Introduction of a Herbert Pendulum Hardness Tester Equipped with Raspberry Pi and Research on a Method for Converting Hardness Values Obtained from It

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Abstract. Present paper introduces a Herbert pendulum hardness tester equipped with a wire-less accelerometer and a Raspberry Pi. The configuration of the tester is shown. The tester can evaluate hardness stand-alone without relying on any external system. Touch screen operation makes it easy to evaluate hardness with the tester. Hardness tests with an accelerometer and a laser displacement meter are performed based on the test procedures described in the paper. The devices give different Matsubara hardness values. Matsubara hardness conversion method is shown when the swing angle of the Herbert hardness tester was measured by different methods.

1. Introduction

Indentation or rebound hardness testing is commonly used for measuring hardness of a smooth-surfaced specimen. It is difficult for the testing to measure hardness of surfaces with special shapes such as the cutting edge of a blade. Herbert hardness tester has the shape of an inverted pendulum [1, 2]. It has been suggested that the tester could measure hardness of the cutting edge of milling cutters and drills. The hardness of an object is measured by observing the freely damped oscillation of the tester on a specimen. The motion is influenced on rolling resistance between an indenter of the tester and a specimen surface. The observed oscillation quantities are considered to reflect the hardness of the specimen. It was necessary for original Herbert hardness testing to visually check the position of the bubble in the bubble tube and measure the time with a stopwatch. The hardness measured could be a quantity that would be influenced by human error. The authors continue to improve the Herbert hardness tester for many years to overcome the shortcomings of the original tester. The following techniques were introduced to observe the movement of the tester.

1) Non-contact rotary potentiometer [3]
2) Laser displacement meter [4, 5]
3) Motion capture [6]

With these technologies, data was imported into a measurement system outside the tester and processed to evaluate the hardness described later.

Therefore, the author aimed to develop a Herbert hardness tester that can evaluate hardness stand-alone without relying on any external system. The tester is equipped with a wire-less accelerometer

[7] for measuring its movement of it, swing angle and time data, and a Raspberry Pi [8, 9] for processing the data to evaluate the hardness. It has the following features:

1) An affordable and compact single-board microcomputer.
2) Sufficient processing performance.
3) Low electric power consumption.

Equipped with the devices enables the tester to be stand-alone. Hardness evaluation is now possible by operating the touch screen of the tester, making hardness testing easier than ever before. Present paper describes a stand-alone type Herbert hardness tester developed.

Hardness value conversion is necessary to maintain the equivalence of hardness values between testing machines that have different specifications. This is because it is difficult to fix these at present. For this reason, an example of how to convert hardness values between testing machines is shown below.

2. Tester configuration and structure

1) Accelerometer: KXR94-2050, Kionix Inc. for measuring swing angle and time data.
2) Computer board: Raspberry Pi zero W, Raspberry Pi Ltd. for processing the data input via GPIO.
3) Touch screen: PiTFT 320 x 240 2.8" TFT + Touch screen, Adafruit Industries for Giving instructions required for testing via touch.
4) Battery: Quality Protected Li-ion Rechargeable Battery P1835J, Keeppower Technology 3.6 x 2.0 voltage power supply in series.
5) DC/DC converter: 106990005, Seeed Technology Co., Ltd. for Stepping down from 7.2V, the supply voltage to 5.0 V.
6) A/D converter: MCP3204-BI/P, Microchip Technology for A/D conversion of measurement data values.

The stand-alone type Herbert hardness tester was designed with SolidWorks as shown in Fig. 1.

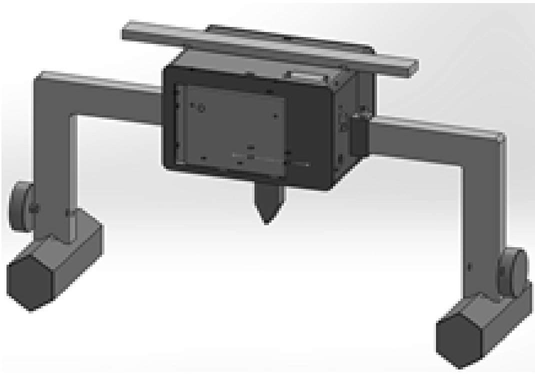

Fig. 1. 3-D model of the stand-alone type Herbert hardness tester.

