No. STD-010

TECHNICAL INFORMATION

An Introduction To Hardness Testing Machines

Mitutoyo

CONTENTS

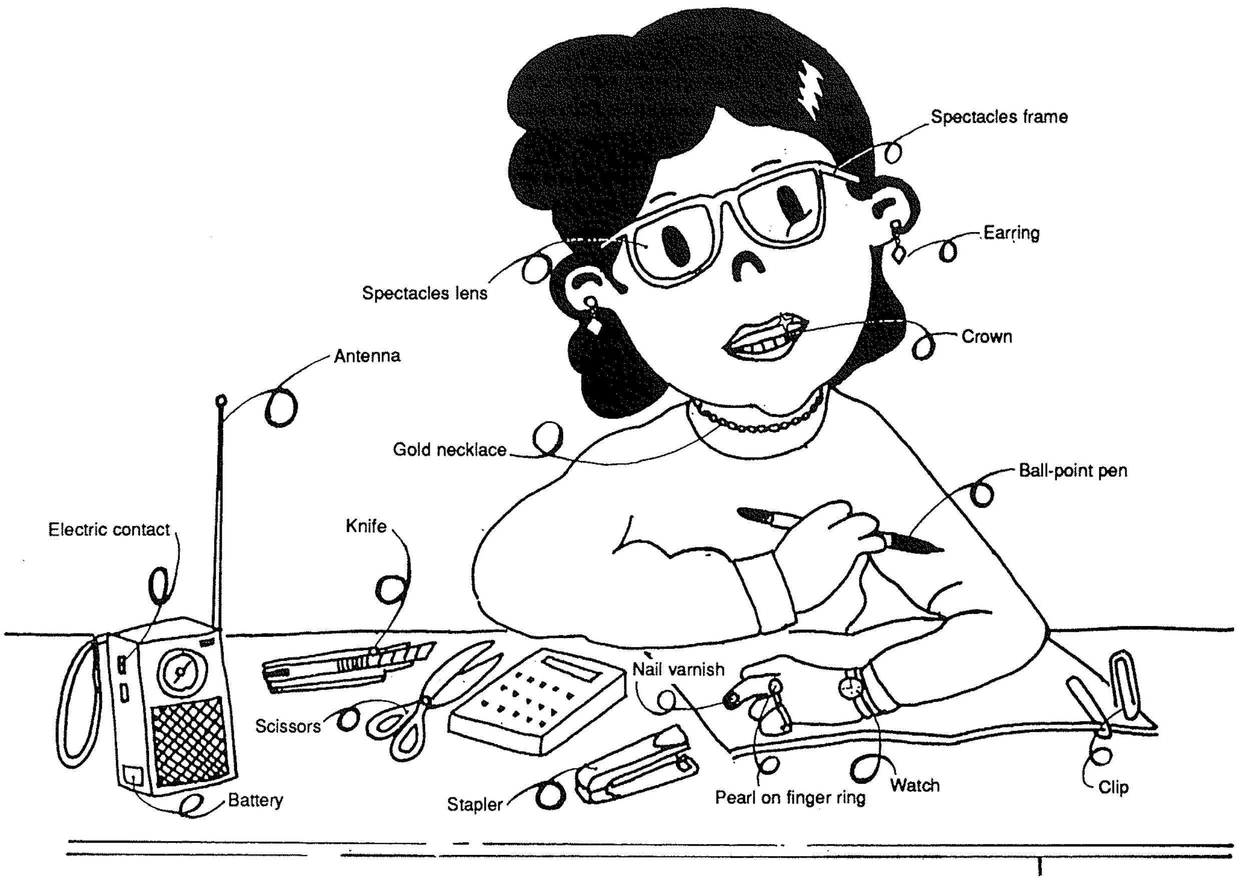
Introduction

Since ancient times man has sought for harder and harder materials, from wood to stone, from stone to bronze, and finally from bronze to iron. Today, man can compose or synthesize new materials such as fine ceramics that are harder than iron. However, harder doesn't always mean better. In other words, softness or suppleness is no less important a property of a material than hardness. A superb combination of hardness and softness can be found in the blade of a *katana*,the Japanese sword. The subtle blend of hardness and softness can only formed by the hand of an experienced craftsman.

Modern industry has contrived methods for quantifying the hardness of diverse materials. Instruments that determine the hardness of materials are called "hardness testers" or "hardness testing machines." Scientifically, hardness is defined as "the degree of resistance of a material to deformation (which includes indentation, scratching, abrasion, or cutting) when it is subjected to load." There are several methods for determining hardness. They will be outlined in this guidebook.

[Let's try!]

Name the articles around you whose hardness is tested in their manufacturing process.



Departments and Sections That Use Hardness Testing Machine Classified According to the Type of Company

The departments and sections that use or maintain hardness testing machine vary depending on the industrial field and company type. They are classified by application, as follows:

Industrial field	Main users (typical company name)	Inspected items	Relevant section (sales target)
Heat treatment	XXX Heat Treatment XXX Induction Hardening	Hardened parts	Quality control section Acceptance inspection section
Automobiles, vehicles	XXX Motors XXX Automobile	Hardened parts	Laboratory (Material R&D lab) Heat treatment section Quality control section Inspection section
Shipbuilding and heavy equipment	XXX Machinery	Materials Welding	Laboratory (Material R&D lab) Quality control section Inspection section
Metal working	XXX Steel XXX Metal Works	Materials Welding	Inspection section Testing section
Electric wires	XXX Electric Wires	Materials	Material inspection section Material R&D section
Petroleum, chemicals, ceramics	XXX Chemical XXX Plastics	Materials (plastics)	Laboratory Analysis section
Household appliances	XXX Electric XXX Electronics	Electrical parts (contacts, ICs, batteries)	Engineering section Laboratory
Jewelry	XXX Jewelry XXX Optical	Materials Spectacle frame	Inspection section
Printing	XXX Printing XXX Copying Machine	Printing drum Photosensitive drum	Inspection section Engineering section

Guideline for Selecting the Method of Rating Hardness

Hardness type / **Material**	Micro-Vickers	Vickers	Knoop	Rockwell	Rockwell superficial	Brinell	(Portable hardness tester)
IC wafer	○						
Carbide, ceramics (cutting tool)	△	○	△	○ 1)	△		△
Steel (Heat treated, raw material)	○	○	△	○	○	○	△
Nonferrous metals	○	○	△	○	○		
Plastics	△	△		○	○		
Grinding stone				○ 2)			
Shape/type							
Thin plate (safety razor, metal foil)	○	○	△		○		
Plating, painting, surface layer (Nitrided layer)	○	△	△				
Small parts, Needle parts (watch parts, sewing machine needles)	△	△	△				
Large parts (structural parts)						○	○
Metal structure (hardness of each phase of multi-phase metals)	○		△				
Inspection item							
Strength	△	○		○	○		△
Heat treatment process	○	○		○	○		△
Carburized layer depth	○ 3)	○ 6)					
Decarburized layer depth	○ 4)	○ 6)			○ 11)		
Flame/Induction hardening depth	○ 5)			○ 9)			
Hardenability test		○		○ 9)			
Maximum hardness of weld		○ 7)					
Hardness of deposited metal		○ 8)		○ 10)			
Hot-hardness (high-temperature characteristics, hot workability)		○ 12)					
Suitable models	MVK-G3 MVK-G2 MVK-G1 MVK-E3 MVK-VL	AVK-C1 AVK-C2 AVK-A2	MVK-G3 MVK-G2 MVK-G1 MVK-E3 MVK-VL AVK-C1 AVK-C2 AVK-A2	ARK-F1000 ARK-F2000 ARK-F3000 ARK-500 AR-10	ATK-F1000 ATK-F2000 ATK-F3000	ABH	PHT

1) A scale
2) H scale
3) Test force: 300gf, 1kgf
4) Test force: 100gf, 1kgf
5) Test force: 300gf or more
6) Test force: 1kgf
7) Test force: 10kgf
8) Test force: 30kgf
9) C scale
10) B and C scales
11) 15N and 30N scales
12) Available by using a high-temperature module to AVK-A2L.

