# Physical Properties and Methods of Test For Some Sheet Non-Ferrous Metals

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This paper covers an investigation which was undertaken to secure a simple and reliable method of test for sheet non-ferrous metals. An account of the early development work leading to the adoption of the Rockwell hardness tester for a preliminary inspection of sheet metals and the tensile test as the basic test to be referred to in case the Rockwell test results were near to or outside the established Rockwell limits for a given lot of material was published in 1927.[1] The continuation of this work including establishment of test limits for four grades of brass and for two grades each of nickel silver and phosphor bronze will be published this year.[2]
This present paper describes the development work reported by these two papers.

Considerable attention has been given to the Rockwell tester, which, as a result of this work, has been found satisfactory for use as a specification instrument for brasses 0.020 in. and thicker, when used under standardized methods of test and calibrated with standard test blocks. Other tests such as the bend test, ductility test and other hardness tests have been studied but further development work is necessary.

The Rockwell hardness and tensile strength limits are given for four alloys of brass, and two alloys each of nickel silver and phosphor bronze. The physical properties of the rolling series upon which these limits were based are presented as well as experience data obtained on shipments of commercial material. The limits for brass alloys A, B and E are considered final, but the limits for the other metals are tentative until more complete experience is available.

Grain size limits are given for annealed brass and nickel silver sheet. For inspection purposes the grain size is estimated by comparison with the standard photomicrographs reproduced in the 1929 report of Committee E4 of the A. S. T. M. on Metallography.

Refinements in the calibration of the Rockwell tester are given, as well as the development of testing technique. An experimental model of a motor-driven bend test machine is described.

THE investigation which this paper covers was undertaken because of the need for a simple method of test which would afford a more definite determination of the properties of thin-sheet non-ferrous metals than any which has yet been developed. Large quantities of

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[1] "Physical Properties and Methods of Test for Sheet Brass," by H. N. Van Deusen, L. I. Shaw, and C. H. Davis, *Proceedings of the American Society for Testing Materials*, 1927.

In addition to the authors the following took an important part in the investigational work. Messrs. H. N. Van Deusen C. H. Greenall and W. S. Hayford, of the Bell Telephone Laboratories, Messrs. W. H. Bassett, R. M. Tree, Alden Merrill and G. S. Mallett of the American Brass Co., and Messrs. L. I. Shaw, M. D. Helfrick H. F. Culver and G. R. Brown of the Western Electric Co. Messrs. N. E. Newton and W. H. Eastlake of the Northern Electric Co., Montreal, participated in the conferences which were held as the work progressed.

[2] "Physical Properties and Methods of Test for Sheet Non-Ferrous Metals," by J. R. Townsend, W. A. Straw and C. H. Davis, presented before A. S. T. M., June 1929.

brass, nickel silver and phosphor bronze are used in the manufacture of telephone apparatus as structural members, springs, and bearings. Because of space limitations, the parts are necessarily small; many are formed into irregular shapes; spring parts must maintain accurate adjustments and have long fatigue life; certain other parts must resist wear. All requirements are steadily becoming more exacting because of the increasing complexity of telephone systems and it, therefore, became necessary to insure more closely the uniformity of the material used in the apparatus.

The methods of test developed to check the uniformity of material are of equal concern to both consumer and supplier. Both are interested in a test rapid enough for use in inspection work and also so simple that specially trained men are not necessary for the actual testing. Due to the large amount of material that must be inspected it is necessary that any tests used require little time to apply and be adaptable to modern production methods. Furthermore, close agreement in test results is necessary. Since no test method was available fulfilling these requirements, it became necessary either to develop new methods of test or to modify existing methods. In addition, limits were desired that would represent the best quality of material obtainable consistent with commercial mill practices.

As a result of this need a cooperative program of tests was laid out which would lead to the drafting of requirements on thin-sheet metals. Those cooperating in this program were associated in the production and use of such material, and each member had already done preliminary work which evidenced his interest in the problem. The group was limited to one producer and one consumer in order that the work might be expedited, and the results that have been obtained justify the plan.

The results of the investigation are given herein for such value as they may have to the industry. It is hoped that this work may act as a stimulus to others interested in this problem so that ultimately definite standards may result, including the refinements demanded by modern industry.

The results of the study of the methods of test suitable for high and clock brass sheet of the order of 0.020 in. and thicker are presented and it is shown that the Rockwell tester gives the most reliable information of the several hardness testing machines available at the present time. Methods of operation of the Rockwell hardness tester were worked out by the cooperating laboratories and a method of carrying on tension tests was developed. The limitations in the use of the Rockwell hardness tester for sheet metal are pointed out and the need for the development of a tester capable of higher precision in the harder materials and also capable of making hardness tests on material less than 0.020 in. thick is emphasized.

The tensile strength limits are determined by the following procedure. The tension test results of the rolling series are plotted against the actual percentage of reduction by cold rolling. Two limiting curves are drawn in giving the minimum and maximum tensile strength for all reductions covering the range of commercial anneals. These two curves are based on years of experience with these metals and also on the rolling series. The tensile strength limits were taken from these curves for the theoretically correct reduction for each temper. Rockwell hardness tests are made on the grip ends of the tension test specimens, thus establishing the Rockwell hardness-tensile strength relationship for the material. Having established the tensile strength-reduction relationship, the corresponding hardness values are obtained from the Rockwell hardness-tensile strength curve. These limits are then subjected to trial on a large number of shipments of material.

The Rockwell test is considered a preliminary inspection test and is mainly useful because of its economy of time and material. The tension test, on the other hand, is considered the test upon which the acceptance or rejection of the material is based. In practice, material within the Rockwell hardness limits is accepted unless the hardness reading is near or outside the hardness limits, in which case a tension test is made.

This paper covers high and clock brass sheet and four other alloys of brass. One of these contains less lead than clock brass and is designed for use where a material combining moderate drawing and cutting properties is desired. Another has a nominal composition of 72 per cent of copper and 28 per cent of zinc. Grain size requirements are given for two others mainly used for drawing purposes. One of these consists of nominally 85 per cent of copper and 15 per cent of zinc and the other of 75 per cent of copper and 25 per cent of zinc. This paper also covers two nickel-silver alloys and two phosphor-bronze alloys.

The Rockwell hardness and tensile strength limits given for all of these alloys other than high, clock and alloy E brass may be considered tentative in view of the limited experience had with commercial shipments of materials purchased in accordance with these limits up to the present time. The requirements for high, clock and alloy E brass are considered final. Alloy E brass has a lead content midway between high and clock-brass.

## METHOD OF HANDLING WORK

The round-robin tests on the Rockwell hardness tester, standard test blocks and calibration of the machines were made by the American Brass Co. (Waterbury, Buffalo and Kenosha Branches), Bell Telephone Laboratories, and the Western Electric Co. The tension tests were also made by these laboratories. All of the rolling series were manufactured by the American Brass Co. Experience data on shipments of non-ferrous metals were obtained jointly by the American Brass Co. and the Western Electric Co.

## METHODS OF TEST

### *Tension Test:*

As stated previously, the tension test is considered the basic mechanical test for cold worked materials. Complete data on tensile properties were therefore obtained on the rolling series. All tests were made in accordance with the standard testing procedure developed for use in the Bell System and given in Appendix II. This method has been in use over 4 years and has been found satisfactory to all concerned. Three tension test specimens were made from each sample. The tensile strength, proportional limit, percentage of elongation in 2 in. and modulus of elasticity were determined for each sample of the high-brass rolling series. The specimen 14 in. in length was used which allowed the use of an 8-in. gage length Anderson [3] extensometer. The shorter specimen with the 2-in. gage length was used for the clock brass and all later work. The tests were made on an Amsler tension testing machine. The machine was carefully calibrated, the load indications being correct to less than ½ of 1 per cent.

The tensile strength and percentage of elongation on the high-brass sheet rolling series are plotted in Fig. 8 against per cent reduction by rolling. Nearly a straight line relation exists between the tensile strength and percentage reduction by rolling and the values are grouped closely about this line. The curve is plotted to show the average result, but separate curves could readily be drawn for each thickness. This test also has little sensitivity in the harder tempers where the curve becomes asymptotic. The proportional limit is difficult to measure with any degree of accuracy on account of the personal factor involved in interpreting curves. The results in this case showed no definite relation to any of the other values.

In order to evaluate the test results, it is necessary to establish control limits to determine whether any variations in the data

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[3] H. A. Anderson, "Tension Tests of Thin Gage Metals and Ligh Alloys," *Proc. A. S. T. M.*, Vol. 24, Part II, p. 990 (1924).

are significant. By significant variations are meant variations that can be assigned to definite sources, such as measuring errors, defects in the metal tested, testing errors, etc. For the case under consideration, a method of analysis was employed which allows for small sample numbers. The method used is described elsewhere.[4]

Figure 1 shows an engineering analysis of the tensile strength results for alloy B nickel silver plotted in two ways.[5] The data in Fig. 1 (*a*) were obtained by computing, for each of the laboratories, the average tensile strength and the standard deviation [5] of all the specimens milled by that laboratory and tested by each of the four laboratories *A*, *B*, *C* and *D*. The data in Fig. 1 (*b*) were obtained

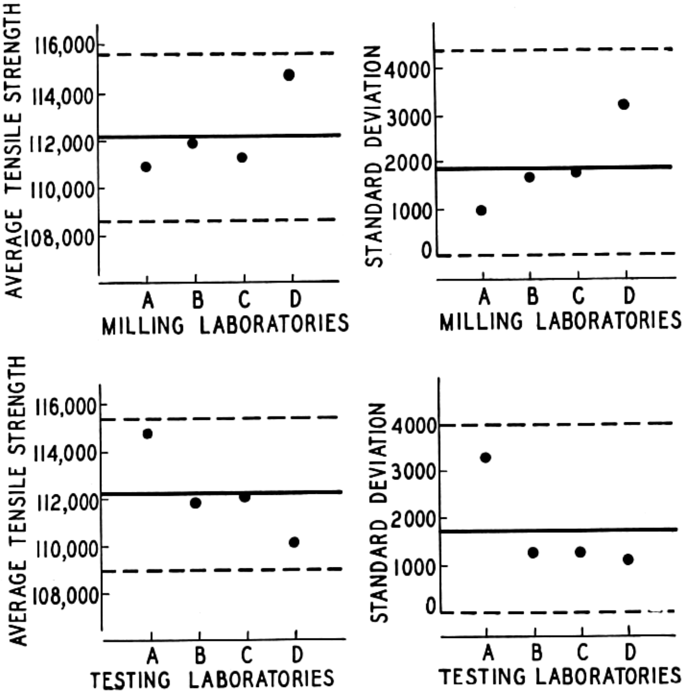

Fig. 1—Statistical Analysis of Round-Robin Tension Tests on Alloy B Nickel Silver.
(*a*) Points are average of all specimens milled at laboratories indicated, and tested by the four laboratories.
(*b*) Points are average of all specimens tested at laboratories indicated, and milled at the several laboratories.

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[4] See Modified Criterion No. 1 in Appendix I to the Report of Sub-Committee XV on Die-Cast Metals and Alloys appended to the report of Committee B-2 on Non-Ferrous Metals and Alloys, presented before the American Society for Testing Materials, June 1929.

[5] The methods used are those described by W. A. Shewhart in a paper on "Quality Control," *The Bell System Technical Journal*, Vol. VI, October 1927.

by computing, for each of the laboratories, the average tensile strength and the standard deviation of the specimens milled in the four laboratories and tested in each of the respective laboratories. In each instance the specimens tested or milled by an individual laboratory are grouped together. The dotted lines on the diagrams represent the control limits within which the data should fall without leaving anything to chance, which means that points falling without these control limits indicate variations due to assignable causes, such as errors in measurements, defects in the material, etc. These diagrams show, therefore, that the tensile strength results between laboratories do not reveal significant or assignable difficulties other than those which could be attributed to chance. In other words, the analysis gave no indication of the presence of assignable variations between the testing laboratories.

These specimens were prepared by cross milling the gage length with a milling cutter shaped to conform to the final shape of the specimen desired. This method, which has been described elsewhere,[6] results in the saving of time and produces specimens of a uniform character.

*Scleroscope Hardness Tests:*

Previous to this investigation Bell System specifications on non-ferrous materials were written in terms of scleroscope hardness, but considerable trouble was encountered between the suppliers and users of metal due to difficulty in checking each other's readings. Because results could not be duplicated on two instruments, it was necessary to allow rather wide limits in each temper of material. This resulted in considerable overlapping in scleroscope limits of the tempers of materials accepted under these specifications. Experience had shown it to be impossible to make correction curves for any two instruments which would hold for any reasonable length of time, and if any replacements such as new hammers were necessary the calibration was changed.

In order to obtain more definite information as to what could be expected from the scleroscope, comparisons were made between four type "C" sclerscopes located in four laboratories using the same samples of materials. Great care was taken in preparing the samples so that they were flat and free from any dirt and roughness. The instruments were in good commercial adjustment and were employed in the usual manner, the magnifier hammer being used. A single

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[6] R. L. Templin, "Methods for Determining the Tensile Properties of Thin Sheet Metals," *Proc. A. S. T. M.*, Vol. 27, 1927.

thickness of material was used in each case. The results of one of these comparison tests are shown in Fig. 2. Two other such comparisons were made incidental to the work being done to establish operating technique on the Rockwell tester, but the results shown here are typical. At least five readings were made on each sample and the average was used in preparing these curves. It will be noted that the readings on the different scleroscopes varied as much as eight points from each other on cold-rolled materials. The variations in readings between the machines follow no apparent law, one machine reading higher at one part of the scale and lower at another. It will also be noted from the curves that the range of the scleroscope

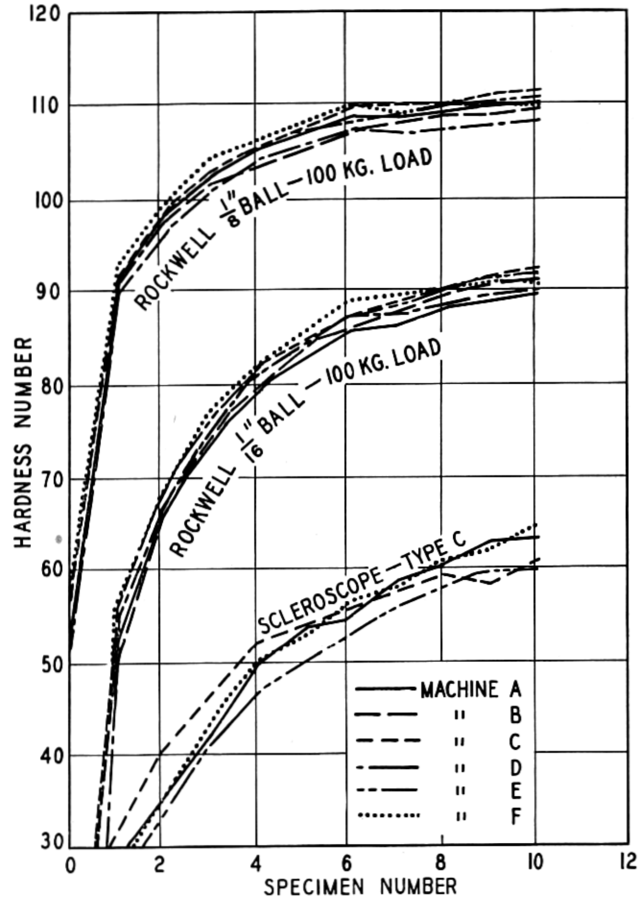

Fig. 2—Brass "Round-Robin" Series. Comparison of Rockwell and Scleroscope Testers.

is much smaller than that of the Rockwell on the same samples. In other words, the sensitivity of the scleroscope is considerably less than that of the Rockwell.

An investigation was made of the type "D" recording scleroscope equipped with a universal hammer to obtain a comparison with the type "C" instruments. The conclusion reached was that there was little difference between the two instruments as regards precision. It was not considered worth while, therefore, to make elaborate comparison tests. Hence, this type of instrument was not used in the round-robin tests.

In view of the difficulties encountered in using the scleroscope, which have also been brought out by previous investigators, no further effort was made to adapt it for use as a specification instrument.

*Rockwell Hardness Tests:*

While the Rockwell hardness tester has been used quite extensively and with considerable success in testing steels it has been used comparatively little for testing non-ferrous metals. Our experience previous to this investigation indicated that it might prove satisfactory as a specification instrument for non-ferrous metals. Considerable work had already been done by various laboratories to determine the limitations of this machine. Furthermore, the routine testing with the Rockwell of all incoming shipments of material had been instituted for the purpose of accumulating specification data. While each individual machine seemed to give satisfactory results to the user there was little information available as to what agreement could be obtained with machines in other laboratories. Figure 3 gives results of tests on identical samples with five different machines in the laboratories of one of the participating companies before any attempt was made to eliminate mechanical irregularities in the machines. While there was considerable difference between machines, there was a probability that these differences could be reduced by carefully going over the machines and establishing technique of test.

Before making any further comparative tests, careful study was made of each machine and various mechanical irregularities were eliminated. In order to get close comparative results the ball penetrators must be in good condition, the load must be applied without impact and at approximately the same rate in different machines, the value of the load must be the same, and the method of supporting the specimen across the anvil is important. Due to the lever system of applying load and measuring the amount of penetration of the material under this load, a slight amount of friction in the bearings may result in variations in readings which are not apparent without comparisons with standard blocks. A set of directions for calibrating the Rockwell tester was drawn up which called for a thorough check of these various features of the machine. (See Appendix I.)

Other questions had to be settled, such as the size of ball penetrator to be used and the amount of the load. The possibility of varying the load and size of ball renders the Rockwell machine capable of broad application for testing purposes. Preliminary tests made to determine the most suitable combination of ball and load to be used indicated that the standard "B" scale of the instrument ($\frac{1}{16}$-in. ball and 100-kg. load) would be the most satisfactory for brass. However, it was decided to try also a $\frac{1}{8}$-in. ball with the same load. In our later work on nickel silver and phosphor bronze it was found that the 150-kg. load gave more satisfactory results with those materials. A larger ball is desirable to get readings on annealed brass and copper but with harder materials sensitivity of reading is increased by increasing the load and retaining the $\frac{1}{16}$-in. ball.

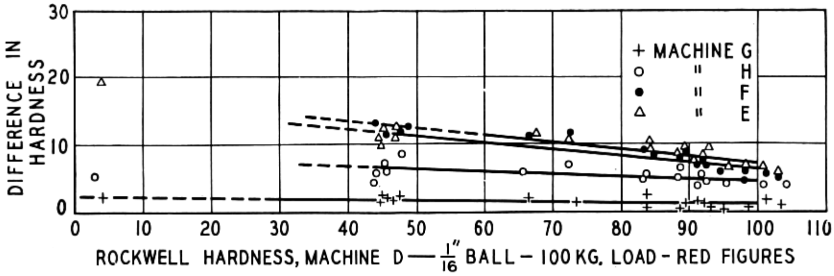

Fig. 3—Preliminary Comparison of Rockwell Testers.

The question of the number of thicknesses of material to be tested was also given consideration. On very thin materials there is a distinct anvil effect which can be reduced or eliminated by superposing several samples on each other. However, this method of testing soon proved to be objectionable. The Rockwell tester does not distinguish between actual penetration of the material and descent of the penetrator from any other cause, and since one hardness number of the Rockwell machine corresponds to an 0.00008-in. movement of the penetrator, great care must be taken to insure that movement of the penetrator is due only to actual penetration of the material. Unless the spaces under the penetrator between two or more layers are completely closed by the 10-kg. minor load, low readings will be obtained. With spring materials, which are frequently curved due to coiling, this condition is often encountered. Furthermore, in very thin materials there is a side flow so that the upper sheets fail to take their share of the load and tend to curl up around the penetrator in such a manner as to prevent the proper measurement of depth. There is also a possibility of including small particles of dirt between the specimens which would result in lower hardness readings. These matters must be very closely watched. An indentation in the anvil just barely visible on a polished surface in strongly reflected light will cause erroneous readings. It is necessary, therefore, that the anvils be sufficiently hard for the purpose. During the past year, harder anvils have been furnished and greatly improved results have been obtained in the testing of thin materials.

A comparison of the methods used by the laboratories in making tests indicated that personal factors might account for some of the differences in readings. One of these personal factors which appeared to be of major importance was the amount of time allowed for the drift of the penetrator after the major load is completely applied. It was the custom of some of the participating laboratories to allow this drift to continue until it had practically ceased while others removed the major load and read the hardness as soon as possible after the major load had been completely applied. This drift is very noticeable in the softer tempers of non-ferrous metals and may amount to as much as 10 Rockwell numbers. In general, it is more noticeable with non-ferrous metals than with steels. In order to eliminate this personal factor, the practice of operating the reset mechanism which removes the major load, immediately upon the full application the major load was adopted.

