



modulo: Proprietà viscoelastiche e proprietà meccaniche dei polimeri

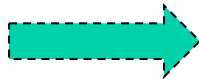
Misure di proprietà meccaniche di superficie

R. Pantani

Standard per prove meccaniche

Table 1 ASTM and ISO mechanical test standards for plastics

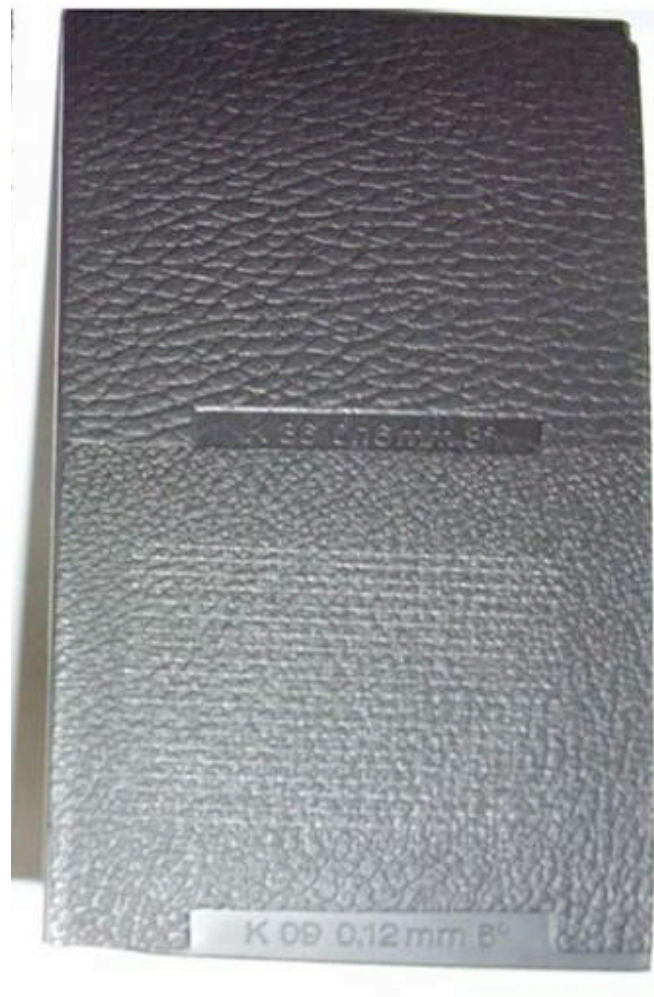
ASTM standard	ISO standard	Topic area of standard
Specimen preparation		
D 618	291	Methods of specimen conditioning
D 955	294-4	Measuring shrinkage from mold dimensions of molded thermoplastics
D 3419	10724	In-line screw-injection molding of test specimens from thermosetting compounds
D 3641	294-1,2,3	Injection molding test specimens of thermoplastic molding and extrusion materials
D 4703	293	Compression molding thermoplastic materials into test specimens, plaques, or sheets
D 524	95	Compression molding test specimens of thermosetting molding compounds
D 6289	2577	Measuring shrinkage from mold dimensions of molded thermosetting plastics
Mechanical properties		
D 256	180	Determining the pendulum impact resistance of notched specimens of plastics
D 638	527-1,2	Tensile properties of plastics
D 695	604	Compressive properties of rigid plastics
D 785	2039-2	Rockwell hardness of plastics and electrical insulating materials
D 790	178	Flexural properties of unreinforced and reinforced plastics and insulating materials
D 882	527-3	Tensile properties of thin plastic sheeting
D 1043	458-1	Stiffness properties of plastics as a function of temperature by means of a torsion test
D 1044	9352	Resistance of transparent plastics to surface abrasion
D 1708	6239	Tensile properties of plastics by use of microtensile specimens
D 1822	8256	Tensile-impact energy to break plastics and electrical insulating materials
D 1894	6601	Static and kinetic coefficients of friction of plastic film and sheeting
D 1922	6383-2	Propagation tear resistance of plastic film and thin sheeting by pendulum method
D 1938	6383-1	Tear propagation resistance of plastic film and thin sheeting by a single tear method
D 2990	899-1,2	Tensile, compressive, and flexural creep and creep-rupture of plastics
D 3763	6603-2	High-speed puncture properties of plastics using load and displacement sensors
D 4065	6721-1	Determining and reporting dynamic mechanical properties of plastics
D 4092	6721	Dynamic mechanical measurements on plastics
D 4440	6721-10	Rheological measurement of polymer melts using dynamic mechanical procedures
D 5023	6721-3	Measuring the dynamic mechanical properties of plastics using three-point bending
D 5026	6721-5	Measuring the dynamic mechanical properties of plastics in tension
D 5045	572	Plane-strain fracture toughness and strain energy release rate of plastic materials
D 5083	3268	Tensile properties of reinforced thermosetting plastics using straight-sided specimens
D 5279	6721	Measuring the dynamic mechanical properties of plastics in torsion



