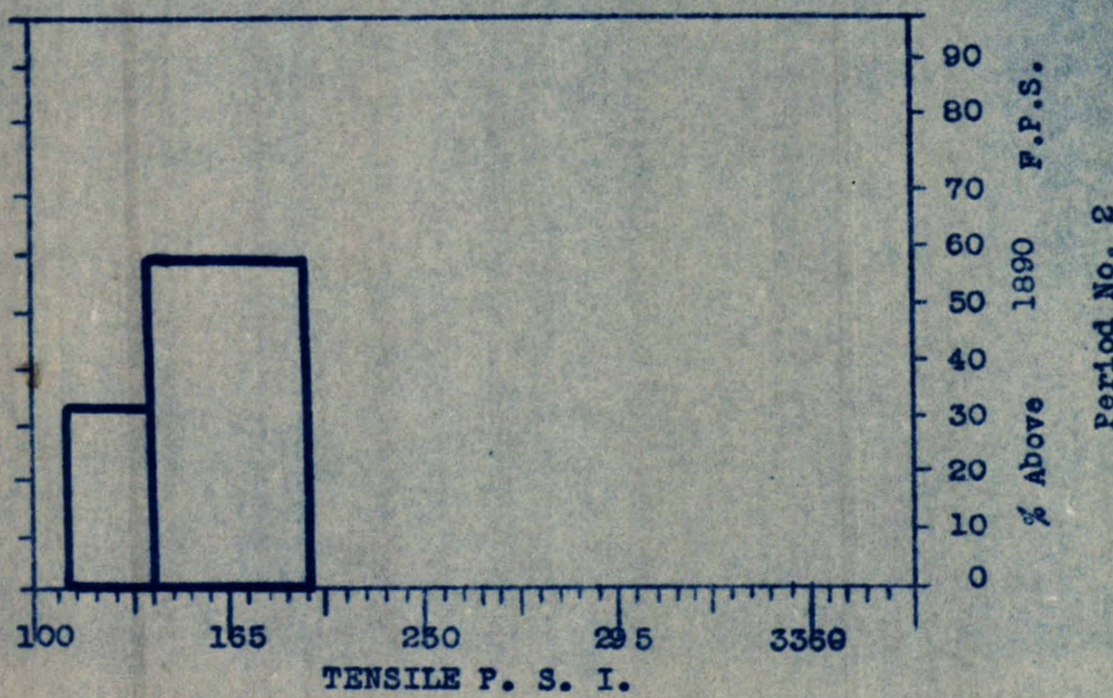
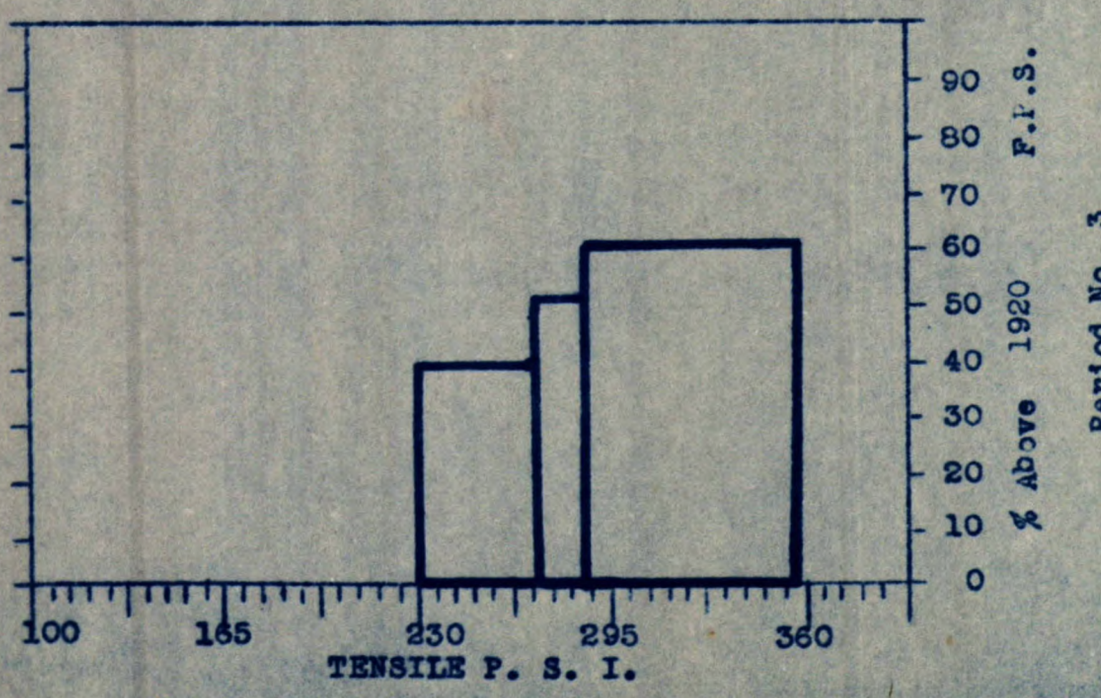
NUMBER IN " " NO. OF RESULTS

