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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.

When testing thin wall or small diameter tubes some of the commonly used test methods, such as 'Rockwell' are not ideally used as the relatively high load (90kg) can distort surfaces or even punch a hole through the wall thickness. The ball impression can also fall away due to the curvature of the surface. In this context 'Vickers' hardness testing is seen as more accurate. When using 'Vickers' testing an equivalence with the 'Rockwell' scale is often desired. This correlation is not linear and comparison scales vary subjectively and between different metals.

Fine Tubes performed detailed research with the UK National Physics Laboratory to find a meaningful comparison between hardness scales.

Rockwell 'C' Scale	Diamond Pyramid Scale HV10 HV30	Brinell			Tensile Stress Equivalents			Rockwell		Diamond Pyramid Scale HV10 HV30	Typical Hardness Values
		Dia. Imp for 10mm Ball	Carbide Ball	Standard Ball	Tons/in²	Kg/mm²	Mpa {N/mm²}				
67.7	900							85.6	67.7	900	
67	880							85.0	67.0	880	
66.3	860							84.7	66.3	860	
65.5	840							84.2	65.5	840	
64.8	820							83.8	64.8	820	
64	800							83.4	64.0	800	
63.3	780							83.0	63.3	780	
62.5	760							82.6	62.5	760	
61.7	740							82.2	61.7	740	
61	725	2.44	630	-	-	-	-	81.8	61.0	725	
60.5	710	2.45	627	-	-	-	-	81.5	60.5	710	
60	698	2.50	601	-	132	208	2039	81.2	60.0	698	
58.9	670	2.55	578	-	127	200	1961	80.6	58.9	670	
57.1	630	2.60	555	-	122	192	1884	79.6	57.1	630	
56.1	609	2.65	534	-	117	184	1807	79.0	56.1	609	
54.4	572	2.70	514	-	112	176	1729	78.2	54.4	572	
51.9	532	2.75	495	495	108	170	1668	76.9	51.9	532	
50.7	517	2.80	477	477	105	165	1621	76.3	50.7	517	
49.5	497	2.85	461	461	101	160	1559	75.5	49.5	497	
47.5	470	2.90	444	444	98	155	1513	74.2	47.5	470	
46.0	452	2.95	429	429	95	150	1467	73.5	46.0	452	MP35 Ni-Co Age Hardenable
44.8	437	3.00	415	415	92	145	1420	73.0	44.8	437	
43.7	422	3.05	401	401	88	139	1359	72.5	43.7	422	
42.4	408	3.10	388	388	85	134	1312	71.5	42.4	408	
41.3	395	3.15	375	375	82	129	1266	71.0	41.3	395	
39.9	381	3.20	363	363	80	126	1235	70.3	39.9	381	17-4PH precipitation Hardened & Aged
38.8	370	3.25	352	352	77	121	1189	69.8	38.8	370	
37.7	359	3.00	341	341	75	118	1158	69.2	37.7	359	
36.7	349	3.35	331	331	73	114	1127	68.8	36.7	349	

Datasheet

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Rockwell 'C' Scale	Diamond Pyramid Scale HV10 HV30	Brinell			Tensile Stress Equivalents			Rockwell		Diamond Pyramid Scale HV10 HV30	Typical Hardness Values
		Dia. Imp for 10mm Ball	Carbide Ball	Standard Ball	Tons/in^2	Kg/mm^2	Mpa {N/mm^2}				
35.0	337	3.40	321	321	71	111	1096	68.0	35.0	337	
34.0	327	3.45	311	311	68	107	1050	67.5	34.0	327	Super Duplex Cold Worked Min
33.0	318	3.50	302	302	66	104	1019	66.8	33.0	318	Duplex Cold Worked Min
32.0	308	3.55	293	293	64	101	988	66.2	32.0	308	
30.9	300	3.60	285	285	63	99	973	65.7	30.9	300	Super Duplex Annealed Max
29.8	292	3.65	277	277	61	96	942	65.2	29.8	292	Duplex Annealed
29.0	284	3.70	269	269	59	93	911	64.6	29.0	284	Ni Alloy 625 Cold Worked Min
27.5	275	3.75	262	262	58	91	895	64.0	27.5	275	
26.6	269	3.80	255	255	56	89	865	63.6	26.6	269	
25.2	261	3.85	248	248	55	87	849	62.9	25.2	261	Ni Alloy 625 Annealed max
24.3	255	3.90	241	241	53	84	818	62.6	24.3	255	Ni Alloy 825 Cold Worked Min
23.0	247	3.95	235	235	51	81	787	62.0	23.0	247	6Mo Cold Worked min
22.0	241	4.00	229	229	50	79	772	61.6	22.0	241	
20.8	234	4.05	223	223	49	77	756	60.7	20.8	234	
	228	4.10	217	217	48	76	741	-	-	228	

