The Hardness Test

What is Hardness?

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting.

Why Use a Hardness Test?

- Easy to perform
- Quick - 1 to 30 seconds
- Relatively inexpensive
- Non-destructive
- Finished parts can be tested - but not ruined
- Virtually any size and shape can be tested
- Practical QC device - incoming, outgoing

The most common uses for hardness tests is to verify the heat treatment of a part and to determine if a material has the properties necessary for its intended use. Establishing a correlation between the hardness result and the desired material property allows this, making hardness tests very useful in industrial and R&D applications.

Hardness Scales

There are five major hardness scales:

- **Rockwell - HR**
- **Brinell - HB**
- **Vickers - HV**
- **Knoop - HK**
- **Shore - HS**

Each of these scales involves the use of a specifically shaped diamond, carbide or hardened steel indenter pressed into the material with a known force using a defined test procedure. The hardness values are determined by measuring either the depth of indenter penetration or the size of the resultant indent. All of the scales are arranged so that the hardness values determined increase as the material gets harder. The hardness values are reported using the proper symbol, HR, HV, HK, etc. indicating the test scale performed.

Rockwell Hardness Test

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load *F0* (Fig. 1A) usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration (Fig. 1B). When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Fig. 1C). The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

$$HR = E - e$$

F0 = preliminary minor load in kgf
F1 = additional major load in kgf
F = total load in kgf
e = permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm
E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter
HR = Rockwell hardness number
D = diameter of steel ball

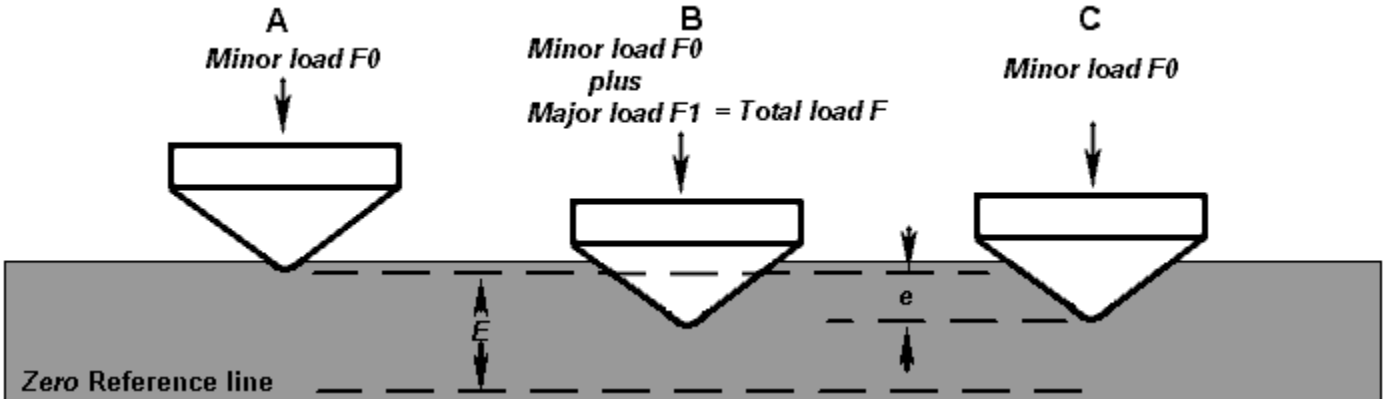


Fig. 1.Rockwell Principle

Rockwell Hardness Scales

Scale	Indenter	Minor Load *F0* kgf	Major Load *F1* kgf	Total Load *F* kgf	Value of *E*
A	Diamond cone	10	50	60	100
B	1/16" steel ball	10	90	100	130
C	Diamond cone	10	140	150	100
D	Diamond cone	10	90	100	100
E	1/8" steel ball	10	90	100	130
F	1/16" steel ball	10	50	60	130
G	1/16" steel ball	10	140	150	130
H	1/8" steel ball	10	50	60	130
K	1/8" steel ball	10	140	150	130
L	1/4" steel ball	10	50	60	130
M	1/4" steel ball	10	90	100	130
P	1/4" steel ball	10	140	150	130
R	1/2" steel ball	10	50	60	130
S	1/2" steel ball	10	90	100	130
V	1/2" steel ball	10	140	150	130