Three separate rolling series were used in the round-robin tests which were made after the various machines had been checked up. In each case tests were made with both $\frac{1}{16}$ and $\frac{1}{8}$-in. balls using the 100-kg. load. All tests were made on each of six machines located in the six different laboratories. Typical results of one of these series are shown in Fig. 2 which gives the results of a brass rolling series using both the $\frac{1}{8}$ and $\frac{1}{16}$-in. ball. It will be noted that the greatest sensitivity is obtained by using the $\frac{1}{16}$-in. ball, and this was later adopted as a standard ball for testing brass. Much better agreement between Rockwell testers than between scleroscope testers is also apparent.

Rockwell data were obtained on the high-brass and clock-brass rolling series in all thicknesses and tempers using one thickness of material and the standard "B" scale. The plot of the results of these tests on high brass is shown in Fig. 6. These curves appear normal for thicknesses of 0.012 in. and above, but below this thickness the hardness readings bear no relation to tensile strength due to the anvil effect.

The Rockwell hardness test is carried on in the same manner as given in Appendix I of this paper. All of the Rockwell hardness tests were made on the two grip ends of the tension test specimens. This was done in order to have Rockwell hardness tests and tension tests made on as nearly identical material as possible. Commercial experience with the Rockwell machine in the routine testing of sheet non-ferrous metals has indicated the importance of the following precautions.

*Ball Penetrator.*—Slight variations in the size and sphericity of the ball penetrators are to be expected and must be guarded against. The results of several hundred measurements made at various points on the "B" scale show that a deviation of less than 0.00002 in. in the diameter of the $\frac{1}{16}$-in. ball has no effect on the hardness readings. Balls showing a greater variation give noticeable error in hardness readings. Penetrator balls have been held within this limit.

*Anvil Surface.*—It is desirable that the penetrator be perpendicular to the testing surface of the anvil. It is assumed that the penetrator is operating perpendicular to the seating surface and in line with the capstan head. Any lack of perpendicularity would then be due to lack of parallelism of the seating and testing surfaces of the anvil. This is checked by a fixture designed to hold the anvil so that the specimen supporting surface might be checked. A hardened flat, 2 in. square and $\frac{7}{8}$ in. thick, having a $\frac{13}{16}$-in. hole through its center, was lapped so that its two surfaces were flat and parallel to within 0.00005 in. By placing the fixture holding the anvil on the table of an optimeter and sliding the supporting surface of the anvil under a ball-pointed feeler gage, errors in flatness and parallelism may be measured to 0.00005 in. Anvils whose surfaces were found to be plane to within 0.0001 in. were considered satisfactory.

*Machine Errors.*—Observations on four Rockwell machines at the Western Electric Co., one of which handles approximately 10,000 tests per month and all of which were overhauled and calibrated for their entire range once a week, showed that changes in calibration occurring in this interval were less than one hardness number. Before beginning a series of readings the correction to be applied was determined by taking readings on a standard block. The average change on all three scales was about one hardness number. Variations from calibration were rarely greater than 1.5 numbers unless the penetrator was damaged or the instrument was out of adjustment due to misuse.

The effectiveness with which standard test blocks may be used in bringing Rockwell testers into agreement is shown by the following calibration:

| | Approximate Hardness, "B" Scale, 1/16-in. Ball, 100-kg. Load (Red Figures) | | |
|---|---|---|---|
| | 25 | 60 | 80 |
| Before overhauling and checking the entire scale, average difference in hardness readings between three testers.................................. | 6.0 | 3.7 | 3.4 |
| After overhauling and checking the entire scale, average difference in hardness readings between three testers.................................. | 0.9 | 1.2 | 0.9 |

*Calibration of Test Blocks.*—It was first thought that a Rockwell hardness machine would hold its adjustment over a long period if carefully maintained and could serve as a standard machine to be used for the calibration of test blocks. More complete experience has shown, however, that wear of the operating parts and slight variations in friction caused the "standard machine" to vary slightly in its readings. Naturally, the calibration of standard test blocks under these conditions is unsatisfactory because it might result in the establishment of several sets of standard blocks, leading to confusion in the application of the Rockwell hardness test limits to commercial material.

A new method of calibrating the Rockwell hardness tester was devised. This method consisted in preparing a set of test blocks covering the range of hardness of the high-brass and clock-brass rolling series. These blocks were checked by the various cooperating laboratories as well as the manufacturers of the Rockwell hardness tester, namely, the Wilson-Maeulen Co. These blocks were considered the basic standards for the Rockwell tests. Sub-standard blocks were calibrated in comparison with these standard blocks and placed in use by the various cooperating laboratories. The high-brass rolling series and the clock-brass rolling series were then retested for Rockwell hardness using the new calibration. It was found that the hardness readings differed one to two points from the values previously determined for several tempers. At the same time experience with commercial shipments of material showed that a shift was necessary in the Rockwell hardness-tensile strength relationship. This verified our conclusions with regard to the adoption of the new method of calibration.

After the establishment of the standard brass test blocks it was seen that blocks would also be required to cover the nickel-silver and the phosphor-bronze alloys. To prepare new series of blocks especially for these materials would have resulted in a wide variety of blocks and would have been found burdensome to the laboratories. Consequently, a single series of test blocks covering the brass, nickel-silver, and phosphor bronze alloys was selected. This series of test blocks started with the original blocks to which were added a few additional blocks made necessary in order to cover the range of the nickel-silver and phosphor-bronze alloys. The data upon which the calibration of these blocks was based have been submitted to the Section on Indentation Hardness of the A. S. T. M. Committee E-1 on Methods of Testing.

*Hardness of Thin Sheet.*—The Rockwell hardness test has certain limitations in its application to the testing of thin sheet stock. Material less than 0.020 in. thick gives hardness readings different from thicker sheet of the same temper. Referring to the curves shown hereinafter of Rockwell hardness plotted against tensile strength for materials thinner than No. 24 B. & S. gage the points fall below the curve. This apparently is due to lack of support of the metal about the penetrator and consequently a low reading is given. For still thinner material the penetrator passes nearly through the metal and the hardness reading recorded is inaccurate due to the effect of the supporting anvil in addition to lack of support of the metal.

*Cleaning Anvil and Specimen.*—Inasmuch as the Rockwell hardness tester measures hardness in terms of penetration, any movement of the penetrator affects the hardness reading. In other words, if the metal has a roughened surface or if the anvil is not polished smooth the metal will flow under the high unit pressure involved and this will cause the Rockwell hardness reading to be lower than its true value. It is considered necessary therefore that the anvil should be polished flat and the material tested should be reasonably free from surface imperfections and oxide film. Table III shows the effect on the hardness readings of polishing the anvil.

In addition to the need of polishing the anvils, if close agreement is to be had, some refinement is also needed in the use of the standard test blocks. It is difficult to obtain test blocks that will not show a variation in hardness. It has been customary, therefore, in calibrating test blocks to take five readings, one in each corner of the test block and one in the center. These readings are made on a machine which has been calibrated with the standard test blocks both before and after calibration of the secondary blocks. Experience in calibrating the Rockwell hardness machine with standard test blocks has empha-

TABLE III—ROCKWELL HARDNESS TESTS ON ALLOY G BRASS SHEET SHOWING EFFECT OF USING UNPOLISHED AND POLISHED ANVIL

| Sample | | Tensile Strength, lb. per sq. in. | Unpolished Anvil, "B" Scale, $\frac{1}{16}$-in. Ball, 100-kg. Load (Red Figures) | | | | Polished Anvil, "B" Scale, $\frac{1}{16}$-in. Ball, 100-kg. Load (Red Figures) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| B. & S. Gage | Temper, B. & S. Numbers Hard | | Average of 15 Readings | Maximum | Minimum | Range | Average of 15 Readings | Maximum | Minimum | Range |
| No. 20 | 2 | 64,000 | 73.3 | 74.0 | 72.8 | 1.2 | 72.9 | 73.6 | 71.8 | 1.8 |
| | 4 | 77,800 | 83.5 | 83.8 | 82.9 | 0.9 | 83.5 | 83.7 | 83.0 | 0.7 |
| | 6 | 85,400 | 87.0 | 87.6 | 86.2 | 1.4 | 86.7 | 86.7 | 86.0 | 0.7 |
| | 8 | 93,800 | 90.3 | 90.0 | 90.0 | 0.8 | 90.7 | 90.8 | 90.3 | 0.5 |
| | 10 | 99,000 | 92.1 | 92.7 | 91.3 | 1.4 | 92.7 | 92.8 | 92.6 | 0.2 |
| No. 22 | 2 | 65,100 | 74.2 | 75.0 | 73.6 | 1.4 | 72.6 | 73.5 | 71.3 | 2.2 |
| | 4 | 79,100 | 83.4 | 83.8 | 83.2 | 0.5 | 83.8 | 84.2 | 83.0 | 1.2 |
| | 6 | 88,200 | 88.3 | 88.9 | 88.0 | 0.8 | 88.0 | 88.3 | 87.8 | 0.5 |
| | 8 | 99,300 | 90.0 | 90.2 | 89.7 | 0.5 | 90.1 | 90.2 | 89.8 | 0.4 |
| | 10 | 98,200 | 91.8 | 92.2 | 91.7 | 0.5 | 92.2 | 92.4 | 91.8 | 0.6 |
| No. 24 | 2 | 61,000 | 67.6 | 68.8 | 67.1 | 1.7 | 63.9 | 65.3 | 61.6 | 3.7 |
| | 4 | 81,600 | 84.3 | 84.7 | 83.7 | 1.0 | 82.7 | 83.0 | 82.2 | 0.8 |
| | 6 | 91,400 | 89.0 | 89.7 | 88.7 | 1.0 | 87.8 | 88.0 | 87.6 | 0.4 |
| | 8 | 96,600 | 91.0 | 91.2 | 90.7 | 0.5 | 89.7 | 89.9 | 89.3 | 0.6 |
| | 10 | 97,800 | 91.9 | 92.7 | 91.2 | 1.5 | 91.2 | 91.5 | 90.9 | 0.6 |
| No. 26 | 2 | 58,100 | 64.4 | 65.9 | 63.0 | 2.9 | 58.4 | 59.4 | 56.8 | 2.6 |
| | 4 | 71,800 | 77.3 | 77.8 | 76.9 | 0.9 | 75.1 | 75.5 | 74.4 | 1.1 |
| | 6 | 88,600 | 87.4 | 88.0 | 86.7 | 1.3 | 86.2 | 86.5 | 85.8 | 0.7 |
| | 8 | 95,600 | 90.2 | 90.7 | 89.9 | 0.8 | 89.5 | 89.9 | 89.2 | 0.7 |
| | 10 | 99,100 | 91.2 | 91.7 | 90.8 | 0.9 | 91.0 | 91.3 | 90.6 | 0.7 |
| No. 28 | 2 | 61,100 | 65.4 | 66.9 | 64.2 | 2.7 | 55.7 | 57.6 | 52.3 | 5.3 |
| | 4 | 71,400 | 77.0 | 77.9 | 76.0 | 1.7 | 72.1 | 73.3 | 71.1 | 2.2 |
| | 6 | 83,600 | 83.2 | 83.8 | 82.1 | 1.7 | 81.2 | 81.5 | 80.7 | 0.8 |
| | 8 | 94,700 | 89.6 | 90.3 | 89.1 | 1.2 | 88.2 | 88.5 | 88.0 | 0.5 |
| | 10 | 100,100 | 91.5 | 92.0 | 90.5 | 1.5 | 90.4 | 90.8 | 90.1 | 0.7 |

sized the need for keeping these blocks clean and free from oxide, grease or other accumulated matter. This applies with equal force to the test specimens. Various methods of cleaning the test blocks have been tried. A successful and convenient method is to rub the surfaces of the test block by hand with chiffon velvet or other lap material dipped in tripoli and water. Test blocks cleaned in this way do not show a greater variation in readings than that of the original test for uniformity.

A variation in hardness must be permitted in these five readings and on the basis of experience with a large number of blocks it is considered that test blocks should have no greater variation than as follows: When tested using the "B" scale, $\frac{1}{16}$-in. ball, 100-kg. load (red figures); for blocks under 40, 3 points variation is allowed; for blocks from 40 to 60, 2½ points; and for blocks over 60, 1½ points. Acceptance or rejection of blocks is based on these limits, except where a minus reading results and in this case the 60-kg. load is used. Blocks of this uniformity are calibrated for use with the 60, 100 and 150-kg. loads.

*Rockwell Scales Employed.*—It has been found that the Rockwell "B" scale employing the 100-kg. load, the $\frac{1}{16}$-in. diameter ball and reading the red figures, is satisfactory for rolled brass sheet; but in the case of the nickel-silver and phosphor-bronze alloys it was found that the Rockwell hardness-tensile strength curve became asymptotic, showing very little change in hardness for a large increase in tensile strength in the harder tempers. A load of 150 kg. was substituted for the 100-kg. load and resulted in an improvement since by using the larger load, a greater depth of penetration was obtained and consequently better sensitivity in the higher tempers. The curve, shown by Fig. 13, gives the Rockwell hardness-tensile strength relationship employing the 100 and 150-kg. loads on the Rockwell tester. The 150-kg. load has been adopted for nickel-silver and

TABLE IV

DIAMETER[a] OF AVERAGE GRAIN FOR ANNEALED BRASS AND NICKEL SILVER

| Material | Anneal | Average Tensile Strength, lb. per sq. in. | Rockwell Hardness, "B" Scale, $\frac{1}{16}$-in. Ball, 60-kg. Load, Maximum | Diameter of Average Grain m.m. | |
|---|---|---|---|---|---|
| | | | | Minimum | Maximum |
| High-Brass....... | Light....... | 50,000 | 80 | 0.010 | 0.035 |
| | Drawing.... | 47,000 | 65 | 0.035 | 0.090 |
| | Soft Drawing | 43,000 | 55 | 0.090 | 0.200 |
| Alloy C Brass..... | Light....... | 42,000 | 76 | 0.010 | 0.030 |
| | Drawing.... | 40,000 | 61 | 0.030 | 0.070 |
| | Soft Drawing | 39,000 | 55 | 0.070 | 0.150 |
| Alloy D Brass.... | Light....... | 53,000 | 82 | 0.010 | 0.030 |
| | Drawing.... | 49,000 | 72 | 0.030 | 0.075 |
| | Soft Drawing | 45,000 | 59 | 0.075 | 0.200 |
| Alloy E Brass..... | Light....... | 50,000 | 80 | 0.010 | 0.035 |
| | Drawing.... | 46,000 | 67 | 0.035 | 0.080 |
| | Soft Drawing | 44,000 | 57 | 0.080 | 0.160 |
| Alloy A Nickel Silver......... | Light....... | 55,000 | 87 | 0.010 | 0.025 |
| | Drawing.... | 54,000 | 80 | 0.025 | 0.050 |
| | Soft Drawing | 52,500 | 77 | 0.040 | 0.100 |

[a] The method for determining the grain size of the material is the Jeffries method as described in the note under Section 9 of the Society's Standard Rules Governing the Preparation of Micrographs of Metals and Alloys (E 2–27), see 1927 Book of A. S. T. M. Standards, Part I, p. 778.

phosphor-bronze alloys and the Rockwell hardnesses reported hereinafter for these materials are the values obtained using a 150-kg. load, a $\frac{1}{16}$-in. diameter ball and reading on the "B" scale or red figures. The 60-kg. load is used for testing annealed material. (See Table IV.)

*Fatigue Tests:*

The endurance limit of each of the metals covered by this paper has been determined for the annealed condition and as rolled four and ten numbers hard. The results of these tests are covered by another paper.[7]

*Bend Test Machine:*

In connection with the Amsler bend test machine, an improvement on this machine has been developed employing a motor drive and accurately prepared and aligned jaws. Figure 4 shows a model of

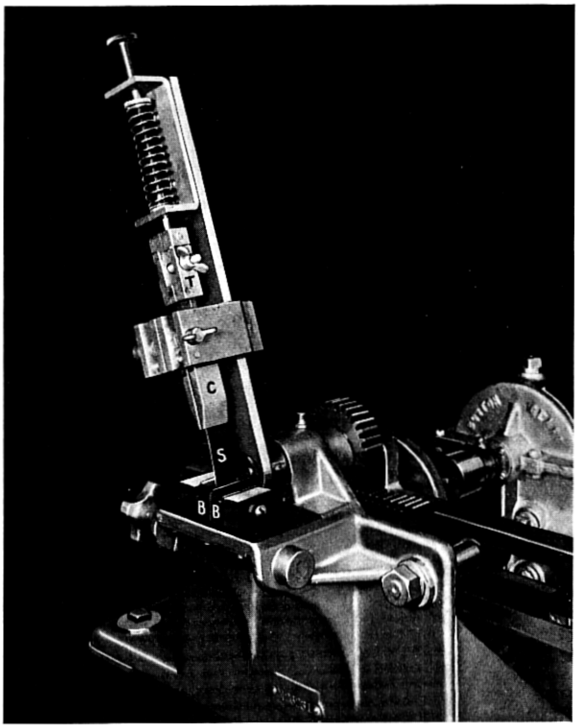

Fig. 4—Experimental Bend Testing Machine.

*T* is the tensioning grip.
*C* is the guide clamp.
*S* is the specimen.
*B* is the radius block.

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[7] J. R. Townsend and C. H. Greenall, "Fatigue Studies of Non-Ferrous Sheet Metals," presented before the American Society for Testing Materials in June, 1929

this machine built for experimental purposes. A strip of metal *S*, ½ in. wide, is clamped between a pair of radius blocks, *B*, selected at random. The upper portion of the specimen is held by a tensioning grip, *T*, and guided by two clamps, *C*. The specimen is bent back and forth over the pair of radius blocks and each bend of 90 deg. and return is recorded as one bend by a counter. Using another strip of the same metal but a pair of radius blocks of different radii another result is obtained. If the number of bends is plotted on log paper against the ratio of the thickness of the metal to the radius of the blocks, a straight line results. It is possible therefore to select any standard ratio of block radius to thickness of metal and

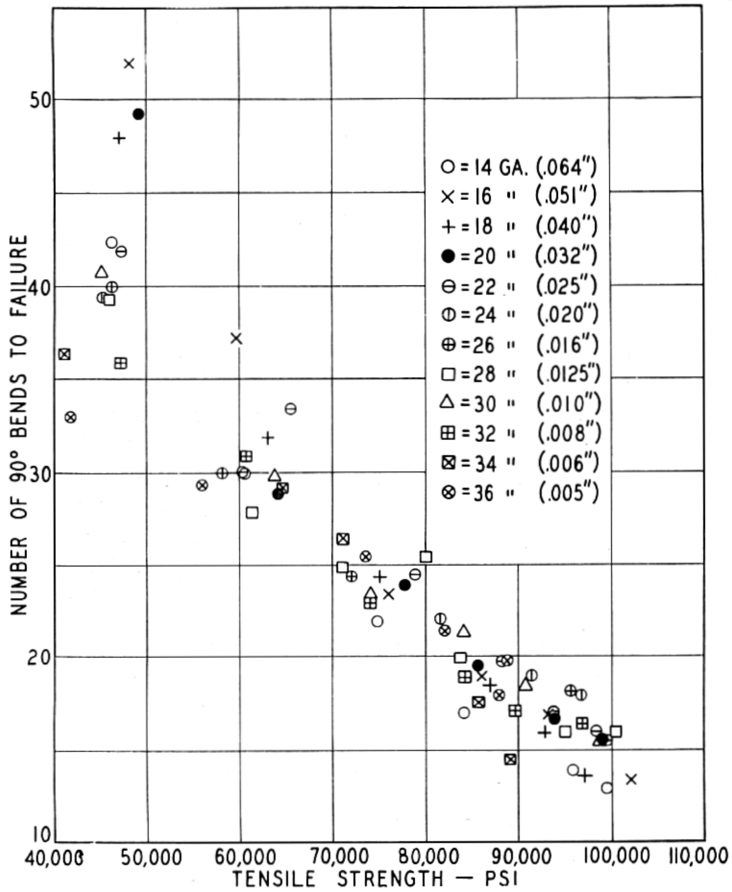

Fig. 5—Relation of Number of 90-deg. Bends to Failure to Tensile Strength of Alloy G Brass. Ratio of Mandrel Radius to Thickness, 8 to 1.

by two tests employing two different pairs of radius blocks to determine the number of bends for this predetermined ratio by interpolation. The ratio finally selected as most representative was 8 to 1. Figure 5 gives the bend test results for alloy G brass.

The bend test reveals the ductility and toughness of the metal under test. It should show a close correlation to the forming and drawing properties of sheet metal. Further studies will be required to work out such relationships.

