HARDNESS TEST

(Attention: This lab is a demonstration session. Both the lecture and the demonstration will be held simultaneously in Room G25 ESB)

**Definition of hardness**
Hardness is the property of a material that enables it to resist plastic deformation, usually by indentation. It is determined by measuring the permanent depth of the indentation. Given a fixed load and a specific indenter, the smaller the indentation is, the harder the material is. However, hardness may also be assessed by the resistance to scratching or cutting by another material.

**Method for hardness testing**
Typically, three types of testing methods are used to measure hardness of metals, i.e., Brinell hardness test, Rockwell hardness test, and Vickers hardness test. They distinguish from each other by the use of different indenters. A 10 mm diameter hardened steel or carbide ball usually is used as an indenter in the Brinell hardness test, a diamond or steel cone in the Rockwell hardness test, and a pyramidal shaped diamond indenter in the Vickers hardness test.

The hardness value is dependent on the defined measurement procedure. And it cannot be defined in terms of fundamental units of mass, length and time.

**Vickers hardness test (ASMT-E384)**
Vickers hardness test is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces. The indenter used is a square-based pyramid whose opposite sides meet at the apex at an angle of 136° (Figure 1a). The diamond is pressed into the surface of the material at a load. After a dwell time, the load is removed. And then the size of the residual indent (Fig.1b) is measured under a calibrated microscope due to the small size of the indent (usually no more than 0.5 mm).

The Vickers number (HV) is calculated by the following formula:
\[ HV = \frac{2F \sin 136^\circ}{d^2} \]
\[ HV = 1.854 \cdot \frac{F}{d^2} \]

Where \( F \) is the applied load (measured in kilograms-force) and \( d^2 \) is the area of the indentation (measured in square millimeters).

**Brinell hardness test (ASTM-E10)**

In the Brinell hardness test, a hardened steel ball is pressed into the surface of the specimen with the load up to 3000 kilogram. A small load less than 1500 kilogram is applied to relatively soft materials such as aluminum castings and copper alloys. After the load is held for 10 to 15 seconds, the ball will be removed. And a residual round indent is left on the specimen surface. The diameter of the residual indent is measured for calculation of the area of the curved surface of the indentation hardness, which is further used to estimate the Brinell hardness as follows:

\[
BHN = \frac{F}{\frac{\pi}{2} \cdot D \cdot (D - \sqrt{D^2 - d^2})}
\]

Figure 1(a) Brinell hardness test, \( D \), ball diameter; \( d \) = indent diameter; \( F \), load; (http://www.hardness testers.com/hardness-method-2.htm)

**Rockwell Hardness Test (ASTM-E18)**

The Rockwell method measures the permanent depth of indentation produced by a load on an indenter. Hardness numbers have no units and are commonly given in the R, L, M, E and K scales. The higher the number in each of the scales means the harder the material. The Rockwell hardness method is characteristic of the direct readout of the hardness number and rapid testing time. However, many arbitrary non-related scales and possible effects may arise from the specimen support anvil.
**Hardness measurements on the different scales**

Hardness can be measured on the macro-, micro- or nano-scale according to the forces applied and the displacements obtained. The macro-hardness (bulk hardness) measurement is carried out under the load greater than 1000gf. And the indent usually is visible to the naked eye. Most microhardness testing is typically performed on the smooth samples that have been metallographically mounted and polished. The applied load typically ranges from 15 to 1000 gf. As a result, the indentation is so small that it must be measured with a microscope. Microhardness is used to evaluate the hardness of different microconstituents within a structure due to small size of the indent. Nano-indentation testing is used to measure the hardness via using a very small indentation load (pico-Newton to nano-Newton) and via measuring the depth of the indentation. Nano-indentation is extensively applied to nanoscale materials such as ultra-thin films, and to soft matters such as biological cells.

**Correlation of hardness with yield strength**

Hardness represents the resistance of materials to deformation. It is well known that hardness is correlated with tensile strength of materials in tension, while resistance to deformation is dependent on modulus of elasticity. Empirically, the yield strength of steels is about 1/3 of the hardness. An approximate relationship between the hardness and the tensile strength of steel is expressed by,

\[
\text{Tensile strength (MPa)} =\begin{cases} 
3.55\text{HB} & (\text{HB} \leq 175) \\
3.38\text{HB} & (\text{HB} > 175) 
\end{cases}
\]

\[
\text{Tensile strength (psi)} =\begin{cases} 
515\text{HB} & (\text{HB} \leq 175) \\
490\text{HB} & (\text{HB} > 175) 
\end{cases}
\]

Where HB is the Brinnell Hardness of the material measured with a standard indenter at the load of 3000 kgf.

*(To be continued on next page)*
Nano-indentation on Al alloy under atomic force microscope, by Nick Wu [1]

Nano-hardness cross grain boundary of Al alloy, by Nick Wu [1]