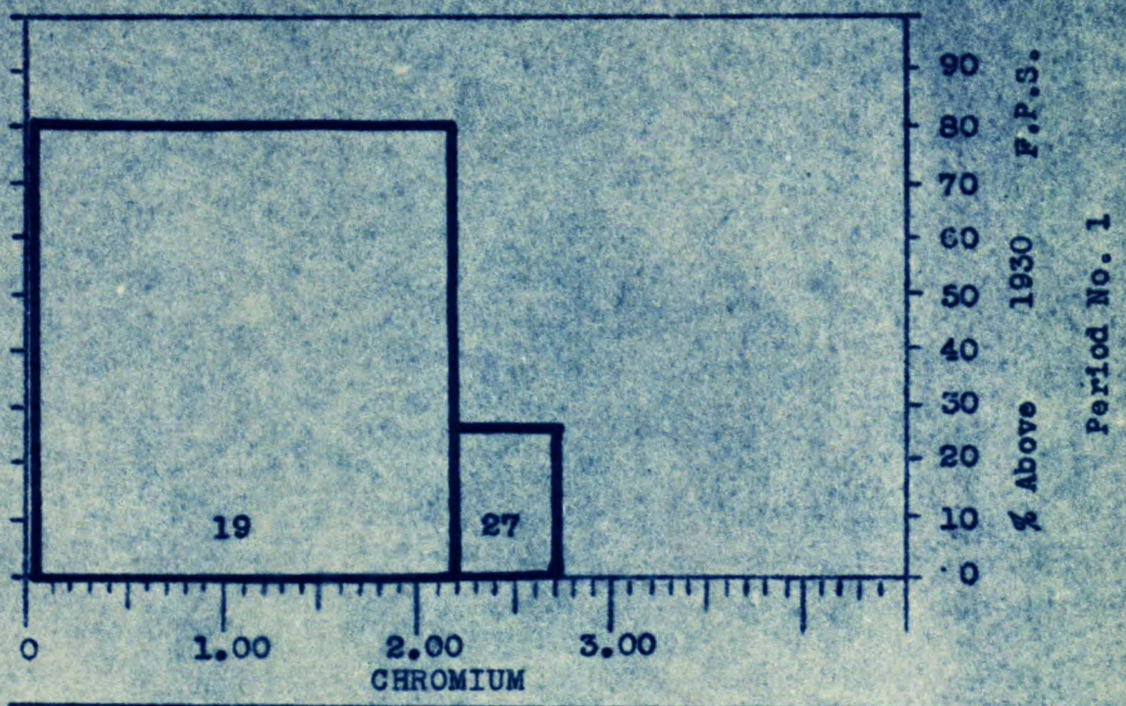


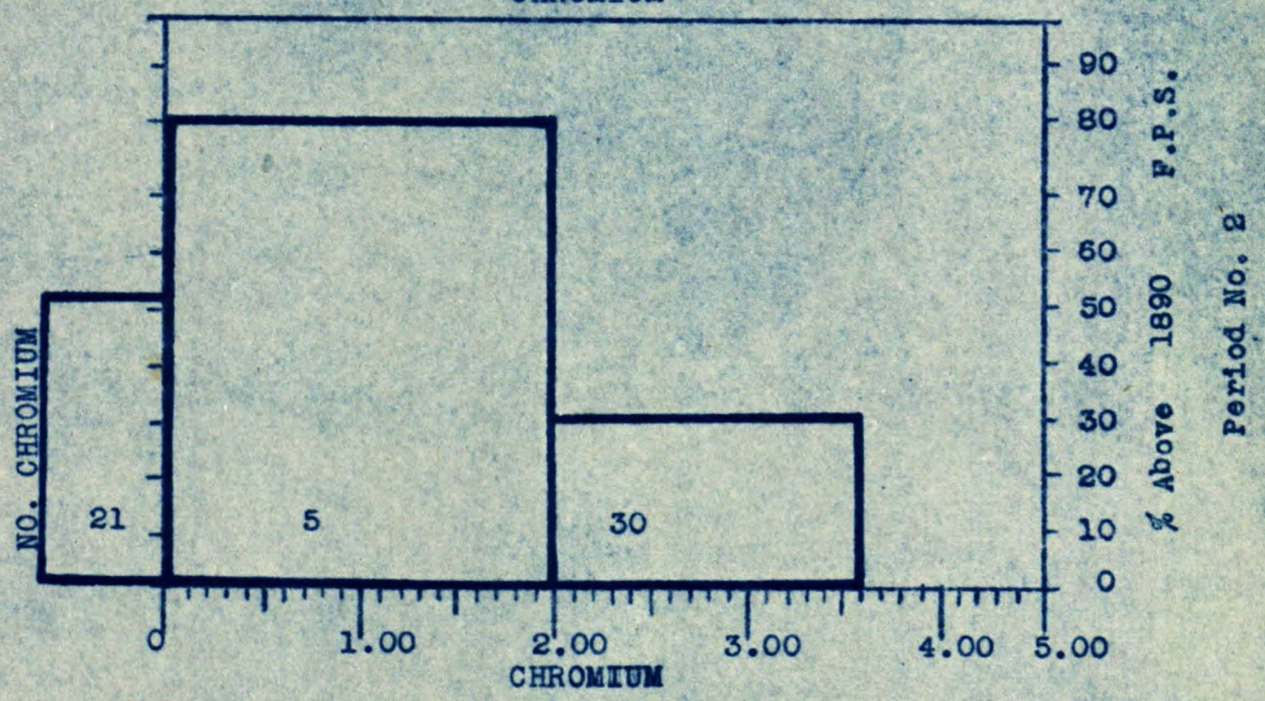


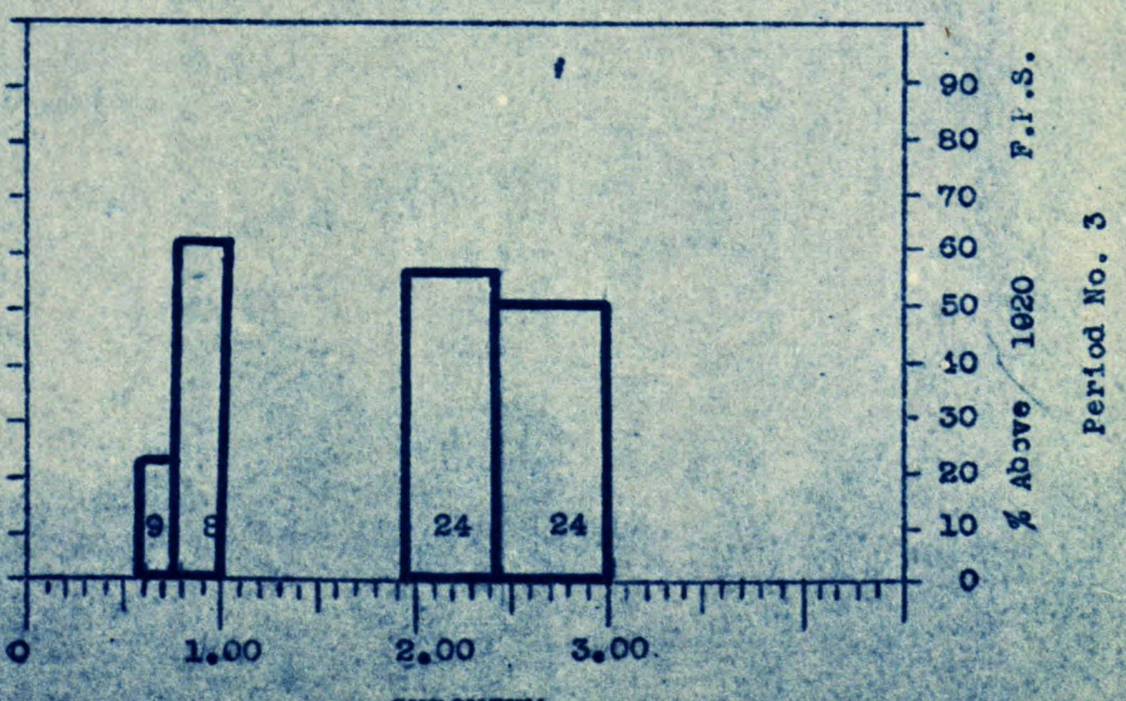


CORRELATION BETWEEN CHROM. AND BALLISTIC LIMIT

HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO. OF RESULTS







FACTORS HAVING LITTLE CONNECTION WITH ARMOUR QUALITY:

Pages 21 to 25 show the results of comparing test values with ballistic limits over three 6-month periods. The results, of course, apply only to the source and should not be taken to be of general application.

