

# Hardness Test

## Objective:

This experiment will lead the student to proper understanding of the principals of hardness tests and measure the hardness of different metallic specimens using the available hardness tester.

## Introduction:

The hardness test is a useful and rapid metallurgical non-destructive test, so it can serve as a check on heat treatment given to a metal. It also provides a quick and simple means of checking the tensile strength of ferrous materials since this property can be correlated with the hardness.

## Apparatus:

Universal hardness tester includes a direct reading through an electronic digital display of hardness test results. The machine carries out Vickers, Rockwell and Brinell Hardness testing at different loads (see figure below).

## Theory:

The hardness of any metal is its resistance to surface indentation under standard test conditions. Three main test methods are used: Brinell, Vickers & Rockwell.

### **The Brinell test:**

In this test (figure 2) an indenter consisting of a hardened steel ball of a diameter **D**, mounted in a suitable holder, is forced into a prepared surface of the test piece using a suitable load **P**, which is maintained for 15 second. The diameter **d** of the circular indentation left in the surface after removal of the load is measured in two directions at right angles using a low power graduated microscope and the average diameter is taken. The Brinell harness number (BHN) maybe found from table relating hardness to the diameter (each table of such relationship refers to a specific load and ball diameter) or calculated from the formula given below:

$$BHN = \frac{\text{Load (kgf)}}{\text{Area of curved surface of indentation in } mm^2} = \frac{P \text{ (kgf)}}{\frac{1}{2}\pi D[D - \sqrt{(D^2 - d^2)}] mm^2}$$

The larger the ball it is possible to use, the more accurate the result is likely to be. Balls of 10, 5, 2 and 1 mm diameter are available, enabling one of a suitable size for the thickness of the test piece to be chosen. Having decided on a suitable ball diameter, a load must now be chosen which will give an indentation of reasonable size. For different materials the ratio ( $P/D^2$ ) has been standardized in order to obtain reliable and comparable results. Four standard values of ( $P/D^2$ ) have been adopted, namely 30, 10, 5 and 1 as shown in table 1.

Ball Diameter (D mm)	Load (F kgf)			
	Steels & Cast Irons	Copper, Copper Alloys Aluminum Alloys	Aluminum	Tin, Lead & their Alloys
	$F/D^2 = 30$	$F/D^2 = 10$	$F/D^2 = 5$	$F/D^2 = 1$
1	30	10	5	1
2	120	40	20	4
5	750	250	125	25
10	3000	1000	500	100

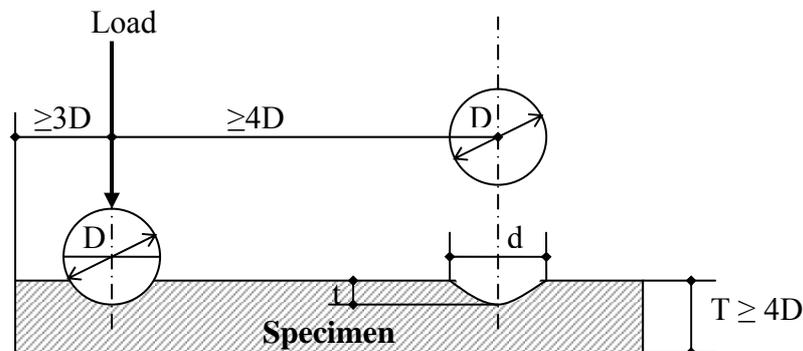
**Table 1: Standard values of  $F/D^2$  (Brinell test).**

It is not advisable to apply Brinell tests to materials having a hardness, which exceeds (BHN) 450, since the ball maybe easily deformed and this will introduce errors into the test results. The hardness of the ball should be at least 1.7 times higher than the test specimen to prevent permanent set in the ball. By using special work hardened balls, the range of hardness can be extended to 630. For testing the harder steel carbon alloy (WC) balls are often used.

The Brinell test makes a relatively large indentation, which is desirable when it is necessary to obtain the average hardness of a heterogeneous material (e.g. gray cast iron), however large indentation maybe objectionable.

In a Brinell test certain requirements must be met;

1. The depth of indentation,  $t$ , must not be too great relative to the thickness of the test piece  $T$ , otherwise the table supporting the test piece would be taking the load and not the test piece itself. For soft materials,  $T/t \geq 15$ , whereas  $T/t \geq 7$  for hard materials.
2. It should not be used on work pieces less than 3.2 mm (1/8") thickness.
3. If several readings must be taken on the same specimen, they should be spaced away from each other and away from the edges of the work piece (figure 2).
4. The test maybe unreliable for hard or very soft materials.