Si distinguono due categorie di test per la durezza:

(a) Resistenza al graffio

(b) Resistenza alla penetrazione



Resistenza ai graffi (“Scratch resistance”)

Il primo criterio di resistenza ai graffi, **la scala di durezza Mohs**, è stato concepito nel 1812.

E' ancora utilizzato per classificare i vari minerali e consiste di un elenco selezionato e ordinato in modo che ogni minerale è in grado di graffiare quelli che lo precedono.

La scala di Mohs è utile per definire la resistenza ai graffi delle plastiche rispetto a materiali con le quali la plastica può venire in contatto durante l'esercizio. E' di valore limitato, tuttavia, per fare differenze tra le varie materie plastiche, poiché praticamente tutti i polimeri, sia termoindurenti che e termoplastici,

Mohs' scale of hardness

Hardness number	Mineral	Hardness number	Mineral
1	Talc	6	Orthoclase
2	Gypsum	7	Quartz
3	Calcite	8	Topaz
4	Fluorite	9	Corundum
5	Apatite	10	Diamond

sono nell'intervallo di **2-3 della scala di Mohs**. Molti dei materiali con cui le plastiche entrano a contatto durante l'esercizio sono superiori a 3 nella scala Mohs.

Nell'esaminare un polimero, la durezza può essere stimata utilizzando un'unghia (Mohs 2), uno stilo di ottone (Mohs 3), una lama di coltello (Mohs 4), o un pezzo di vetro (Mohs 5).

La resistenza al graffio relativa dei due polimeri può essere facilmente determinata osservando il graffio lasciato sulla superficie di uno con l'angolo del altro.

La resistenza al graffio di polimeri rigidi è correlata all'abrasione. In generale, la resistenza al graffio dei polimeri è **proporzionale al modulo**. La gomma reticolata mostra tuttavia una elevata resistenza ai graffi, dovuta alla elevata deformabilità e resilienza.

Durezza alla penetrazione (“Indentation hardness”)

Il test di resistenza alla penetrazione viene effettuato comunemente sulle plastiche. In questo test una punta molto dura (una sfera di acciaio nella prova Brinell, una piramide diamantata nel test Vickers) viene spinta sotto l'azione di un determinato carico sulla superficie del materiale.

Quando una punta preme su una superficie, il materiale si deforma elasticamente. Se il carico aumenta, lo sforzo supera il limite elastico e la deformazione diventa plastica. Quanto il carico viene rilasciato, la deformazione plastica permane.

La durezza **Brinell** H in N/mm^2 (ISO 2039-1, 2, DIN 53456) è il quoziente fra la forza di prova F , che agisce mediante una sfera di 5 mm di diametro sulla superficie di materiale plastico e la superficie dell'impronta generata sotto il carico della sfera. La superficie dell'impronta viene calcolata dalla profondità di penetrazione misurata sotto il carico, 30 secondi dopo l'applicazione. Secondo la durezza del materiale plastico viene impiegato un valore delle seguenti scale di carico: 49, 132,358 oppure 961 N; il valore viene usato come indice nell'indicazione dei valori, per esempio $H\ 132$.