While definite trends are seen for short periods, changes in analysis or mill practice eliminate or reverse these trends.

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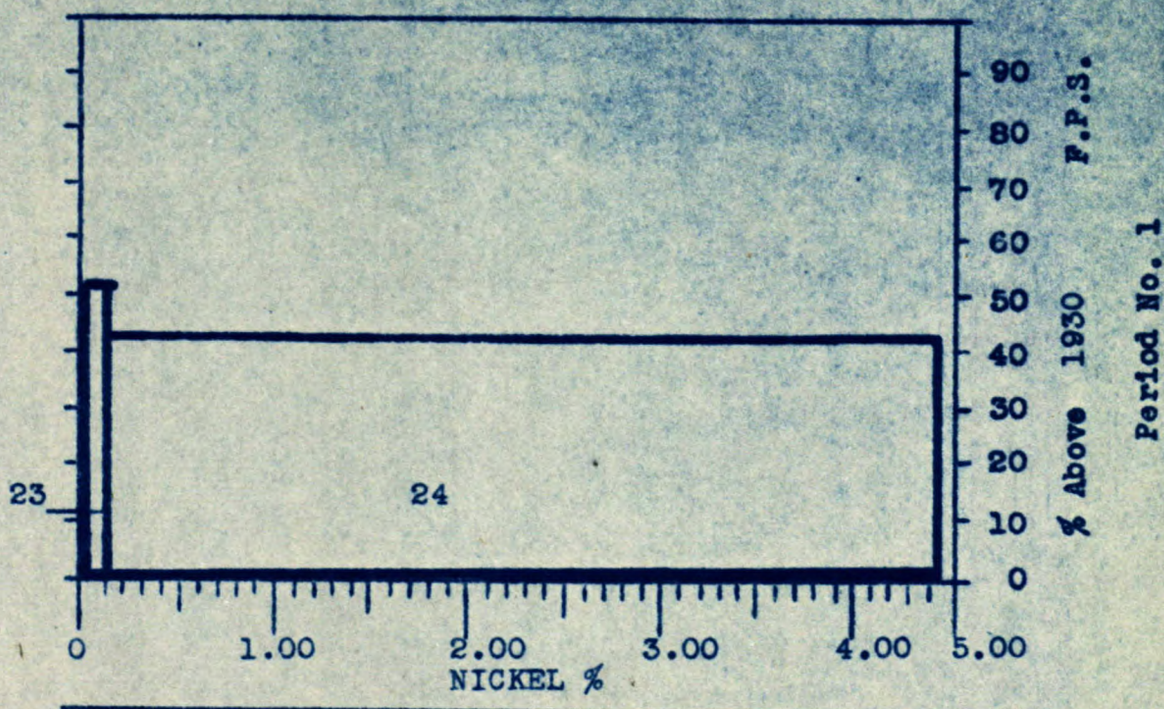
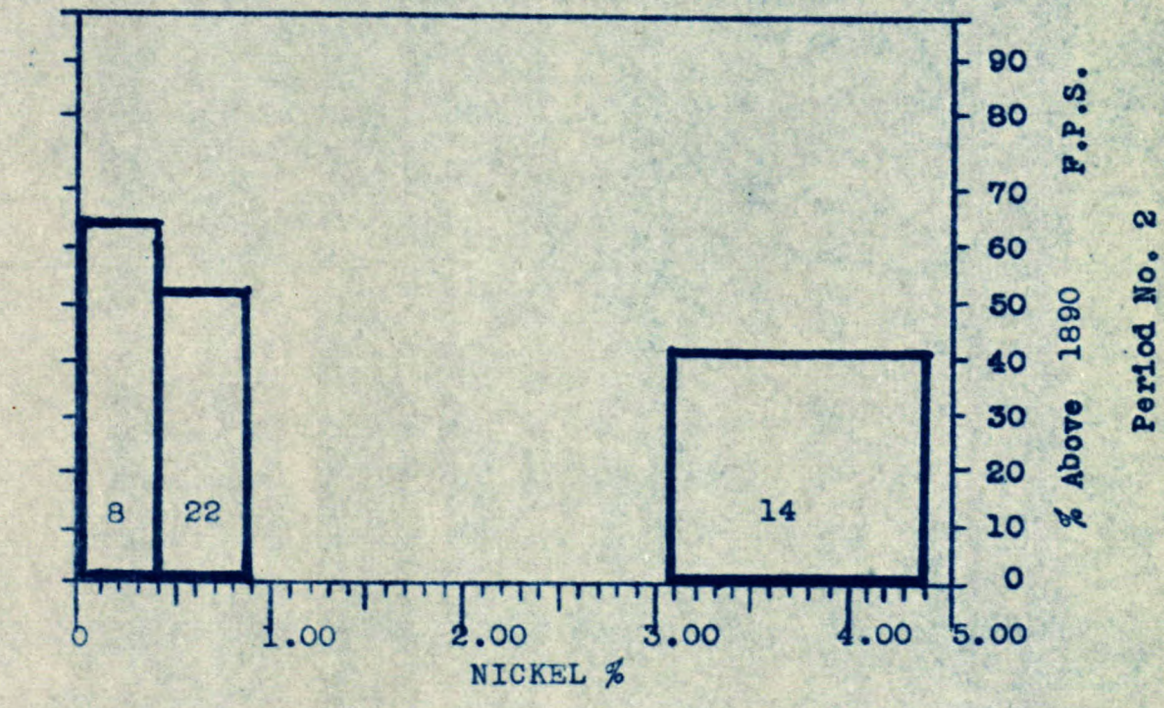
HHF:GHB.

