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hardness measurement & testing

Hardness testing is one of the oldest mechanical testing methods. It is widely used in quality control as it is quick to perform, relatively cheap and often non-destructive to the component being tested.

Hardness is the ability of a material to resist surface indentation or scratching. Hardness is not a fundamental property of a material hence its value varies according to the test method used.

The basic principal is that hardness is measured from an indentation produced in the component by applying a constant load on a specific indentor in contact with the component surface for a specified time.

The most commonly used hardness tests are:

ROCKWELL		BRINELL 10 mm ball 3000 kg load		VICKERS DIAMOND	Typical Results	
C scale HRC 120 deg diamond brale 150 kg load	B Scale HRB 1/16" steel bal 100 kg load	Diam. of ball impression in mm	Hardness Number	Hardness number HV	Material	Hardness HV
80	87			1865		
72	86			1787		
78	85			1710		
77	84			1633		
76	83			1556		
75	83			1478		
74	82			1400		
73	81			1323		
72	80			1245		
71	80			1160		
70	79			1076		
69	78			1004		
68	77			942		
67	76			894		
66	76			854		
65	75	2.25	745	820		
64	74	2.3	710	789		
63	73	2.3	710	763		
62	73	2.35	682	746		
61	72	2.35	571	720		
60	71	2.4	653	697		
59	70	2.45	627	674		
58	69	2.55	578	653		
57	69	2.55	578	633		
56	68	2.6	555	613		
55	67	2.6	555	595		
54	66	2.65	534	577		
53	65	2.7	514	560		
52	65	2.75	495	544		
51	64	2.75	495	528		
50	63	2.8	477	513		
49	62	2.85	461	498		
48	61	2.9	444	484		
47	61	2.9	444	471		
46	60	2.95	432	458	MP35 Ni-Co Age Hardenable	450-520HV
45	59	3	415	446		
44	59	3	415	434		
43	58	3.05	401	423		
42	57	3.1	388	412		
41	56	3.1	388	402		
40	55	3.15	375	392		

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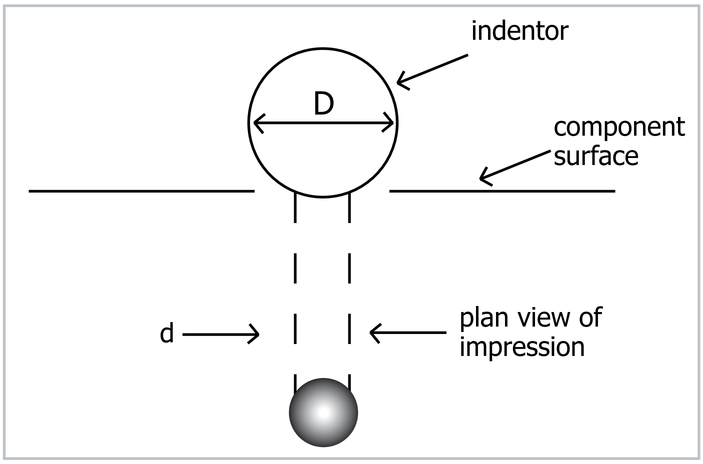
39	55	3.5	363	382	17-4PH precipition hardened	380-400 HV
38	54	3.25	352	372	solution treated & aged	
37	53	3.3	341	363		
36	52	3.35	331	354		
35	52	3.35	331	345		
34	51	3.4	321	336		
33	50	3.45	311	327		
32	49	3.5	302	318		
31	48	3.55	293	310		
30	48	3.6	285	302		
29	47	3.65	277	294	Duplex Stainless Steel	290 HV max
28	46	3.7	269	286	annealed & straightened	
27	45	3.75	262	279		
26	45	3.8	255	272		
25	44	3.8	255	266		
24	43	3.85	248	260	Cold Worked Stainless Steel	260 HV min
23	42	3.9	241	254	625 Ni -Cr-Mo	260 HV
22	42	3.95	235	248	annealed & straightened	
21	41	4	229	243		
20	40	4.05	223	238		
18		4.1	217	230		
		4.15	212	222		
		4.25	203	213		
		4.35	192	204		
		4.4	187	195		
		4.5	179	187		
		4.6	170	180		
		4.65	166	173		
		4.8	156	166		
		4.8	156	160		
		4.9	149	156		
		5	143	150	Annealed Stainless Steel	150 HV max
		5.1	137	143		
		5.2	131	137		
		5.3	126	132		
		5.4	121	127		
		5.5	116	122		
		5.6	112	117		

Brinell Test

An indentor comprising of a hardened steel or tungsten carbide ball is pressed into the surface for a standard time (10-15 secs) under a standard load. After removing the load, the circular indentation is then measured in two mutually perpendicular directions taking the average of the two readings. The Brinell Hardness Number (HB) is then calculated from

$$HB = \frac{\text{Applied Load}}{\text{Surface area of impression (mm}^2\text{)}}$$



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With a soft material and a large load it would be possible to push the indentor in so far that it could only produce an impression $d = D$. In order to obtain accurate Brinell values the relationship $d = 0.25D$ to $0.50D$ must be maintained. Hence the ball diameter and load applied is specified for the material under test e.g. for steels,