Durezza alla penetrazione (“Indentation hardness”)

Durezza α **Rockwell** $R\alpha$ (ISO 2039-2, ASTM D 785). Una sfera di 12,7 mm di diametro agisce sulla superficie con una forza di 588,4 N. Vengono misurate le profondità di penetrazione dopo 15 secondi (d_h) e 10 secondi (d_s).

La durezza α Rockwell risulta allora:

$$R\alpha = 150 - (d_h - d_s)$$

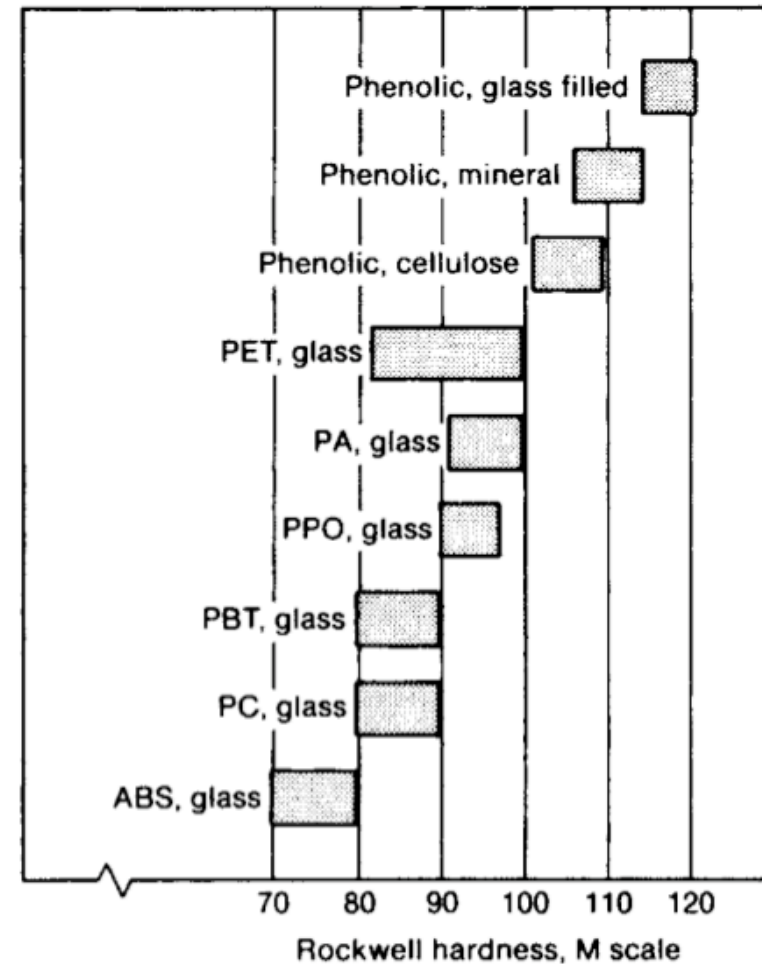
La Durezza **Rockwell HR** (ISO 2039-2, ASTM D 785) viene determinata dalla profondità di penetrazione e misurata *dopo il ritiro del carico principale* (durata azione 15 secondi):

HR = 130 - e.

Si fa distinzione fra 4 scale di durezza (R, L, M ed E), secondo la forza di prova F e il diametro della sfera d. Risulta:

		F	
d		588 N	980 N
12,7	mm	R	
6,35	mm	L	M
3,175	mm		E

Durezza alla penetrazione (“Indentation hardness”)



Rockwell hardness of engineering plastics.
PET, polyethylene terephthalate; PA, polyamide; PPO, polyphenylene oxide; PBT, polybutylene terephthalate; PC, polycarbonate; ABS, acrylonitrile-butadiene-styrene

Durezza alla penetrazione (“Indentation hardness”)

Durezza **Vickers HV** (DIN 50133). Una piramide di diamante, a base quadrata, viene posta per 40 secondi sulla superficie con carichi di prova F di 100, 300 oppure 600 N. Dopo l'eliminazione del carico viene misurata la lunghezza della diagonale dell'impronta d in mm.