The Basics of Hardness

1.1 Introduction

Hardness is a measure of resistance of a material to deformation when an external force or load is applied to the material. Many methods of applying load and quantifying the resistance to deformation have been suggested or used in industry. The hardness scales most commonly used today are Brinell hardness (J.B. Brinell, 1900), Vickers hardness (R. Smith and G. Sandland, 1925), Rockwell hardness (S. P. Rockwell, 1919), Rockwell superficial hardness, Shore hardness (A. F. Shore, 1907), and Knoop hardness (F. Knoop, 1939). The internationally standardized (ISO) hardness scales are Brinell hardness, Vickers hardness, Rockwell hardness, and Rockwell superficial hardness.
Like many other mechanical characteristics, hardness is a relative value that has no fundamental quantity or absolute standard, which is different from physical quantities such as length, time, mass, or electric current. Experiments have proved that hardness is correlated to other mechanical characteristics such as tensile strength, yield strength, elastic limit, resistance to wear, ductility, etc. Because of this fact, and because when compared with other types of material tests, hardness testers are less expensive and hardness tests are easier and less costly in specimen fabrication and measuring operations, hardness is often used as a substitute measure to determine other physical characteristics.

1.2 Hardness scales

Table 1 shows ISO/JIS hardness related standards. Although hardness is a relative value, Brinell, Vickers, and Knoop hardnesses are expressed by a unit of stress (kgf/mm^2). These hardness scales are closely correlated to tensile strength, which can be expressed as $H \approx 0.3\sigma_B$ (H: hardness, σ_B: tensile strength, MPa). This approximation will vary slightly for different materials. However, Rockwell, Rockwell superficial, and Shore hardnesses are unitless quantities and are expressed by a relative hardness number under given test conditions. The hardnesses that are quantified by units are determined by measuring the dimensions of the indentation using a microscope or profile projector (optical comparator). The unitless hardness numbers can be indicated directly on the hardness testing machine; this is where automated hardness measurement is becoming prevalent.
Shore hardness is determined by measuring the amount of rebound of a hammer that is dropped on the specimen from a known height. This is called dynamic hardness. The other hardness scales are classified as an indentation hardness or a static hardness because hardness numbers are given by the size of the indentation when an indenter is slowly pressed into the specimen.

Table 1a ISO hardness related standards

Hardness	Test method	Standard block	Testing machine
Brinell	6506-'81	726-'82	156-'82
Vickers (0.2 – 100kgf)	6507/1-'82 6507/2-'83	640-'83	146-'83
Rockwell	6508-'86	674-'88	716-'86
Rockwell superficial	DIS1024	DIS1355	DIS1079
Vickers (less than 0.2kgf)	DIS6507/3	DIS640/2	DIS146/2
Knoop	DIS4545	DIS4547	DIS4546

Table 1b JIS hardness related standards

Hardness	Test method	Standard block	Testing machine
Brinell	Z2243	B7736	B7724
Vickers	Z2244	B7735	B7725
Micro	Z2251	B7735	B7734
Rockwell	Z2245/K7202	B7730	B7726
Shore	Z2246	B7731	B7727

1.3 Applications of different hardness scales

The optimum hardness scale may not be uniquely determined for the type of specimen to be tested. **Table 2** is a guide for selecting the appropriate hardness scale according to the application, material, and conditions. Other factors, such as the predominant practice of the specific trade, should be taken into consideration when selecting the hardness scale.

Table 2 Hardness scales according to application

Hardness	Brinell	Vickers	Knoop	Rockwell	Rockwell superficial	Shore
Main application	Raw metals	Not specified	Brittle materials Surface layer	Select the scale according to the material (see Table 3).		Large specimen
Eligible material	Metals of HB650 or less [*1]	• Metals • Carbide	• Metals • Glass • Ceramics	• Metals • Plastics	Metals	Steels
Minimum thickness of specimen	8h or more h: Depth of indentation [*2]	1.5*d* or more d: Diagonal length of indentation	0.3*d* or more d: The longer diagonal length of indentation	10h or more (B, C scales) h: Depth of indentation		10mm or more
Size of indentation	Diameter < 0.6*D* Depth < 0.1*D* D: Indenter diameter	See Fig. 3		Depth < 0.26mm	Depth ≤ 0.1mm	
Remarks		For mirror-finish surfaces (Note: Measured hardness varies with the degree of surface finish.)		A close fit between the specimen and anvil is required.		Specimen weight: 100g or more (Preferably heavier than standard block)
Example	Castings	–	Nitrided surface	Bearings	Thin sheet steel	Rolls

Notes

*1: HB320 or less when a steel ball indenter is used.

*2: $h \approx F/\pi DHB$ (mm), *F*: Test force (kgf), *D*: Diameter (mm) of indenter, *HB*: Brinell hardness

1.4 Indentation hardness and load conditions

Indentation hardness is the resistance of a material to indentation when subjected to a static force. This requires that the indenter be slowly pressed into the material. Indentation hardness measurements vary depending on the loading speed and load duration. It is important to select a hardness testing machine that has appropriate load settings and highly reproducible load conditions.

(1) Loading speed and hardness
Fig. 1 shows the relationship between the loading speed and the hardness determined under given load and specimen conditions. The measured hardness of a specimen decreases at lower and higher loading speeds, as compared to an intermediate loading speed, where the measured hardness remains fairly constant. This is because the indentation depth of the indenter increases due to the inertia of the loading mechanism at higher speeds and, at lower speeds, due to the extended load duration. The optimum loading speed should provide constant hardness measurements and short operation time. The "stable" range, for a given load, is different for different loading mechanisms. For this reason, the optimum loading speed should be selected according to the type of the hardness tester. Normally, the load need only be applied for a few seconds for most hardness tests – from microhardness tests with a 10gf load to Brinell hardness tests with a 3000kgf load.