The tester consists of the following as shown Fig. 2:

① An A5052 arm frame.
② Brass weights for horizontal balance.
③ A SUS304 indenter holder.
④ A 2.0 mm diameter cemented carbide columnar indenter.
⑤ A nylon polymer plastic box containing electronic devices, batteries and a weight for adjusting the vertical center of gravity position.
⑥ A laser reflector for swing angle measurement using laser light.

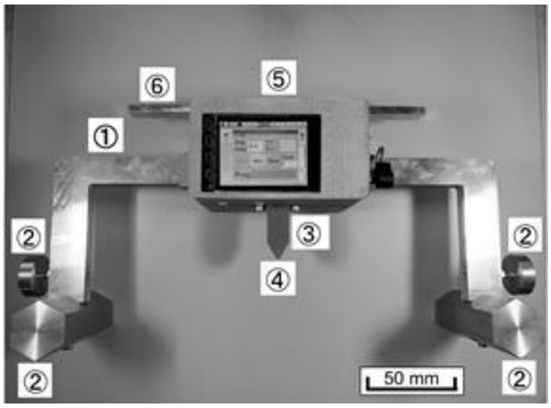

Fig. 2. The stand-alone type Herbert hardness tester configuration.

3. Hardness test procedure

Before the hardness test, follow steps 1) to 6) below to set the oscillation period of the tester on the artificial sapphire to 20.0 s. To achieve this, position the weight for adjusting the vertical center of gravity position correctly. This means that the vertical center of gravity position is indirectly determined. The procedure for the hardness test is as follows (See Fig. 3):

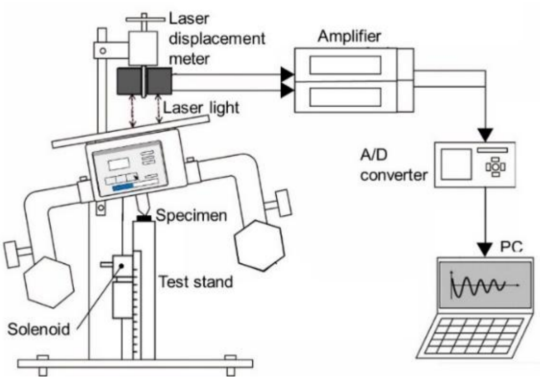

Fig. 3. Herbert hardness testing configuration.

1) Place the specimen on the test stand.
2) Place the tester so that the indenter is in contact with the specimen.
3) Keep the tester tilted at 30.0°, π/6 rad on the specimen.
4) Press the start button on the touch screen to put it into measurement standby mode. Fig. 4 shows an example of the touch screen.

Fig. 4. An example of the touch screen.

5) Press the rec button on the touch screen and release the tester and allow it to swing.
6) When the accelerometer detected a change in swing angle of the tester, the computer starts acquiring the data.

A VNC Viewer can remotely connect the tester to external devises such as smartphones and computers through Wi-Fi or Bluetooth from anywhere in the world.

4. Three kinds of Hardness evaluated

Fig. 5 shows the schematic diagram of a freely damped oscillation waveform of the tester, swing angle θ - time t observed during testing.

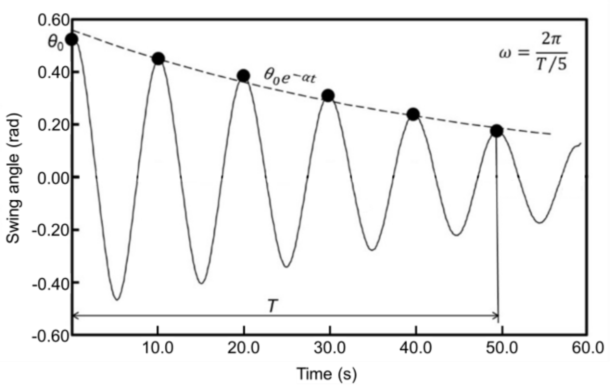

Fig. 5. The schematic diagram of a freely damped oscillation waveform of the tester.

The θ-t relationship is expressed by the following equation.

$$\theta(t) = \theta_0 e^{-\propto t} \cos \omega t \tag{1}$$

where θ_0 is the initial swing angle. α is damping factor which indicates the amount of damping in the tester and ω is natural angular frequency.

The authors proposed the following three types of hardness values assuming that not only α but also ω is related to hardness of materials [10].

1) Damping hardness = damping factor, α
2) Frequency hardness = natural angular frequency, ω
3) Matsubara hardness = ω / α, *Hmat*

The hardness evaluation uses waveform data up to the end of five cycles, as shown in Fig. 5.

