Several methods for improving the accuracy of Rockwell hardness testing

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Abstract. In order to reduce the testing errors in Rockwell hardness of metal specimens and improve the accuracy of hardness testing, several methods had been tried out and examined based on GB/T 230 and other relevant inspection specifications, firstly, correct the hardness of testing pieces directly by using the hardness reference blocks to calibrate the hardness tester; secondly, correct the hardness of testing pieces by linear calculation of the errors in different hardness values to calibrate the hardness tester; for a great deal of testing pieces, check the hardness twice and the second time in a reverse order. The result shows that the applied methods are effective to further improve the accuracy of Rockwell hardness testing.

1. Introduction

The Rockwell hardness test is one of the most common testing methods in materials and heat treatment. There are many factors that affect the accuracy of hardness test, such as the error of the hardness tester, the conditions of the surface and support surface, the operation method of the testing, et al [1][2].

In order to ensure the testing accuracy, GB/T230 and some related technical manuals and textbooks have detailed instructions for Rockwell hardness test in the testing instruments, the testing parts, and the testing methods of Rockwell hardness tests. However, due to different purposes and objects of the hardness testing, the accuracy requirements of the testing are different. As for the military products of some critical parts and specimen, the testing error sometimes may too big if only according to the
requirement of some standard(s), hence, it is necessary to find out another method to reduce testing errors.

2. The basis for reducing and eliminating testing errors of Rockwell hardness testing is to follow the requirements in some standard(s) strictly

In order to reduce and eliminate testing errors of Rockwell hardness testing, it is quite necessary to detect the hardness of specimens by strictly following GB/T 230 and relevant inspection specifications. Besides, the hardness tester should be in good condition and checked regularly, and its testing errors should be within the allowable range; Recheck if an abnormality occurs. The inspection surface of the specimen should be flat without oxide or other dirt. The surface roughness is generally not greater than Ra1.6μm. As for the test tested by diamond taper presser, the thickness of specimens or testing layer should not be less than 10 times of the residual indentation depth. The hardness testing layer should be checked by the standard Rockwell hardness block which is similar to the hardness value of the specimen before testing the hardness. Surfaces of the test bench and the pressure plug, the inspection surface and support surface of specimens should be cleaned, the specimens on the bench should be placed firmly to ensure no displacement or deformation during testing process. The distance between the two adjacent indentation centers is at least 4 times of the indentation diameter, and not less than 2mm; the distance between any indentation center and the edges of specimen is at least 2.5 times of the indentation diameter, and should not be less than 1mm. The Rockwell hardness test[6] is not used for materials with large structure, such as gray cast iron and coarse grained materials. When the hardness test is carried out on a cylinder or spherical surface, the measured value needs to be modified [7].

The hardness test is performed strictly according to methods and requirements specified in some standard(s), which is quite necessary for reducing and eliminating the testing errors.

3. Necessity for further reducing testing errors

In the heat treatment workshop, strictly according to the requirements of standard(s) mentioned above and the relevant inspection specifications, the measured error for specimens is not large, meeting demands of production and inspection. But if more accurate readings are needed for some military specimens, the accuracy of data sometimes is not satisfactory only according to the standard.

For example, the hardness value of the same specimen tested in two different testing places is different, nearly (1~2) HRC difference. The hardness testers in two places are verified and qualified, and both of them are within the validity period. Before the hardness testing, the standard Rockwell hardness block was used to check the hardness tester. The testing errors for both hardness testers are within the standard allowance range, both are qualified hardness testers, but the value of one site on the low side, the other on the high side, hence, the same specimen in different sites have obvious different testing results. Moreover, different harness testers in the same place sometimes have somewhat differences. Table 1 shows the hardness values tested by two Rockwell hardness testers in the same site for the same specimen in high strength steel vacuum annealing test.
Table 1. Measured values inspected by two Rockwell hardness testers for the same specimen.

| Ser. No. of Hardness tester | Measured hardness value (HRC) | Mean value (HRC) | Hardness difference |
|-----------------------------|-------------------------------|------------------|--------------------|
| 1                           | 28.7 30 27.9 29.3 29.9 28.3  | 29.0             | 1.6                |
| 2                           | 31 29.8 31                      | 30.6             |                    |

In order to reduce testing errors, following measures should be taken for those specimens needed higher accuracy.