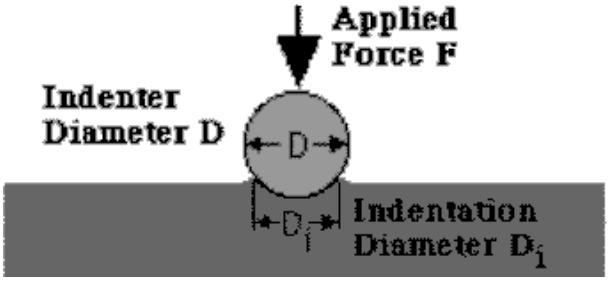
Typical Application of Rockwell Hardness Scales

HRA . . . . Cemented carbides, thin steel and shallow case hardened steel
HRB . . . . Copper alloys, soft steels, aluminium alloys, malleable irons, etc.
HRC . . . . Steel, hard cast irons, case hardened steel and other materials harder than 100 HRB
HRD . . . . Thin steel and medium case hardened steel and pearlitic malleable iron
HRE . . . . Cast iron, aluminium and magnesium alloys, bearing metals
HRF . . . . Annealed copper alloys, thin soft sheet metals
HRG . . . . Phosphor bronze, beryllium copper, malleable irons HRH . . . . Aluminium, zinc, lead
HRK . . . . }
HRL . . . . }
HRM . . . .} . . . . Soft bearing metals, plastics and other very soft materials
HRP . . . . }
HRR . . . . }
HRS . . . . }
HRV . . . . }

Advantages of the Rockwell hardness method include the direct Rockwell hardness number readout and rapid testing time. Disadvantages include many arbitrary non-related scales and possible effects from the specimen support anvil (try putting a cigarette paper under a test block and take note of the effect on the hardness reading! Vickers and Brinell methods don't suffer from this effect).

The Brinell Hardness Test

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell harness number is calculated by dividing the load applied by the surface area of the indentation.



$$BHN = \frac{F}{\frac{\pi}{2} D \cdot (D - \sqrt{D^2 - D_i^2})}$$

Fig. 2. The Brinell Hardness Test

The diameter of the impression is the average of two readings at right angles and the use of a Brinell hardness number table can simplify the determination of the Brinell hardness. A well structured Brinell hardness number reveals the test conditions, and looks like this, "75 HB 10/500/30" which means that a Brinell Hardness of 75 was obtained using a 10mm diameter hardened steel with a 500 kilogram load applied for a period of 30 seconds. On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material. This method is

the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures.

Vickers Hardness Test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.