**Figure 2**

### The Vickers test:

The Vickers Hardness test uses a square based diamond pyramid indenter. It gives geometrically similar indentations under different loads. Therefore, the accuracy of the result will not vary with the depth of indentation, through the relationship between the depth of the indentation and thickness of test piece must still be observed.

The diamond indenter, in the form of a right pyramid with a square base and an angle of  $136^\circ$  between opposite faces, is forced into the prepared surface of the test material under a selected load; **P**. The diamond produces a square indentation and the average is taken of the diagonal lengths which are measured by means of a microscope with a variable slit built into the eye piece. The width of the slit is adjusted so that its edges coincide with the corners of the indentation, and the diagonal length (**d**) is then obtained from a revolution counter geared to the movement of the slit. The ocular reading obtained is converted to a Vickers Hardness number (VHN) by reference to tables. However, as with the Brinell test, the hardness is defined as:

$$VHN = \frac{\text{Load (kgf)}}{\text{Surface area of indentation in mm}^2} = \frac{P \text{ (kgf)}}{d^2 / 2 \sin \frac{1}{2}(136^\circ)} = 1.854 P / d^2$$

Loads of 1, 2.5, 5, 10, 20, 30, 50 and 100 (kgf) can be used on the hardness and thickness of the material being tested.

Vickers Hardness test requires a smoother finish on the test material. Thus, it is more suitable than the Brinell test for testing finished components. The Vickers test provides a suitable hardness scale for materials ranging from the very soft to very hard material.

Up to hardness number of  $\approx 300$  the Brinell and Vickers Hardness values are nearly the same, but at higher values the Brinell results are the lower due to distortion of the ball indenter.

### Rockwell test:

In Rockwell test the indentation depth is measured by the instrument and this is directly indicated as a hardness value. No subsequent measurement on the indentation is involved. The test piece is placed on the table of the machine and the indenter is brought into contact with the prepared surface under a minor load 10 kgf. The major load is then applied and when the reading on the indicator is steady the major load is taken off. The test piece remains under the minor load while the hardness value is read directly from the indicator.

Nine scales of the hardness are available (A to K inclusive) but the most commonly used are the B & C scales.

### Approximate Hardness Conversions:

Hardness conversion data have been determined approximately and found to be dependent on material type and characteristics (see table 2).

Hardness is not a well defined material property, and because of the experimental dissimilarities among the various techniques, a comprehensive conversion scheme has not been devised. Therefore, care should be taken when conversions are used.

### Determination of the tensile strength:

An approximate value of the tensile strength may be deduced from the Brinell number according to the following relation:

$$\text{Tensile strength (MPa)} = 3.4 \sim 3.5 \text{ (BHN)}.$$

Brinell		Rockwell		Tensile Strength (kpsi) Approximately
Indentation Diameter Mm	No.	B	C	
2.25	745	-	65.3	-
2.3	712	-	-	-
2.35	682	-	61.7	-
2.4	653	-	60	-
2.45	627	-	58.7	-
2.5	601	-	57.3	-
2.55	578	-	56	-
2.6	555	-	54.7	298
2.65	534	-	53.5	288
2.7	514	-	52.1	274
2.75	495	-	51.6	269
2.8	477	-	50.3	258
2.85	461	-	48.8	244
2.9	444	-	47.2	231
2.95	429	-	45.7	219
3	415	-	44.5	212
3.05	401	-	43.1	202
3.1	388	-	41.8	193
3.15	375	-	40.4	184
3.2	363	-	39.1	177
3.25	352	(110.0)	37.9	171
3.3	341	(109.0)	36.6	164
3.35	331	(108.5)	35.5	159
3.4	321	(108.0)	34.3	154
3.45	311	(107.5)	33.1	149
3.5	302	(107.0)	32.1	146
3.55	293	(106.0)	30.9	141
3.6	285	(105.5)	29.9	138
3.65	277	(104.5)	28.8	134
3.7	269	(104.0)	27.6	130
3.75	262	(103.0)	26.6	127
3.8	255	(102.0)	25.4	123
3.85	248	(101.0)	24.2	120
3.9	241	100.0	22.8	116
3.95	235	99.0	21.7	114
4	229	98.2	20.5	111
4.05	223	97.3	(18.8)	-
4.1	217	96.4	(17.5)	105
4.15	212	95.5	(16.0)	102
4.2	207	94.6	(15.2)	100
4.25	201	93.8	(13.8)	98
4.3	197	92.8	(12.7)	95
4.35	192	91.9	(11.5)	93
4.4	187	90.7	(10.0)	90
4.45	183	90.0	(9.0)	89
4.5	179	89.0	(8.0)	87
4.55	174	87.8	(6.4)	85
4.6	170	86.8	(5.4)	83
4.65	167	86.0	(4.4)	81
4.7	163	85.0	(3.3)	79
4.8	156	82.9	(0.9)	76
4.9	149	80.8	-	73
5	143	78.7	-	71
5.1	137	76.4	-	67
5.2	131	74.0	-	65
5.3	126	72.0	-	63
5.4	121	69.8	-	60
5.5	116	67.6	-	58
5.6	111	65.7	-	56