4. Directly correct the measured value of the hardness tester according to the standard hardness block

Before inspecting the hardness of the specimen, use the standard Rockwell hardness block to calibrate the hardness tester, and record the error. After inspecting the hardness of specimen, calibrate the hardness tester with standard Rockwell hardness block and record its error again. Take the average error before and after the inspection as the corrected value, and the hardness value will be got through correction calculation on the measured value of the specimen.

4.1. Calculation formula

\[ y = x + (B - x_1) \]

Among them:
- \( y \) —— The actual hardness value of the testing workpiece through correction
- \( B \) —— The hardness value of the standard hardness block
- \( x \) —— Hardness reading of the workpiece on the measured spot (mean value)
- \( x_1 \) —— Calibration hardness reading of standard hardness block (mean value)

This method is suitable for the hardness value of the specimen which is the same or similar hardness value with the standard block.

4.2. Application example

The mean value of hardness reading of carburizing location after quenching was 61.2 HRC, and the average hardness of 63.8 HRC standard hardness block was 63.3 HRC. The average hardness value of non-carburizing location was 45.5 HRC, and the average hardness of 46.3 HRC standard hardness block was 45.6 HRC.

The hardness (mean value) of the carburizing location is \( y_c \):

\[ Y_c = x_c + (B - x_1) = 61.2 + (63.8 - 63.3) = 61.7 \text{ HRC} \]

The hardness (mean value) of the non-carburizing location is \( y_n \):

\[ y_n = x_n + (B - x_1) = 44.5 + (46.3 - 45.6) = 45.2 \text{ HRC} \]

5. According to the error of the hardness tester, use the method of linear calculation to correct the measured value

The hardness of specimen is often quite different from that of the standard Rockwell hardness block, and it is not suitable to correct the measured value directly according to the hardness tester of standard hardness block. In this case, the hardness tester is checked by several standard blocks with different hardness, and the error of the hardness test is measured. Then take the higher and the lower testing
error values of standard hardness block compared with the hardness of the specimen, and then according to the following linear calculation formula to correct the measured value of the specimen.

5.1. Calculation formula

\[ y = \frac{B_2-B_1}{x_2-x_1}x + B_2 - \frac{B_2-B_1}{1-x_1/x_2} \]

Among them:
- \( y \)—— The actual hardness value of workpiece through correction.
- \( B_1 \)—— Label hardness value of standard hardness block 1.
- \( B_2 \)—— Label hardness value of standard hardness block 2.
- \( x \)—— Hardness reading of the work piece on the measured spot (mean value).
- \( x_1 \)—— Calibration hardness reading of standard hardness block 1 (mean value).
- \( x_2 \)—— Calibration hardness reading of standard hardness block 2 (mean value).

Because the hardness values of different locations on the same work piece are often different, sometimes quite different, “\( x \)” in the formula refers to the direct reading or the mean value obtained from the average readings on a tested portion, rather than the mean value from the average readings on different locations on the work piece.

The above formula can be used to correct the average reading of several hardness measurement spots in a location; “\( x \)” takes the mean value of readings of several testing locations respectively. It is also possible to correct the measured values of each measuring spot respectively. At this time, “\( x \)” takes the readings of each testing location respectively.

5.2. Formula derivation process

The derivation process of the formula above is as follows:

The mean value of the direct hardness reading of specimen on a certain spot is regarded as “\( x \)”, the hardness value for the standard hardness block 1 is \( B_1 \); the mean value of the calibration hardness reading of standard hardness block 1 is \( x_1 \); the hardness value for the standard hardness block 2 is \( B_2 \); the mean value of the calibration hardness reading of standard hardness block 2 is \( x_2 \); the actual hardness value of specimens is \( y \).

The testing error of the hardness tester reading \( x_1 \) and \( x_2 \) interval is regarded as a linear relationship.

\[ Y = kx + b \]

Where the coefficient \( k \) is the slope and the coefficient \( b \) is the intercept.