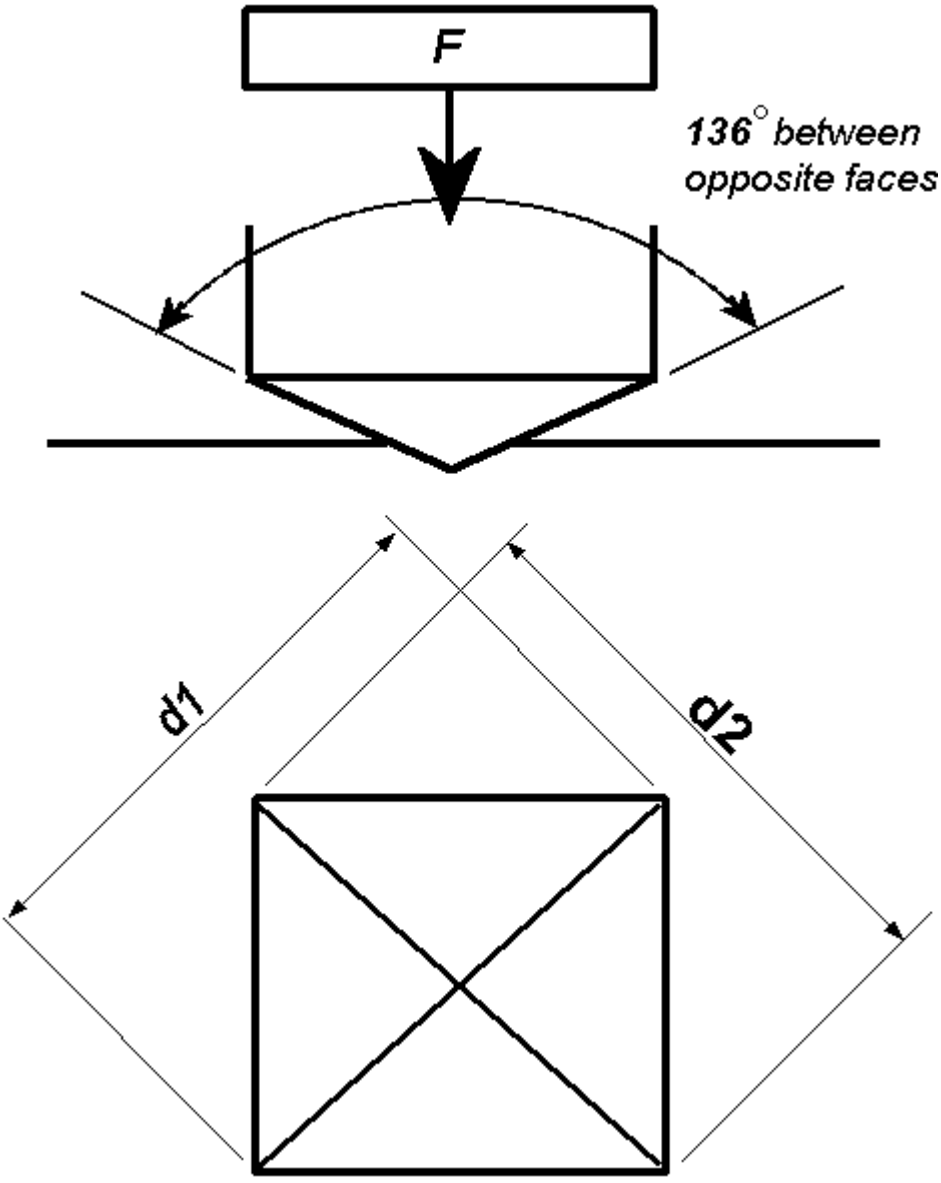


Fig. 3. The Vickers Hardness Test

F= Load in kgf
d = Arithmetic mean of the two diagonals, *d1* and *d2* in mm

HV = Vickers hardness

$$HV = \frac{2F\sin\frac{136^\circ}{2}}{d^2} \qquad HV = 1.854\frac{F}{d^2} \text{ approximately}$$

When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kgf force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is more expensive than the Brinell or Rockwell machines.

Hardness Conversion Table

Table 1. Approximate Hardness Equivalents Covering Range of Rockwell C and Rockwell B Scales

VPN	ROCKWELL SCALES															BRINELL		SCLERO-SCOPE	U.T.S.	
DPH HV/10	A	B	C	D	E	F	G	H	K	15 N	30 N	45 N	15 T	30 T	45 T	BHN 500kg	BHN 3000kg		Kpsi	Mpa
1865	92		*80*	87						97	92	87								
1787	92		*79*	86						96	92	87								
1710	9		*7*	8						96	91	86								

	1		*8*	5															
1633	91		*77*	84						96	91	85							
1556	90		*76*	83						96	90	84							
1478	90		*75*	83						95	89	83							
1400	89		*74*	82						95	89	82							
1323	89		*73*	81						95	88	81							
1245	88		*72*	80						95	87	80							
1160	87		*71*	80						94	87	79							
1076	87		*70*	79						94	86	78					101		
1004	86		*69*	78						94	85	77					99		
940	86		*68*	77						93	84	75					97		
900	85		*67*	76						93	84	74					95		
865	85		*66*	75						93	83	73					92		
832	84		*65*	75						92	82	72				*739*	91		
800	84		*64*	74						92	81	71				*722*	88		
772	83		*63*	73						91	80	70				*705*	87		
746	83		*62*	72						91	79	69				*688*	85		
720	82		*61*	72						91	79	68				*670*	83		
697	81		*60*	71						90	78	67				*654*	81	320	2206
674	81		*59*	70						90	77	66				*634*	80	310	2137
653	80		*58*	69						89	76	64				*615*	78	300	2069
633	8		5	6						89	75	63				*595*	76	290	200