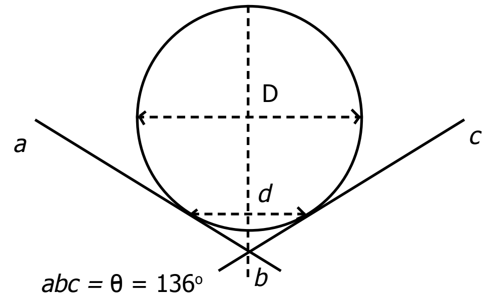
$$\frac{F}{D^2} = 30$$

The Brinell Test has the following limitations.

a) The impression is large (typically 2-4 mm in diameter) and this may act as a stress raiser in a component. It may also be unacceptable on grounds of appearance e.g., a car body panel, although acceptable on a car cylinder block.

b) The large depth of the impression precludes its use on plated or surface hardened components as the impression would also measure the underlying structure.

c) Very hard materials will deform the indentor, hence the Brinell Test is limited to materials of up to 450HB for a steel ball, and 600HB for a tungsten carbide ball.



(lines *abc* represent the faces of the pyramidal indentor)

Vickers Test

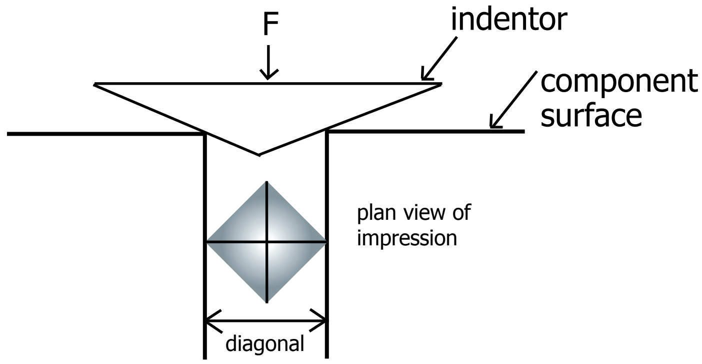
The Vickers indentor is a square based pyramid with an included angle of 136°, made from diamond. This indentor was designed to overcome the problems inherent in the Brinell Test of using a spherical indentor. The Vickers hardness (HV) is again a function of the applied load on the indentor and size of the resulting impression in the material being tested.

The advantage of 0 = 136° is that HP ≈ HV, up to about 300. The Vickers Test has the following advantages over the Brinell Test.

a) Suitable for hard materials as well as soft materials.
b) There is no need to use the F/D^2 ratio for the material to be tested because all impressions are geometrically similar. The only criterion for load selection now is that the impression should be large enough to be read accurately. The Vickers hardness range is proportional, so a material of HV 400 is twice as hard as a material having a HV = 200.

The limitations of the Vickers Test.

a) The impression is small (difficult to see with the naked eye) and so the surface of the component must be polished flat with silicon carbide paper and the component surface must be secured per pendicular to the indentor during the test.
b) It takes a relatively long time to perform a Vickers Hardness Test.



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Rockwell Test

The principle of the Rockwell Test differs from that of the others in that the depth of the impression is related to the hardness rather than the diameter of diagonal of the impression. This greatly speeds up the measurement because the Rockwell machine is designed to record the depth of penetration of the indentor. There are many Rockwell scales, but the most commonly used are the:

B-scale ($^{1}/_{16}$ inch diameter steel ball indentor; 100 kg load), used to measure the hardness (HRB) of non-ferrous metals.

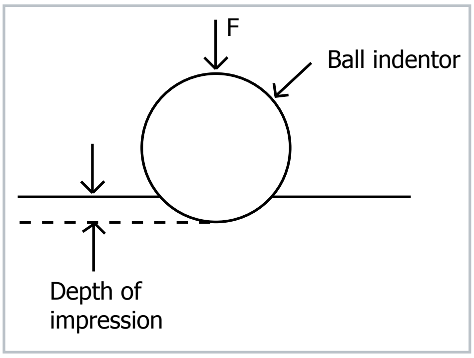
C-scale (120° diameter cone indentor (called a BRALE); 150 kg load), used to measure the hardness (HRC) of steels.

The advantages of the Rockwell Test are as follows:

a) It is a quickly made test and can be fitted into a production line, providing quality control on a line of components.

b) The impression size produced is between those of the Vickers and Brinell tests and some surface irregularity can be accomodated.

It is not as accurate as the Vickers test, which is usually preferred by technologists in research and development work.



A comparison of the most commonly used hardness tests is shown below.

Test	Indentor	Load	Typical Applications
Brinell (HB)	1-10 mm diameter steel or tungsten carbide ball	Up to 3000 kg for depending upon F/D^2 ratio of material	Forged, rolled, cast components in ferrous and non-ferrous alloys.
Vickers (HV)	Square based diamond pyramid	1-120 kg	All metal alloys and ceramics needs surface preparation.
Rockwell B-Scale (HRB)	$^{1}/_{16}$ inch diameter steel ball	10 kg Minor Load 100 kg Major Load	Low-strength steels and non-ferrous up to HV of 240.
Rockwell C-Scale (HRC)	Diamond cone of Brale	10 kg Minor Load 150 kg Major Load	All metals with a machined surface finish or equivalent. High strength steels from HV 240-1 000.

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