### *Grain Count:*

A series of photomicrographs of annealed brass has been adopted covering the grain sizes 0.010 to 0.200 mm. diameter of average grain.[8] Inasmuch as the alpha phase grain structure of nickel silver is similar to that of brass, one set of standards may be employed for these metals. Those standards were carefully counted by the Jeffries method as described in the note to Section 9 of the A. S. T. M. Standard Rules Governing the Preparation of Micrographs of Metals and Alloys (E 2–27) [9] and were photographed at a magnification of 75 diameters. The grain size of a specimen under examination is estimated by comparing the specimen with the standard photomicrographs. For alloy A nickel silver, a magnification of 150 is employed because of the smaller grain size of this material compared with brass. The limits of diameter of average grain of the alloys used for drawing purposes are given in Table IV, namely for high brass sheet, alloys C, D, and E brass, and alloy A nickel silver. (See Table VI for chemical composition.) The grain size limits are based on the range of commercial annealing practice. Inasmuch as these annealed materials are employed only for drawing purposes, no tensile strength limits are necessary. Maximum Rockwell hardness limits are given to exclude cold-worked metal.

## DETERMINATION OF LIMITS

### *High and Clock Brass:*

Three separate rolling series were used for the round-robin hardness tests. The first of these consisted of a group of materials so arranged as to give a complete range of the hardnesses desired. The second was high brass with a nominal composition of 65 per cent copper and 35 per cent zinc. The third was nickel silver with a nominal composition of 64 per cent copper, 18 per cent zinc, and 18

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[8] Report of Committee E-4 on Metallography, presented before the American Society for Testing Materials in June, 1929.

[9] 1927 Book of A. S. T. M. Standards, Part I, p. 778.

per cent nickel. Each of these series included eleven tempers ranging from annealed material to the hardness resulting from 10 B. & S. gage numbers reduction. The samples were approximately 6 in. square and $\frac{1}{8}$ in. thick.

Complete series of samples comprising a fairly wide range of thicknesses were obtained for high-brass sheet in order to thoroughly evaluate the methods of tests. These series were prepared in the following B. & S. gages: Nos. 14, 16, 20, 24, 28, 32 and 36. In each gage the samples had the following hardnesses: Annealed and 2, 4, 6, 8 and 10 B. & S. gage numbers reduction. These rolling series, therefore, included forty-two samples covering the usual commercial range of hardness and the range of thickness of greatest importance in telephone apparatus. These series were made under regular mill conditions with careful supervision to insure representative rolling practice and with complete records of the operations, special attention being given to accurate records of the percentage of reduction. Care was taken to have the metal given approximately a 50 per cent reduction before annealing to insure a uniform grain growth. The temperature of annealing was equivalent to about 600° C. for one-half hour, giving material of about average properties. These series were rolled from four bars of the following compositions:

| | Bar No. 1 | Bar No. 2 | Bar No. 3 | Bar No. 4 |
|---|---|---|---|---|
| Copper, per cent........... | 65.19 | 64.94 | 65.10 | 65.13 |
| Zinc, " " ........... | 34.77 | 35.02 | 34.85 | 34.82 |
| Lead, " " ........... | 0.01 | 0.02 | 0.02 | 0.02 |
| Iron, " " ........... | 0.03 | 0.02 | 0.03 | 0.03 |

The samples were flat strips 10 ft. long and 6 in. wide.

The rolling series on clock brass were made in the following gages and tempers: Nos. 12, 14, 16 and 18 B. & S. gages and 2, 4, 6 and 8 B. & S. gage numbers reduction. The composition was: Copper 61.63 per cent, zinc 36.75 per cent, lead 1.57 per cent, iron 0.05 per cent. This material is so nearly like high-brass sheet in its properties that the data collected when added to that already available were considered sufficient for the preparation of a set of requirements. The tensile strength-percentage of reduction curve for high brass is shown by Figure 10. The physical properties of high and clock brass are shown by Tables I and II.

As mentioned above, Rockwell hardness limits given have been revised to agree with the more recently established Rockwell standards. These limits have been verified by experience data collected on

## TABLE I

### PHYSICAL TESTS ON HIGH-BRASS SHEET ROLLING SERIES

| B. & S. Gage | Thickness, in. | Numbers Hard | Percentage Reduction by Rolling | Proportional Limit, lb. per sq. in. | Tensile Strength, lbs per sq. in. | Elongation in 2 in. per cent | Scleroscope Hardness, Diamond Magnifier Hammer, One Thickness | Rockwell Hardness, "B" Scale, One Thickness | Meyer's Analysis "A," 1/16-in. Ball. 1 mm. in diameter indentation, kg. | Erichsen Ductility, Large Penetrator, mm. | Erichsen Ductility, Small Penetrator, mm. | Olsen Ductility, Large Penetrator, in. | Olsen Ductility, Small Penetrator, in. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. 36 | 0.0058 | Annealed | 0 | 9,500 | 44,200 | 40 | 15 | 76 | 80 | 12.20 | 3.17 | 0.462 | 0.113 |
| No. 36 | 0.0055 | 2 | 12.7 | 33,000 | 57,200 | 17 | 33 | 76 | 102 | 5.64 | 2.38 | 0.202 | 0.064 |
| No. 36 | 0.0058 | 4 | 29.25 | 32,000 | 67,600 | 3 | 41 | 72 | 110 | 4.48 | 2.17 | 0.149 | 0.062 |
| No. 36 | 0.0054 | 6 | 46.0 | 38,000 | 81,000 | 1.5 | 50 | 76 | 137 | 3.27 | 1.93 | 0.128 | 0.062 |
| No. 36 | 0.0057 | 8 | 53.6 | 39,000 | 86,000 | 2 | 54 | 74 | 143 | 3.35 | 1.88 | 0.122 | 0.048 |
| No. 36 | 0.0060 | 10 | 62.5 | 35,500 | 90,400 | 1 | 58 | 72 | 151 | 2.86 | 1.86 | 0.107 | 0.046 |
| No. 32 | 0.0087 | Annealed | 0 | 7,900 | 44,400 | 53.5 | 13 | 48 | 83 | 13.24 | 3.37 | 0.488 | 0.116 |
| No. 32 | 0.0078 | 2 | 22.0 | 31,600 | 60,300 | 16 | 36 | 54 | 107 | 5.63 | 2.41 | 0.209 | 0.060 |
| No. 32 | 0.0090 | 6 | 43.75 | 29,200 | 81,200 | 2 | 47 | 59 | 134 | 4.30 | 2.37 | 0.153 | 0.061 |
| No. 32 | 0.0085 | 8 | 60.8 | 40,800 | 91,800 | 1.5 | 53 | 64 | 160 | 4.00 | 2.10 | 0.135 | 0.057 |
| No. 28 | 0.0127 | Annealed | 0 | 8,300 | 44,500 | 60 | 9 | 13 | 62 | 13.69 | 3.73 | 0.542 | 0.129 |
| No. 28 | 0.0144 | 2 | 10.0 | 38,800 | 58,000 | 25.5 | 24 | 60 | 104 | 7.21 | 2.94 | 0.262 | 0.087 |
| No. 28 | 0.0135 | 4 | 37.8 | 30,500 | 75,900 | 5 | 31 | 78 | 132 | 6.11 | 2.76 | 0.209 | 0.074 |
| No. 28 | 0.0127 | 6 | 49.2 | 40,300 | 84,400 | 2 | 38 | 82 | 142 | 5.16 | 2.52 | 0.188 | 0.059 |
| No. 28 | 0.0134 | 8 | 59.1 | 34,300 | 89,600 | 2 | 49 | 86 | 150 | 4.37 | 2.27 | 0.144 | 0.054 |
| No. 28 | 0.0136 | 10 | 66.0 | 44,300 | 95,900 | 1.5 | 51 | 89 | 157 | 3.94 | 2.32 | 0.149 | 0.050 |
| No. 24 | 0.0221 | Annealed | 0 | 12,000 | 46,600 | 58 | 10 | 16 | 66 | 13.62 | 3.79 | 0.532 | 0.119 |
| No. 24 | 0.0204 | 2 | 18.4 | 23,600 | 58,300 | 29 | 25 | 60 | 101 | 8.51 | 3.22 | 0.308 | 0.089 |
| No. 24 | 0.0199 | 4 | 39.3 | 32,000 | 77,200 | 6 | 33 | 79 | 133 | 6.37 | 2.87 | 0.233 | 0.071 |
| No. 24 | 0.0202 | 6 | 49.5 | 31,000 | 85,500 | 4 | 40 | 83 | 142 | 5.44 | 2.65 | 0.204 | 0.058 |
| No. 24 | 0.0210 | 8 | 59.4 | 31,300 | 90,500 | 2 | 44 | 86 | 150 | 4.59 | 2.35 | 0.178 | 0.052 |
| No. 24 | 0.0211 | 10 | 67.6 | 30,000 | 95,600 | 2 | 50 | 87 | 155 | 4.07 | 2.26 | 0.163 | 0.046 |

TABLE I—*Continued*

| B. & S. Gage | Thickness, in. | Numbers Hard | Percentage Reduction by Rolling | Proportional Limit, lb. per sq. in. | Tensile Strength, lbs. per sq. in. | Elongation in 2 in. per cent | Scleroscope Hardness, Diamond Magnifier Hammer, One Thickness | Rockwell Hardness, "B" Scale One Thickness | Meyer's Analysis "A," $\frac{1}{16}$-in. Ball. 1 mm. in diameter indentation, kg. | Erichsen Ductility, Large Penetrator, mm. | Erichsen Ductility, Small Penetrator, mm. | Olsen Ductility, Large Penetrator, in. | Olsen Ductility, Small Penetrator, in. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. 20...... | 0.0334 | Annealed | 0 | 6,100 | 46,300 | 63 | 9 | 10 | 63.5 | 14.17 | 4.10 | 0.559 | 0.124 |
| No. 20...... | 0.0345 | 2 | 13.75 | 23,200 | 57,300 | 32 | 26 | 60 | 103 | 9.05 | 3.46 | 0.348 | 0.107 |
| No. 20...... | 0.0336 | 4 | 35.1 | 23,500 | 72,100 | 11 | 34 | 77 | 125 | 7.52 | 3.05 | 0.272 | 0.076 |
| No. 20...... | 0.0333 | 6 | 48.9 | 27,100 | 83,800 | 5 | 48 | 80 | 138 | 6.27 | 2.48 | 0.231 | 0.065 |
| No. 20...... | 0.0340 | 8 | 58.0 | 33,300 | 89,000 | 4 | 51 | 86 | 147 | 4.83 | 1.84 | 0.175 | 0.063 |
| No. 20..... | 0.0331 | 10 | 67.6 | 33,800 | 92,700 | 3.5 | 56 | 88 | 152 | 3.32 | 1.90 | 0.130 | 0.061 |
| No. 16...... | 0.0529 | Annealed | 0 | 8,300 | 45,500 | 70 | 10 | —4 | 63 | 15.00 | .... | .... | .... |
| No. 16...... | 0.0524 | 2 | 19.6 | 22,900 | 59,300 | 35 | 36 | 67 | 106 | 10.08 | .... | .... | .... |
| No. 16...... | 0.0525 | 4 | 35.2 | 23,100 | 71,700 | 9.5 | 42 | 79 | 123 | 7.50 | .... | .... | .... |
| No. 16...... | 0.0523 | 6 | 48.7 | 27,600 | 80,700 | 7.5 | 46 | 84 | 137 | 6.53 | .... | .... | .... |
| No. 16...... | 0.0521 | 8 | 59.3 | 30,500 | 87,900 | 5.5 | 51 | 87 | 146 | 4.16 | .... | .... | .... |
| No. 16...... | 0.0510 | 10 | 68.5 | 29,600 | 94,500 | 5 | 59 | 91 | 155 | 2.86 | .... | .... | .... |
| No. 14...... | 0.0661 | Annealed | 0 | 7,900 | 46,600 | 63 | 13 | 8 | 66 | 14.99 | .... | .... | .... |
| No. 14...... | 0.0651 | 2 | 19.6 | 23,600 | 58,900 | 38 | 34 | 68 | 105 | 10.05 | .... | .... | .... |
| No. 14...... | 0.0662 | 4 | 35.1 | 21,600 | 71,100 | 13 | 36 | 80 | 125 | 8.92 | .... | .... | .... |
| No. 14...... | 0.0648 | 6 | 49.4 | 22,000 | 81,700 | 8 | 39 | 85 | 137 | 5.66 | .... | .... | .... |
| No. 14..... | 0.0664 | 8 | 59.0 | 30,600 | 89,300 | 6.5 | 47 | 89 | 147 | 2.97 | .... | .... | .... |
| No. 14..... | 0.0648 | 10 | 67.1 | 28,300 | 93,500 | 6 | 49 | 90 | 154 | 2.08 | .... | .... | .... |

TABLE II

Physical Tests on Clock-Brass Sheet Rolling Series

| Sample Number | Thickness, in. | Temper | B. & S. Gage Numbers Hard | Reduction by Rolling, per cent | Tensile Strength, lb. per sq. in. | Elongation in 2 in., per cent | Scleroscope Steel Magnifier Hammer, One Thickness | Rockwell "B" Scale, One Thickness | Meyer's Analysis "A," kg. |
|---|---|---|---|---|---|---|---|---|---|
| 502–2 | 0.081 | .... | 2 | 20.4 | 59,250 | 32 | 35 | 68 | 106 |
| 502–4 | 0.064 | .... | 4 | 36.6 | 72,750 | 9 | 48 | 80 | 125 |
| 502–6 | 0.050 | .... | 6 | 49.8 | 83,700 | 6 | 54 | 85 | 137.5 |
| 502–8 | 0.039 | .... | 8 | 60.4 | 90,000 | 4 | 58 | 88 | 152 |
| 340 | 0.143 | Soft | .. | .... | 45,900 | 62 | 15 | 21 | 67 |
| 341 | 0.081 | Quarter Hard | .. | .... | 51,400 | 40 | 25 | 56 | 86 |
| 414 | 0.040 | Half Hard | .. | .... | 61,800 | 25 | 35 | 70 | 106 |
| 412 | 0.079 | " | .. | .... | 64,500 | 23 | 40 | 77 | 119 |
| 342 | 0.033 | " | .. | .... | 70,200 | 14 | 39 | 78 | 125 |
| 190 | 0.020 | " | .. | .... | 64,600 | 13 | .. | 65 | 113.5 |
| 415 | 0.040 | Hard | .. | .... | 74,300 | 8 | 46 | 82 | 127 |
| 413 | 0.078 | " | .. | .... | 74,800 | 8.5 | 45 | 84 | 125 |
| 191 | 0.032 | " | .. | .... | 74,500 | 5.5 | .. | 79 | 123.5 |

material furnished under the limits by a number of suppliers. Table V shows the Rockwell hardness limits. Figure 6 shows Rockwell hardness plotted against tensile strength for the high-brass rolling

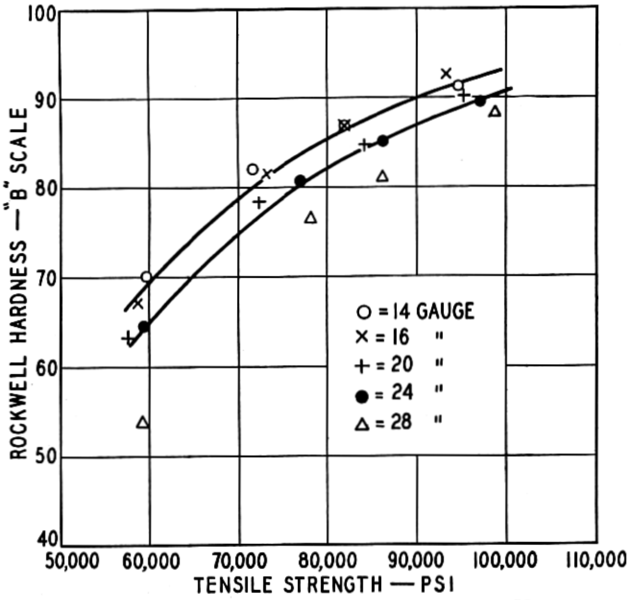

Fig. 6—Relation of High Brass Rolling Series. Rockwell Hardness to Tensile Strength, Using Standard Rockwell Blocks.

## TABLE V

### REVISED ROCKWELL HARDNESS AND TENSILE STRENGTH LIMITS FOR HIGH, CLOCK AND ALLOY E BRASS SHEET

| Thickness | Temper, B. & S. Numbers Hard | Per-centage Reduction by Rolling | Tensile Strength,[a] lb. per sq. in. | | | | | | Rockwell Hardness, "B" Scale, 1/16-in. Ball, 100-kg. Load (Red Figures), for High, Clock and Alloy E Brass Sheet | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | High Brass | | Clock Brass | | Alloy E Brass | | | |
| | | | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| 0.040 in. and over.... | Quarter hard. 1 | 10.9 | 46,000 | 56,000 | 47,000 | 57,000 | 47,000 | 57,000 | 30 | 60 |
| 0.020 to 0.040 in..... | | 10.9 | 46,000 | 56,000 | 47,000 | 57,000 | 47,000 | 57,000 | 30 | 56 |
| 0.040 in. and over.... | Half hard.... 2 | 20.7 | 53,500 | 63,500 | 54,500 | 64,500 | 54,000 | 64,000 | 50 | 73 |
| 0.020 to 0.040 in..... | | 20.7 | 53,500 | 63,500 | 54,500 | 64,500 | 54,000 | 64,000 | 49 | 71 |
| 0.040 in. and over.... | Three-quarters hard...... 3 | 29.5 | 61,000 | 71,000 | .... | .... | .... | .... | 70 | 80 |
| 0.020 to 0.040 in..... | | 29.5 | 61,000 | 71,000 | .... | .... | .... | .... | 67 | 77 |
| 0.040 in. and over.... | Hard........ 4 | 37.1 | 68,000 | 78,000 | 68,000 | 78,000 | 68,000 | 78,000 | 78 | 85 |
| 0.020 to 0.040 in..... | | 37.1 | 68,000 | 78,000 | 68,000 | 78,000 | 68,000 | 78,000 | 75 | 83 |
| 0.040 in. and over.... | Extra hard... 6 | 50.0 | 79,000 | 88,500 | 79,000 | 88,500 | .... | .... | 85 | 89 |
| 0.020 to 0.040 in..... | | 50.0 | 79,000 | 88,500 | 79,000 | 88,500 | .... | .... | 83 | 87 |
| 0.040 in. and over.... | Spring...... 8 | 60.5 | 86,000 | 95,000 | 85,000 | 94,500 | .... | .... | 88 | 92 |
| 0.020 to 0.040 in..... | | 60.5 | 86,000 | 95,000 | 85,000 | 94,500 | .... | .... | 85 | 89 |
| 0.040 in. and over.... | Extra spring. 10 | 68.7 | 89,500 | 98,500 | 88,000 | 97,500 | .... | .... | 89 | 93 |
| 0.020 to 0.040 in..... | | 68.7 | 89,500 | 98,500 | 88,000 | 97,500 | .... | .... | 86 | 90 |

[a] Tensile strength values for high and clock brass sheet are the same as in the previous paper by H. N. Van Deusen, L. I. Shaw and C. H. Davis, "Physical Properties and Methods of Test for Sheet Brass," *Proc. A. S. T. M.*, Vol. 27, 1927.

TABLE VI

CHEMICAL COMPOSITION LIMITS FOR NON-FERROUS METAL SHEET

| | | High Sheet Brass | Clock Brass | Alloy C Brass | Alloy D Brass | Alloy E Brass | Alloy G Brass | Alloy A Nickel Silver | Alloy B Nickel Silver | Alloy A Phosphor Bronze | Alloy C Phosphor Bronze |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Copper, per cent........ | minimum | 64.50 | 61.00 | 83.00 | 73.00 | 64.00 | 70.50 | 70.50 | 53.50 | 94.40 | 91.00 |
| | maximum | 67.50 | 64.00 | 86.00 | 76.00 | 67.00 | 73.50 | 73.50 | 56.50 | .... | .... |
| Lead, per cent........ | minimum | 0.00 | 1.25 | .... | .... | 0.80 | .... | .... | .... | .... | .... |
| | maximum | 0.30 | 2.00 | 0.15 | 0.25 | 1.10 | 0.10 | .... | 0.10 | 0.05 | 0.02 |
| Iron, per cent........ | minimum | 0.00 | 0.00 | .... | .... | .... | .... | .... | .... | .... | .... |
| | maximum | 0.05 | 0.06 | 0.05 | 0.05 | 0.08 | 0.05 | 0.35 | 0.35 | 0.10 | 0.10 |
| Zinc, per cent........ | minimum | Balance | Balance | Balance | Balance | Balance | Balance | 8.50 | 25.50 | .... | .... |
| | maximum | Balance | Balance | Balance | Balance | Balance | Balance | 11.50 | 28.50 | 0.30 | 0.20 |
| Nickel, per cent........ | minimum | .... | .... | .... | .... | .... | .... | 16.50 | 16.50 | .... | .... |
| | maximum | .... | .... | .... | .... | .... | .... | 19.50 | 19.50 | .... | .... |
| Manganese, per cent........ | minimum | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | maximum | .... | .... | .... | .... | .... | .... | .... | 0.50 | .... | .... |
| Tin, per cent........ | minimum | .... | .... | .... | .... | .... | .... | .... | .... | 3.80 | 7.50 |
| | maximum | .... | .... | .... | .... | .... | .... | .... | .... | 4.80 | 8.50 |
| Phosphorus, per cent........ | minimum | .... | .... | .... | .... | .... | .... | .... | .... | 0.05 | 0.05 |
| | maximum | .... | .... | .... | .... | .... | .... | .... | .... | 0.35 | 0.25 |
| Antimony, per cent........ | minimum | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | maximum | .... | .... | .... | .... | .... | .... | .... | .... | 0.01 | 0.01 |
| Impurities, per cent........ | minimum | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | maximum | 0.10 | 0.10 | .... | .... | 0.10 | 0.10 | .... | .... | trace | trace |

series retested using standard blocks. There have been no changes in tensile strength limits. Figure 19 shows Rockwell hardness plotted against tensile strength, for high and clock brass, the individual point representing determinations of Rockwell hardness and tensile strength on commercial shipments of material. The lines drawn show the grouping of the data according to thickness.