(Pages 21 to 25)
(are photostats)

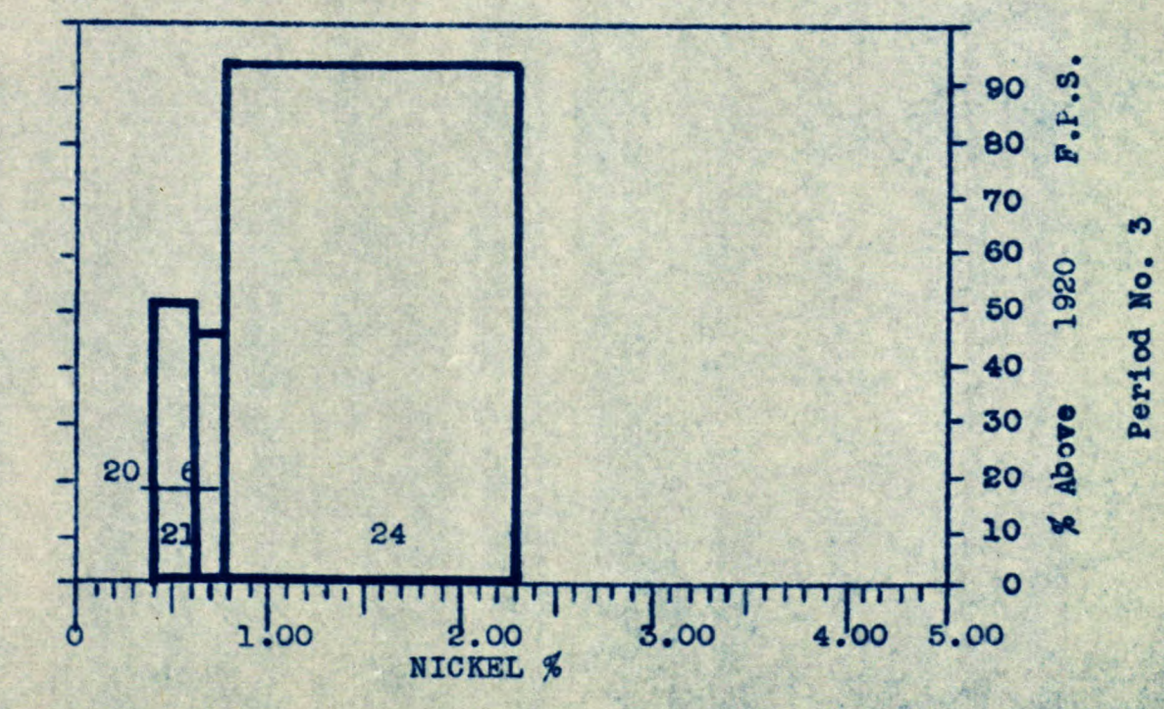
CORRELATION BETWEEN NICKEL AND BALLISTIC LIMIT
HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO. OF RESULTS



Period No. 1



Period No. 2



Period No. 3

CORRELATION BETWEEN ELONG. AND BALLISTIC LIMIT

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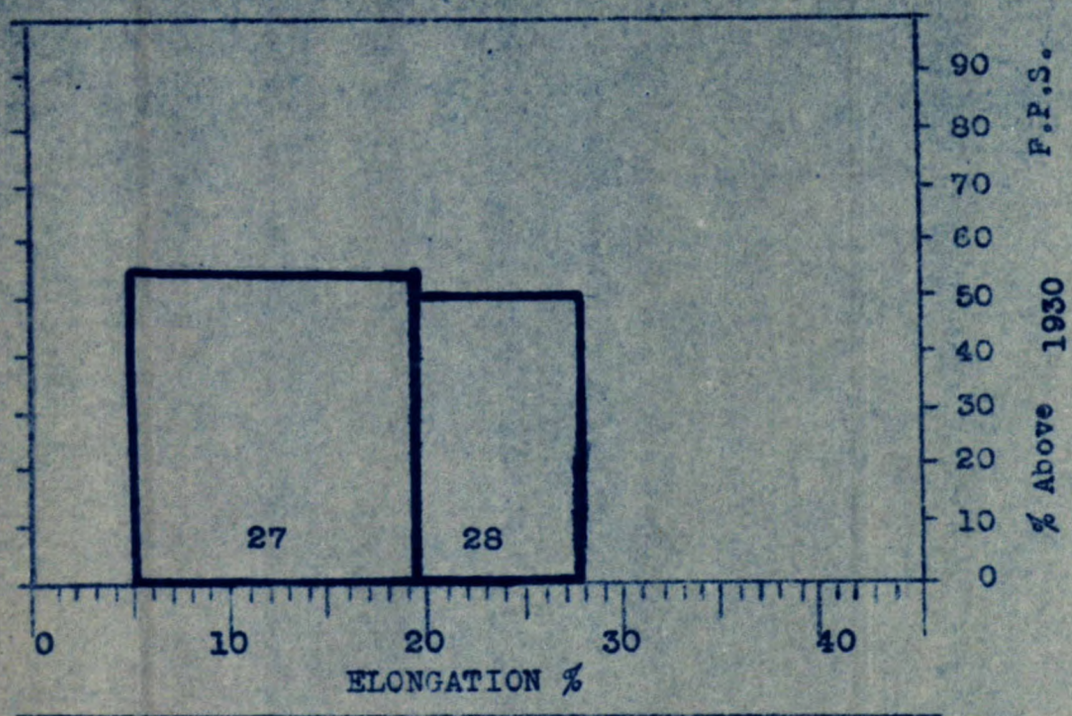
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO. OF RESULTS