**Note:**

Values in ( ) are beyond normal range and are presented for information only.

VHN	BHN	RHB	RHC
20	19	-	-
40	38	-	-
60	57	-	-
80	76	31.9	-
100	95	52.5	-
120	114	66.3	-
140	133	67.1	-
160	152	83.4	-
180	171	89.2	-
200	190	93.8	14.0
220	209	97.5	18.0
240	228	-	21.8
260	247	-	25.1
280	266	-	28.2
300	285	-	30.0
320	304	-	33.4
340	323	-	35.7
360	342	-	37.8
380	361	-	39.8
400	380	-	41.7
420	399	-	43.5
440	418	-	45.1
460	437	-	46.7
480	452	-	48.2
500	467	-	49.7
520	482	-	51.1
540	497	-	52.4
560	512	-	53.7
580	527	-	54.8
600	542	-	55.7
620	555	-	56.7
640	568	-	57.6
660	580	-	58.5
680	592	-	59.3
700	602	-	60.1
720	-	-	60.9
740	-	-	61.7
760	-	-	62.5
780	-	-	63.3
800	-	-	64.0
820	-	-	64.8
840	-	-	65.5
860	-	-	66.3
880	-	-	67.0
900	-	-	67.7
920	-	-	-
940	-	-	-
960	-	-	-
980	-	-	-
1000	-	-	-

**Table 2: Hardness and tensile strength comparison table.**

**Procedure:**

1. Set the Universal hardness testing machine as shown in table (3).
2. Switch on display by the main switch at the back.
3. Select the desired hardness test by cycling using the RANGE cycle key (\*) button on the electronic display.
4. Set the upper limit to 999.9 then ENTER (#) and the lower limit to 19.9 then ENTER (#).
5. Ensure that the main load is unloaded.
6. Recheck the selection of the indenter, main load, pre-load, test specimen and the proper hardness test from table 3.
7. Rise the test specimen gradually against the indenter by means of the hand wheel to apply the preload until a reading between 100 to 130 is reached on the digital display and wait till you observe a PASS green led on.
8. Load the specimen by moving the main load operating handle to the load position.
9. Wait till the system is stabilized; normally 5 – 8 seconds.
10. Unload the specimen by moving the main load operating handle to the unload position.
11. Wait 5-8 seconds the read the digital display for the hardness test value.
12. Repeat from step 5 to step 11 when testing other specimens.
13. Press the RESET button (4) for other hardness tests.
14. Repeat from step 5 to step 12 when using other hardness tests.

**Universal hardness testing machine settings:**

Setting \ Test	Brinell Hardness Test (HB)	Vickers Hardness Test (HV)		Rockwell Hardness Test (HRC)	Rockwell Hardness Test (HRB)
		10	30		
<b>Indenter</b>	Ball 2.5 mm	Pyramid	Pyramid	Cone	Ball (1/16")
<b>Preload</b>	3	3	3	10	10
<b>Main Load</b>	187.5	10	30	150	100

**Table 3: Universal hardness testing machine settings**

### Hardness test Data Sheet

Material \ Test	Brinell Hardness Test (HB)	Vickers Hardness Test (HV)		Rockwell Hardness Test (HRC)	Rockwell Hardness Test (HRB)	Ultimate Tensile Strength	Theoretical Tensile Strength	%Error
		10	30					
Mild Steel			X	X				
High Speed Steel	X	X			X			
Aluminum			X	X		X	X	X
Brass			X	X		X	X	X

**X**: test is out of range for the selected specimen.

#### Analysis:

1. Find the Ultimate tensile strength based on the hardness test.
2. Find the theoretical tensile strength and compare your results.
3. Compare types of hardness tests together and state the advantages of each test over the other (Vickers, Brinell, and Rockwell).
4. Check from conversion tables the validity of the experiment results.