La durezza Vickers HV risulta allora:

$$HV = \frac{0,189}{d^2} \cdot F$$

La durezza **Knoop HKn** (ASTM D1474) utilizza come corpo di penetrazione una piramide a base romboidale; la diagonale longitudinale e trasversale sono in rapporto 7/1.

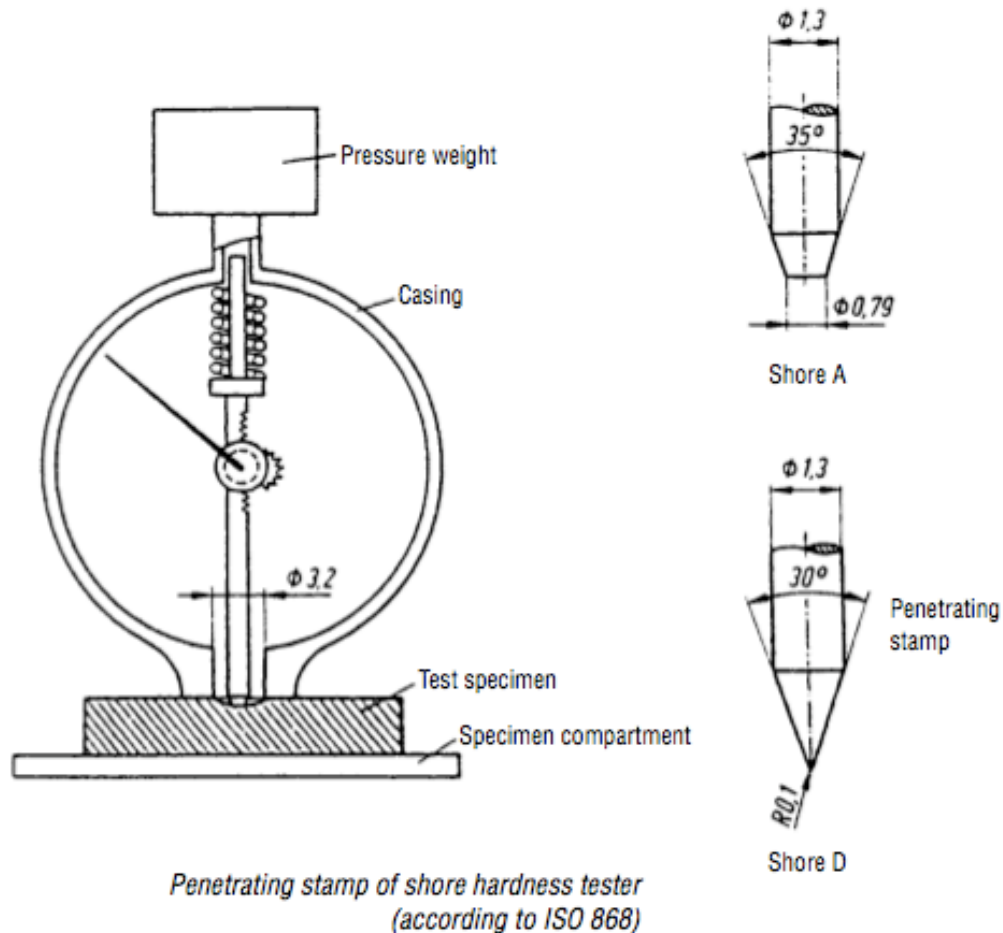
La durezza Knoop si calcola dal carico di prova F (in g) e dalla lunghezza della diagonale maggiore dell'impronta (in mm), dopo l'eliminazione del carico, secondo la seguente formula:

$$HKn = \frac{14230}{l^2} \cdot F$$

Le durezze Vickers e Knoop appartengono alle prove di durezza con piccolo carico; esse vengono prese in considerazione per il calcolo di effetti meccanici anisotropi, per esempio di orientamenti e tensioni proprie in strati vicini alla superficie.