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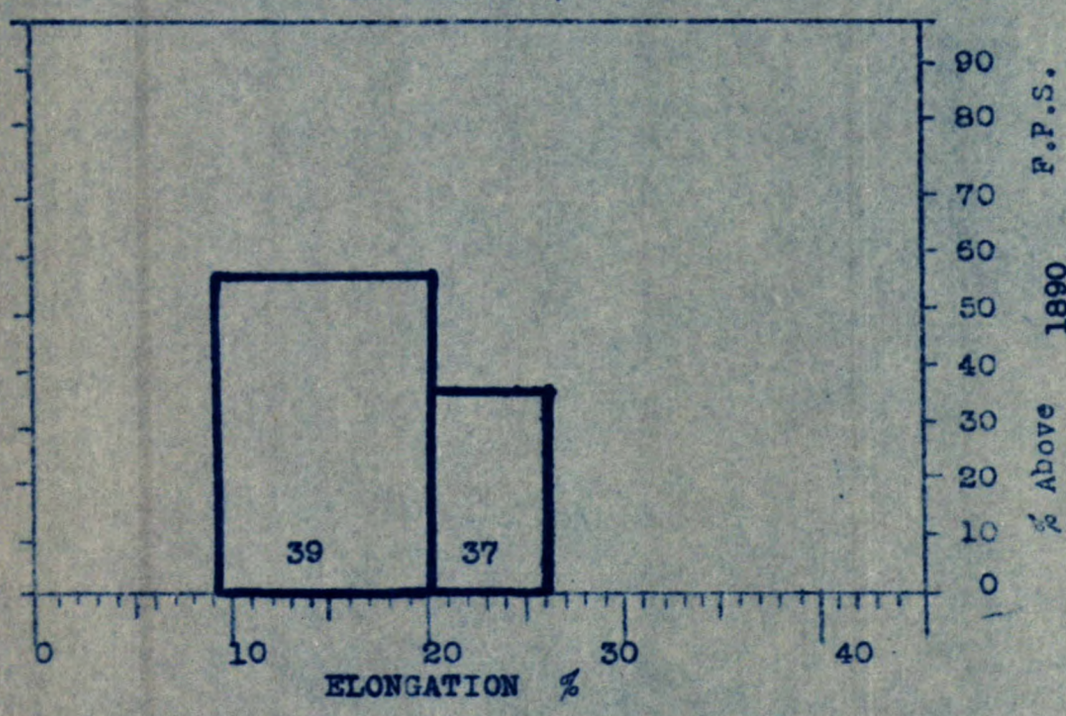
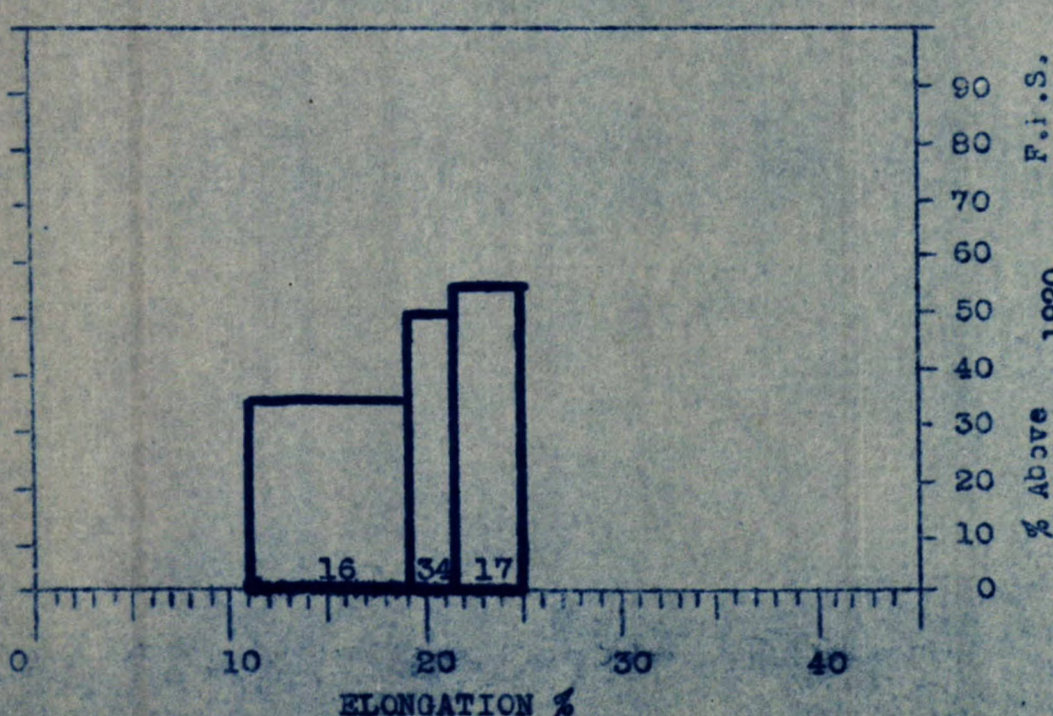
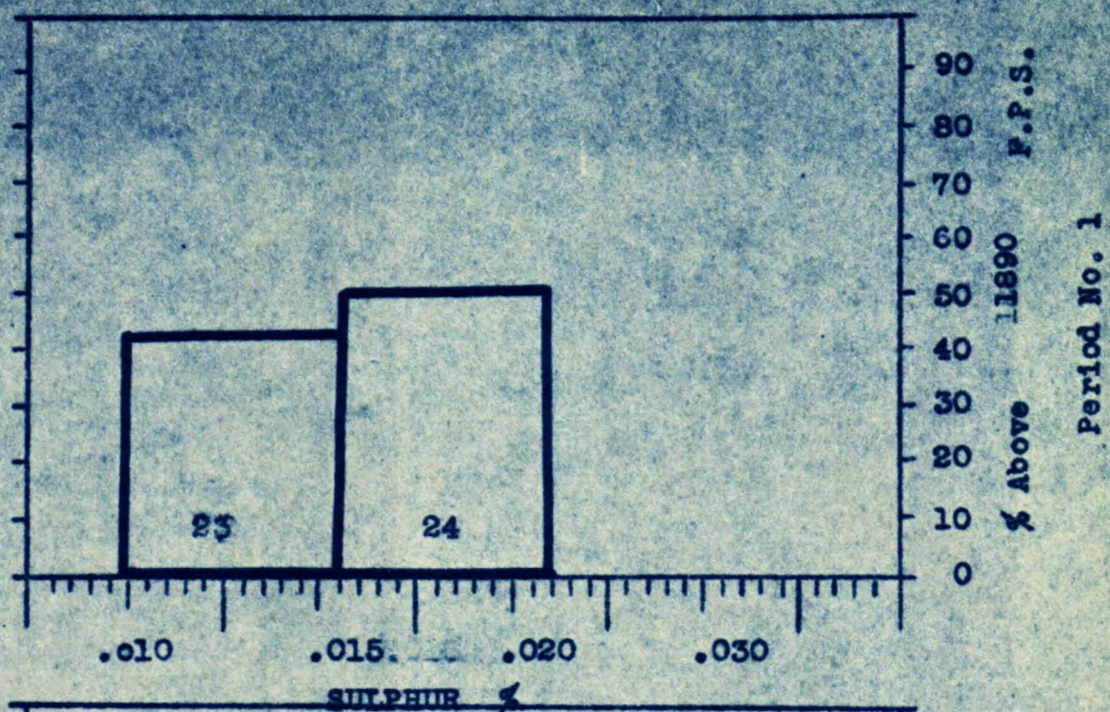