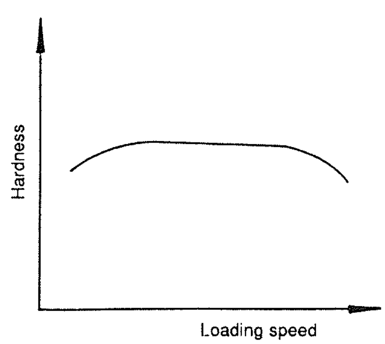


Fig. 1 Loading speed and hardness

(2) Load duration and hardness
The longer the load is applied, the lower the measured hardness. Variations in measurements, however, tend to remain constant for different load durations. The standard load duration specified in ISO is between 10 and 15 seconds.

1.5 Conversion between different hardness scales

Because hardness has no absolute standard, conversion between different hardness scales cannot be represented theoretically and can only be given in empirical values which differ depending on the material. Conversion values given in a hardness conversion table (example: ASTM E140) are average values for the materials listed in the table and should be considered as approximate values.
Vickers hardness and Rockwell hardness will be compared for example. The diagonal length of indentation in a Vickers hardness test changes very little between when a load is applied, and after it is removed. The indentation depth of the indenter in a Rockwell hardness test changes significantly between when a load is applied, and after it is removed (e.g., for 60HRC, the indentation depth is 100μm and the measured hardness, indicated after the load is removed, is about 80μm due to an elastic recovery of 20μm).
Thus, Vickers hardness is basically determined by the depth of indentation when the load is applied, which is a function of the strength (σ_B) of the material. Rockwell hardness is determined by both the depth of indentation when the load is applied, and the amount of elastic recovery, which are functions of tensile strength (σ_B) and Young's modulus (E), respectively. These relationships may be expressed as follows:

$$HV \approx f(\sigma_B)$$
$$HR \approx f(\sigma_B, E)$$

The above facts indicate that when two materials, having the same strength and different Young's moduli, are measured, Rockwell hardness measurements vary significantly, while Vickers hardness measurements will be almost free from variation.

Definitions of Hardness

2.1 Brinell hardness

The Brinell hardness testing method was first standardized hardness scale.
In the Brinell hardness test, a steel or carbide ball indenter (diameter: *D*) is pressed into the specimen under a test force. The hardness number (*HB*) is obtained by dividing the applied test force, *F* (N), by the area, *S* (mm^2), of contact between the indenter and specimen. This area is calculated from the diameter, *d* (mm), of the indentation when the indenter is removed. HBS and HBW are used to express Brinell hardness when a steel indenter or carbide ball indenter is used respectively.

$$HBS\,(HBW) = 0.102\frac{F}{S} = 0.102\frac{2F}{\pi D\left(D-\sqrt{D^2-d^2}\right)}$$

There is very little variation in Brinell hardness measurements when different loads are applied to a given material if the load condition (*F/D²*) is the same. Because of this feature, Brinell hardness tests that use a small load are common in many countries. Brinell hardness tests using a load of 2452N (250kgf) or less can be performed by installing the appropriate ball indenter and weight on a Rockwell, Rockwell superficial, or Vickers hardness testing machine.

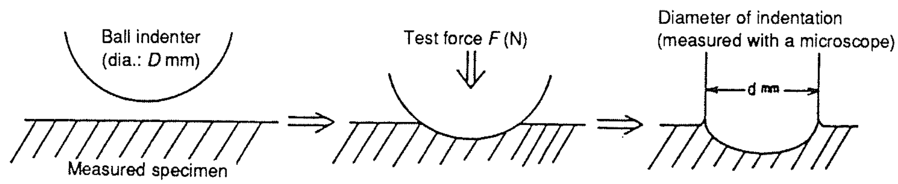


Fig. 2

2.2 Vickers hardness

In the Vickers hardness test, a diamond pyramid indenter with a 136° angle between opposite faces is pressed into the specimen under a test force. The hardness number is obtained by dividing the applied test force, *F* (N), by the area, *S* (mm^2), of contact between the indenter and specimen. This area is calculated from the diagonal length (average of the two diagonals), *d* (mm), of the indentation when the indenter is removed.

$$HV = 0.102\frac{F}{S} = 0.102\frac{2F\sin(\theta/2)}{d^2} = 0.1891\frac{F}{d^2}$$

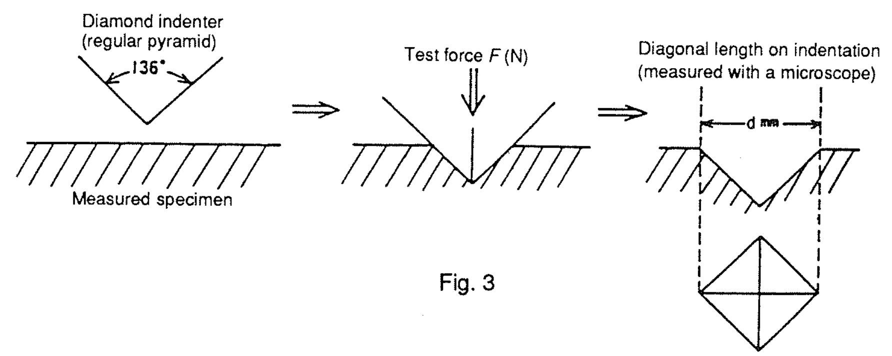


Fig. 3

2.3 Knoop hardness

In the Knoop hardness test, a diamond pyramid indenter, which has a rhombic base with included apical angles of 172°30' and 130°, is pressed into the specimen under a test force. The hardness number is obtained by dividing the applied test force, *F* (N), by the projected area, *A* (mm^2), of the indentation. This area is calculated from the longer diagonal length, *d* (mm), of the indentation when the indenter is removed.