Durezza alla penetrazione (“Indentation hardness”)

Le durezze **Shore A e D** (ISO 868/DIN 53505, ASTM D 2240) vengono determinate con apparecchi manuali su materiali plastici flessibili ed elastomeri. Si determina la resistenza alla penetrazione di un tronco di cono (Shore A) oppure di un cono con punta arrotondata (Shore D), come deformazione di una molla, 3 secondi dopo la compressione del durometro sulla superficie; nel caso di materiale plastico con un comportamento chiaramente plastico il tempo risulta di 15 secondi dopo la compressione



Durezza alla penetrazione (“Indentation hardness”)

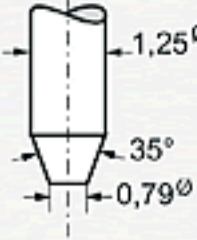
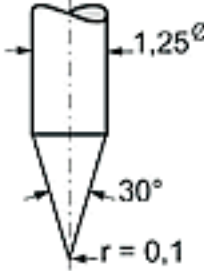
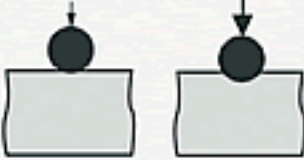
La durezza **Barcol** (DIN EN 59, ASTM D2583) viene determinata come la durezza Shore con un apparecchio manuale e un tronco di cono con una punta piatta di 0,157 mm

il test viene principalmente usato per misurare la durezza di plastiche rigide (rinforzate e non rinforzate). Il valore di durezza è ottenuto misurando la resistenza alla penetrazione di un punto d'acciaio tagliente sotto un carico della molla. Lo strumento, chiamato Barcol Impressor , consente una lettura diretta su una scala da 0 a 100. Il valore di durezza viene spesso utilizzato come misura del grado di polimerizzazione di una plastica o per il controllo del processo di indurimento (ad es. in resine di poliestere insature).