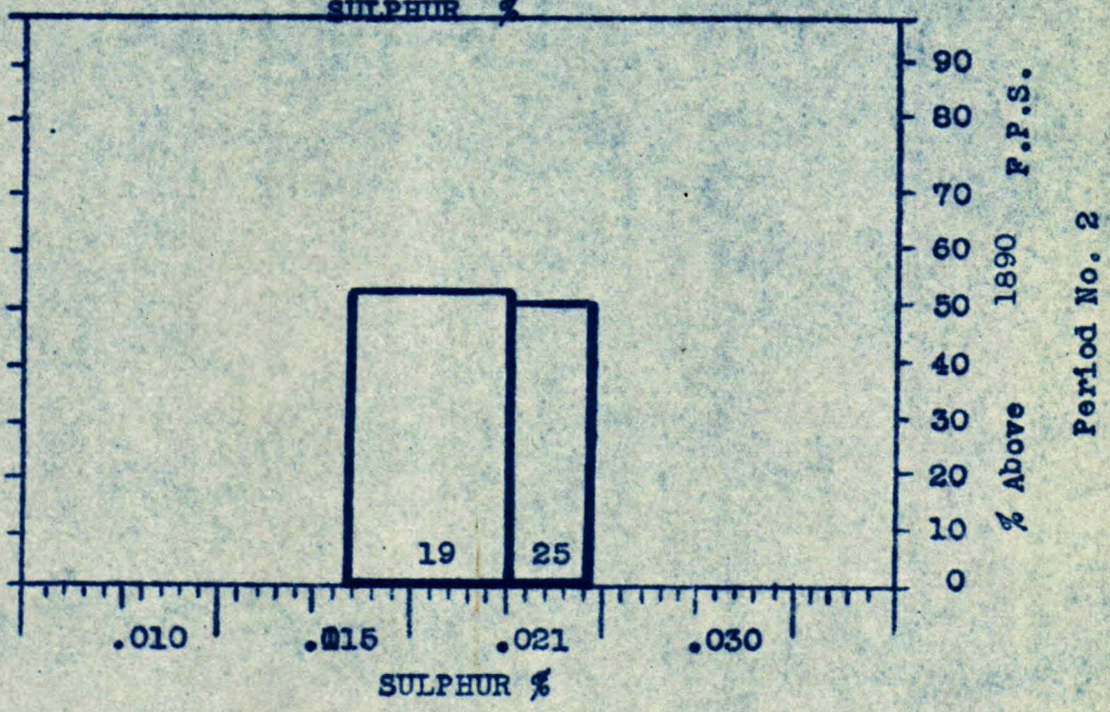
Period No. 2

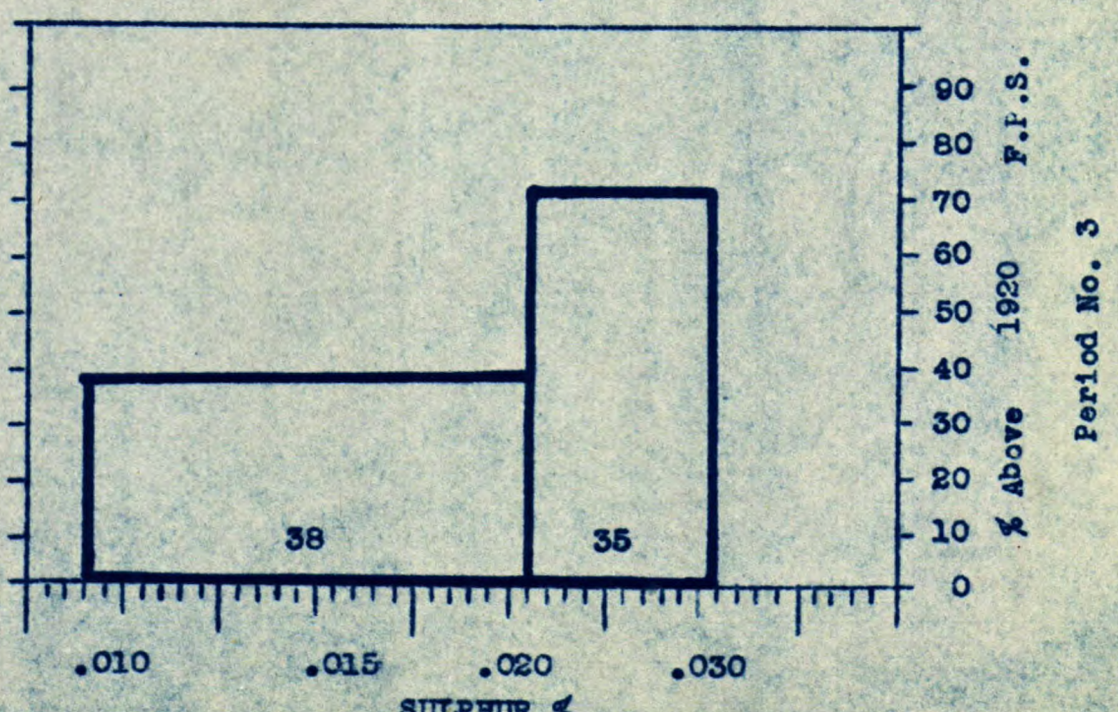


Period No. 3

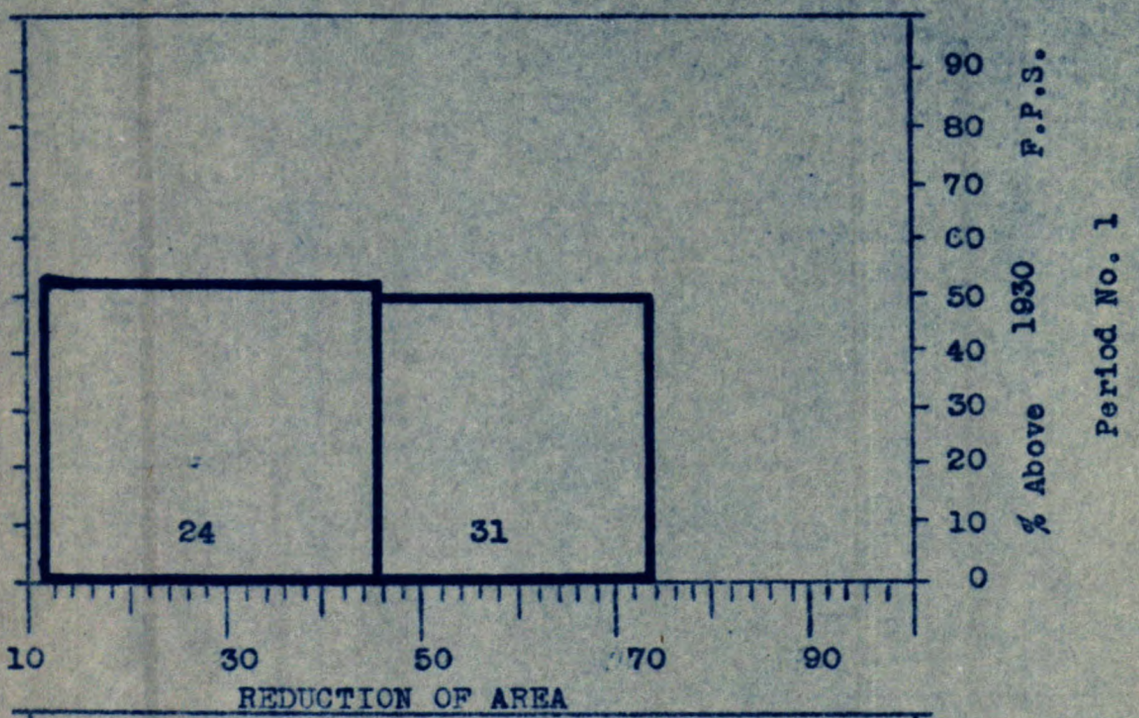
CORRELATION BETWEEN SULPHUR AND BALLISTIC LIMIT
HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO OF RESULTS