Hardness 'B' Scale	Diamond Pyramid Scale HV10 HV30	Brinell			Tensile Stress Equivalents			Hardness		Diamond Pyramid Scale HV10 HV30	Typical Hardness Values
		Dia. Imp for 10mm Ball	Carbide Ball	Standard Ball	Tons/in^2	Kg/mm^2	Mpa {N/mm^2}				
98	222	4.15	212	212	46	73	710	-	98	228	
97	218	4.20	207	207	45	71	695	-	97	226	6Mo Annealed Max
96	212	4.30	197	197	43	68	664	-	96	224	304L/316L Austenitic Cold worked Min
93	196	4.40	187	187	41	65	632	-	93	217	904L Cold Worked min
91	188	4.50	179	179	39	62	602	-	91	211	
88.5	178	4.60	170	170	36	57	556	-	88.5	206	Ni Alloy 825 An-nealed Max
86	171	4.70	163	163	35	55	540	-	86	200	304L/316L Austenitic Annealed Max
84.2	163	4.80	156	156	34	54	525	-	84.2	195	Alloy 400 Cold Worked Min
82	156	4.90	149	149	32	51	494	-	82	189	
80	150	5.00	143	143	31	49	479	-	80	184	904L Annealed Max
77	143	5.10	137	137	30	48	463	-	77	176	
75	137	5.20	131	131	29.5	47	455	-	75	171	Alloy 400 Annealed Max
72.5	132	5.30	126	126	29	46	448	-	72.5	166	
70	127	5.40	121	121	28	44	432	-	70	160	
67	122	5.50	116	116	26	42	401	-	67	153	

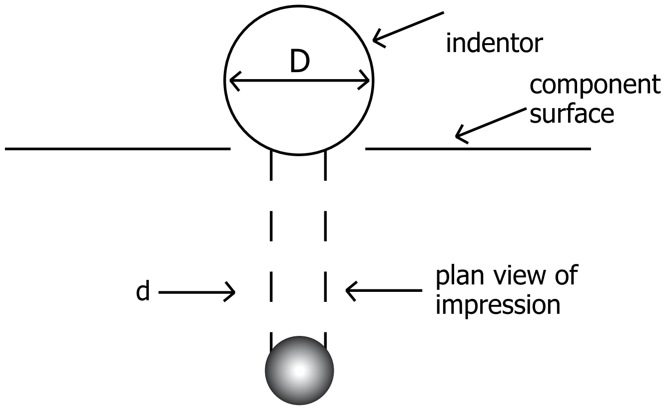
Datasheet

The most commonly used hardness test are:

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

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



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,

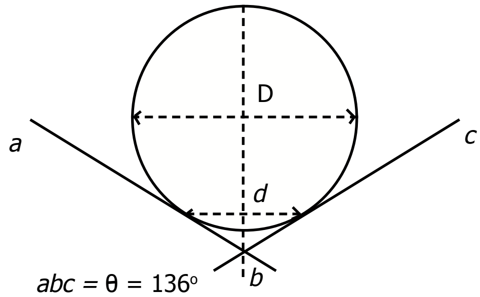
$$\frac{F}{D^2} = 30$$

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.

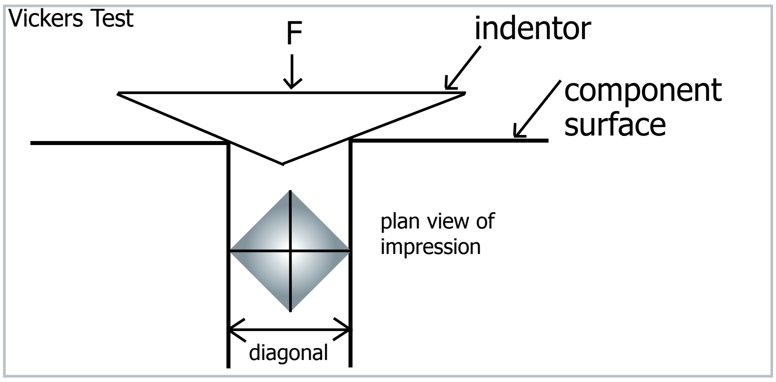
a) Suitable for hard materials as well as soft materials.

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 perpendicular to the indentor during the test.

b) It takes a relatively long time to perform a Vickers Hardness Test.



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.

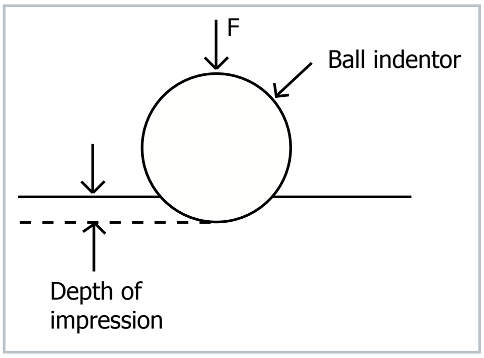
C-scale (120° diameter cone indentor (called a BRALE); 150 kg load), used to measure the hardness (HRC) of steels.

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.



Datasheet

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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