Because:
- When \( y = B_1 \), \( x = x_1 \).
- When \( y = B_2 \), \( x = x_2 \).

So:

\[ B_1 = kx_1 + b \] ①
\[ B_2 = kx_2 + b \] ②

We can solve this system:

\[ K = \frac{B_2 - B_1}{x_2 - x_1}, \quad b = B_2 - \frac{B_2 - B_1}{1 - x_1/x_2} \]
5.3. Application examples

Before the heat treatment experiment of a kind of T250 steel parts, the hardness of the specimen in the material supply state (solid solution state) should be tested. The mean value “x” of four specimens, No. 1~4, is 35.7 HRC, 34.9 HRC, 35.5 HRC, 35.4 HRC respectively. Because there were no standard hardness blocks whose hardness were close to the hardness of the four specimens on the production site, only blocks with a greater difference compared with the specimens. The mean value of the standard hardness block 26.2 HRC calibrated by the hardness tester is 27.2 HRC, the mean value of the standard hardness block 45.1 HRC calibrated by the hardness tester is 45.2 HRC.

The above calculation formula is applied to calculate the data as follows:

\[ B_2-B_1=45.1-27.2=17.9 \]
\[ x_2-x_1=45.2-27.2=18 \]
\[ 1- \frac{x_1}{x_2}=1-27.2/45.2=0.398 \]
\[ \left( \frac{B_2-B_1}{x_2-x_1} \right) =17.9/18=0.944 \]
\[ \left( \frac{B_2-B_1}{1- \frac{x_1}{x_2}} \right) =17.9/0.398=44.975 \]

The hardness value of the specimen No.1 is corrected as:

\[ y_1=0.944x+B_2-44.975=0.944\times35.7+45.1-44.975=33.8 \text{ (HRC)} \]

The hardness value of the specimen No. 2 is corrected as:

\[ y_2=0.944x+B_2-44.975=0.944\times34.9+45.1-44.975=33.1 \text{ (HRC)} \]

The hardness value of the specimen No. 3 is corrected as:

\[ y_3=0.944x+B_2-44.975=0.944\times35.5+45.1-44.975=33.6 \text{ (HRC)} \]

The hardness value of the specimen No. 4 is corrected as:

\[ y_4=0.944x+B_2-44.975=0.944\times35.4+45.1-44.975=33.5 \text{ (HRC)} \]

6. Repeated inspection method in positive and negative orders

6.1. Method

The actual measured hardness value in our factory sometimes have distinctive difference between two times of inspection for a large quantity of specimens, the value checked in the second time is a bit higher than that in the first time, the hardness tends to be gradually ascending. If check the harness once more on the same specimen, the harness is found higher than before. In principle, the increase phenomenon for the value is not allowed. But in actual production conditions, the situation is not always ideal. Therefore, repeated inspection method in positive and negative orders is developed.

Firstly, check the hardness of the specimens in positive order, then in negative order, take the hardness according to the data from two times.

6.2. Application examples

After quenching respectively on 13 heat treatment specimens (No. 0 ~ No. 12) with local carburizing by different processes, first check the hardness from No.0 to No.12, then from No.12 to No.0, see the measured value in table 2. The standard block is also calibrated by the same repeated method.
Table 2 shows the mean value on the non-carburizing locations in negative order is higher than that in positive order, the standard hardness block also has similar situation. This indicates that the measured value gradually increases during inspections due to the hardness tester.

In order to reduce testing errors, take the mean value using the repeated inspection method in positive and negative orders when the measure value gradually increases because of the hardness tester. In this case, according to the measured value data of the standard block from two times, take the measured value in negative order but not in positive order for locations of specimens with non-carburizing.

Because of the repeated inspection method in positive and negative orders and the data correction calculation method mentioned above, the hardness accuracy in the heat treatment process is improved. Secondly, optimize the heat treatment process through contrast and evaluation on the test results of different heat treatment processes. Thus, it prevents mistaken judges on the test effect and mistaken selection on the technologies due to errors of the data.