*Alloys C and D Brass Sheet:*

The chemical composition limits for alloys C and D brass sheet are given in Table VI.

*Alloy E Brass Sheet:*

Four rolling series were made from one bar of metal having the analysis shown in Table VII. These series begin at B. & S. gage Nos. 10, 14, 18 and 22 and were rolled 1, 2 and 4 B. & S. gage numbers from commercial anneals in the 500 to 650° C. range. Figure 7 shows Rockwell hardness plotted against tensile strength for alloy E brass.

TABLE VII

CHEMICAL ANALYSES OF ROLLING SERIES

| | Alloy E Brass | Alloy G Brass | Alloy A Nickel Silver | Alloy B Nickel Silver | Alloy A Phosphor Bronze | Alloy C Phosphor Bronze |
|---|---|---|---|---|---|---|
| Copper, per cent........ | 66.02 | 71.73 | 71.31 | 55.23 | 95.35 | 91.84 |
| Lead, per cent.......... | 1.08 | 0.02 | .... | 0.005 | 0.01 | 0.02 |
| Iron, per cent.......... | 0.03 | 0.03 | 0.12 | 0.06 | 0.05 | 0.03 |
| Zinc, per cent.......... | 32.87 | 28.21 | 10.74 | 26.27 | 0.00 | 0.00 |
| Nickel, per cent........ | .... | 0.01 | 17.62 | 18.38 | 0.00 | 0.00 |
| Manganese, per cent.... | .... | .... | 0.12 | 0.11 | .... | .... |
| Tin, per cent........... | .... | 0.00 | .... | .... | 4.48 | 8.08 |
| Phosphorus, per cent.... | .... | .... | .... | .... | 0.08 | 0.03 |
| Graphite, per cent...... | .... | .... | 0.00 | 0.00 | .... | .... |
| Combined Carbon, per cent................. | .... | .... | 0.013 | 0.018 | .... | .... |

In a previous paper[10] it was shown that different Rockwell hardness values were required for material 0.040 in. and thicker, and materials less than 0.040 in. thick. This change in limits is dependent upon thickness and is not sharply defined, but it has been found sufficiently accurate for all practical purposes to consider that the division occurs at 0.040 in. In the case of the alloy E brass rolling series results shown by Fig. 7, only one curve was drawn since not sufficient data were available to show this division. The curve practically agrees with the curves given in a previous paper[10] for the

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[10] H. N. Van Deusen, L. I. Shaw and C. H. Davis, *loc. cit.*

high-brass rolling series, and also with the data shown on Fig. 19 for commercial shipments of high and clock brass.

The composition of alloy E brass is midway between that of high and clock-brass, and consequently it was to be expected that the Rockwell hardness limits for this material would be the same as for the foregoing. The tension test is more sensitive to such changes in chemical composition and since it is the test upon which acceptance or rejection of material is based, separate tensile strength limits are given. The separate tensile strength and the combined Rockwel hardness limits for these alloys are given in Table V. The physical properties of alloy E brass are given in Table VIII.

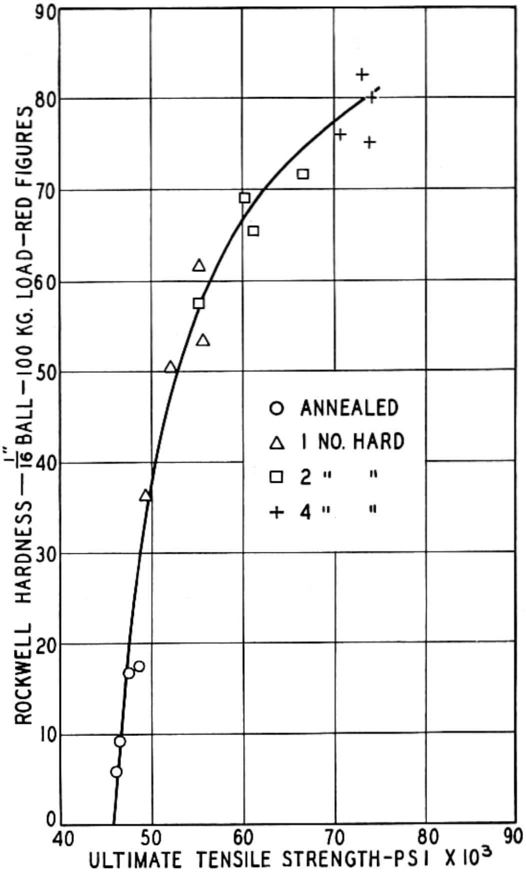

Fig. 7—Relation of Rockwell Hardness to Tensile Strength of Alloy E Brass.

TABLE VIII

PHYSICAL PROPERTIES OF ALLOY E BRASS SHEET

| B. & S. Gage | Temper, B. & S. Numbers Hard | Thickness, in. | Percentage Reduction by Rolling |  | Proportional Limit, lb. per sq. in. | Tensile Strength, lb. per sq. in. | Rockwell Hardness, "B" Scale, 1/16-in. Ball, 100-kg. Load (Red Figures) | Modulus of Elasticity, lb. per sq. in. | Elongation in 2 in., per cent |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | At Edges | At Center |  |  |  |  |  |
| No. 10 | 0 | 0.1057 | 0 | 0 | ...... | 48,330 | 17.4 | .......... | 65.8 |
| No. 11 | 1 | 0.0903 | 14.2 | 15.2 | 20,050 | 55,130 | 61.6 | 13,740,000 | 41.0 |
| No. 12 | 2 | 0.0817 | 22.0 | 23.4 | 30,417 | 60,630 | 71.8 | 14,600,000 | 30.7 |
| No. 14 | 4 | 0.0657 | 37.2 | 38.5 | 27,230 | 72,930 | 82.6 | 16,540,000 | 10.8 |
| No. 14 | 0 | 0.0656 | 0 | 0 | ...... | 46,230 | 9.1 | .......... | 64.3 |
| No. 15 | 1 | 0.0568 | 10.6 | 10.6 | 18,525 | 52,000 | 50.3 | 16,460,000 | 46.5 |
| No. 16 | 2 | 0.0508 | 23.1 | 22.8 | 25,870 | 60,200 | 69.2 | 16,760,000 | 28.5 |
| No. 18 | 4 | 0.0402 | 38.5 | 38.5 | 29,670 | 74,066 | 80.1 | 14,480,000 | 8.0 |
| No. 18 | 0 | 0.0402 | 0 | 0 | ...... | 46,130 | 5.8 | .......... | 67.3 |
| No. 19 | 1 | 0.0371 | 9.2 | 9.3 | 18,870 | 49,600 | 36.3 | .......... | 52.3 |
| No. 20 | 2 | 0.0338 | 17.4 | 17.2 | 20,885 | 55,230 | 57.6 | 15,380,000 | 37.8 |
| No. 22 | 4 | 0.0260 | 36.7 | 36.3 | 23,385 | 70,530 | 76.0 | 17,000,000 | 11.2 |
| No. 22 | 0 | 0.0256 | 0 | 0 | ...... | 47,500 | 16.8 | .......... | 59.0 |
| No. 23 | 1 | 0.0225 | 15.8 | 14.1 | 25,410 | 55,500 | 53.2 | 12,340,000 | 38.7 |
| No. 24 | 2 | 0.0205 | 23.2 | 21.8 | 36,460 | 61,010 | 65.7 | 12,300,000 | 29.0 |
| No. 26 | 4 | 0.0169 | 36.7 | 35.1 | 34,090 | 74,050 | 75.2 | .......... | 7.5 |

*Note.*—Tensile strength and percentage elongation are an average of 3 specimens in each case; Rockwell hardness values are an average of 15 determinations of 5 readings on each of 3 tension test specimens.

It will be noted that the Rockwell hardness and tensile strength limits for alloy E brass are given only for material 1, 2 and 4 numbers hard. This alloy is not normally used in higher tempers as it is especially adapted for use where both forming and machining operations are involved, so that higher leaded or harder materials would not be suitable.

The chemical composition requirements for alloy E brass sheet are given in Table VI.

TABLE IX

Physical Properties of Alloy G Brass Sheet

| B. & S. Gage | Temper, B. & S. Numbers Hard | Thickness, in. | Actual Percentage Reduction by Rolling | Rockwell Hardness, "B" Scale, $\frac{1}{16}$-in. Ball, 100-kg. Load (Red Figures) | Tensile Strength, lb. per sq. in. | Elongation in 2 in., per cent |
|---|---|---|---|---|---|---|
| No. 14...... | 0 | 0.0655 | 0 | 8.5 | 46,200 | 68 |
| | 2 | 0.0655 | 20.6 | 70.1 | 60,500 | 32.5 |
| | 4 | 0.0660 | 35.0 | 83.4 | 74,600 | 11 |
| | 6 | 0.0658 | 50.6 | 88.2 | 83,800 | 7.5 |
| | 8 | 0.0655 | 60.4 | 92.6 | 95,600 | 6.5 |
| | 10 | 0.0655 | 68.8 | 93.4 | 98,600 | 6.5 |
| No. 16...... | 0 | 0.0520 | 0 | 22.7 | 48,300 | 60 |
| | 2 | 0.0522 | 21.4 | 69.0 | 59,700 | 33 |
| | 4 | 0.0515 | 37.6 | 83.7 | 76,200 | 9 |
| | 6 | 0.0500 | 49.9 | 87.7 | 86,400 | 6 |
| | 8 | 0.0503 | 61.5 | 91.0 | 93,000 | 6.5 |
| | 10 | 0.0512 | 68.6 | 93.5 | 102,000 | 4.5 |
| No. 18...... | 0 | 0.0424 | 0 | 21.8 | 48,700 | 63 |
| | 2 | 0.0409 | 21.0 | 73.2 | 63,400 | 25.5 |
| | 4 | 0.0412 | 36.8 | 81.6 | 74,900 | 9.5 |
| | 6 | 0.0408 | 49.6 | 87.9 | 86,800 | 6 |
| | 8 | 0.0415 | 59.4 | 90.1 | 92,700 | 4 |
| | 10 | 0.0412 | 69.6 | 92.4 | 96,900 | 3 |
| No. 20...... | 0 | 0.0339 | 0 | 27.6 | 48,900 | 57 |
| | 2 | 0.0333 | 22.2 | 73.3 | 64,000 | 25 |
| | 4 | 0.0329 | 37.4 | 83.5 | 77,800 | 7.5 |
| | 6 | 0.0330 | 49.9 | 87.0 | 85,400 | 5 |
| | 8 | 0.0324 | 60.7 | 90.3 | 93,800 | 3 |
| | 10 | 0.0320 | 68.5 | 92.1 | 99,000 | 3 |
| No. 22...... | 0 | 0.0256 | 0 | 15.4 | 47,100 | 64 |
| | 2 | 0.0260 | 23.0 | 74.2 | 65,100 | 22.5 |
| | 4 | 0.0265 | 39.9 | 83.4 | 79,100 | 7.5 |
| | 6 | 0.0263 | 50.5 | 88.3 | 88,200 | 2.5 |
| | 8 | 0.0260 | 60.7 | 90.0 | 93,300 | 3 |
| | 10 | 0.0255 | 68.8 | 91.8 | 98,200 | 2.5 |
| No. 24...... | 0 | 0.0201 | 0 | 16.0 | 46,300 | 61 |
| | 2 | 0.0203 | 21.1 | 67.6 | 61,000 | 26 |
| | 4 | 0.0204 | 39.6 | 84.3 | 81,600 | 6 |
| | 6 | 0.0204 | 53.3 | 89.0 | 91,400 | 3.5 |
| | 8 | 0.0208 | 59.3 | 91.0 | 96,600 | 2 |
| | 10 | 0.0207 | 66.6 | 91.9 | 97,800 | 2 |

TABLE IX—*Continued*

| B. & S. Gage | Temper, B. & S. Numbers Hard | Thickness, in. | Actual Percentage Reduction by Rolling | Rockwell Hardness, "B" Scale, 1/16-in. Ball, 100-kg. Load (Red Figures) | Tensile Strength, lb. per sq. in. | Elongation in 2 in., per cent |
|---|---|---|---|---|---|---|
| No. 26...... | 0 | 0.0169 | 0 | 11.0 | 46,200 | 58.0 |
| | 2 | 0.0167 | 17.3 | 64.4 | 58,100 | 26.5 |
| | 4 | 0.0168 | 34.3 | 77.3 | 71,800 | 9 |
| | 6 | 0.0168 | 50.9 | 87.4 | 88,600 | 2 |
| | 8 | 0.0165 | 62.4 | 90.2 | 95,600 | 1.5 |
| | 10 | 0.0172 | 66.5 | 91.2 | 99,100 | 1.5 |
| No. 28...... | 0 | 0.0133 | 0 | 13.2 | 45,800 | 61.5 |
| | 2 | 0.0135 | 21.1 | 65.4 | 61,100 | 24 |
| | 4 | 0.0134 | 33.5 | 77.0 | 71,400 | 8 |
| | 6 | 0.0135 | 49.0 | 83.2 | 83,600 | 2 |
| | 8 | 0.0135 | 60.1 | 89.6 | 94,700 | 1.5 |
| | 10 | 0.0132 | 67.7 | 91.5 | 100,100 | 1 |
| No. 30...... | 0 | 0.0108 | 0 | 28.5 | 45,600 | 54 |
| | 2 | 0.0103 | 18.8 | 55.7 | 63,600 | 20 |
| | 4 | 0.0106 | 36.6 | 75.7 | 74,000 | 4 |
| | 6 | 0.0106 | 48.7 | 81.2 | 84,000 | 2 |
| | 8 | 0.0108 | 58.6 | 86.1 | 90,600 | 1.5 |
| | 10 | 0.0108 | 68.4 | 90.3 | 98,600 | 1 |
| No. 32...... | 1 | 0.0085 | 0 | .... | 46,800 | 51.5 |
| | 2 | 0.0084 | 17.8 | .... | 60,500 | 24.5 |
| | 4 | 0.0085 | 33.6 | .... | 73,900 | 5 |
| | 6 | 0.0087 | 46.0 | .... | 84,300 | 1.5 |
| | 8 | 0.0086 | 59.4 | .... | 89,700 | 1 |
| | 10 | 0.0085 | 63.0 | .... | 96,700 | 0.5 |
| No. 34...... | 0 | 0.0071 | 0 | .... | 41,200 | 39 |
| | 2 | 0.0065 | 29.2 | .... | 64,400 | 20.5 |
| | 4 | 0.0071 | 39.6 | .... | 70,900 | 4.5 |
| | 6 | 0.0071 | 46.9 | .... | 79,800 | 1.5 |
| | 8 | 0.00705 | 57.1 | .... | 85,700 | 1 |
| | 10 | 0.0072 | 64.5 | .... | 89,200 | 0.75 |
| No. 36...... | 0 | 0.0057 | 0 | .... | 41,600 | 33 |
| | 2 | 0.0054 | 16.7 | .... | 55,700 | 18 |
| | 4 | 0.0056 | 34.1 | .... | 73,400 | 4 |
| | 6 | 0.0056 | 51.5 | .... | 81,900 | 2 |
| | 8 | 0.0056 | 60.9 | .... | 87,700 | 2 |
| | 10 | 0.0052 | 68.3 | .... | 93,100 | 1 |

*Note.*—Tensile strength and percentage elongation are an average of 3 specimens in each case; Rockwell hardness values are an average of 15 determinations of 5 readings on each of 3 tension test specimens.

### *Alloy G Brass Sheet:*

It has been pointed out in a previous paper[11] that this material, consisting nominally of 72 per cent of copper and 28 per cent of zinc, gives the maximum tensile properties possible with the alpha

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[11] W. H. Bassett and C. H. Davis, "Physical Characteristics of Copper and Zinc Alloys," *Proceedings*, Inst. Metals Div., Am. Inst. Mining and Metallurgical Engrs., 1928.

brasses in the cold-rolled condition. A bar of alloy G brass of the chemical composition shown in Table VII was rolled 2, 4, 6, 8 and 10 numbers hard in every even B. & S. gage number from No. 14 to No. 36, inclusive. Table IX gives the physical properties of the rolling series. The Rockwell hardness-tensile strength curve is shown in Fig. 8 and the tensile strength-reduction curve is shown by Fig. 9. The chemical composition limits are given in Table VI, and the tensile strength and Rockwell hardness limits are given in Table X.

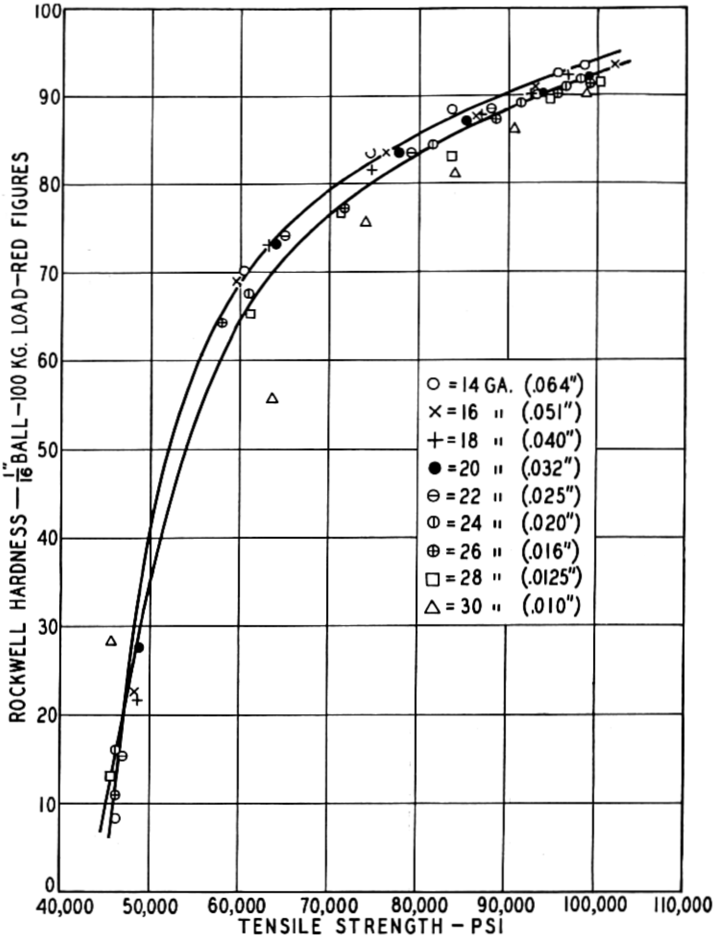

Fig. 8—Relation of Rockwell Hardness to Tensile Strength of Alloy G Brass Rolling Series.

*Nickel Silver:*

Two nickel-silver alloys were investigated, one containing nominally 72 per cent of copper, 10 per cent of zinc and 18 per cent of nickel, which will be designated "alloy A"; and the other containing 55 per cent of copper, 27 per cent of zinc, and 18 per cent of nickel and designated "alloy B." Alloy A is used mainly for forming and deep drawing purposes, whereas alloy B is used for springs.

