Trial of Low-Temperature and High-Temperature Hardness Testing Using the Small-Ball Rebound Test eNM3A10

T YAMAMOTO, M YAMAMOTO, M WATANABE
Yamamoto Scientific Tool Laboratory Co., Ltd.
E-mail: info@ystl.jp
K MIYAHARA
National Institute for Materials Science (NIMS)

Abstract. The small-ball rebound hardness test measures the coefficient of restitution (rebound hardness) of a sample by shooting a 3 mm diameter alumina ball indenter at a speed of 10 m/s and measuring the rebound speed. The obvious advantages of this test are a remarkably small “mass effect” and satisfaction of the similarity rule of hardness. In addition, the test is also considered suitable for measuring high- and low-temperature hardness because the indenter comes into contact with the specimen only for an extremely short time. For this application, samples made of steel were cooled and heated to various temperatures ranging from −196°C to 1000°C. It was found that there was no damage to the tester or the indenter, making it possible to easily perform reproducible low- and high-temperature rebound hardness tests.

1 Introduction
The small-ball rebound hardness test (eNM) measures rebound hardness by striking a sample with a tiny ball. Compared to conventional tests, it is characterized by a reduction of the mass effect (allowing smaller samples to be measured) and establishment of the similarity rule of hardness (rebound hardness is independent of the ball diameter). The authors have always considered the small-ball rebound test, which measures hardness instantly, to be suitable for both high- and low-temperature testing. In this paper, we report the results of a simple demonstration test of the applicability of the small-ball rebound test to high and low temperatures.

2 Test method
The samples were made of SK85 steel in the state in which it was received from the steel manufacturer. This was processed into φ64 × t 15 mm shapes, and then #100 grinding was performed on the test surfaces. Ten target cooling/heating temperatures were established for the test pieces: −196 °C, −80 °C, 0 °C, room temperature (~27 °C), 240 °C, 440 °C, 640 °C, 740 °C, 840 °C, and 1,000 °C.
The tests at room temperature and below were carried out by retaining five samples in the respective temperature environments for at least 20 min, and then taking them out into a room-temperature atmosphere and performing the test immediately (within 5 s). One test was performed per sample (central area of test surface), and the same test pieces were used repeatedly under different temperature conditions.

Meanwhile, for the tests above room temperature, five samples were prepared for each temperature, and these were loaded into a box furnace (introducing nitrogen) maintained at the target temperature and retained inside for 20 min after the furnace temperature had temporarily dropped and then risen back to the target temperature. They were then taken out into a room temperature atmosphere, and the test was performed immediately (within 5 s). Again, one test was performed per sample (central area of test surface).

To measure the coefficient of restitution (rebound hardness), an eNM3A10 prototype tester (eNM2014 −3 mm I) was provided, and, in the usual way, a 3-mm alumina ball indenter was fired at \( V_1 = 10 \text{ m/s} \), the velocity after impact \( V_2 \) was measured, and the coefficient of restitution \( e = V_2/V_1 \) was found. However, to prevent a drop in the temperature of the sample and failure of the tester, the test was performed with the tester fixed 10 mm away from the sample. Figure 1 shows the body of the tester, and Figure 2 shows the appearance (state of light emission) of a test piece heated to 1,000 °C immediately after being taken out of the furnace and immediately after the test.

3 Test results
Apart from the several seconds of testing, the body of the tester did not approach a high-temperature environment, and, even during testing, there was a clearance of approximately 10 mm between the

![Fig. 1. Appearance of testing machine used](image)

![Fig. 2. Photos of specimen before and after testing (heated at 1,000°C)](image)
body of the tester and the sample. Therefore, no abnormalities were identified in the body of the tester or the alumina ball indenter after completion of testing.

Figure 3 shows the measurement results for the coefficient of restitution at each temperature. For reference, Figure 4 shows the coefficients of restitution from Figure 3 converted into Vickers hardness values using a conversion formula for steel hardness at room temperature (change in Young's modulus of the sample due to temperature is not taken into account at all). As mentioned above, the samples were taken out into room temperature each time they were measured, and the temperature of the samples was not measured directly. Also, the length of time that the samples were retained in the target temperature environment varied depending on the order in which the five samples were taken out (retention time difference of about 10 min between the first sample and the fifth sample). For these reasons, the testing cannot be said to be precise, but the approximate temperature dependence of hardness from a low temperature to a high temperature was obtained relatively easily, and the applicability of the test was adequately demonstrated. An advantage of the small-ball rebound test is that, because it measures hardness instantly in a setup where the indenter and the sample or temperature drift, which tend to cause problems in conventional high-temperature hardness testers. Hereafter, we intend to make improvements, such as designing a system that allows measurements to be taken without taking the sample out of the target temperature environment.

![Figure 3](image1.png)  
**Fig. 3. Coefficient of restitution at heated and cooled temperature**

![Figure 4](image2.png)  
**Fig. 4. Approximate (converted) HV value at heated and cooled temperature**
References
Takashi YAMAMOTO, Kensuke MIYAHARA: Introduction of Small Ball Rebound Test (aimed at eliminating mass effect), Journal of Material Testing Research Association of Japan, Vol. 61, No. 3, p.132 (2016).