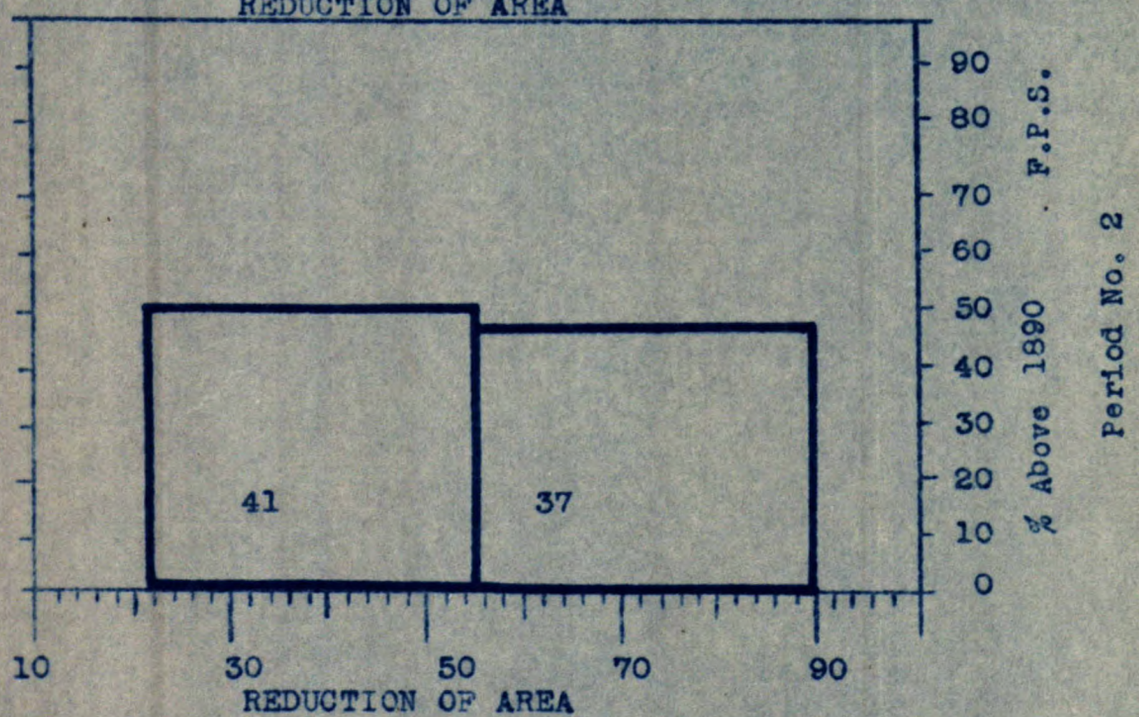


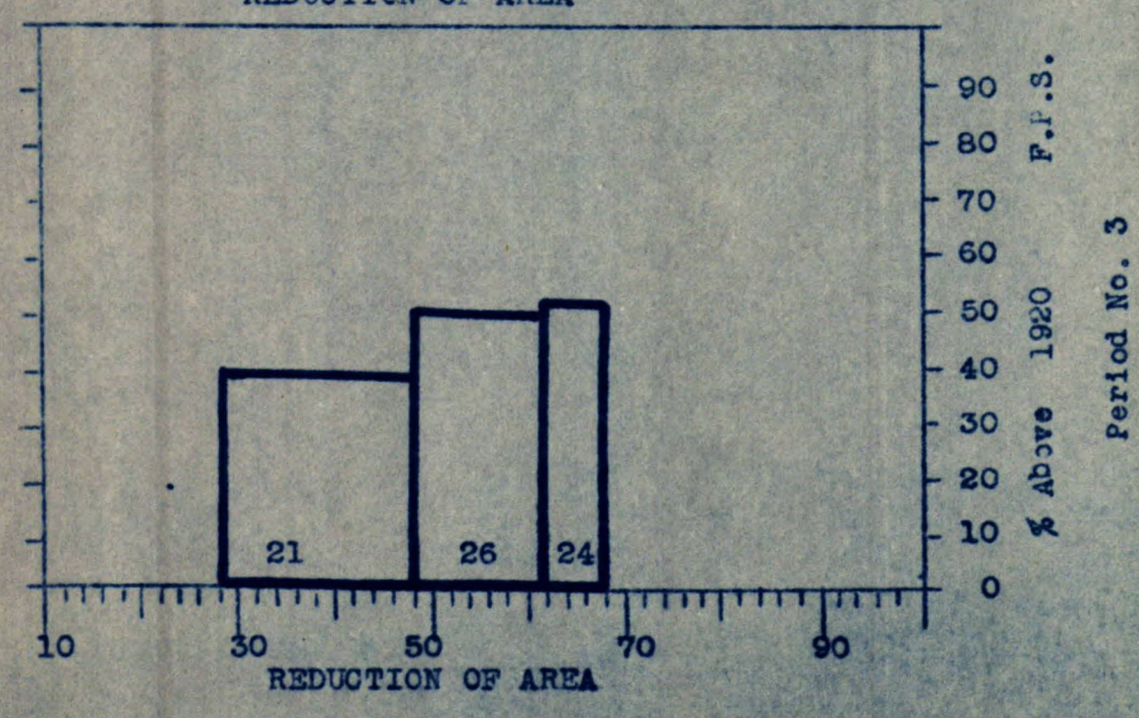




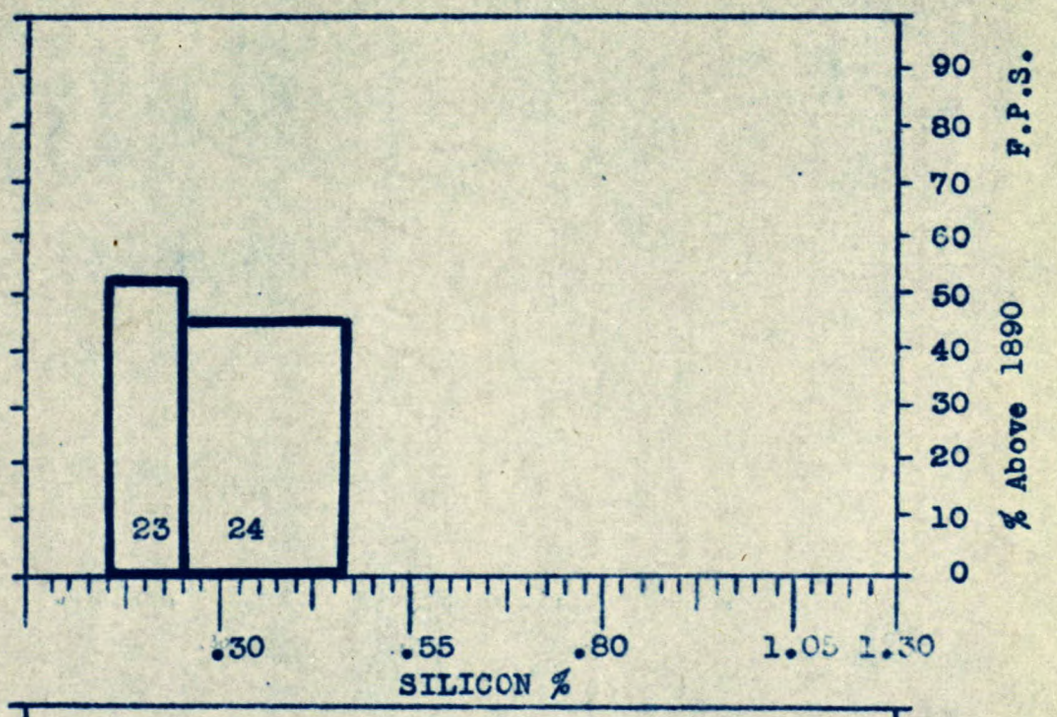
CORRELATION BETWEEN AND BALLISTIC LIMIT
HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO. OF RESULTS