$$HK = 0.102\frac{F}{A} = 0.102\frac{F}{0.07028d^2} = 1.451\frac{F}{d^2}$$

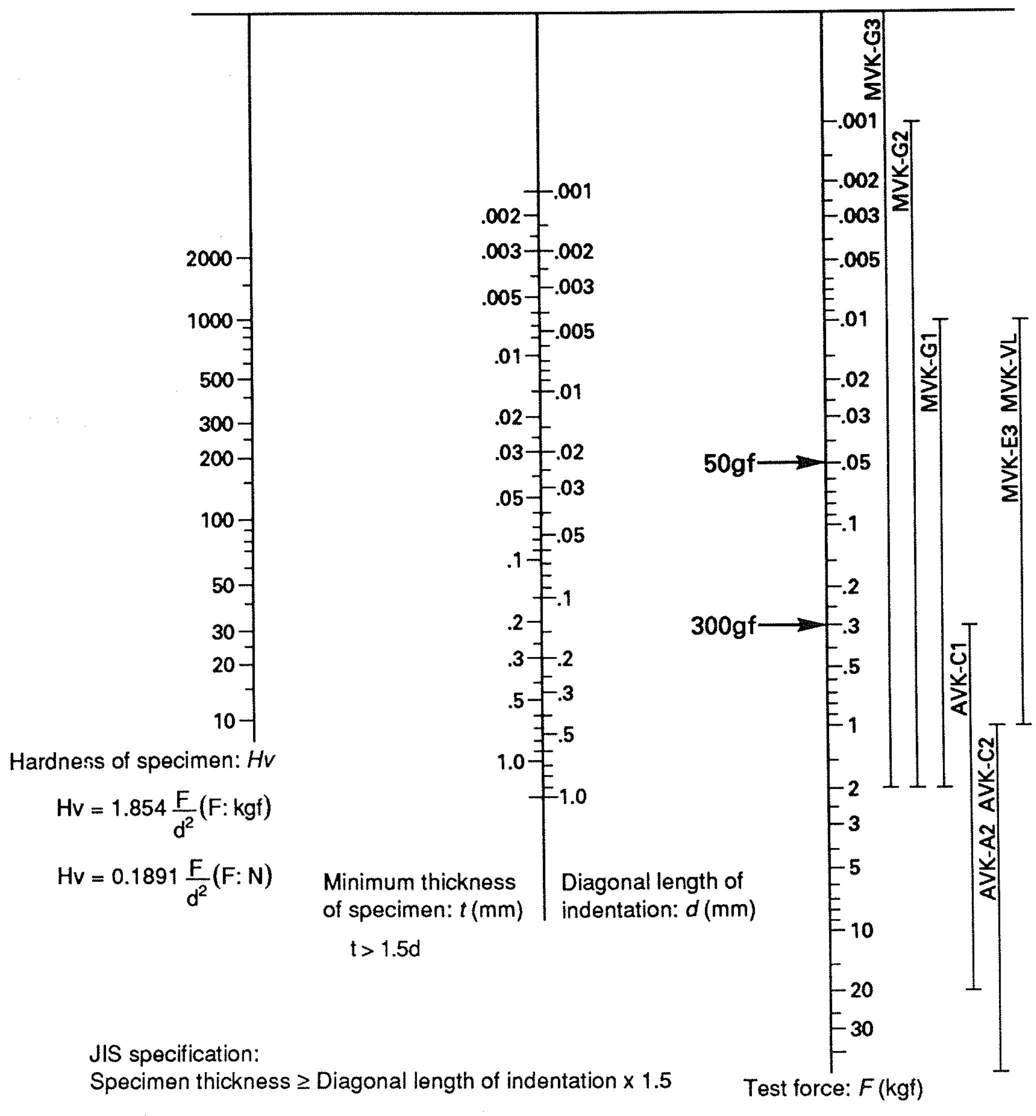
Knoop hardness can be measured by installing a Knoop indenter on a Vickers hardness or microhardness testing machine. The machine must be adjusted to match the type of indenter.

Exercise

Determine the model of Mitutoyo hardness tester that is best suited to each of the following tests:

Ex. 1: Testing the hardness of a small part of a machine.
Thickness of the part: 20mm
Test force: 300gf and 50gf

Relationship between Vickers hardness and minimum thickness

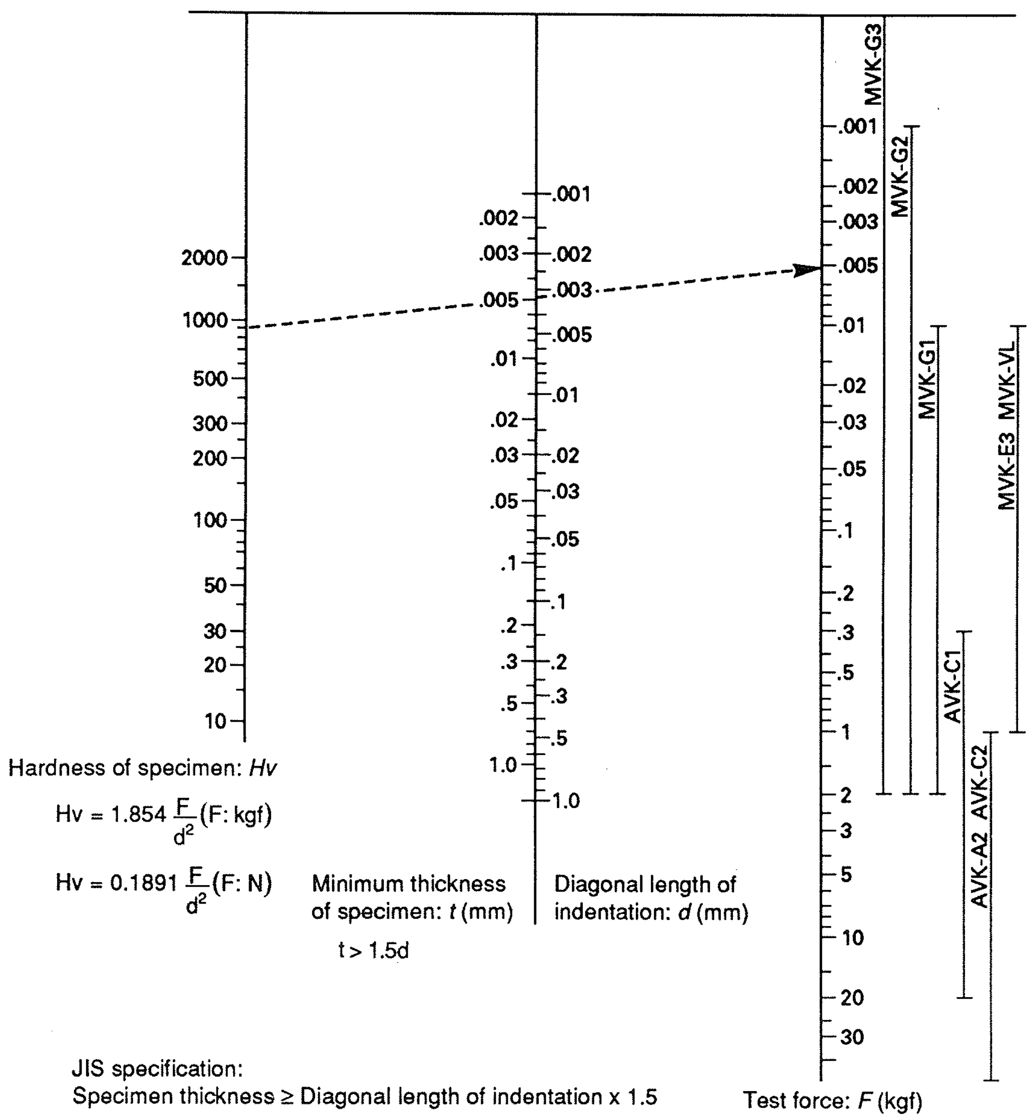


Answer: MVK-VL, MVK-G1, MVK-E3.