	0		7	9																0
613	79		56	68						88	74	62					*577*	75	282	1944
595	79	*120*	55	67						88	73	61					*560*	74	274	1889
577	78	*120*	54	66						87	72	60					*543*	72	266	1834
560	78	*119*	53	65						87	71	59					*523*	71	257	1772
544	77	*119*	52	65						86	70	57					*512*	69	245	1689
528	77	*118*	51	64						86	69	56					496	68	239	1648
513	76	*117*	50	63						86	69	55					481	67	233	1607
498	75	*117*	49	62						85	68	54					469	66	227	1565
484	75	*116*	48	61						85	67	53					455	64	221	1524
471	74	*116*	47	61						84	66	51					443	63	217	1496
458	74	*115*	46	60						84	65	50					432	62	212	1462
446	73	*115*	45	59						83	64	49					421	60	206	1420
434	73	*114*	44	59						83	63	48					409	58	200	1379
423	72	*113*	43	58						82	62	47					400	57	196	1351
412	72	*113*	42	57						82	61	46					390	56	191	1317
402	71	*112*	41	56						81	60	44					381	55	187	1289
392	71	*112*	40	55						80	60	43					371	54	182	1255
382	70	*111*	39	55						80	59	42					362	52	177	1220
372	70	*110*	38	54						79	58	41					353	51	173	1193
363	69	*110*	37	53						79	57	40					344	50	169	1165
354	6	*10*	3	5						78	56	38					336	49	165	113

	9	*9*	6	2															8
345	68	*109*	35	52						78	55	37					327	48	160	1103
336	68	*108*	34	51						77	54	36					319	47	156	1076
327	67	*108*	33	50						77	53	35					311	46	152	1048
318	67	*107*	32	49						76	52	34					301	44	147	1014
310	66	*106*	31	48			91			76	51	33					294	43	144	993
302	66	*105*	30	48			91			75	50	31					286	42	140	965
294	65	*104*	29	47			89			75	50	30					279	41	137	945
286	65	*104*	28	46			88			74	49	29					271	41	133	917
279	64	*103*	27	45			87			73	48	28					264	40	129	889
272	64	*103*	26	45			86			73	47	27					258	39	126	869
266	63	*102*	25	44			85			72	46	26					253	38	124	855
260	63	*101*	24	43			84			72	45	24					247	37	121	834
254	62	100	23	42			83			71	44	23	93	82	72	201	240	36	118	814
248	62	99	22	42			81			71	43	22	93	82	71	195	234	35	115	793
243	61	98	21	41			79			70	42	21	93	81	70	189	228	35	112	772
238	61	97	20	40			78			69	42	20	92	81	69	184	222	34	109	752
234	60	97	19				77						92	80	69	181	218	34	107	738
230	59	96	18				76						92	80	68	179	214	33	106	731
226	59	96	17				75						92	80	68	177	210	33	104	717
222	58	95	16				74						92	79	67	175	208	32	102	703
217	5	95	1				7						92	79	67	171	205	31	100	690

	8		5				3												
213	58	94	14				73						91	79	66	169	203	31	99	683
208	57	93	13				71						91	78	66	167	200	30	98	676
204	57	92	12				70		100				91	78	65	163	195	30	96	662
200	56	92	11				69		100				91	77	64	162	193	29	95	655
196	56	91	10				68		100				90	77	64	160	190	28	93	641
192	56	90	9				66		99				90	76	63	157	185	27	91	627
188	55	89	8				64		98				90	76	62	154	180	26	88	607
184	54	88	7				63		97				90	75	61	151	176	26	86	593
180	54	87	6				61		97				89	75	60	148	172	26	84	579
176	53	86	5				59		96				89	74	59	145	169	25	83	572
172	53	85	4				58		95				89	74	58	142	165	25	81	558
168	52	84	3				56		94				88	73	57	140	162	25	79	545
164	51	83	2				54		93				88	72	56	137	159	24	78	538
160	51	82	1				53		92				88	72	55	135	156	24	76	524
156	50	81	0				51		91				87	71	54	133	153	24	75	517
152	50	80					49		91				87	70	53	130	150		73	503
148	49	79					48		90				87	70	52	128	147			
144	49	78					46		89				86	69	51	126	144			
141	48	77					44		88				86	68	50	124	141			
139	47	76					43		87				86	68	49	122	139			
137	4	75				10	4		86				85	67	49	120	137			

