OTTAWA September 24th, 1942.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1299.

Variation in Results of Physical and Chemical Tests on Steel.

(This is Report No. 6 of the Canadian Bureau of Mines 1942 Armour Plate Statistics Series.)

===========

(Copy No.____.)

I 1299

1299

OTTAWA September 24th, 1942.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1299.

Variation in Results of Physical and Chemical Tests on Steel.

(This is Report No. 6 of the Canadian Bureau of Mines 1942 Armour Plate Statistics Series.)

==========

Abstract.

The spread of physical and chemical test results from ten different sources has been charted to serve as a reference.

This has been done to show that no two steel plants have identical processes and that the limits within which a test property can be controlled vary from plant to plant. Good control is a relative condition. Control of carbon

(Abstract, cont'd) -

varies from a range of ± 0.02 per cent to a range of ± 0.055 per cent. If these ranges are considered representative of the industry, then ± 0.02 per cent represents good control, ± 0.05 represents average control, and so on.

among the ~~The~~ reason for variation in ability to control a test property ~~lies in~~: might be;

(a) Equipment.
(b) Raw materials.
(c) Skill of personnel.
(d) Sampling technique.
(e) Testing technique.

From the frequency distributions an idea of what is normally possible can be obtained. New data can be compared to these in order to get an idea of how the control compares with other steel plants.

INTRODUCTION:

Interpreting the meaning of test results depends on viewpoint and experience.

Consider the following two heats of steel:

Test.	Heat No. 831	Heat No. 1129
Ultimate strength, p.s.i.	268,000	298,500
Yield strength, p.s.i.	227,500	252,100
Elongation, per cent in 2 inches	22.0	18.0
Reduction of area, per cent	65.0	58.0
Brinell hardness	281.5	311.0
Izod impact, foot pounds	47.5	59.0
Carbon, per cent	0.28	0.30
Silicon, "	0.24	0.32
Manganese, "	0.75	0.60
Sulphur, "	0.021	0.022
Phosphorus, "	0.034	0.027
Nickel, "	0.63	0.59
Chromium, "	2.40	2.21
Molybdenum, "	0.78	0.67
Ballistic limit of 60-mm. armour plate; speed of 2-pdr. shot in feet per second	1,861 ft./sec.	2,003 ft./sec.

(Continued on next page)
(Continued on next page)

(Introduction, cont'd) -

Heat No. 1129 has recorded ballistic properties considerably in excess of Heat No. 831.

Those making use of results similar to these are called upon to interpret their significance. Questions which might be asked are:

(Q) From the results would you say that the manufacturing process had remained constant?

(Q) Is a constant quality of armour plate being made?

(Q) Assuming ballistic limit alone as the criterion of excellence for armour plate, what are the ideal physical and chemical test values?

Answers to these questions depend on the viewpoint of the interpreter. Without any other evidence than that submitted one might assume that the properties of Heat No. 1129 indicate a changed process resulting in higher ballistic properties, and the physical and chemical properties of Heat No. 1129 should be immediately adopted as being vastly superior to those of Heat No. 831.

A laboratory research worker would say that the only way to determine the relationship between ballistic limit and physical and chemical tests would be to hold all other properties constant and vary one thing at a time. This, of course, is impractical ~~for~~ under industrial conditions.

The experienced steel plant metallurgist, engineer, or executive would say that such variations are, or are not, normal for a well-run steel-making operation. Constant quality of steel or armour or any product, agricultural or industrial, is represented by test values falling not at an exact point every time, but within certain limits. Thus, if the specification for armour plate calls for ballistic limit 1850 - 2050

(Introduction, cont'd) -

then, in the two heats above mentioned, a constant quality of plate is being produced. The only way to find out whether Heat No. 1129's analysis is definitely better than Heat No. 831's analysis is to make ~~about ten~~ many heats, ~~or more~~, of each type and then compare results.

The statistical view-point is almost identical with that of the experienced metallurgist, engineer, or executive; that is, before venturing an opinion on these questions, considerable experience in the form of part results must be available. Statistical methods condense past experience into a useful form. Having available past records to use as a basis for answering the above questions, answers might then be formulated as follows:

(a) Past performance has indicated that in this case the normal range of variation for physicals and chemicals has not been exceeded. A consistent method of operation is probably still in effect.

(a2) Armour plate from this source has a normal variation of from blank to blank feet per second ballistic limit. The two results quoted above are therefore normal for the practice employed.

(a3) Correlation charts can be developed to show ideal ranges for each property (See Report of Investigation No. 1144, Bureau of Mines (Canada)).

The statistical view-point and the practical man's view-point are virtually identical. They involve the same principle, namely, that a background of experience is necessary to permit of intelligent interpretation of current conditions in a process. Of course, the practical man has a great advantage over the most precise theorist, because he does not consider only the evidence presented by the sample. He has a knowledge of the process and of the conditions relating to

(Introduction, cont'd) -

the product under test. Also, he is familiar with the test method and its reliability.

Statistical methods, therefore, merely serve to condense and depict graphically the parts of the practical man's experience which have to do with measuring properties of material. A part of the background of experience necessary for logical interpretation is graphically presented in correlation charts and frequency distributions.

The correlation between, say, tensile strength and ballistic limit may be guessed at and an arbitrary standard set up, or a sufficient number of production results may be gathered and presented in the form of Figure 1.

Figure 1.