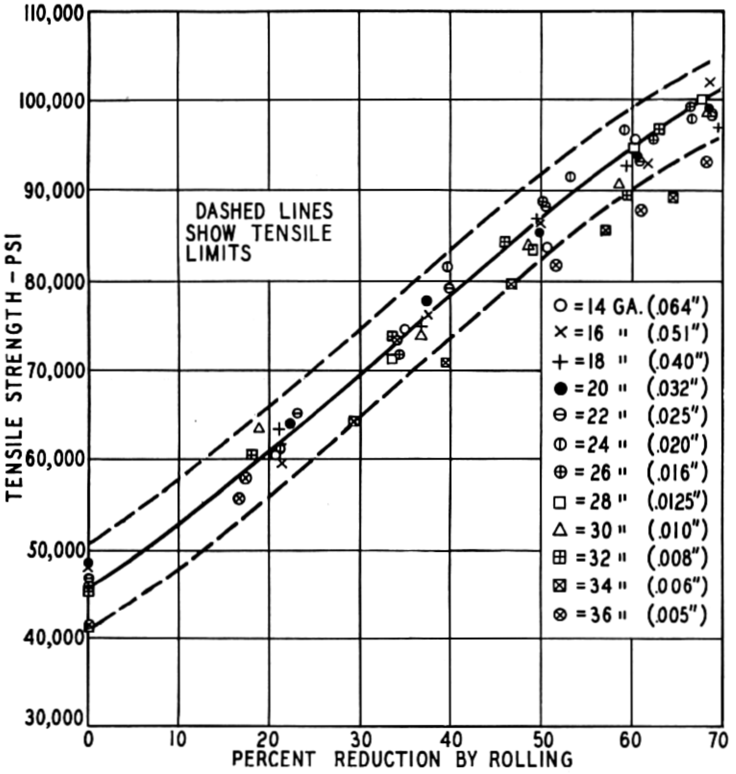

Fig. 9—Relation of Tensile Strength to Percentage of Reduction by Rolling of Alloy G Brass Rolling Series.

*Alloy A Nickel-Silver Sheet.*—The average composition of three bars of alloy A cast from the same pot of metal are given in Table VII. Table XI shows the physical properties of alloy A. Figure 11 shows the Rockwell hardness-tensile strength relationship and Fig. 12 shows the tensile strength limits plotted against percentage of reduction. The tensile strength and Rockwell hardness limits for this material are given in Table XII and the composition limits in Table VI.

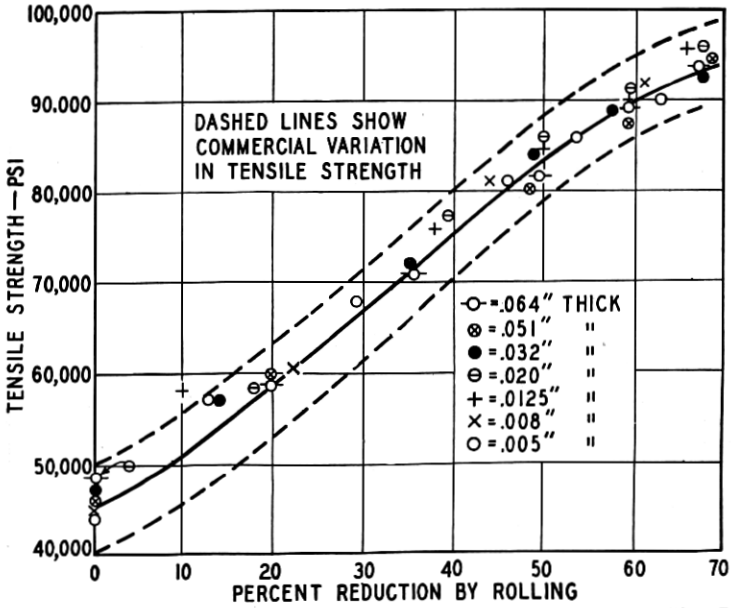

Fig. 10—Tensile Strength *versus* Reduction by Rolling. High-Brass Rolling Series

TABLE X

ROCKWELL HARDNESS AND TENSILE STRENGTH LIMITS FOR ALLOY G BRASS SHEET

| Thickness | Temper, B. & S. Numbers Hard | Percentage Reduction by Rolling | Tensile Strength, lb. per sq. in. | | Rockwell Hardness, "B" Scale, 1/16-in. Ball, 100-kg. Load (Red Figures) | |
|---|---|---|---|---|---|---|
| | | | Minimum | Maximum | Minimum | Maximum |
| 0.040 in. and over... | Quarter hard.. 1 | 11.0 | 49,000 | 59,000 | 35 | 67 |
| 0.020 to 0.040 in.... | | 11.0 | 49,000 | 59,000 | 30 | 63 |
| 0.040 in. and over... | Half hard..... 2 | 20.7 | 56,500 | 66,500 | 63 | 76 |
| 0.020 to 0.040 in.... | | 20.7 | 56,500 | 66,500 | 57 | 73 |
| 0.040 in. and over... | Hard......... 4 | 37.1 | 71,000 | 81,000 | 80 | 86 |
| 0.020 to 0.040 in.... | | 37.1 | 71,000 | 81,000 | 77 | 84 |
| 0.040 in. and over... | Extra hard.... 6 | 50.0 | 82,500 | 91,500 | 87 | 91 |
| 0.020 to 0.040 in.... | | 50.0 | 82,500 | 91,500 | 85 | 89 |
| 0.040 in. and over... | Spring........ 8 | 60.5 | 90,500 | 99,500 | 90 | 94 |
| 0.020 to 0.040 in.... | | 60.5 | 90,500 | 99,500 | 88 | 92 |
| 0.040 in. and over... | Extra spring...10 | 68.7 | 95,000 | 104,000 | 92 | 96 |
| 0.020 to 0.040 in.... | | 68.7 | 95,000 | 104,000 | 90 | 94 |

## TABLE XI

### Physical Properties of Alloy A Nickel-Silver Sheet

| B. & S. Gage | Temper, B. & S. Numbers Hard | Thickness, in. | Actual Percentage Reduction by Rolling | Elongation in 2 in., per cent | Rockwell Hardness, "B" Scale, $\frac{1}{16}$-in. Ball (Red Figures) | | Tensile Strength, lb. per sq. in. |
|---|---|---|---|---|---|---|---|
| | | | | | 100-kg. Load | 150-kg. Load | |
| No. 10..... | 0 | 0.1034 | 0 | 37.5 | 37.5 | —13.5 | 54,500 |
| No. 11..... | 1 | 0.0910 | 7.3 | 17.5 | 73.3 | 37.5 | 62,200 |
| No. 10..... | 2 | 0.1022 | 21.1 | 8.5 | 80.1 | 48.7 | 70,400 |
| No. 10..... | 4 | 0.1037 | 36.9 | 5.5 | 84.0 | 55.2 | 79,500 |
| No. 10..... | 6 | 0.1035 | 49.8 | 5.0 | 86.7 | 59.7 | 82,900 |
| No. 16..... | 0 | 0.0517 | 0 | 36.5 | 37.3 | —16.7 | 55,100 |
| No. 17..... | 1 | 0.0460 | 10.6 | 21.5 | 69.1 | 30.1 | 61,300 |
| No. 16..... | 2 | 0.0516 | 22.3 | 7.5 | 78.7 | 45.5 | 69,500 |
| No. 16..... | 4 | 0.0503 | 39.5 | 3.5 | 84.5 | 56.2 | 79,700 |
| No. 16..... | 6 | 0.0512 | 49.8 | 4.0 | 86.3 | 59.0 | 82,800 |
| No. 22..... | 0 | 0.0257 | 0 | 32.0 | 36.4 | .... | 54,400 |
| No. 23..... | 1 | 0.0301 | 7.8 | 20.0 | 66.6 | 26.1 | 60,600 |
| No. 22..... | 2 | 0.0266 | 17.2 | 7.0 | 75.5 | 41.1 | 69,100 |
| No. 22..... | 4 | 0.0263 | 36.1 | 2.5 | 81.4 | 51.0 | 79,600 |
| No. 22..... | 6 | 0.0263 | 48.7 | 2.0 | 83.3 | 55.0 | 83,700 |
| No. 28..... | 0 | 0.0128 | 0 | 35.5 | 23.0 | .... | 54,500 |
| No. 27..... | 1 | 0.0145 | 11.5 | 16.0 | 65.6 | .... | 62,800 |
| No. 28..... | 2 | 0.0132 | 21.2 | 4.5 | 72.2 | .... | 69,200 |
| No. 28..... | 4 | 0.0137 | 35.6 | 1.5 | 77.1 | .... | 80,700 |
| No. 28..... | 6 | 0.0130 | 47.4 | 1.0 | 81.1 | .... | 84,900 |
| No. 30..... | 0 | 0.0105 | 0 | 30.5 | .... | .... | 54,600 |
| No. 32..... | 0 | 0.0085 | 0 | 32.0 | .... | .... | 55,100 |
| No. 34..... | 0 | 0.0059 | 0 | 28.5 | .... | .... | 55,600 |
| No. 34..... | 1 | 0.0077 | 12.5<br>17.6 | 6.0 | .... | .... | 65,200 |
| No. 34..... | 2 | 0.0058 | 25.0<br>29.4 | 2.5 | .... | .... | 74,400 |
| No. 34..... | 4 | 0.0062 | 41.2 | 1.0 | .... | .... | 78,800 |
| No. 34..... | 6 | 0.0060 | 50.8 | 1.0 | .... | .... | 87,900 |

*Note.*—Tensile strength and percentage elongation are an average of 3 specimens in each case; Rockwell hardness values are an average of 15 determinations of 5 readings on each of 3 tension test specimens.

*Alloy B Nickel-Silver Sheet.*—The five bars of alloy B had the average analysis given in Table VII. The rolling series made from these five bars consisted of the tempers 2, 4, 6, 8 and 10 numbers hard for each of the even B. & S. gage numbers from No. 14 to No. 36, inclusive. The physical properties of this material are given in Table XIII. The Rockwell hardness-tensile strength relationship is shown by Fig. 13 and the tensile strength limits plotted against

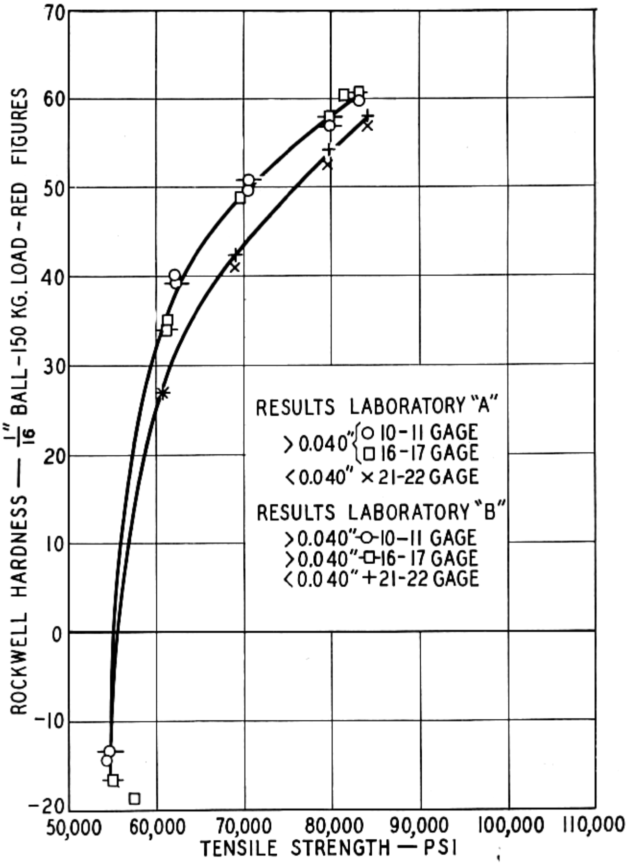

Fig. 11—Relation of Rockwell Hardness to Tensile Strength of Alloy A Nickel Silver Rolling Series.

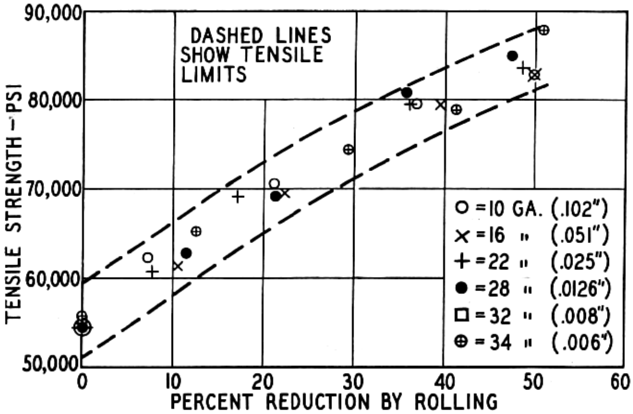

Fig. 12—Relation of Tensile Strength to Percentage of Reduction of Alloy A Nickel Silver Rolling Series.

## TABLE XII

### ROCKWELL HARDNESS AND TENSILE STRENGTH LIMITS FOR ALLOYS A AND B NICKEL-SILVER SHEET

| Thickness | Temper, B. & S. Numbers Hard | Nominal Percentage Reduction by Rolling | Alloy A |  |  |  | Alloy B |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Tensile Strength, lb. per sq. in. |  | Rockwell Hardness, "B" Scale, 1/16-in. Ball, 150-kg. Load (Red Figures) |  | Tensile Strength, lb. per sq. in. |  | Rockwell Hardness, "B" Scale, 1/16-in. Ball, 150-kg. Load (Red Figures) |  |
|  |  |  | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| 0.040 in. and over | Quarter hard 1 | 11.0 | 58,500 | 67,000 | 26 | 47 | ...... | ...... | .. | .. |
| 0.020 to 0.040 in. |  | 11.0 | 58,500 | 67,000 | 19 | 40 | ...... | ...... | .. | .. |
| 0.040 in. and over | Half hard 2 | 20.7 | 65,500 | 73,500 | 44 | 54 | 78,000 | 93,000 | 54 | 70 |
| 0.020 to 0.040 in. |  | 20.7 | 65,500 | 73,500 | 38 | 48 | 78,000 | 93,000 | 48 | 67 |
| 0.040 in. and over | Hard 4 | 37.1 | 75,000 | 82,000 | 54 | 61 | 92,000 | 106,500 | 69 | 77 |
| 0.020 to 0.040 in. |  | 37.1 | 75,000 | 82,000 | 49 | 55 | 92,000 | 106,500 | 66 | 75 |
| 0.040 in. and over | Extra hard 6 | 50.0 | 81,000 | 88,000 | 59 | 64 | 102,000 | 115,000 | 75 | 82 |
| 0.020 to 0.040 in. |  | 50.0 | 81,000 | 88,000 | 54 | 60 | 102,000 | 115,000 | 72 | 79 |
| 0.040 in. and over | Spring 8 | 60.5 | ...... | ...... | .. | .. | 108,000 | 120,000 | 78 | 84 |
| 0.020 to 0.040 in. |  | 60.5 | ...... | ...... | .. | .. | 108,000 | 120,000 | 75 | 81 |
| 0.040 in. and over | Extra spring 10 | 68.7 | ...... | ...... | .. | .. | 111,000 | 123,000 | 80 | 85 |
| 0.020 to 0.040 in. |  | 68.7 | ...... | ...... | .. | .. | 111,000 | 123,000 | 77 | 82 |

TABLE XIII

PHYSICAL PROPERTIES OF ALLOY B NICKEL-SILVER SHEET

| B. & S. Gage | Temper, B. & S. Numbers Hard | Thickness, in. | Actual Percentage Reduction by Rolling | Tensile Strength, lb. per sq. in. | Elongation in 2 in., per cent | Rockwell Hardness, "B" Scale, 1/16-in. Ball (Red Figures) | |
|---|---|---|---|---|---|---|---|
| | | | | | | 100-kg. Load | 150-kg. Load |
| No. 14..... | 0 | 0.0666 | 0 | 66,100 | 45.5 | 53.6 | 9.5 |
| No. 14..... | 2 | 0.0653 | 22.6 | 81,300 | 13.0 | 87.6 | 62.2 |
| No. 14..... | 4 | 0.0664 | 37.2 | 93,400 | 5.0 | 92.8 | 70.5 |
| No. 14..... | 6 | 0.0670 | 47.8 | 103,400 | 3.0 | 96.0 | 76.2 |
| No. 14..... | 8 | 0.0659 | 58.8 | 108,600 | 3.5 | 97.9 | 69.0 |
| No. 14..... | 10 | 0.0654 | 68.3 | 114,300 | 3.8 | 99.1 | 82.3 |
| No. 16..... | 0 | 0.0513 | 0 | 65,100 | 47.0 | 51.1 | 5.3 |
| No. 16..... | 2 | 0.0522 | 21.6 | 85,600 | 12.0 | 89.6 | 65.4 |
| No. 16..... | 4 | 0.0506 | 40.1 | 97,400 | 3.0 | 93.8 | 70.6 |
| No. 16..... | 6 | 0.0513 | 51.3 | 104,500 | 3.0 | 96.6 | 75.3 |
| No. 16..... | 8 | 0.0500 | 60.8 | 111,400 | 3.0 | 98.9 | 79.3 |
| No. 16..... | 10 | 0.0510 | 67.6 | 114,500 | 3.0 | 99.7 | 80.9 |
| No. 18..... | 0 | 0.0418 | 0 | 65,300 | 45.5 | 50.6 | 7.4 |
| No. 18..... | 2 | 0.0413 | 19.4 | 81,100 | 16.0 | 85.3 | 59.0 |
| No. 18..... | 4 | 0.0415 | 37.6 | 97,400 | 4.0 | 93.4 | 70.7 |
| No. 18..... | 6 | 0.0415 | 50.9 | 103,600 | 2.5 | 94.9 | 73.4 |
| No. 18..... | 8 | 0.0398 | 62.1 | 110,400 | 2.0 | 96.8 | 77.2 |
| No. 18..... | 10 | 0.0419 | 66.8 | 115,000 | 2.5 | 98.9 | 79.1 |
| No. 20..... | 0 | 0.0326 | 0 | 67,600 | 44.0 | 56.2 | 14.7 |
| No. 20..... | 2 | 0.0335 | 19.9 | 80,700 | 16.5 | 85.0 | 59.6 |
| No. 20..... | 4 | 0.0330 | 35.4 | 96,300 | 3.0 | 90.9 | 69.9 |
| No. 20..... | 6 | 0.0325 | 51.4 | 107,200 | 2.0 | 94.6 | 74.9 |
| No. 20..... | 8 | 0.0328 | 61.4 | 109,500 | 2.0 | 95.3 | 76.3 |
| No. 20..... | 10 | 0.0339 | 67.8 | 113,600 | 2.0 | 96.7 | 77.8 |
| No. 22..... | 0 | 0.0286 | 0 | 74,600 | 35.5 | 67.6 | 34.5 |
| No. 22..... | 2 | 0.0271 | 16.5 | 80,600 | 19.5 | 83.4 | 57.2 |
| No. 22..... | 4 | 0.0259 | 37.8 | 98,700 | 2.0 | 91.3 | 70.1 |
| No. 22..... | 6 | 0.0260 | 49.6 | 107,000 | 1.5 | 94.0 | 74.2 |
| No. 22..... | 8 | 0.0262 | 60.6 | 112,200 | 1.5 | 95.5 | 76.6 |
| No. 22..... | 10 | 0.0264 | 68.7 | 113,500 | 2.0 | 96.0 | 77.3 |
| No. 24..... | 0 | 0.0209 | 0 | 66,900 | 42.0 | 60.6 | 19.0 |
| No. 24..... | 2 | 0.0210 | 19.4 | 94,900 | 8.5 | 90.6 | 68.8 |
| No. 24..... | 4 | 0.0211 | 34.9 | 98,700 | 2.0 | 90.9 | 69.0 |
| No. 24..... | 6 | 0.0208 | 49.1 | 107,000 | 1.0 | 93.4 | 73.2 |
| No. 24..... | 8 | 0.0211 | 58.8 | 112,400 | 1.5 | 95.5 | 76.1 |
| No. 24..... | 10 | 0.0209 | 68.9 | 116,200 | 1.5 | 96.6 | 78.5 |