	7					0	1												
135	46	74				99	39		85				85	66	48	118	135			
132	46	73				99	38		85				85	66	47	116	132			
130	45	72				98	36		84				84	65	46	114	130			
127	45	71			100	98	35		83				84	64	45	112	127			
125	44	70			100	97	33		82				84	64	44	110	125			
123	44	69			99	96	31		81				83	63	43	109	123			
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115	42	65			96	94	25		78				82	60	39	102	116			
114	42	64			96	94	24		77				82	60	38	101	114			
113	41	63			95	93	22		76				81	59	37	99	112			
112	41	62			95	92	21		75				81	58	36	98	110			
111	40	61			94	92	19		74				81	57	35	96	108			
110	40	60			93	91	18		73				81	57	34	95	107			
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104	38	55			90	88	10		69				79	53	28	89	99			
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101	36	52			88	87	6		66				78	51	25	85			
100	36	51			88	86	4		65				78	51	24	84			
100	35	50			87	86	3		65				77	50	23	83			
99	35	49			87	85			64				77	49	22	82			
98	35	48			86	85			63				77	49	21	81			
97	34	47			85	84			62				76	48	20	80			
96	34	46			85	83			61				76	47	19	79			
95	33	45			84	83			60				76	46	18	79			
95	33	44			84	82			59				75	46	17	78			
94	32	43			83	82			58				75	45	16	77			
93	32	42			82	81			58				75	44	15	76			
92	31	41			82	81			57				74	44	14	75			
91	31	40			81	80			56				74	43	13	74			
90	31	39			80	79			55				74	42	11	74			
90	30	38			80	79			54				73	42	10	73			
89	30	37			79	78			53				73	41	9	72			
88	29	36			79	78		100	52				73	40	8	71			
88	29	35			78	77		100	52				72	40	7	71			
87	28	34			77	77		99	51				72	39	6	70			
87	2	33			77	76		99	50				72	38	5	69			

	8																		
86	28	32			76	75		99	49				71	38	4	68			
86	27	31			76	75		98	48				71	37	3	68			
85	27	30			75	74		98	47				71	36	2	67			
85	26	29			74	74		98	46				70	36	1	66			
84	26	28			74	73		97	45				70	35		66			
84	25	27			73	73		97	45				70	34		65			
83	25	26			73	72		97	44				69	33		65			
83	24	25			72	71		96	42				69	33		64			
82	24	24			71	71		96	42				69	32		64			
82	24	23			71	70		96	41				68	31		63			
81	23	22			70	70		95	40				68	31		63			
81	23	21			70	69		95	39				68	30		62			
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80	22	19			68	68		94	38				67	29		61			
79	21	18			68	67		94	37				67	28		61			
79	21	17			67	67		93	36				67	27		60			
78	21	16			67	66		93	35				66	26		60			
78	20	15			66	66		93	34				66	26		59			
77		14			65	65		92	33				66	25		59			
77		13			65	65		92	32				65	24		58			
76		12			64	64		92	32				65	24		58			
76		11			64	64		91	31				65	23		57			

75		10			63	63		91	30				64	22		57			
75		9			62	62		91	29				64	22		56			
74		8			62	62		90	28				64	21		56			
74		7			61	61		90	27				63	20		56			
73		6			61	61		90	26				63	20		55			
73		5			60	60		89	26				63	19		55			
72		4			59	60		89	25				62	18		55			
72		3			59	59		88	24				62	17		54			
71		2			58	58		88	23				62	17		54			
71		1			58	58		88	22				61	16		53			
70		0			57	57		87	21				61	15		53			
DPH HV/10	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**K**	**15 N**	**30 N**	**45 N**	**15 T**	**30 T**	**45 T**	**BHN 500kg**	**BHN 3000kg**		**Kpsi**	**Mpa**
VPN	**ROCKWELL SCALES**															**BRINELL**		**SCLERO-SCOPE**	**U.T.S.**	