Exercise

Ex. 2: Testing the hardness of the coating of a product.
Expected hardness of the coating: 900HV (Vickers hardness)
Thickness of the coating: 5μm

Relationship between Vickers hardness and minimum thickness

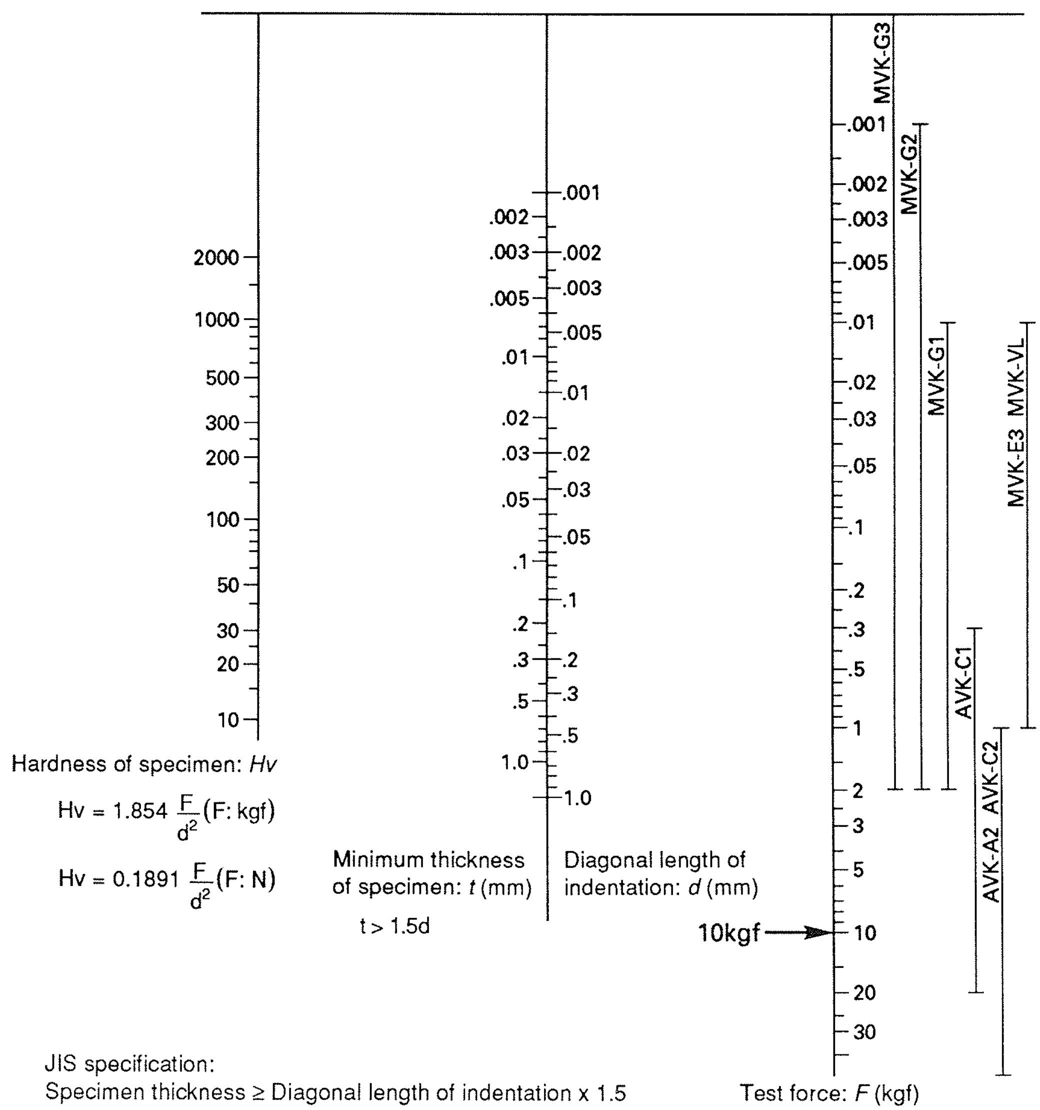


Answer: MVK-G3, MVK-G2.

Exercise

Ex. 3: Determining the optimum hardness of weld based on JIS Z 3101.
Test force: 10kgf

Relationship between Vickers hardness and minimum thickness

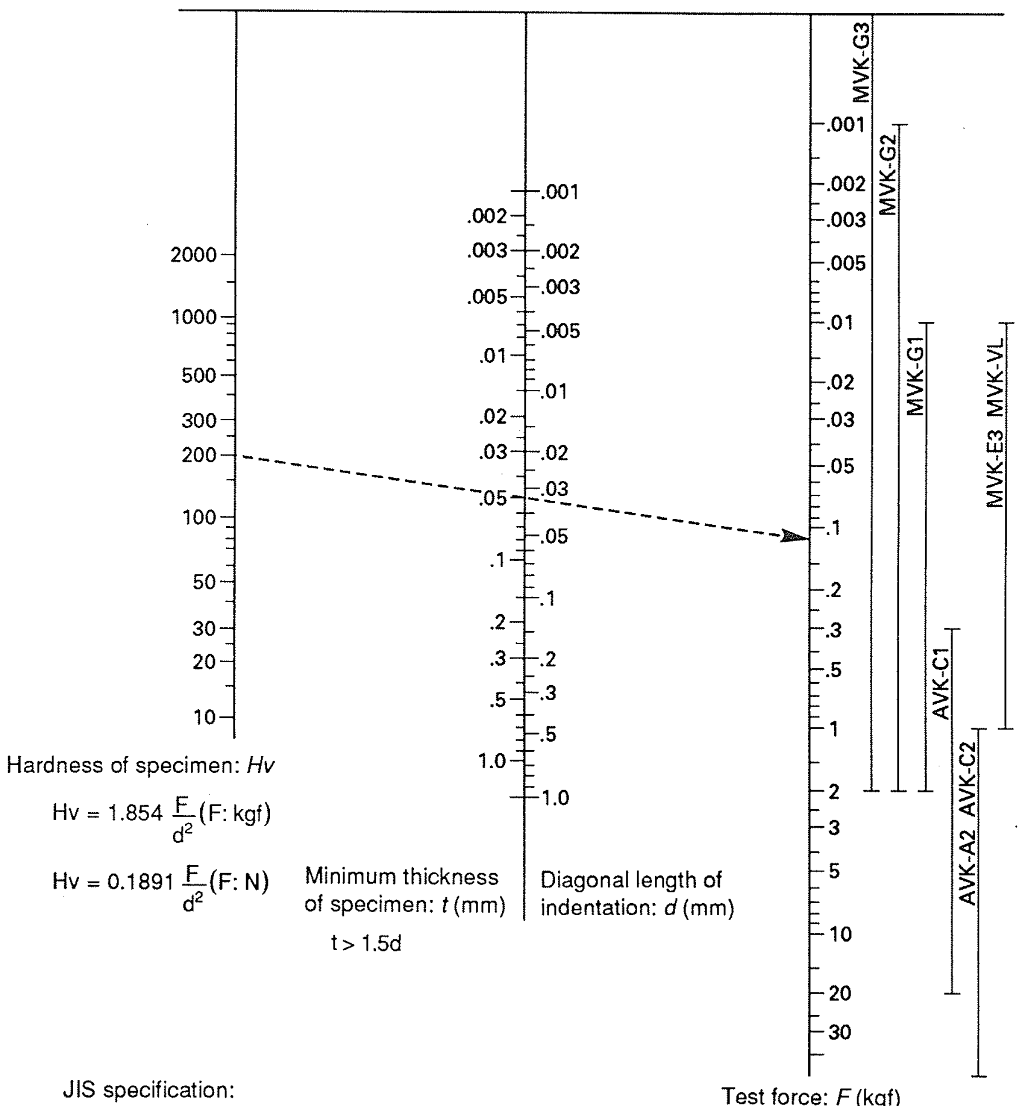


Answer: AVK-A2, AVK-C2 (AVKC-1)

Exercise

Ex. 4: Testing the hardness of a small part made of brass.
Expected hardness of the part: 200HV
Thickness of the part: 50µm

Relationship between Vickers hardness and minimum thickness



JIS specification:
Specimen thickness ≥ Diagonal length of indentation x 1.5

Answer: MVK-VL, MVK-G1, MVK-E3, (MVK-G2, MVK-G3).