Hardness evaluation is also carried out using a laser displacement meter to consider a method of converting between hardness values obtained using different measurement methods. Please refer to the previous report for the method.

5. Results and discussion

The prescribed measurement methods evaluate Matsubara hardness against 11 types of standard blocks for nominal Brinell hardness ranging from 100.0 to 600.0.

Fig. 6 shows *Hmat* evaluated by the two methods against the Brinell hardness of blocks, *HB*. The plot shows the average hardness at five different positions on the same block. The subscript A stands for acceleration and L for laser. As shown in Fig. 6, the change in Matsubara hardness with increasing Brinell hardness for each measurement method is similar, but the values are different.

The relationship between Matsubara hardness and Brinell hardness using each method is expressed by the following equation.

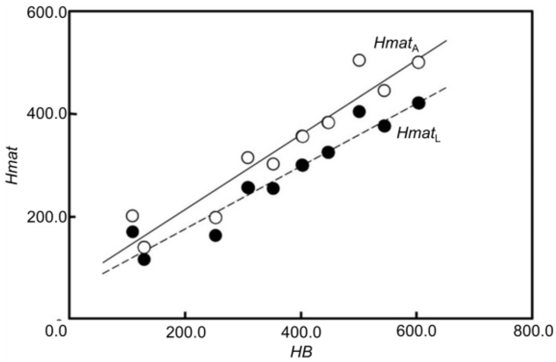

Fig. 6. *Hmat* vs. *HB*.

$$HB = 0.73Hmat_{\mathrm{A}} + 66.0 \tag{2}$$

$$HB = 0.61Hmat_{\mathrm{L}} + 54.0 \tag{3}$$

Eq. (4) is the conversion equation obtained from Eqs (2) and (3).

$$Hmat_{\mathrm{L}} = 0.84Hmat_{\mathrm{A}} - 1.0 \tag{4}$$

Fig. 7 shows the straight line shown in the conversion Eq. (4) and experimental results for $Hmat_L$ and $Hmat_A$ on the prescribed standard blocks. Fig. 7 makes clear that Eq. (4) can provide good conversion between $Hmat_L$ and $Hmat_A$.

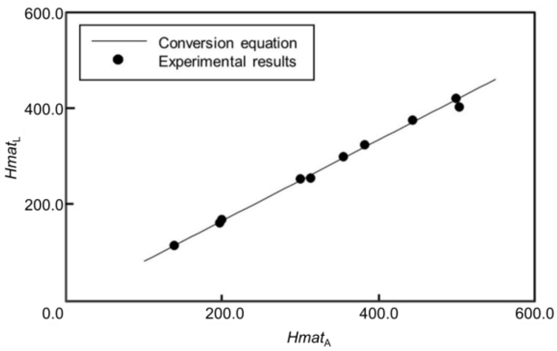

Fig. 7. $Hmat_L$ vs. $Hmat_A$.

As research and technological development progress,

1) the shape
2) dimensions
3) hardness evaluation method

of the tester would change. If the need to convert hardness values obtained with different versions of the Herbert hardness tester, the conversion can be performed in a similar procedure.

In the present tester, the resolution of the swing angle of the accelerometer and the laser is 0.0870° and 0.00750°, respectively. In addition, accelerometers are known to be prone to errors due to drift and noise. It is considered that the laser displacement sensor $Hmat_L$ measures hardness more accurately than $Hmat_A$. Eq. (4) can be used to calibrate $Hmat_A$ to $Hmat_L$, therefore, it is possible to obtain an accurate Matsubara hardness using an accelerometer.

The present tester is lighter and more portable than previous models that used potentiometers, laser displacement transducers, and motion capture to detect the swing angle. Therefore, it can easily evaluate the strength of products directly and nondestructively at the production site. This tester can also be used for hardness testing of minerals and other materials in field work. Combined with a robotic arm, the system could be used to automatically monitoring the strength of structural members in situ as aging progresses.

In order to accurately measure the Matsubara hardness with accelerometer, calibration using an accurate swing angle detection mechanism, such as a laser displacement meter, is necessary. It is known that accurate swing angle detection can be achieved by using multiple sensors, not only accelerometers but also gyro-sensors [11]. In order to enable accurate measurement of the Matsubara hardness without calibration by a laser displacement meter, future research will examine the installation of multiple sensors for detection of the swing angle of the tester.

6. Conclusions

Present paper shows the following about Hebert hardness tester.

1) Introduction of the tester equipped with Raspberry Pi.
2) Hardness conversion when the same tester has different measurement methods.

Acknowledgements

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