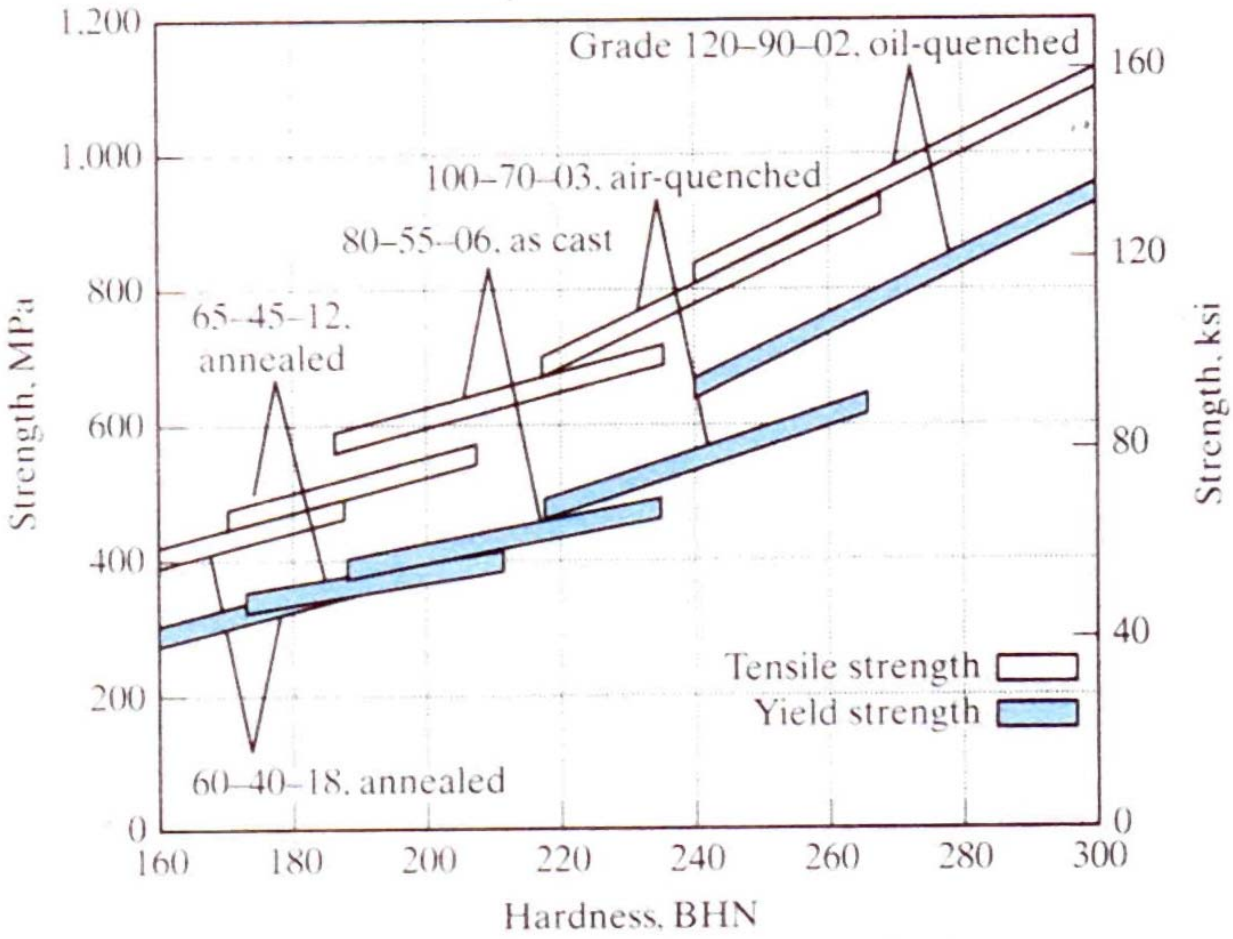

Fig. 4. Tensile properties of ductile iron versus hardness