2.4 Rockwell hardness and Rockwell superficial hardness

In the Rockwell hardness and Rockwell superficial hardness tests, a conical diamond indenter with a 120° angle and a radius of curvature of 0.2mm, or a steel or carbide ball indenter is pressed into the specimen. First, a preliminary test force is applied, then a total test force is applied, and then the test force is reduced to the preliminary test force. The hardness number is determined from the difference, *h*, of the indentation depth of the indenter between the first and second applications of the preliminary test force.

The Rockwell hardness test uses a preliminary test force of 98.07N (10kgf), and the Rockwell superficial hardness test uses a preliminary test force of 29.42N (3kgf).

The Rockwell and Rockwell superficial hardness have multiple scales to indicate specific combinations of indenter type, test force and a formula to obtain the hardness, as shown in **Table 3**.

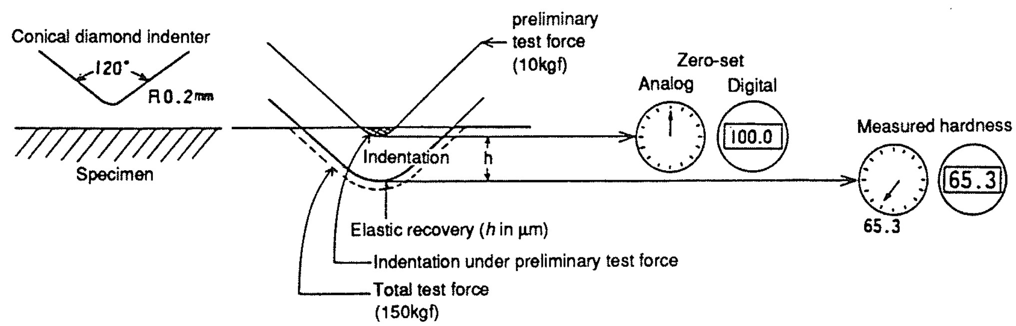


Fig. 4

Table 3 Rockwell hardness and Rockwell superficial hardness

			Rockwell hardness			Rockwell superficial hardness			Applications
Preliminary test force N (kgf)			98.07 (10)			29.42 (3)			
Total test force N (kgf)			588.4 (60)	980.7 (100)	1471 (150)	147.1 (15)	294.2 (30)	441.3 (45)	
Indenter	Diamond indenter		A	D	C	15N	30N	45N	Steel
	Ball indenter (Diameter: mm)	1.5875	F	B	G	15T	30T	45T	Mild steel, copper alloys
		3.175	H	E	K	15W	30W	45W	Soft metals, plastics
		6.35	L	M	P	15X	30X	45X	
		12.7	R	S	V	15Y	30Y	45Y	
Formula to calculate hardness [1]			100 − 0.5h [2] 130 − 0.5h [3]			100 − h			

1) h: indentation depth (µm)
2) Using a diamond indenter
3) Using a ball indenter

The error factors involved in Rockwell hardness tests include test force errors, indicator errors, return deformation of the machine frame*, and form errors of the indenter. The form error of diamond indenters is the most significant cause of errors. **Table 4** shows JIS standards of the maximum permissible overall errors.

* Return deformation of the machine frame: The difference in deformation, in the loading direction, of the machine frame between the first and second applications of the preliminary test force.

Table 4 Permissible overall errors* of hardness testers (JIS)

60 – 65 HRC	±0.8	77 – 82 HR30N	±1.5
40 – 50 HRC	±0.8	65 – 70 HR30N	±1.5
30 – 35 HRC	±1.2	52 – 57 HR30N	±1.5
90 – 95 HRB	±1.2	73 – 78 HR30T	±1.5
30 – 35 HRB	±2.0	35 – 40 HR30T	±1.5

* Overall error: mean value of five measurements – standard value

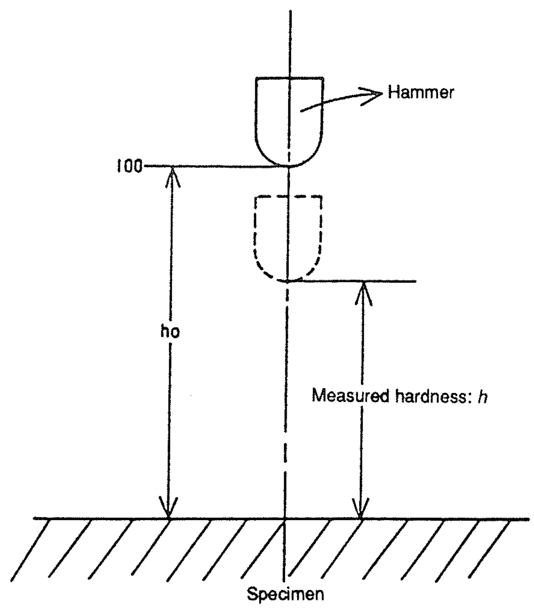


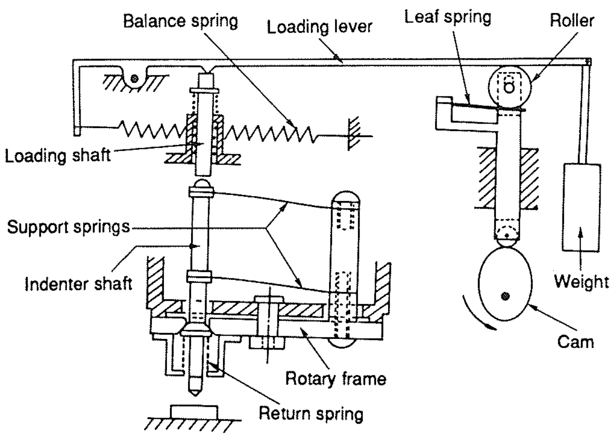
Fig. 5

2.5 Shore hardness

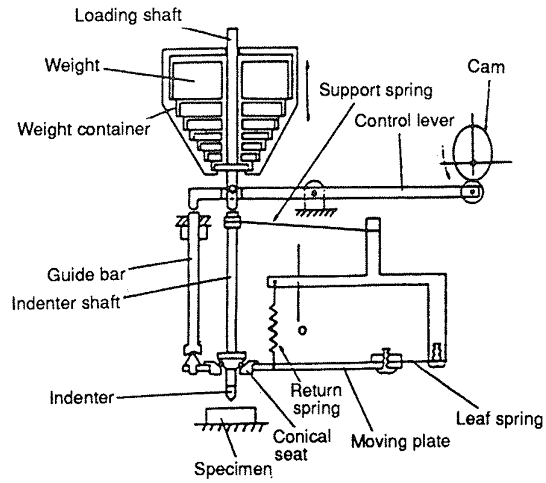
Shore hardness is determined by measuring the amount of rebound of a diamond-tipped hammer that is dropped on the specimen from a given height. The higher the rebound, the harder the material. According to an old manual from Shore Company, Shore hardness numbers are given by rebound heights (expressed as multiples of one-hundredth), relative to the average rebound height (equals 100) of the hammer that is dropped on a standard specimen made of hardened pure high-carbon steel.
JIS derives Shore hardness (HS) from Vickers hardness (HV) using the following conversion formula:

$$HS = (1.743a - 1.150a^2 + 0.5818a^3 - 0.1609a^4) \times 100$$
$$a = HV/1000$$

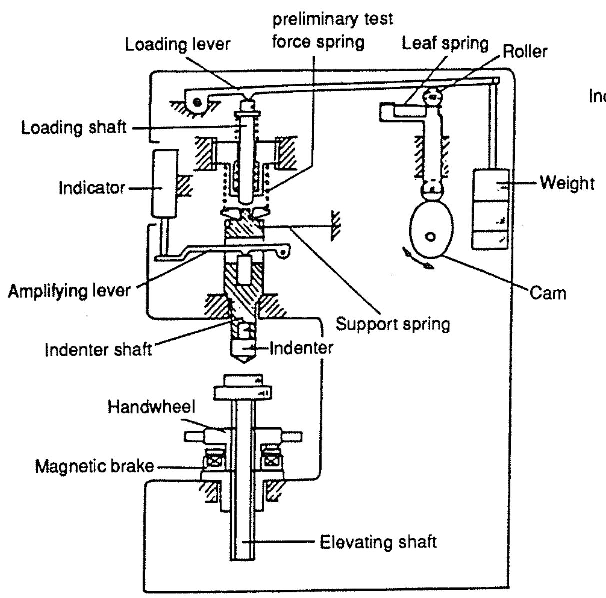
Mechanism of Hardness Testing Machines



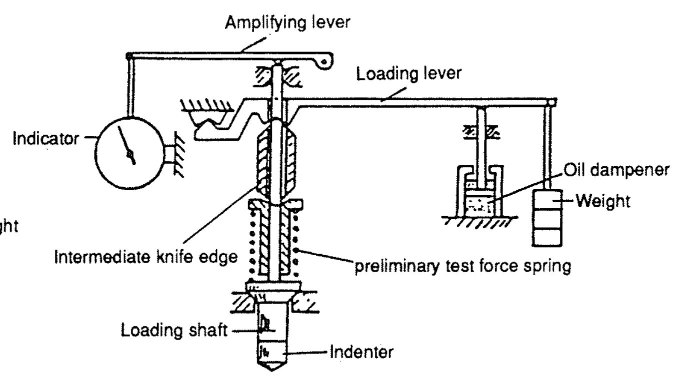
a) Loading mechanism of Vickers hardness testing machine (model AVK)



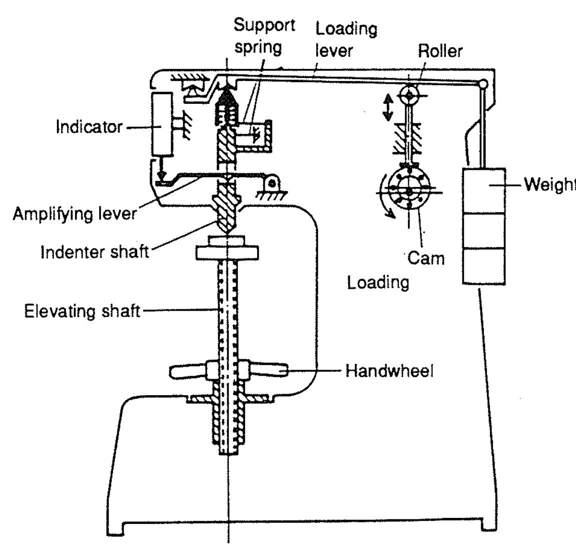
c) Loading mechanism of microhardness testing machine (model MVK-E3)



b) Loading mechanism of Rockwell hardness testing machine (model ARK/ATK-F1000)



d) Loading mechanism of Rockwell hardness testing machine



e) Loading mechanism of Rockwell hardness testing machine (model AR-10)

Fig. 6 Loading mechanism of hardness testing machine

Features of Mitutoyo Micro Hardness Testing Machines

A. The direct loading method minimizes the reduction in measured hardness caused by vibration. (Fig. 7)

B. No lateral force is applied to the indenter shaft. (Fig. 7)

C. The instrumental error of every hardness testing machine has been calibrated against standard hardness testing machines.

D. The loading mechanism has been accurately adjusted using a high precision load measuring machine (accuracy: ±5mg) developed in-house.

E. The glass edge method used in the measuring section provides sharp indentation images, thereby ensuring accurate measurement. (Fig. 9)

F. The test block has a standard indentation which can be used for measurement training.

G. No. 1 sales record in Japan.

H. Standard hardness testing machines are used in many inspection institutes including the Nippon Marine Association and the Japan Bearing Inspection Institute.

I. High durability. (A 30-year-old machine is still in use today.)

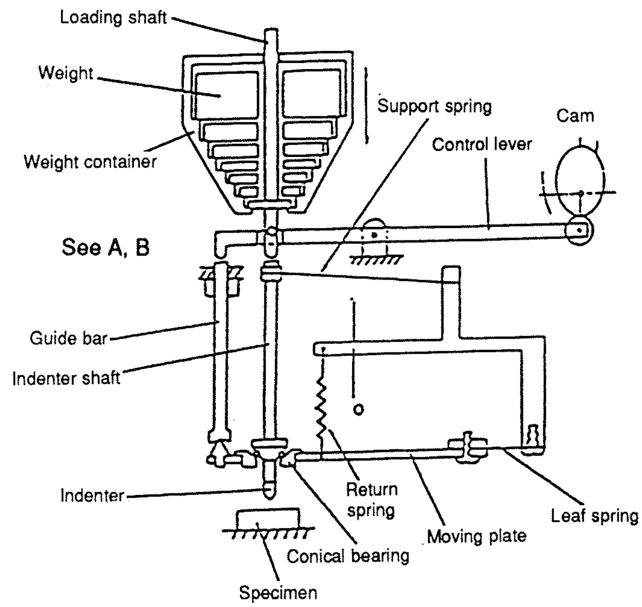


Fig. 7 Loading mechanism of microhardness tester (model MVK-E3)

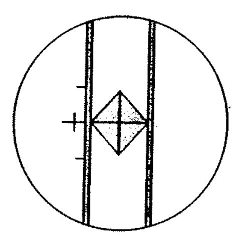


Fig. 8

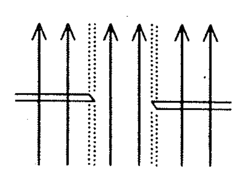


Fig. 9

Performance of Mitutoyo Rockwell Hardness Testing Machines Models ARK-F and ATK-F
(Advantages over hardness testing machines from other manufactures)