Correlation of Carbon and Ballistic Limit, D.F. & S. 60-mm. Armour Plate.

(Continued on next page)

(Introduction, cont'd) -

After an approximate idea of the best range for a property (say, elongation) has been determined, we are then interested in the way in which this property normally occurs. This information can be readily obtained from a frequency distribution.

Figure 2.

Republic Yield Strength,
Frequency of Yield Test Results.

From Figure 2 it can be readily seen that the value of 117,000 - 120,000 p.s.i. occurs most frequently and that deviations from this range become fewer as they occur farther from the central value. This smooth bell-shaped curve is characteristic of a consistent method of operation; that is, the product is under statistical control.

If a property is under statistical control, then each

(Introduction, cont'd) -

test result can be classified as an indicator that

(a) the process is unchanged,

or,

(b) an assignable cause for variation has been introduced in the process.

Limits for judging which of the above two situations exists can be easily derived by the Quality Control method.

If the test results, when arranged in the form of a frequency distribution, do not form a symmetrical single-peaked curve, then it may be that:

(a) The number of results used was insufficient to show the true nature of a product. Several hundred test values should be used to get a smooth curve.

(b) Two different processes are being used.

(c) The process is not under control, but is constantly changing.

(d) A series of experiments has been performed during the time the test data were recorded. Two slightly different processes result in an irregular distribution.

Suppose a manufacturer were to establish a range of 85,000 - 100,000 p.s.i. for yield strength when the normal characteristic of this process was for yield strength to vary between 70,000 - 104,000 p.s.i. The only way to get the product within the narrow limits specified would be either to establish a new process, or to test all of the product and re-heat-treat the rejects so that they would fall within the 85,000 - 100,000 p.s.i. limits. Figure [ ] shows the type of frequency distribution resulting when part of the product is re-processed.

(Continued on next page)

(Introduction, cont'd) -

Figure 3.

American Yield.

Lack of Control - Deliberate or Unnoticed.

Figure 4.

SYMINGTON-GOULD, 1" YIELD.

(Introduction, cont'd) -

Figure 4 shows a condition of lack of control. Frequently this type of distribution occurs in the development stages of a process; later, a specific standard is adopted and the property is gradually brought under control.

What are the Narrowest Possible Limits for a Test Value (Carbon, for example)?

The carbon content of a heat of steel is influenced by the raw materials, heat conditions in the furnace, time, methods used by furnace men, and the equipment as well as accuracy of analysis. The number of combinations of different effects possible, is finite and eventually after about 500 heats the normal range for a definite furnace and a definite charge, with the same personnel, could be stated.

The frequency distributions in this report do not include a sufficient number of tests to show up everything that might happen. However, they condense a wide variety of experience for comparison:

one	source has a	spread	of	5	points.
"	" "	"	"	6	"
3	sources have	"	"	9	"
one	source has	"	"	10	"
3	sources have	"	"	11	"
1	source has	"	"	12	"

In demanding a narrow range for a certain property, the inspector must remember that each process is characterized by certain normal limits. If narrower limits are to be specified, either costly rejections will result or a new more complicated process must be used. Volume of production may be expected to drop off, if narrower limits are to be maintained. The following frequency distributions have been prepared to be used as a reference. Intelligent interpretation of a group of

(Introduction, cont'd) -

test results can be made only after a background of experience has been accumulated. This background consists of:

(1) Knowledge of the relationship between the test value and the performance of the product.

(2) Frequency distribution of the test value characteristic of the producer being inspected.

(3) Frequency distributions characteristic of several different producers in the industry.

The **charts at** the end of this report show the variance in ballistic limit, chemical and physical tests. It is hoped that they will contribute some information on the nature of this phonomena.

THE NORMAL DISTRIBUTION CURVE:

It is characteristic of each species of thing that measurements of a property, when expressed as distribution, form a bell-shaped curve. A classical example of this curve, taken from the U.S. Govt. Printing Office publication, "The Medical Department of the United States Army in the World War" (by Davenport and Lowe), is given in the following table:

Weight at Demobilization of 746 French Soldiers Serving in U.S. Army During the World War.

Weight, in pounds		No of Men
100 and under 110	-	7
110 " " 120	-	39
120 " " 130	-	123
130 " " 140	-	181
140 " " 150	-	183
150 " " 160	-	122
160 " " 170	-	59
170 " " 180	-	19
180 " " 190	-	5
190 " " 200	-	5
200 and over	-	3

(The Normal Distribution Curve, cont'd) -

From this table it can be seen readily that the highest frequency of results occurs at around 130 to 150 pounds. The farther away from this central value, the fewer the results that occur.

This phenomenon is so general in nature and in industry that if a single-peaked distribution does not occur it is assumed that the data do not represent material that has originated from a common source.

Page 12 shows the normal curve of distribution depicted in histogram form, using different group numbers. In general, the number of groups into which data are divided depends upon the amount of data. In order to get a smooth curve approaching normal, 300 to 1,000 results are necessary. The irregular shapes of the distributions in this report are due mainly to the small amount of data available.

**

(Continued on next page)

(The Normal Distribution Curve, cont'd) -

EFFECT OF NUMBER OF GROUPS ON SHAPE OF NORMAL CURVE.

Figure 5.

SEVEN GROUPS.

Figure 6.

ELEVEN GROUPS.

Figure 7.

FIFTEEN GROUPS.

oooooooooooo
oooooo
oo

HHF:GHB.