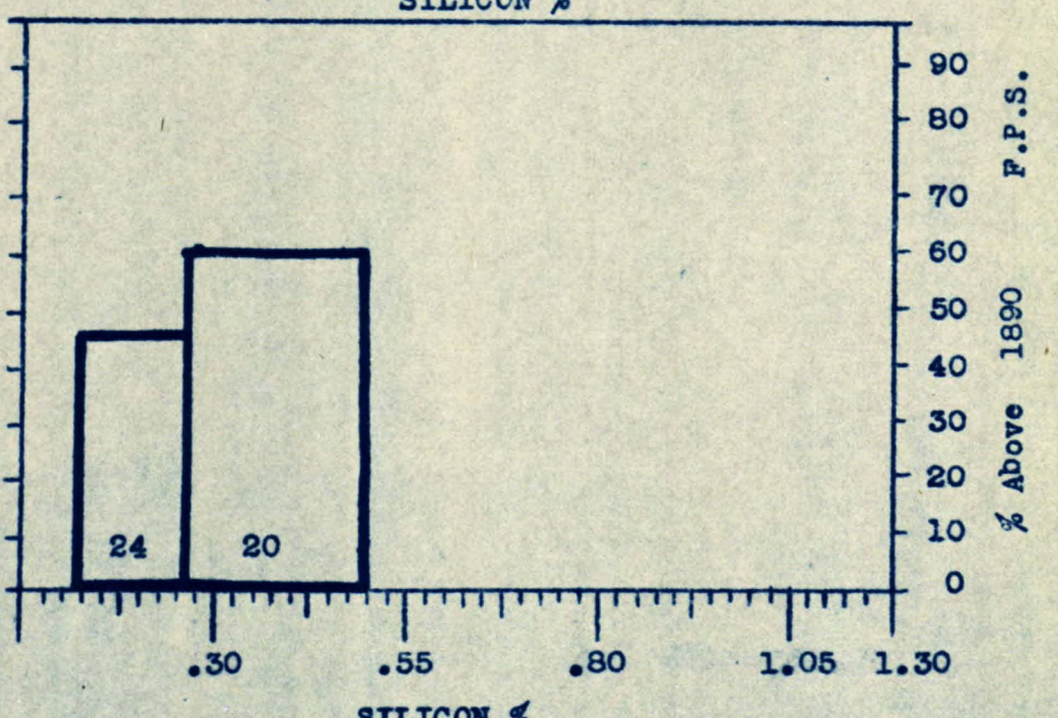




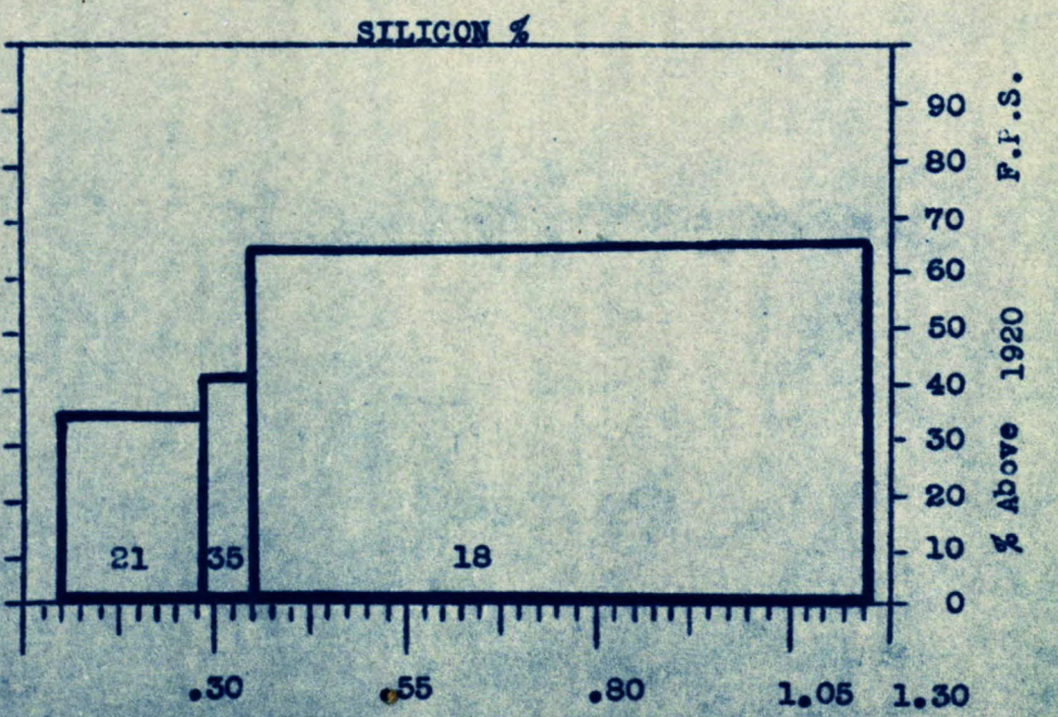
CORRELATION BETWEEN SILICON AND BALLISTIC LIMIT
HEIGHT OF BLOCK INDICATES ARMOUR QUALITY
WIDTH " " " SPREAD OF RESULTS
NUMBER IN " " NO. OF RESULTS



Period No. 1



Period No. 2



Period No. 3