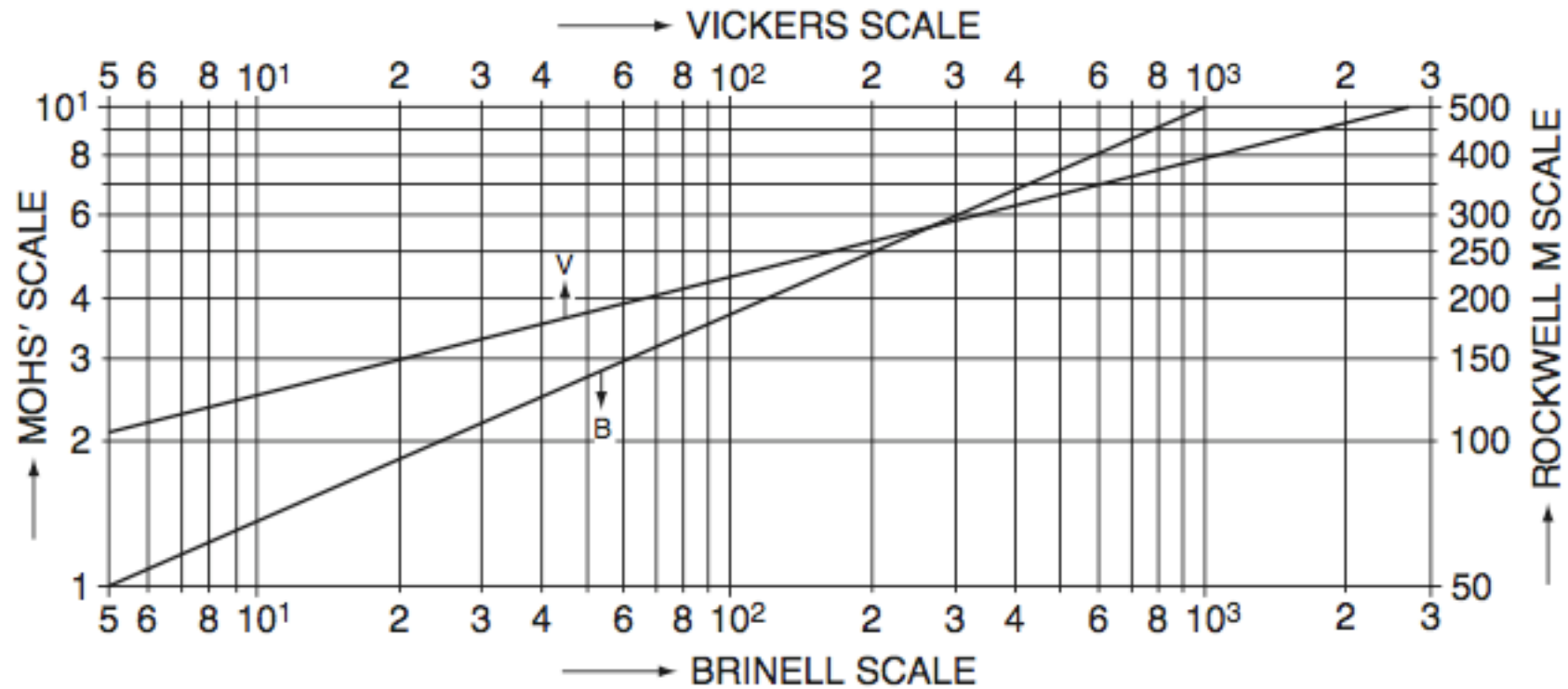


Ball Hardness

The steel ball used for the Ball Hardness test has a diameter of 5mm. Depending on the hardness of the plastic material being tested, it is placed under a load of 49, 132, 358 or 961N. These different loads take account of the fact that for geometrical reasons, the indentation depth does not increase in linear proportion to the load. The load should be chosen so the depth of indentation after 30 seconds lies between 0.15 and 0.35mm. The test piece must be at least 3mm thick.

Process	Shore A	Shore D	Ball Hardness	Rockwell Hardness
Standards	ISO 868 DIN 53 505	ISO 868 DIN 53 505	ISO 2039-1 DIN 53 456	ISO 2039-2
Indenter	Truncated cone 	Cone 	Ball 5 mm Ø Minor load Test load 	Ball Skale M: 6,35 mm Skale R: 12,7 mm Measures only permanent deformation, as measurement is done after removal of load
Test load	9,81 N	49,05 N	Steps for test load 49, 132, 358, 961 N depending on hardness	Skale M: 980 N Skale R: 588 N
Holding time	15 s	15 s	30 s	15 s
Uses	Soft elastomers, very soft thermoplastics	Hard elastomer, soft thermoplastics	Thermoplastics	Thermoplastics

Correlation between the hardness tests



Correlation between the hardness tests

Comparative hardness scales for soft materials

Hardness scale							Types of product
Mohs	Brinell	Rockwell		Shore			
		M	α ($\approx R$)	D	C	A ($\approx IRHD$)	
2	25	100					Hard plastics
	16	80					
	12	70	100	90			
	10	65	97	86			
	9	63	96	83			Moderately hard plastics
	8	60	93	80			
	7	57	90	77			
	6	54	88	74			
1	5	50	85	70			Soft plastics
	4	45		65	95		
	3	40	(50)	60	93	98	
	2	32		55	89	96	
	1.5	28		50	80	94	
	1	23		42	70	90	
	0.8	20		38	65	88	Rubbers
	0.6	17		35	57	85	
	0.5	15		30	50	80	
				25	43	75	
				20	36	70	
				15	27	60	
				12	21	50	
				10	18	40	
				8	15	30	
				6.5	11	20	
				4	8	10	