**Table 2.** Hardness data of local-carburizing specimens after quenching by repeated inspection method in positive and negative orders.

| Ser. No. of specimens hardness of std block | Locations | Check in positive order1 | Check in positive order2 | Mean value in positive order | Check in negative order1 | Check in negative order2 | Mean value in negative order | Total mean value |
|-------------------------------------------|-----------|--------------------------|--------------------------|-----------------------------|--------------------------|--------------------------|---------------------------|-----------------|
| 46.3 HRC std block                        |           | 44.1                     | 45.5                     | 44.8                        | 46.8                     | 46.0                     | 46.40                     | 45.6            |
| 63.8 HRC std block                        |           | 44.1                     | 45.5                     | 44.8                        | 46.8                     | 46.0                     | 46.40                     | 45.6            |
| 0                                         | 0         | 43.5                     | 44.0                     | 43.8                        | 45.8                     | 44.6                     | 45.20                     | 44.5            |
|                                            | 1         | 42.3                     | 42.8                     | 42.6                        | 43.4                     | 43.8                     | 43.60                     | 43.1            |
|                                            | 2         | 42.8                     | 42.6                     | 42.7                        | 44.0                     | 43.7                     | 43.85                     | 43.3            |
|                                            | 3         | 42.1                     | 42.1                     | 42.1                        | 43.0                     | 43.3                     | 43.15                     | 42.6            |
|                                            | 4         | 42.5                     | 42.2                     | 42.4                        | 43.5                     | 43.5                     | 43.50                     | 42.9            |
|                                            | 5         | 44.6                     | 43.9                     | 44.3                        | 45.6                     | 45.6                     | 45.60                     | 44.9            |
|                                            | 6         | 43.6                     | 44.2                     | 43.9                        | 45.3                     | 45.4                     | 45.35                     | 44.6            |
|                                            | 7         | 43.5                     | 43.5                     | 43.5                        | 45.4                     | 44.7                     | 45.05                     | 44.3            |
|                                            | 8         | 44.0                     | 44.7                     | 44.4                        | 45.3                     | 45.4                     | 45.35                     | 44.9            |
|                                            | 9         | 45.0                     | 44.9                     | 45.0                        | 45.6                     | 45.9                     | 45.75                     | 45.4            |
|                                            | 10        | 44.7                     | 44.8                     | 44.8                        | 45.8                     | 45.6                     | 45.70                     | 45.2            |
|                                            | 11        | 45.5                     | 45.0                     | 45.3                        | 45.8                     | 45.8                     | 45.80                     | 45.5            |
|                                            | 12        | 44.7                     | 45.0                     | 44.9                        | 45.7                     | 45.9                     | 45.80                     | 45.3            |
|                                            |           | 61.0                     | 61.3                     | 61.2                        | 61.2                     |                         |                           |                 |
|                                            |           | 60.5                     | 60.5                     | 60.5                        | 60.5                     |                         |                           |                 |
|                                            |           | 56.2                     | 55.5                     | 55.9                        | 55.9                     |                         |                           |                 |
|                                            |           | 48.7                     | 48.5                     | 48.6                        | 48.6                     |                         |                           |                 |
|                                            |           | 45.5                     | 45.9                     | 45.7                        | 45.7                     |                         |                           |                 |
|                                            |           | 63.0                     | 64.0                     | 63.5                        | 63.5                     |                         |                           |                 |
|                                            |           | 61.1                     | 61.4                     | 61.3                        | 61.3                     |                         |                           |                 |
|                                            |           | 56.7                     | 56.0                     | 56.4                        | 56.4                     |                         |                           |                 |
|                                            |           | 52.2                     | 53.5                     | 52.9                        | 52.9                     |                         |                           |                 |
|                                            |           | 63.2                     | 63.6                     | 63.4                        | 63.4                     |                         |                           |                 |
|                                            |           | 62.8                     | 62.8                     | 62.8                        | 62.8                     |                         |                           |                 |
7. Conclusion

The methods mentioned above have been applied in some military enterprises for years, e.g. the heat treatment process and the hardness inspection for some important products; it makes good effect on reducing Rockwell hardness testing errors and guarantees the accuracy and reliability of heat treatment tests and hardness inspection of products. The result of the trial application shows that the inspection method and data correction method mentioned above are effective ways to further improve the accuracy of Rockwell hardness test.

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