TABLE XIII—*Continued*

| B. &. S. Gage | Temper, B. & S. Numbers Hard | Thickness, in. | Actual Percentage Reduction by Rolling | Tensile Strength, lb. per sq. in. | Elongation in 2 in., per cent | Rockwell Hardness, "B" Scale, $\frac{1}{16}$-in. Ball (Red Figures) | |
|---|---|---|---|---|---|---|---|
| | | | | | | 100-kg. Load | 150-kg. Load |
| No. 26.... | 0 | 0.0177 | 0 | 65,200 | 41.0 | 57.9 | 2.7 |
| No. 26.... | 2 | 0.0166 | 21.9 | 83,000 | 11.5 | 86.3 | 58.7 |
| No. 26.... | 4 | 0.0167 | 35.8 | 108,200 | 2.0 | 94.2 | 72.6 |
| No. 26.... | 6 | 0.0172 | 40.3 | 106,600 | 1.5 | 93.3 | 71.9 |
| No. 26.... | 8 | 0.0166 | 60.2 | 112,600 | 1.0 | 95.4 | 74.8 |
| No. 26.... | 10 | 0.0170 | 67.4 | 114,700 | 1.0 | 96.2 | 77.4 |
| No. 28.... | 0 | 0.0139 | 0 | 64,500 | 34.0 | 59.8 | 3.3 |
| No. 28.... | 2 | 0.0136 | 20.3 | 83,300 | 12.5 | 84.9 | 50.3 |
| No. 28.... | 4 | 0.0126 | 38.5 | 102,800 | 1.5 | 92.4 | 63.8 |
| No. 28.... | 6 | 0.0128 | 51.4 | 116,300 | 1.5 | 96.3 | 72.7 |
| No. 28.... | 8 | 0.0133 | 58.4 | 111,500 | 1.0 | 95.4 | 73.3 |
| No. 28.... | 10 | 0.0133 | 68.0 | 116,400 | 1.0 | 96.3 | 74.7 |
| No. 30.... | 0 | 0.0106 | 0 | 65,300 | 39.0 | 56.2 | .... |
| No. 30.... | 2 | 0.0111 | 18.4 | 77,500 | 14.5 | 80.6 | .... |
| No. 30.... | 4 | 0.0112 | 35.9 | 95,600 | 2.5 | 89.2 | .... |
| No. 30.... | 6 | 0.0105 | 46.4 | 107,500 | 1.0 | 94.0 | .... |
| No. 30.... | 8 | 0.0107 | 59.1 | 119,500 | 1.0 | 97.1 | .... |
| No. 30.... | 10 | 0.0106 | 66.7 | 115,100 | 1.0 | 96.7 | .... |
| No. 32.... | 0 | 0.0092 | 0 | 67,000 | 38.0 | 55.1 | .... |
| No. 32.... | 2 | 0.0087 | 17.0 | 76,800 | 16.0 | 71.5 | .... |
| No. 32.... | 4 | 0.0089 | 34.6 | 91,200 | 2.0 | 83.0 | .... |
| No. 32.... | 6 | 0.0092 | 49.1 | 102,400 | 1.0 | 90.4 | .... |
| No. 32.... | 8 | 0.0084 | 60.5 | 112,600 | 1.0 | 93.4 | .... |
| No. 32.... | 10 | 0.0086 | 66.9 | 122,200 | 1.0 | 97.6 | .... |
| No. 34.... | 0 | 0.0070 | 0 | 66,200 | 33.0 | 66.4 | .... |
| No. 34.... | 2 | 0.0068 | 23.5 | 86,200 | 6.5 | 75.7 | .... |
| No. 34.... | 4 | 0.0066 | 40.0 | 96,300 | 2.0 | 79.1 | .... |
| No. 34.... | 6 | 0.0069 | 50.0 | 100,500 | 1.0 | 81.0 | .... |
| No. 34.... | 8 | 0.0068 | 61.1 | 109,200 | 1.0 | 83.3 | .... |
| No. 34.... | 10 | 0.0067 | 68.3 | 115,900 | 1.0 | 87.2 | .... |
| No. 36.... | 0 | 0.0055 | 0 | 69,400 | 34.0 | 78.9 | .... |
| No. 36.... | 2 | 0.0063 | 23.0 | 83,200 | 8.5 | 81.5 | .... |
| No. 36.... | 4 | 0.0058 | 35.3 | 96,500 | 1.5 | 81.6 | .... |
| No. 36.... | 6 | 0.0055 | 45.0 | 102,700 | 1.0 | 83.1 | .... |
| No. 36.... | 8 | 0.0059 | 57.7 | 104,100 | 1.0 | 82.9 | .... |
| No. 36.... | 10 | 0.0057 | 67.1 | 111,100 | 1.0 | 84.9 | .... |

*Note.*—Tensile strength values are an average of 3 specimens in each case; Rockwell hardness values are an average of 15 determinations of 5 readings on each of 3 tension test specimens.

percentage reduction are shown in Fig. 14. Table XII shows the Rockwell hardness and tensile strength limits for alloy B. The chemical composition limits are given in Table VI.

Referring to the curve plotted in Fig. 14, showing the tensile strength limits plotted against percentage of reduction, it is seen that one series lies close to the upper curve whereas the remaining rolling series are nearer to the lower curve. This is due to the fact that the bar rolled to No. 22 B. & S. gage sheet had a lighter anneal in the ready-to-finish condition than the other bars, but it was felt that this anneal was close to the commercial range of annealing practice and consequently this series was given some weight when the commercial limits were drawn up.

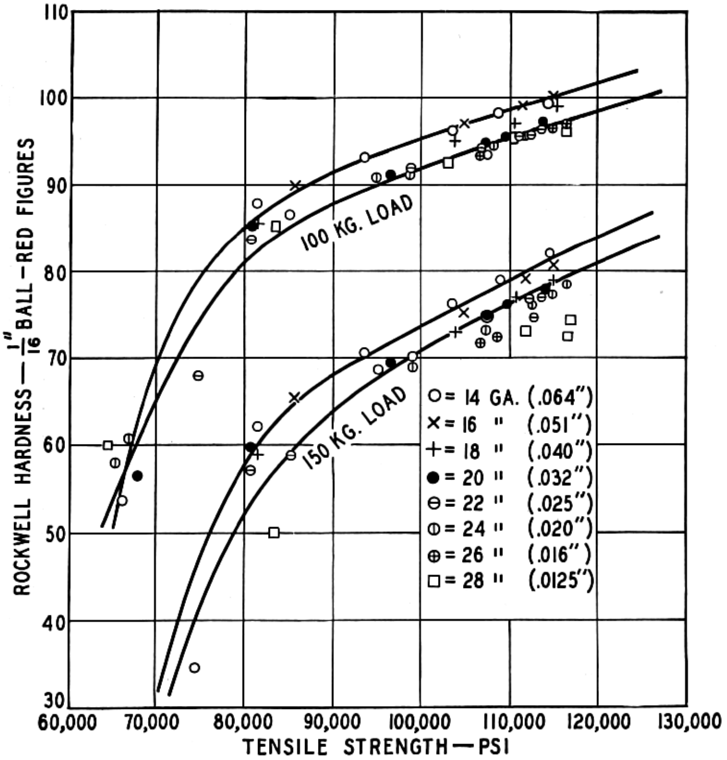

Fig. 13—Relation of Rockwell Hardness to Tensile Strength of Alloy B Nickel-Silver Rolling Series Using 100 and 150-kg. Loads.

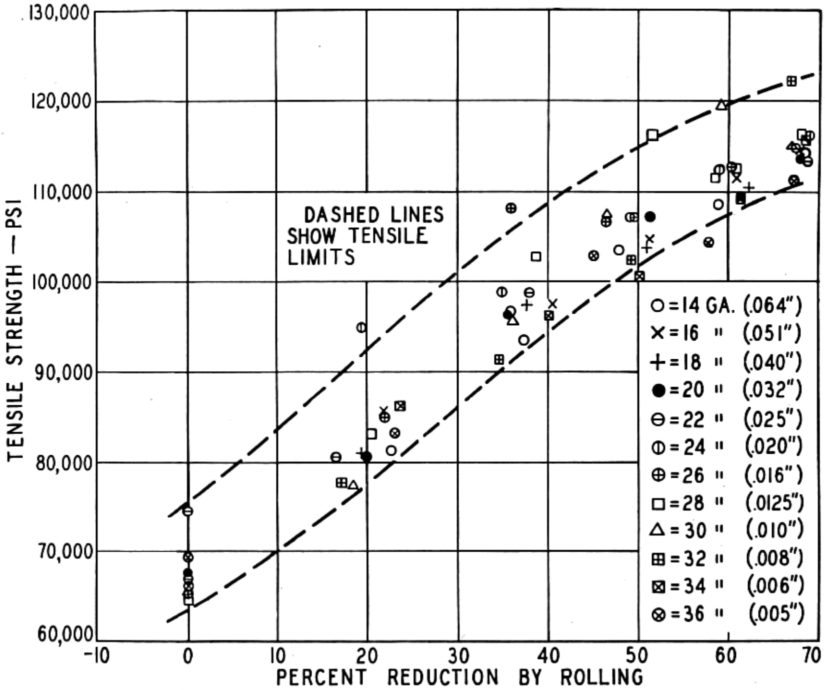

Fig. 14—Relation of Tensile Strength to Percentage of Reduction of Alloy B Nickel-Silver Rolling Series.

TABLE XIV

Physical Properties of Alloy A Phosphor-Bronze Sheet

| Temper, B. & S. Numbers Hard | B. & S. Gage, in. | Actual Percentage Reduction by Rolling | Tensile Strength, lb. per sq. in. | Elongation in 2 in., per cent | Rockwell Hardness, "B" Scale, 1/16-in. Ball (Red Figures) | |
|---|---|---|---|---|---|---|
| | | | | | 100-kg. Load | 150-kg. Load |
| Soft | 0.0636 | 0 | 46,900 | 53 | 23.8 | —6.9 |
| 2 | 0.0501 | 21.2 | 61,200 | 21.8 | 75.9 | 43.3 |
| 4 | 0.0395 | 37.8 | 75,150 | 8.0 | 84.8 | 58.3 |
| 6 | 0.0321 | 49.5 | 85,700 | 4.0 | 88.9 | 65.2 |
| 8 | 0.0248 | 61.0 | 93,900 | 2.5 | 91.4 | 68.8 |
| 10 | 0.0203 | 68.1 | 97,450 | 2.0 | 92.2 | 69.7 |
| Soft | 0.0324 | 0 | 47,000 | 51 | 26.6 | —7.6 |
| 2 | 0.0242 | 25.2 | 62,500 | 15.5 | 75.3 | 43.2 |
| 4 | 0.0199 | 38.6 | 73,600 | 6 | 80.6 | 48.0 |
| 6 | 0.0166 | 48.8 | 83,950 | 2.5 | 84.4 | 55.0 |
| 8 | 0.0126 | 61.0 | 91,900 | 1.5 | 88.1 | .... |
| 10 | 0.0105 | 67.6 | 97,350 | 1.5 | 89.3 | .... |
| Soft | 0.0162 | 0 | 46,350 | 38.5 | .... | .... |
| 2 | 0.0129 | 20.4 | 61,250 | 15.5 | .... | .... |
| 4 | 0.0107 | 33.3 | 72,800 | 4.5 | .... | .... |
| 6 | 0.0082 | 49.2 | 84,900 | 1.5 | .... | .... |
| 8 | 0.0062 | 61.7 | 94,450 | 1.3 | .... | .... |
| 10 | 0.0050 | 68.8 | 96,400 | 1 | .... | .... |

*Note.*—Tensile strength and percentage elongation are an average of 3 specimens in each case; Rockwell hardness values are an average of 15 determinations of 5 readings on each of 3 tension test specimens.

*Phosphor Bronze:*

Two grades of phosphor bronze have been investigated, designated alloys A and C, containing 4 and 8 per cent of tin, respectively.

*Alloy A Phosphor-Bronze Sheet.*—Three rolling series representative of the entire number investigated were made from the bar of metal of the analysis shown in Table VII. These three series were rolled to all even numbers hard from 2 to 10, B. & S. gage for Nos. 14, 20 and 28. The physical properties are given in Table XIV. The Rockwell hardness-tensile strength relationship for alloy A is given in Fig. 15 and the tensile strength-reduction relationship is shown in Fig. 16. The Rockwell hardness and tensile strength limits for alloy A are given in Table XV and the chemical composition requirements are given in Table VI.

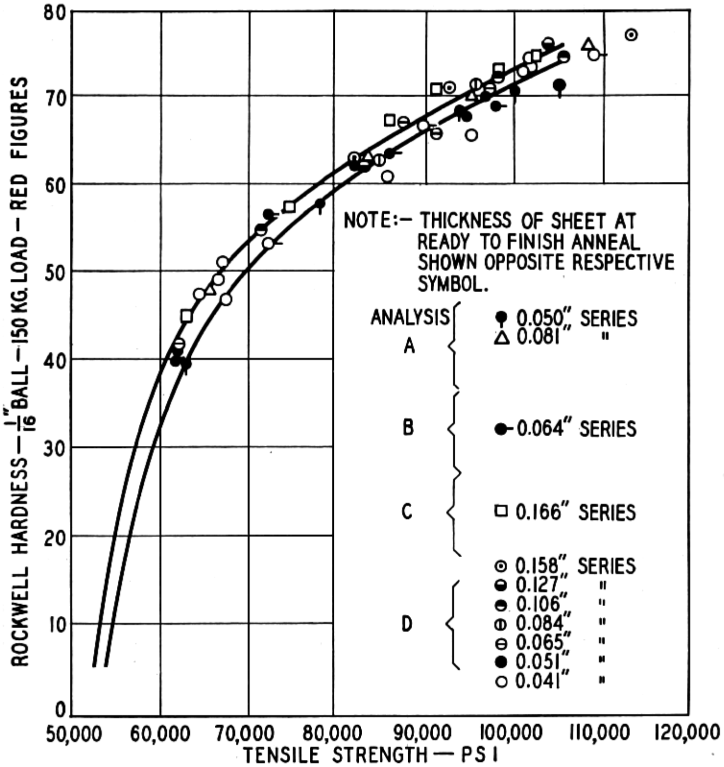

Fig. 15—Relation of Rockwell Hardness to Tensile Strength of Alloy A Phosphor-Bronze Rolling Series.

*Alloy C Phosphor-Bronze Sheet.*—The alloy C rolling series were made from five bars of metal having the average composition shown in Table VII. This material was rolled to all even hardness numbers from 2 to 10 numbers hard, for all even B. & S. gage numbers from No. 14 to No. 36, inclusive. The physical properties of this material are given in Table XVI. The Rockwell hardness-tensile strength relationship is shown in Fig. 17 and the tensile strength-reduction relationship is shown in Fig. 18. The physical requirements for alloy C are given in Table XV and the chemical requirements in Table VI.

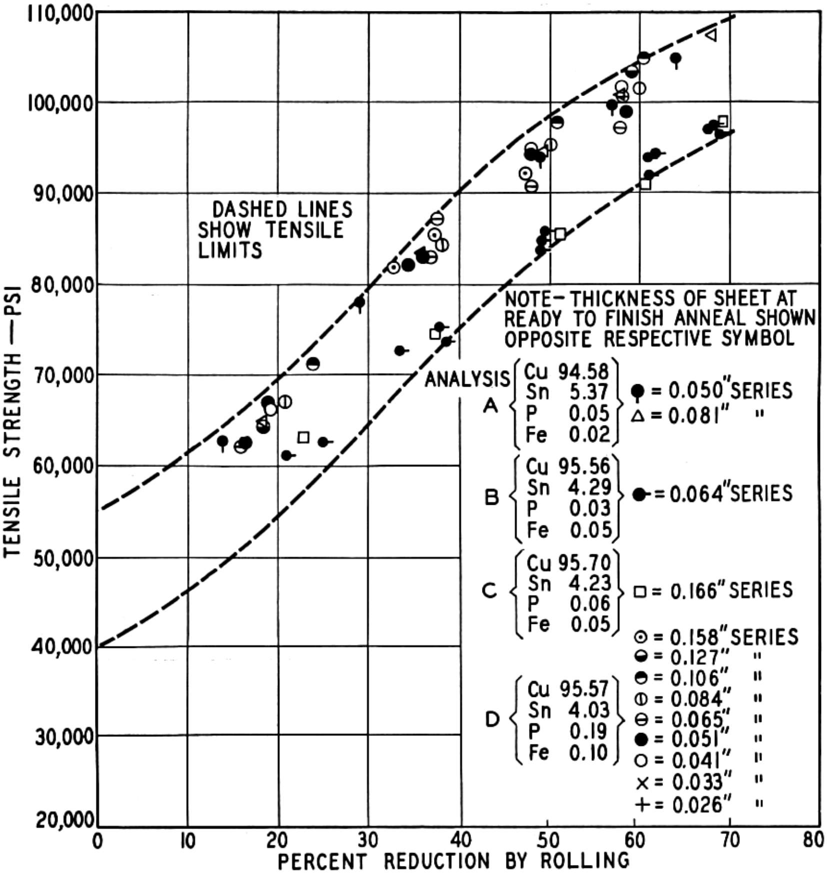

Fig. 16—Relation of Tensile Strength to Percentage of Reduction by Rolling of Alloy A Phosphor-Bronze Rolling Series.

TABLE XV

ROCKWELL HARDNESS AND TENSILE STRENGTH LIMITS FOR ALLOYS A AND C, PHOSPHOR-BRONZE SHEET

| Thickness | Temper, B. & S. Numbers Hard | Nominal Percentage Reduction by Rolling | Alloy A Phosphor Bronze | | | | Alloy C Phosphor Bronze | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Tensile Strength, lb. per sq. in. | | Rockwell Hardness, "B" Scale, 1/16-in. Ball, 150-kg. Load (Red Figures) | | Tensile Strength, lb. per sq. in. | | Rockwell Hardness, "B" Scale, 1/16-in. Ball, 150-kg. Load (Red Figures) | |
| | | | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| 0.040 in. and over....... | Half hard........ 8 | 20.7 | 55,000 | 70,000 | 20 | 53 | 69,000 | 84,000 | 47 | 68 |
| 0.020 to 0.040 in........ | | 20.7 | 55,000 | 70,000 | 15 | 51 | 69,000 | 84,000 | 40 | 64 |
| 0.040 in. and over....... | Hard............ 4 | 37.1 | 72,000 | 87,000 | 55 | 66 | 85,000 | 100,000 | 69 | 77 |
| 0.020 to 0.040 in........ | | 37.1 | 72,000 | 87,000 | 53 | 64 | 85,000 | 100,000 | 65 | 74 |
| 0.040 in. and over....... | Extra hard ...... 6 | 50.0 | 84,000 | 98,500 | 64 | 73 | 97,000 | 111,500 | 76 | 82 |
| 0.020 to 0.040 in........ | | 50.0 | 84,000 | 98,500 | 62 | 71 | 97,000 | 111,500 | 73 | 79 |
| 0.040 in. and over....... | Spring .......... 8 | 60.5 | 91,000 | 105,000 | 69 | 75 | 105,000 | 118,500 | 79 | 85 |
| 0.020 to 0.040 in........ | | 60.5 | 91,000 | 105,000 | 67 | 73 | 105,000 | 118,500 | 76 | 82 |
| 0.040 in. and over....... | Extra spring.....10 | 68.7 | 96,000 | 109,000 | 72 | 77 | 109,500 | 122,000 | 81 | 86 |
| 0.020 to 0.040 in........ | | 68.7 | 96,000 | 109,000 | 70 | 75 | 109,500 | 122,000 | 78 | 83 |

## TABLE XVI

### Physical Properties of Alloy C Phosphor-Bronze Sheet

| B. & S. Gage | Temper, B. & S. Numbers Hard | Thickness, in. | Actual Percentage Reduction by Rolling | Tensile Strength, lb. per sq. in. | Elongation in 2 in., per cent | Rockwell Hardness, "B" Scale, 1/16-in. Ball (Red Figures) | |
|---|---|---|---|---|---|---|---|
| | | | | | | 100-kg. Load | 150-kg. Load |
| No. 14..... | 0 | 0.0663 | 0 | 62,400 | 68.0 | 56.3 | 14.7 |
| No. 14..... | 2 | 0.0640 | 22.0 | 72,800 | 36.0 | 83.7 | 56.0 |
| No. 14..... | 4 | 0.0649 | 37.5 | 86,900 | 17.0 | 93.0 | 71.3 |
| No. 14..... | 6 | 0.0659 | 50.5 | 100,900 | 10.0 | 97.3 | 78.3 |
| No. 14..... | 8 | 0.0671 | 59.4 | 110,300 | 7.5 | 99.6 | 81.6 |
| No. 14..... | 10 | 0.0669 | 67.7 | 116,300 | 6.5 | 101.4 | 84.7 |
| No. 16..... | 0 | 0.0515 | 0 | 54,700 | 76.0 | 42.0 | —7.3 |
| No. 16..... | 2 | 0.0536 | 19.4 | 80,400 | 33.0 | 88.4 | 63.6 |
| No. 16..... | 4 | 0.0539 | 35.4 | 83,800 | 20.0 | 91.9 | 67.7 |
| No. 16..... | 6 | 0.0519 | 49.8 | 97,100 | 9.0 | 96.4 | 76.2 |
| No. 16..... | 8 | 0.0535 | 60.2 | 107,700 | 7.0 | 99.2 | 80.6 |
| No. 16..... | 10 | 0.0549 | 67.1 | 115,700 | 7.0 | 101.1 | 83.2 |
| No. 18..... | 0 | 0.0429 | 0 | 60,400 | 71.0 | 50.7 | 7.7 |
| No. 18..... | 2 | 0.0412 | 20.6 | 71,200 | 36.0 | 82.3 | 55.0 |
| No. 18..... | 4 | 0.0430 | 34.9 | 99,200 | 11.5 | 96.0 | 73.4 |
| No. 18..... | 6 | 0.0431 | 48.2 | 95,700 | 10.0 | 94.5 | 73.4 |
| No. 18..... | 8 | 0.0420 | 59.9 | 106,500 | 5.5 | 97.7 | 78.4 |
| No. 18..... | 10 | 0.0416 | 69.3 | 116,800 | 4.0 | 100.2 | 82.6 |
| No. 20..... | 0 | 0.0336 | 0 | 61,200 | 65.5 | 50.2 | 6.7 |
| No. 20..... | 2 | 0.0344 | 18.6 | 78,300 | 34.0 | 85.4 | 60.3 |
| No. 20..... | 4 | 0.0332 | 35.6 | 87,500 | 15.0 | 91.0 | 69.1 |
| No. 20..... | 6 | 0.0334 | 49.4 | 114,200 | 5.0 | 98.3 | 80.4 |
| No. 20..... | 8 | 0.0347 | 57.9 | 105,900 | 5.0 | 96.1 | 77.1 |
| No. 20..... | 10 | 0.0332 | 68.5 | 113,600 | 3.0 | 98.6 | 80.7 |
| No. 22..... | 0 | 0.0264 | 0 | 53,700 | 74.0 | 45.8 | —0.4 |
| No. 22..... | 2 | 0.0267 | 22.0 | 80,200 | 32.0 | 85.4 | 60.8 |
| No. 22..... | 4 | 0.0273 | 35.5 | 95,400 | 12.0 | 92.9 | 72.8 |
| No. 22..... | 6 | 0.0263 | 49.5 | 102,400 | 7.0 | 94.6 | 75.1 |
| No. 22..... | 8 | 0.0260 | 61.3 | 121,000 | 3.0 | 99.0 | 82.9 |
| No. 22..... | 10 | 0.0266 | 67.7 | 112,100 | 3.0 | 97.3 | 80.3 |
| No. 24..... | 0 | 0.0221 | 0 | 59,700 | 67.5 | 52.3 | 11.0 |
| No. 24..... | 2 | 0.0200 | 22.4 | 77,300 | 26.0 | 85.8 | 60.2 |
| No. 24..... | 4 | 0.0219 | 35.2 | 95,500 | 14.0 | 92.2 | 71.4 |
| No. 24..... | 6 | 0.0221 | 48.8 | 108,500 | 5.0 | 95.9 | 77.1 |
| No. 24..... | 8 | 0.0213 | 55.1 | 110,700 | 3.0 | 96.9 | 78.8 |
| No. 24..... | 10 | 0.0216 | 67.4 | 124,800 | 2.0 | 100.0 | 84.0 |