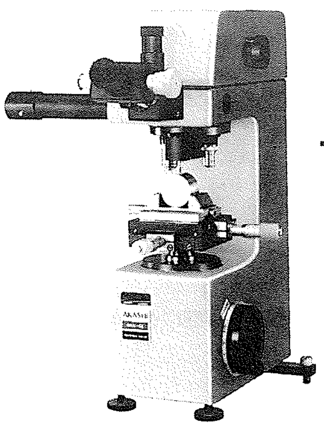
Item	Feature
Loading mechanism	No dynamic force is applied to the specimen because the final loading speed of the total test force is decreased by the damping mechanism.
Force control	High repeatability of measurements because a constant-speed motor is used for automatic application, holding, and removal of test force.
Indenter discrimination	The type of indenter is automatically identified when the indenter is inserted in the holder. The applicable hardness scale is also automatically determined. These functions (available on models ARK-F3000 and ATK-F3000) eliminate the need to check the scale and prevent errors when determining hardness numbers.
Auto-brake for preliminary test force	A brake is automatically applied to the preliminary test force, eliminating the need for repeated measurements (ARK-F1000 and ATK-F1000).
Full-automatic measurement	Fully-automatic operation from the application of preliminary test force and total test force to the display of measured hardness. All the operator has to do is to press the start switch. (Printout of data is available on the ARK-F3000 and ATK-F300 as standard, and on other models as an option.)
Maximum specimen dimensions	Height: 255mm (ARK-F1000, 2000) Height: 225mm (ARK-F3000) Height: 235mm (ATK-F1000, 2000) Height: 205mm (ATK-F3000) Depth: 145mm (common to all models)
Display	Interactive operation on the large-size display (LCD) permits timer setting, hardness conversion and data output selection. Maximum indentation depth is also displayed and output to the printer, allowing stress testing.
Output data	Maximum, minimum, mean, standard deviation, and conversion to other hardness scales can be performed on the measured hardness value. The built-in printer eliminates the need for manual recording of measurements (provided on the ARK-F3000, ATK-F3000 as standard).
Output interface	Centronics and RS-232C interfaces are supplied as standard.

• See specific catalogs for detailed information.

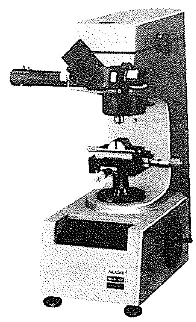
Recent Trends in User's Requirements

Recent sales records show that there are an increasing number of cases where users of conventional hardness testing machines upgrade their system in order to achieve labor saving and high efficiency. It is reported that inspections can be performed by operators without special training and no longer need to be performed by skilled technicians.

1. Example of system upgrade from Vickers and micro hardness testing machine

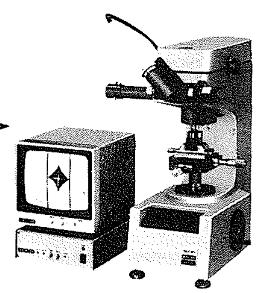


No. 810-100 (K, A, D, E)
MVK-E3



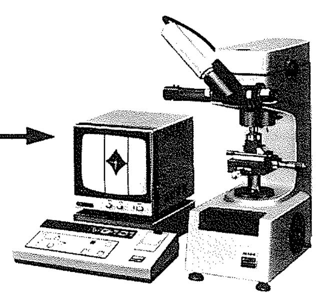
Measured values are digitally displayed and printed, eliminating reading and recording errors.

MVK-G1 No. 810-112 (K, A, D, E)
MVK-G2
MVK-G3



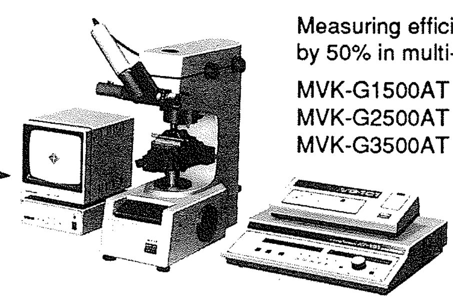
Eliminates eye fatigue and human errors caused by one-eye observation.

MVK-G1000
MVK-G2000
MVK-G3000



The best selling system.

MVK-G1500 No. 810-902 (K, A, D, E)
MVK-G2500
MVK-G3500

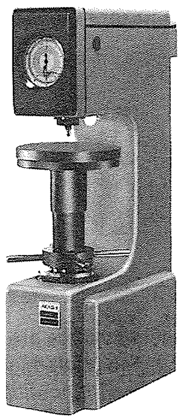


Measuring efficiency can be increased by 50% in multi-point measurement.

MVK-G1500AT
MVK-G2500AT
MVK-G3500AT

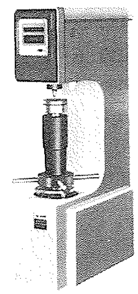
K: 100V
A: 120V
D: 220V
E: 240V

2. Example of system upgrade from Rockwell hardness testing machine



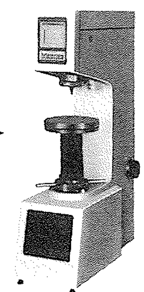
Analog type
AR-10 No. 810-200 (K, A, D, E)

K: 100V
A: 120V
D: 220V
E: 240V



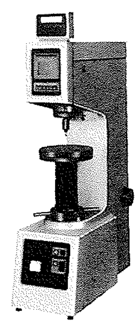
Digital display eliminates reading errors.

ARK-500



Digital display eliminates reading errors.
(Printer is optional.)

ARK-F1000 No. 810-251 (K, A, D, E)



Automatic measurement at a touch of a button. (Built-in printer and data processor)

ARK-F2000
ARK-F3000

Check List for Hardness Testing Machine Scale

	(Example)
1. What is to be measured?	Spectacles frame
2. What is the thickness of the portion to be measured?	20μm
3. What portion is to be measured?	Sides of spectacles frame
4. What hardness scale (Vickers, Rockwell, etc.) is required?	Not specified
5. What is the size of the specimen?	4mm(W) x 10mm(L)
6. Is a special system (digital readout, TV monitor system, etc.) required?	Required

[Let's try!]

Which type of hardness tester would you recommend to a user whose request is as shown in the above list ?

(1) Micro Vickers

Manual	Digital	w/TV	w/TV, DP/Stage	Test force (gf)
MVK-E3	MVK-G1	MVK-G1000	MVK-G1500/AT	10 – 1000
	MVK-G2	MVK-G2000	MVK-G2500/AT	1 – 2000
	MVK-G3	MVK-G3000	MVK-G3500/AT	0.2 – 2000

(2) Vickers

Manual	Digital	w/TV	w/TV, DP/Stage	Test force (kgf)
	AVK-C1	AVK-C1000	AVK-C1500/AT	0.3 – 20
AVK-A2	AVK-C2	AVK-C2000	AVK-C2500/AT	1 – 50

(3) Rockwell

Manual	Motorized	Motorized (Indenter descrimi-nator Calculator)	Preliminary test force (kgf)	Total test force (kgf)
ARK-F1000	ARK-F2000	ARK-F3000	10	60, 100, 150
ARK-500			10	60, 100, 150
AR-10			10	60, 100, 150
ATK-F1000	ATK-F2000	ATK-F3000	3	15, 30, 45
			10	60, 100, 150

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