	Indentation hardness	Pyramid hardness „under load“	Shore hardness		Rockwell hardness						Barcol hardness (with device type No. 834-1)	Characteristics of hardness test process
	Ball 5 mm diam.	Quadratic py- ramid sur- faces = 136°	Truncated cone		Scale α	Scale R	Scale L	Scale M	Scale E	Scale K	Truncated cone d _{0.05} = 0,157 mm; 26°	Test specimen
			d _{0.05} = 0,79 mm; 35°	with spherical cap R = 0,1 mm; 30°	Ball 12,7 mm diam.	Ball 12,7 mm diam.	Ball 6,35 mm diam.	Ball 6,35 mm diam.	Ball 3,175 mm diam.	Ball 3,175 mm diam.		
	49 to 961 *)	0,5 to 4,9 *)	0,55 to 8,1	0 to 44,5	589	589	589	981	981	1472	65 to 77	Test force in N
	DIN 53456	none	DIN 53505	DIN 53505	ASTM D 785	ASTM D 785	ASTM D 785	ASTM D 785	ASTM D 785	ASTM D 785	DIN EN 59 ASTM D 2583	Heat
	H.../30	HV... 9/60	Shore A	Shore D	α HR	HRR	HRL	HRM	HRE	HRK	—	Characteristic
	N/mm ²	N/mm ²	—	—	—	—	—	—	—	—	—	Dimension
PE ND soft	10... 25	10... 20	95... >	40... 50	(<... 110)	<... 25	<	<	<	<	<	
PE HD hard	40... 65	40... 50	>	50... 70	25... 55	50... 75	3... 30	<	<	<	<	
PE-GF	60	45	>	65	50	80	30	<	<	<	<	
PP	40... 80	45... 75	>	65... 75	30... 70	85... 110	40... 85	<... 60	<	<	<	
PP-GF	75... 115	75... 85	>	70... 75	65... 90	100... 110	70... 90	30... 65	<	<	<	
PP-talc	85... 105	80... 110	>	75	80... 90	100... 105	70... 75	35... 40	<	<	<	
PVC hard	95... 145	90... 120	>	75... 80	75... 95	110... 115	80... 95	50... 70	<	<	<... 10	
PVC soft	<... 130	0,3... 140	55... >	<... 82	<... 105	<... 105 ...>	<... 100	<... 100	<	<	<	
PS	145... 195	155... 195	>	80	100... 110	120... >	100... 110	80... 85	<... 10	<	20... 30	
SAN	185... 205	175... 185	>	85	110... 115	125	105	90	15... 25	<	35... 40	
SB	70... 140	65... 140	>	70... 80	60... 90	90... 110...>	45... 95	<... 65	<	<	<... 10	
ABS	95... 120	90... 110	>	75... 80	85... 95	100... 110	70... 85	25... 50	<	<	<... 15	
ASA	70	65	>	75	65	90	45	— 15 resp. <	<	<	<	
AMMA	250	225	>	88	120	125	115	105	60	15	55	
PMMA	185... 210	185... 210	>	87... 88	110	125	115	105	55... 60	10... 20	50... 55	
POM	135... 175	135... 175	>	79... 82	95... 105	115... 120	100... 110	80... 95	<... 40	<	<... 15	
POM-GF	210	185	>	85	110	120	105	90	40	<	25	
PA 6	60... 85	50... 60	>	75	45... 75	95... 105	75... 85	40... 60	<	<	<	
PA 66	120	80	>	80	95	115	95	75... 80	10... 15	<	8	
PA 66-GF	230	150	>	85	115	120	110	100	60	25	40	
PA 610	90	80	>	78	80	105	85	55	<	<	<	