TABLE XVI—*Continued*

| B. & S. Gage | Temper, B. & S. Numbers Hard | Thickness, in. | Actual Percentage Reduction by Rolling | Tensile Strength, lb. per sq. in. | Elongation in 2 in., per cent | Rockwell Hardness, "B" Scale, 1/16-in. Ball (Red Figures) | |
|---|---|---|---|---|---|---|---|
| | | | | | | 100-kg. Load | 150-kg. Load |
| No. 26..... | 0 | 0.0174 | 0 | 54,300 | 69.0 | 57.3 | 25.0 |
| No. 26..... | 2 | 0.0176 | 22.6 | 73,600 | 38.0 | 81.5 | 52.6 |
| No. 26..... | 4 | 0.0178 | 32.9 | 86,800 | 15.0 | 89.2 | 65.9 |
| No. 26..... | 6 | 0.0166 | 49.9 | 108,500 | 4.0 | 96.1 | 76.3 |
| No. 26..... | 8 | 0.0173 | 60.1 | 116,600 | 2.0 | 97.3 | 78.7 |
| No. 26..... | 10 | 0.0168 | 65.7 | 115,700 | 2.0 | 97.7 | 80.3 |
| No. 28..... | 0 | 0.0130 | 0 | 57,500 | 58.0 | 61.6 | 26.5 |
| No. 28..... | 2 | 0.0129 | 23.2 | 73,400 | 30.0 | 82.4 | 46.4 |
| No. 28..... | 4 | 0.0137 | 40.1 | 91,500 | 11.0 | 90.8 | 66.1 |
| No. 28..... | 6 | 0.0128 | 52.9 | 105,300 | 4.0 | 95.1 | 69.6 |
| No. 28..... | 8 | 0.0150 | 55.6 | 107,000 | 3.0 | 95.1 | 74.1 |
| No. 28..... | 10 | 0.0138 | 66.4 | 117,600 | 1.0 | 99.0 | 81.1 |
| No. 30..... | 0 | 0.0110 | 0 | 55,400 | 61.0 | 65.3 | 43.1 |
| No. 30..... | 2 | 0.0110 | 17.6 | 72,400 | 27.5 | 85.2 | 50.3 |
| No. 30..... | 4 | 0.0111 | 34.2 | 86,500 | 12.5 | 90.3 | 54.2 |
| No. 30..... | 6 | 0.0109 | 53.0 | 102,200 | 2.5 | 94.5 | 63.1 |
| No. 30..... | 8 | 0.0115 | 58.8 | 101,900 | 1.0 | 96.1 | 69.7 |
| No. 30..... | 10 | 0.0114 | 66.7 | 111,000 | 1.5 | 98.3 | 74.4 |
| No. 32..... | 0 | 0.0086 | 0 | 58,200 | 52.0 | .... | .... |
| No. 32..... | 2 | 0.0077 | 28.6 | 89,000 | 8.0 | .... | .... |
| No. 32..... | 4 | 0.0087 | 28.6 | 91,400 | 9.0 | .... | .... |
| No. 32..... | 6 | 0.0090 | 47.6 | 97,200 | 3.0 | .... | .... |
| No. 32..... | 8 | 0.0088 | 61.3 | 108,200 | 1.5 | .... | .... |
| No. 32..... | 10 | 0.0088 | 67.0 | 115,300 | 1.5 | .... | .... |
| No. 34..... | 0 | 0.0063 | 0 | 63,900 | 50.0 | .... | .... |
| No. 34..... | 2 | 0.0063 | 24.0 | 81,900 | 17.5 | .... | .... |
| No. 34..... | 4 | 0.0061 | 41.9 | 99,100 | 7.0 | .... | .... |
| No. 34..... | 6 | 0.0063 | 44.5 | 111,300 | 2.5 | .... | .... |
| No. 34..... | 8 | 0.0064 | 63.4 | 110,200 | 1.5 | .... | .... |
| No. 34..... | 10 | 0.0066 | 70.0 | 118,800 | 1.0 | .... | .... |
| No. 36..... | 0 | 0.0054 | 0 | 61,300 | 51.0 | .... | .... |
| No. 36..... | 2 | 0.0054 | 16.1 | 77,900 | 25.0 | .... | .... |
| No. 36..... | 4 | 0.0049 | 35.4 | 97,900 | 4.5 | .... | .... |
| No. 36..... | 6 | 0.0053 | 52.4 | 103,000 | 4.0 | .... | .... |
| No. 36..... | 8 | 0.0054 | 58.0 | 114,800 | 1.5 | .... | .... |
| No. 36..... | 10 | 0.0059 | 68.3 | 110,500 | 1.5 | .... | .... |

*Note.*—Tensile strength and percentage elongation are an average of 3 specimens in each case; Rockwell hardness values are an average of 15 determinations of 5 readings on each of the 3 tension test specimens.

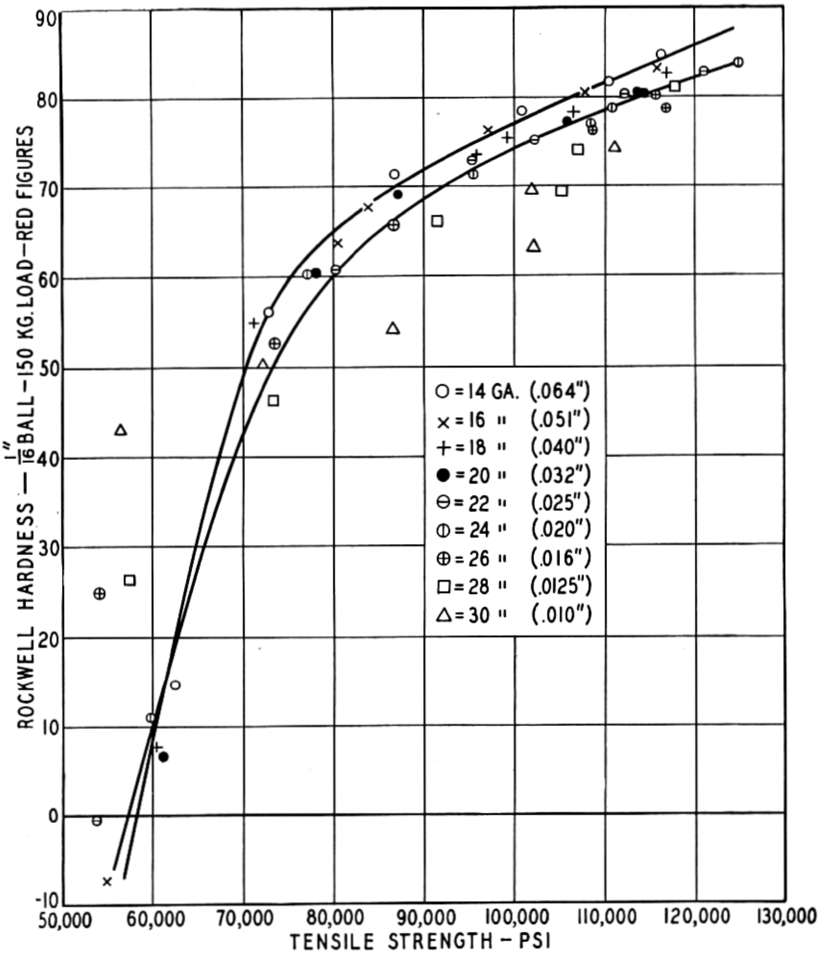

Fig. 17—Relation of Rockwell Hardness to Tensile Strength of Alloy C Phosphor-Bronze Rolling Series.

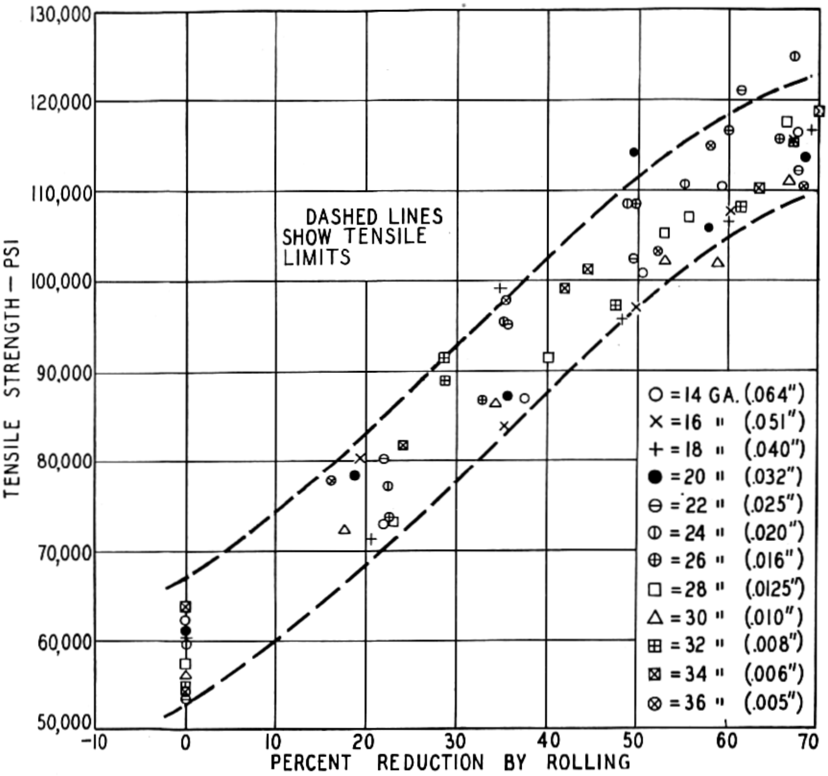

Fig. 18—Relation of Tensile Strength to Percentage of Reduction of Alloy C Phosphor-Bronze Rolling Series.

## Experience Data

During and subsequent to the laboratory work covered in this paper, a series of data was obtained on regular commercial shipments of non-ferrous sheet material. About 700 lots of brass, nickel-silver and phosphor-bronze sheet in various tempers and grades were tested on the Rockwell and scleroscope by both the producer and consumer. The lots ranged in size from 100 to about 50,000 lbs. of sheet metal and included material from at least five different mills. The sheet ranged in thickness from 0.010 to 0.500 in. A representative sample about 6 in. long and from 1 to 6 in. wide was taken from each lot. Tests were made on identical samples, five readings being made with each instrument and the average taken. All tests were made by the inspectors who were normally responsible for the control of the material, even though they were not in all cases familiar with the operation of the Rockwell machine. The Rockwell machines were, of course, put in good mechanical condition and the methods of test outlined in Appendix I were followed. The results obtained constituted an independent verification of the conclusion that the Rockwell machine was more sensitive but much less subject to variation and personal error than the scleroscope.

Figure 19 is representative of the results obtained, showing a direct comparison of the Rockwell and the scleroscope readings on two tempers of high brass. It illustrates the consistency of the readings of the two Rockwell instruments as compared with the two scleroscopes. Figure 20 represents similar results obtained on nickel

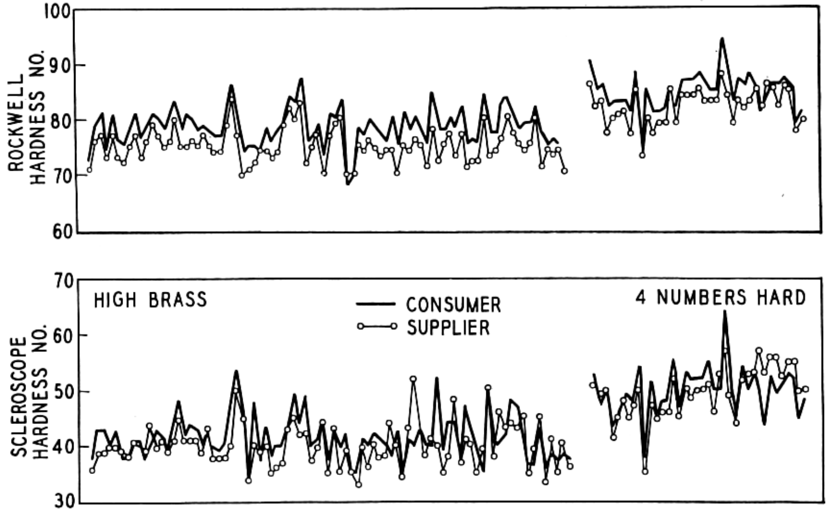

Fig. 19—Typical Comparisons of Rockwell and Scleroscope Machines in Commercial Tests on Brass.

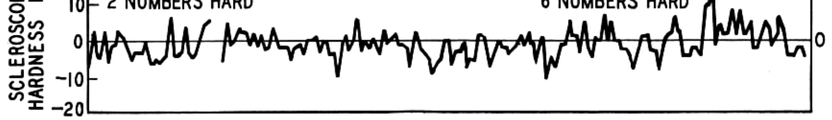

Fig. 20—Typical Results Showing Differences in Rockwell and Scleroscope Machines in Commercial Tests on Nickel Silver.

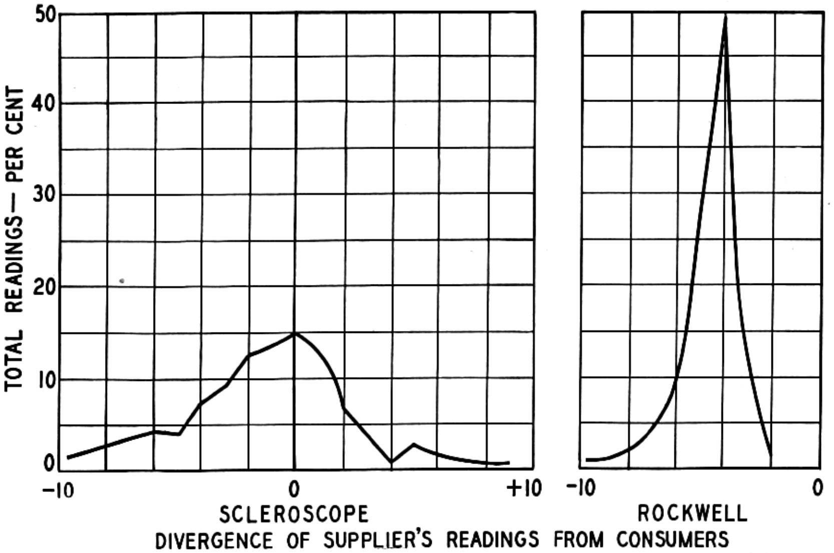

Fig. 21—Typical Results Showing Frequency of Occurrence of Degrees of Difference Between Two Machines.

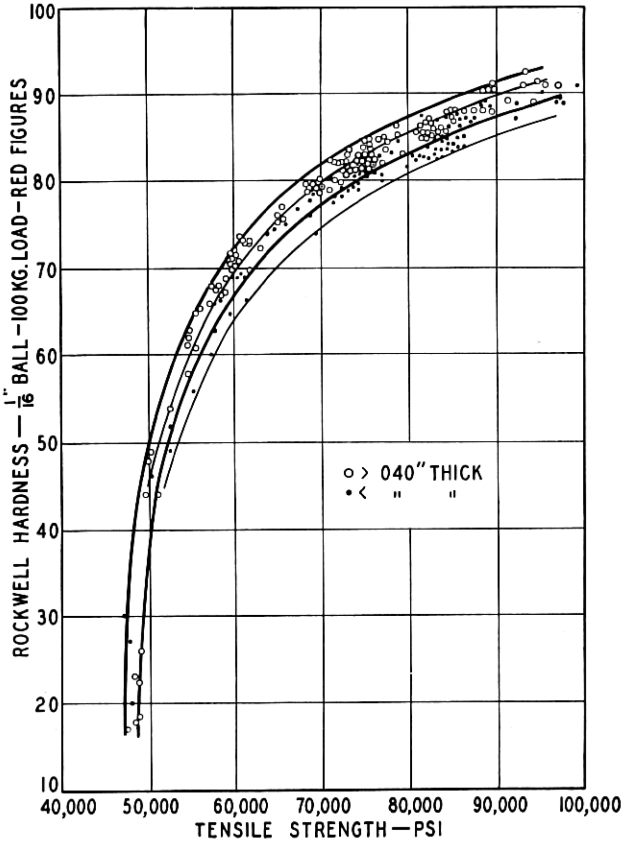

Fig. 22—Accumulated Data on High and Clock-Brass Sheet.

silver plotted to show directly the differences between readings on the two machines of each type, one being assumed as a standard. Figure 21 shows the frequency of occurrence of the various degrees of difference between the two instruments, giving results for both the Rockwell and the scleroscope. One of the instruments was taken as a standard and the variations of the other instrument from it are plotted to left or right as they are negative or positive. The frequency of occurrence of differences of the magnitudes represented by the abscissas are plotted as ordinates in per cent of the total readings made on the group of samples for which the curve is drawn. In this typical case it is seen that about 50 per cent of the Rockwell readings from one machine are 4 points below those from the other machine. Application of a conversion factor would, therefore, move the curve to the right 4 points and very close checks between the two machines would result. The scleroscope curve shows that readings

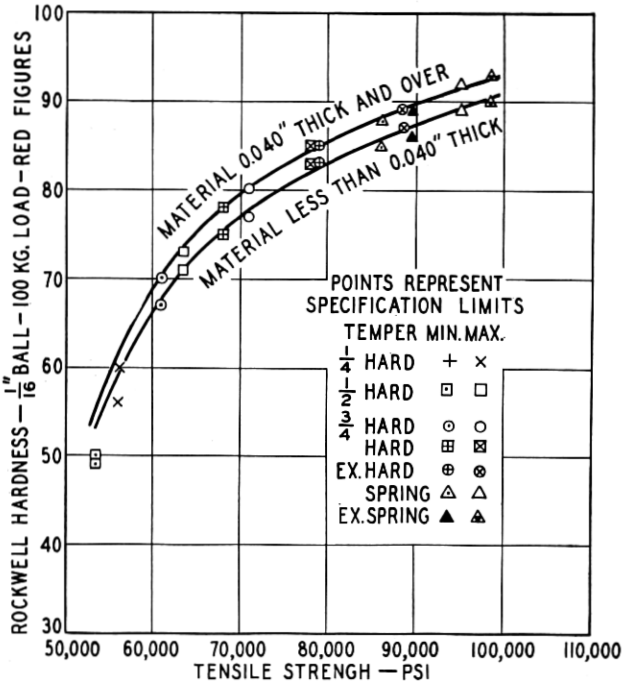

Fig. 23—Comparison of Curves of Results from Experience Data with Limits Adopted, for High-Brass Sheet.

of the two instruments agree on only about 15 per cent of the total, and that in this case the differences are both positive and negative, thus not permitting the application of a conversion factor.

Experience data were also collected for Rockwell hardness and tensile strength of the metals, the values being averages of tests on individual shipments.

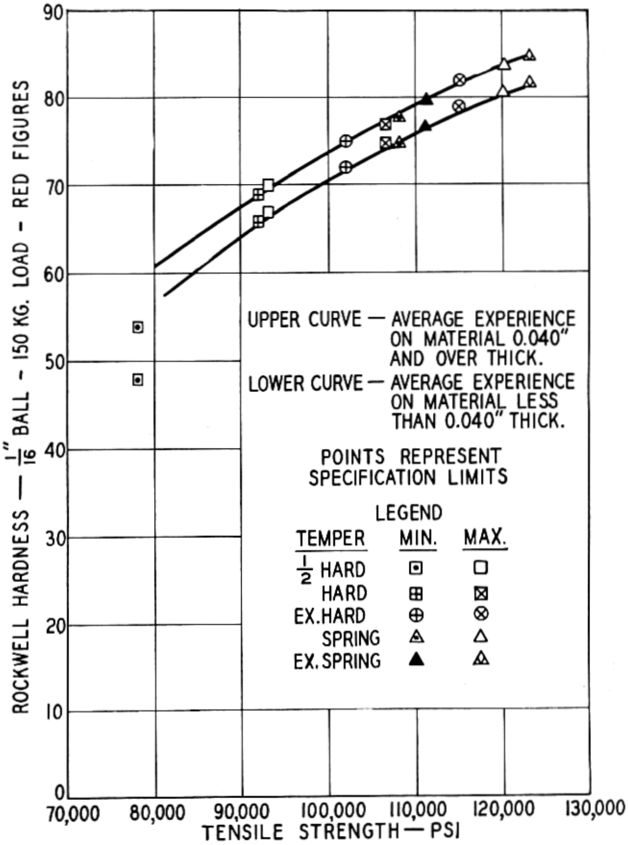

Fig. 24—Comparison of Curves of Results from Experience Data with Limits Adopted, for Alloy B Nickel-Silver Sheet.

Figure 22 shows graphically the data obtained on high and clock-brass sheet, and Fig. 23 the experience data which have been averaged and shown as a smooth curve for comparison with the specification limits shown as points for high-brass sheet. The agreement is close. Figures 24, 25, and 26 show similar smooth curves of experience data for nickel silver and phosphor bronze. In these latter cases the experience data are not sufficiently complete to verify the specification limits in all tempers, but in general the accuracy of the specification limits is verified.

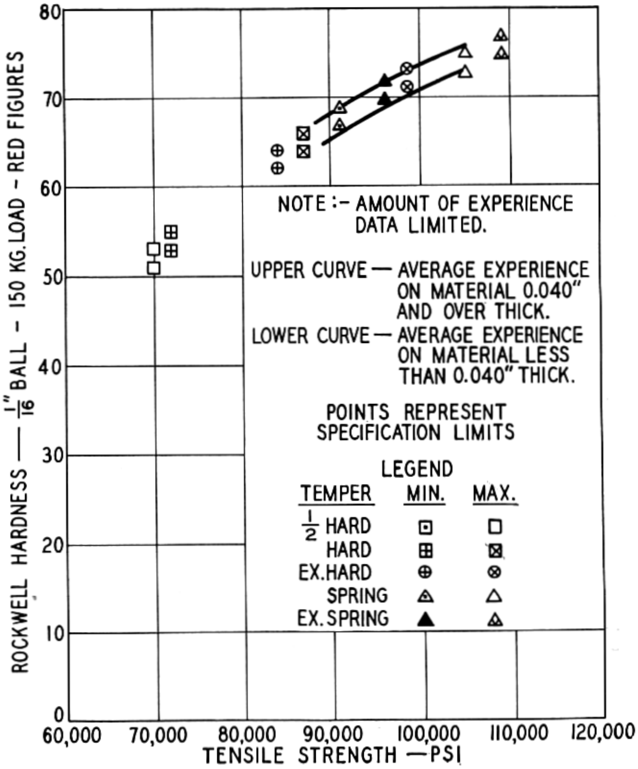

Fig. 25—Comparison of Curves of Results from Experience Data with Limits Adopted, for Alloy A Phosphor-Bronze Sheet.

In addition to the data, the experience of mills supplying material indicates that the limits proposed are satisfactory. Instances where the limits were not met served only to emphasize the advantages of control of the physical properties. Variations from the nominal annealing temperature, composition or percentage reduction in all cases explained the variations from the specification limits.

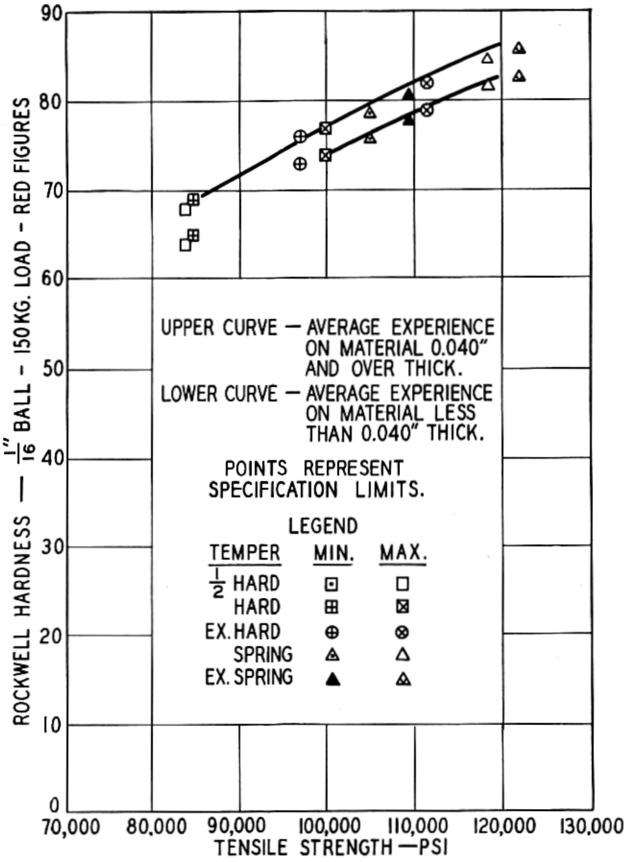

Fig. 26—Comparison of Curves of Results from Experience Data with Limits Adopted, for Alloy C Phosphor-Bronze Sheet.

## CONCLUSION

The purposes stated in this paper have been accomplished, namely, the development of a commercial method of test for sheet non-ferrous metals and limits for use in commercial specifications.

The conclusion reached that the tension test is the best available static test for non-ferrous sheet metal in the hard tempers has been confirmed.

Because of its close correlation to the tension test, the Rockwell hardness test has been adopted for preliminary inspection purposes. Other hardness tests have been studied but this test is the most satisfactory for sheet metals 0.020 in. thick and thicker. It has limited use for material less than 0.020 in. thick. Material near to or outside of the Rockwell hardness limits is subjected to the tension test. Rejection of material is based solely on the tension test.

Refinements in the application of the Rockwell hardness test as an inspection instrument have been worked out and it is shown that close agreement can be obtained between producer and consumer on commercial shipments of material.

The necessity for the adoption of a series of Rockwell standard blocks covering the range of hardness of certain non-ferrous sheet and the calibration of testing machines to these standards is emphasized.

Grain-size limits are given for annealed brass of four compositions and for one nickel-silver alloy. This is the most satisfactory method of controlling the annealed material.

Tentative tensile strength and Rockwell hardness limits for brass alloy G, nickel-silver and phosphor-bronze alloys have been developed. These limits are considered preliminary until more complete information on actual shipments of material is available. The limits for high and clock brass are considered entirely satisfactory.

A modified bend test has been presented as having considerable value in determining the forming and drawing qualities of sheet metals.

## APPENDIX I

## STANDARD TEST PROCEDURE FOR ROCKWELL HARDNESS TESTS

### Standard Test Blocks

1. Standard test blocks are in the possession of the Bell Laboratories and sub-standard blocks are calibrated from these blocks. These sub-standard blocks are used to calibrate the Rockwell machines. All specifications are written in terms of these standard blocks. Before a Rockwell machine is used for tests on metal supplied to specifications it should be calibrated by the sub-standard block.

### Adjustments

2. (*a*) *Dash Pot.*—The dash pot on the Rockwell tester shall be so adjusted that the operating handle completes its travel in from five to ten seconds with no specimen on the machine and with the machine set up to apply a major load of 100 kg.

(*b*) *Index Lever Adjustment.*—As specified in the Rockwell tester instruction book, the following tests (and adjustments, if necessary) should be made.

"Put a piece of material on the anvil and turn the capstan elevating nut to bring the material up against the ball penetrator. Keep turning to elevate the material until the hand feels positive resistance to further turning, which will be felt after the 10-kg. minor load has been picked up and when the major load is encountered. When excessive power would have to be used to raise the work higher, take note of the position of the pointer on the dial. After setting the dial so that C-0 and B-30 are at the top then:

(*1*) If pointer stands between B-50 and B-70 no adjustment is needed.
(*2*) If pointer stands between B-45 and B-50 adjustment is advisable.
(*3*) If it stands anywhere else, adjustment is imperative.

"As the pointer revolves several times when the work is being elevated it is pointed out here that the readings mentioned apply to that revolution of the pointer which occurs as the reference mark on the gage stem disappears into the sleeve. The object of the adjustment is to see that the elevation of the specimen to pick up the minor load shall not be carried so far as to cause even a partial application of the major load, which to make a proper test, must be applied only through the release mechanism."

"*To Make the Index Lever Adjustment, if Necessary.*—When the test piece is elevated until it starts to pick up the major load, loosen the lock nut of the screw through the index lever which carries at its lower end a small steel plate engaging the ball on the penetrator shaft while using a small screw-driver to firmly hold the screw until after the nut is loose. Then turn the screw very slightly and note result on position of gage pointer which should be at B-60 to B-70 before reclamping the screw with its lock nut."

(*c*) *Protection Against Vibration.*—If the bench or table on which the Rockwell tester is mounted is subject to vibration, such as felt in the vicinity of other machines, the tester should be mounted on a metal plate on sponge rubber at least 1 in. thick or on any type of mounting that will effectually eliminate vibration from the machine. Otherwise the pointer will penetrate farther into the material than when such vibrations are absent.

*Cushioning of Latch.*—If, when the operating handle is being returned to its normal position, the latch operates with such a snap as to noticeably change the position of the dial pointer, felt or rubber washers should be placed under the trip button in order to cushion this blow. If this snap is severe, difference in reading of several hardness numbers may result.

### Testing Methods

3. The anvil used shall have a polished bearing surface for the material of about $\frac{3}{16}$ in. in diameter. It shall be hard enough so that no visible indentation is made when the thinnest material is tested.

Before using the machine it shall be operated several times on a piece of scrap material in order to firmly settle the penetrator, anvil and moving parts of the machine. This should be done every day before the machine is used.

Make a reading on at least one of the standard test blocks. This need not be done every day if it has been found that the machine does not change.

The Rockwell ball should be replaced by a new one occasionally and the operator should be on the lookout for any permanent deformation of the ball which will ordinarily be indicated by high readings on the standard test blocks.

When applying the minor load, the capstan screw should be turned up so that the pointer stops at "O" with a maximum variation of ± five divisions. The last movement of this screw must always be in such a direction as to elevate the specimen.

In applying the major load the operating handle shall be allowed to revolve without interference until the major load is completely applied. This may be observed in two ways, (1) when the pointer suddenly slows down, or (2) watching the weight arm to see that it is completely free from the control of the dash pot. When the major load has thus been completely applied, the operating handle shall be immediately brought back to the latched position without waiting for it to complete its revolution. This should be accomplished in less than two seconds after the major load is completely applied.

The test specimen shall be well supported to prevent errors due to the overhang of the specimen.

All tests shall be made upon one thickness of the material.

## APPENDIX II

## STANDARD TEST PROCEDURE FOR TENSION TESTING OF THIN SHEET METALS

### General

1. (*a*) These specifications cover general methods for testing the tensile strength of thin sheet, strip and flat wire materials for use in the manufacture of telephone apparatus. They shall form part of individual specifications covering sheet metals for specific purposes whenever so provided in the individual specifications.

Note.—By thin sheet material is meant material 0.05 in. or less, in thickness. This thickness lies in the range where it becomes necessary to abandon the use of the ordinary micrometer and to use the barrel type micrometer or a still more sensitive device in order to keep the probable error of measurement as low as possible.

(*b*) In case of any difference in the provisions of this and the individual specification, the provisions of the individual specification shall govern.

## Specimens for Tension Tests

2. *Selection of Specimen.*—The test specimens shall be chosen in such numbers and from such locations in each lot of material as to be representative of the quality of this material. The method of selecting specimens will be specified in the individual specifications when found necessary.

3. *Dimensions of Specimens for Tension Test.*—

(*a*) *Materials ½ in. or Less in Width.*—For strip or flat materials less than ½ in. wide, the specimen shall consist of the appropriate length cut from the material as furnished. For gage lengths of 2 and 8 in., the length of the test specimen shall be not less than 8 and 14 in., respectively.

(*b*) *Materials More Than ½ in. in Width.*—For materials over ½ in. wide, two alternative specimens are allowed.

(*1*) *Standard Specimen:*

The specimen which shall be regarded as standard shall have dimensions and be machined as shown in Fig. 27.

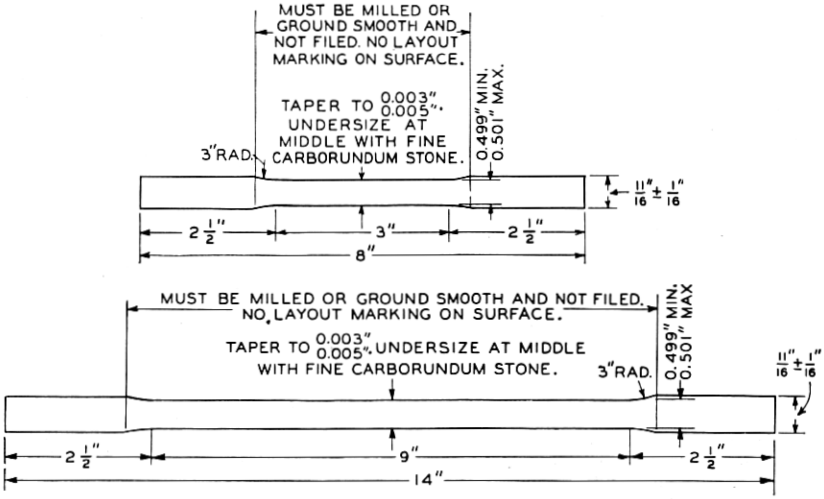

Fig. 27—Tension Test Specimens for Sheet Material Over ½ in. in Width.

(*a*) Specimen for Use in Determining Tensile Strength and Elongation in 2 in.

(*b*) Specimen for Use in Determining Proportional Limit and Modulus of Elasticity.

(*2*) *Alternative Specimen:*

This specimen shall be in the form of a strip up to 1½ in. in width, having parallel sides and having about 0.001 to 0.002 in. of the material removed from the edges of the specimen near the center by grinding with a fine-grained stone. This specimen shall have the lengths given above for materials less than ½ in. wide. It may only be used so long as good breaks (which occur at the point of reduced section and without tearing) are obtained and where the strength of the material does not approximate the acceptance limits. The milled specimens (see Standard Specimen above) are to be regarded as standard and are to be used where good breaks are not obtained with these wider specimens and as referee test specimens where the strength of the material approximates the acceptance limits.

4. *Cleaning of Specimens.*—Before being measured, each test specimen shall be thoroughly cleaned with carbon tetrachloride applied by rubbing with a soft cloth. When being measured, each specimen shall be wiped clear of dust immediately before being inserted in the measuring instrument.

5. *Measurement of Specimens.*—The dimensions of the specimen shall be measured between flat parallel surfaces of hardened steel, or other appropriate material, approximately $\frac{3}{16}$ in. in diameter which shall be applied in such a manner as to exert on the specimen, while the measurement is being taken, a normal pressure of approximately 16 oz.

6. *Calibration of Measuring Instrument.*—The measuring instrument shall be suitably adjusted and calibrated to indicate the distance between the measuring surfaces of the mandrels when exerting a normal pressure of approximately 16 oz. or 35 lb. per sq. in. of mandrel end area with an error not greater than ± 0.00005 in., *i.e.*, to the nearest 0.0001 in.

NOTES

1. When measuring very thin materials, the micrometer or measuring instrument should be adjusted and calibrated with the greatest practicable accuracy.

2. The measuring instrument should be calibrated preferably by means of a hardened steel gage block having flat parallel surfaces and of a thickness approximately equal to that of the material to be measured.

3. In order to obtain an accurate check, it is essential that the mandrel surfaces and faces of the gage be freed from dust immediately before being brought together.

4. If a barrel type micrometer indicating 0.0001 in. per scale division is used, care should be taken to have the instrument in good operating condition. The instrument can then be adjusted to give the first click of the ratchet at a mandrel pressure of 16 oz. ± 4 oz. by suitable adjustment of the ratchet spring, measuring the mandrel pressure by means of a small spring balance, having flat parallel contact surfaces, inserted between the mandrels. The micrometer screw and nut shall be so adjusted that no end play or shake of the spindle may be felt when the spindle is gently pushed back and forth in the direction of the axis of the screw.

5. In calibrating the micrometer against a standard gage block, or in measuring a specimen, the spindle shall be rotated slowly into contact with the work by means of the ratchet until the ratchet clicks once, be retracted about 0.002 in. and again slowly rotated into contact until the ratchet clicks once before reading is taken. In order to avoid exceeding the normal pressure of the mandrels in operating the micrometer, the mandrel shall be brought against the work at a rate not exceeding 0.001 in. per second at both first and second contacts given above. This rate is approximately the maximum rate at which the operator is able to count the half thousandths marks on the barrel as they pass the zero line on the frame.

7. *Method of Computing Cross-Section.*—

(*a*) *Material $\frac{1}{2}$ in. or Less in Width.*—For strip material of flat wire $\frac{1}{2}$ in. or less in width, the width and thickness shall be measured along the major axis of the specimen at the middle point and at distances of approximately 2 and 4 in., respectively, at each side of the middle point. The cross-section of strip and flat wire material shall be assumed to be a rectangle. The area of cross-section to be used in computing the tensile strength of the material shall be the product of the average of the five thickness readings and the average of the five width readings.

(*b*) *Cross-Section of Standard Test Specimen for Material Over $\frac{1}{2}$ in. in Width.*—For the standard test specimen described in Section 3 (*b*), the width shall be measured at the point of minimum width as determined by trial measurements. The thickness shall be measured in a plane normal to the major axis of the specimen at the point of minimum width, at the middle and at each edge of the specimen. When measuring the thickness at the edge of the specimen, the outer edges of the contact surfaces of the measuring instrument shall be approximately $\frac{1}{32}$ in. inside of the edge of the material. The area of cross-section shall be taken as the product of the minimum width and the average of the three thickness readings above specified.

NOTE.—In some cases, it may be found that the thickness of the material near the fillets is so much less than the thickness in the plane of minimum width that the minimum area of cross-section occurs near the fillet. In measuring specimens, the operator should be on the lookout for this condition and, in case it is found, the width of the specimen at the point of minimum width should be further reduced by grinding with a stone until the minimum cross-section is brought to the middle of the specimen.

(*c*) *Cross-Section of Test Specimen Over ½ in. in Width.*—For specimens over ½ in. wide as described in Section 3 (*b*), the measurements shall be made as on the standard specimen, as described in Paragraph (*b*) above.

## METHOD OF TESTING

8. *Testing Machine.*—

(*a*) *Design.*—Testing machines shall be of a design in which the applied load is balanced by increasing the lever arm of a movable weight or by some other means employing weights without the use of springs.

(*b*) *Method of Mounting.*—The testing machine shall be installed on a solid foundation of such a nature that the machine is maintained in a level position.

(*c*) *Range.*—It is desirable that the testing machine should be capable of applying and measuring a load about 50 per cent greater than the normal anticipated breaking strength of the test specimen.

(*d*) *Sensitivity.*—All bearings and knife edges of the testing machine shall be so proportioned and adjusted that the position of the beam, when balanced at the normal breaking load of the specimen, shall be perceptibly changed by a change of load of 0.1 per cent.

(*e*) *Accuracy.*—The machine shall be calibrated with dead weights so that a load equal to the breaking load of the material tested shall be indicated with an error of less than ± 0.1 per cent.

(*f*) *Method of Applying Load.*—The mechanism for applying load to the test specimen shall be such as to advance the pulling head of the machine at a uniform rate, such as may be obtained by a motor drive operating from a well regulated source of power. The machine shall be capable of being operated at different uniform rates of speed, including the rate of approximately 0.05 in. per minute of the moving head. Unless otherwise specified in individual specifications, the maximum speed of the moving head in making a test shall be 0.025 in. per inch free length of specimen per minute.

(*g*) *Jaws.*—The jaws or grips of the testing machine shall be designed so as to produce and maintain axial alignment of the specimen without producing tearing stresses. The edges of the jaws shall be rounded so as not to noticeably deform the specimen near the borders of the region where the specimen comes in contact with the jaws.