>: hardness of material is greater than is measurable with this process

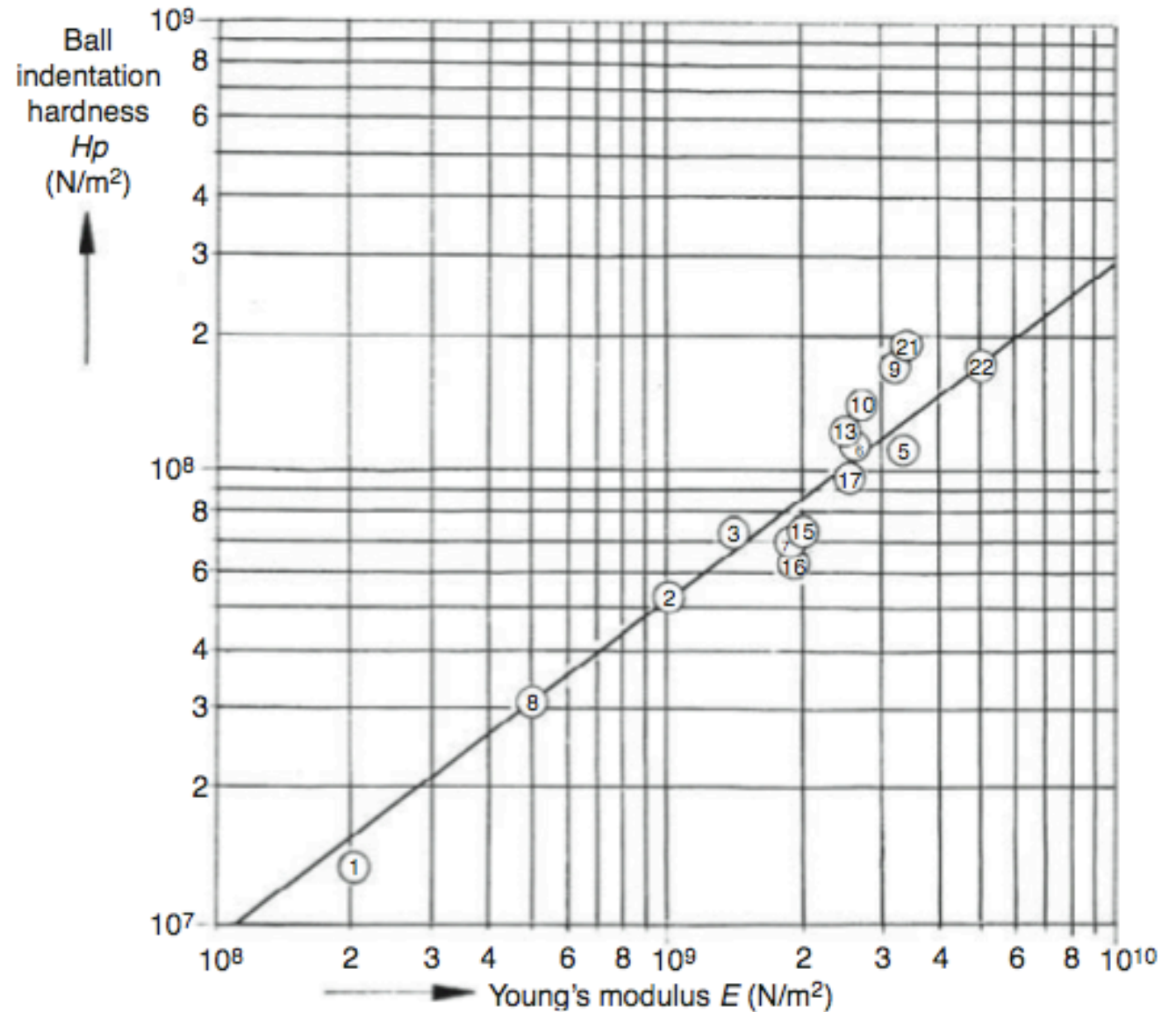
<=: hardness of material is less than is measurable with this process

>= "hardness of material is greater than is measurable with this process
 <= "hardness of material is less than is measurable with this process

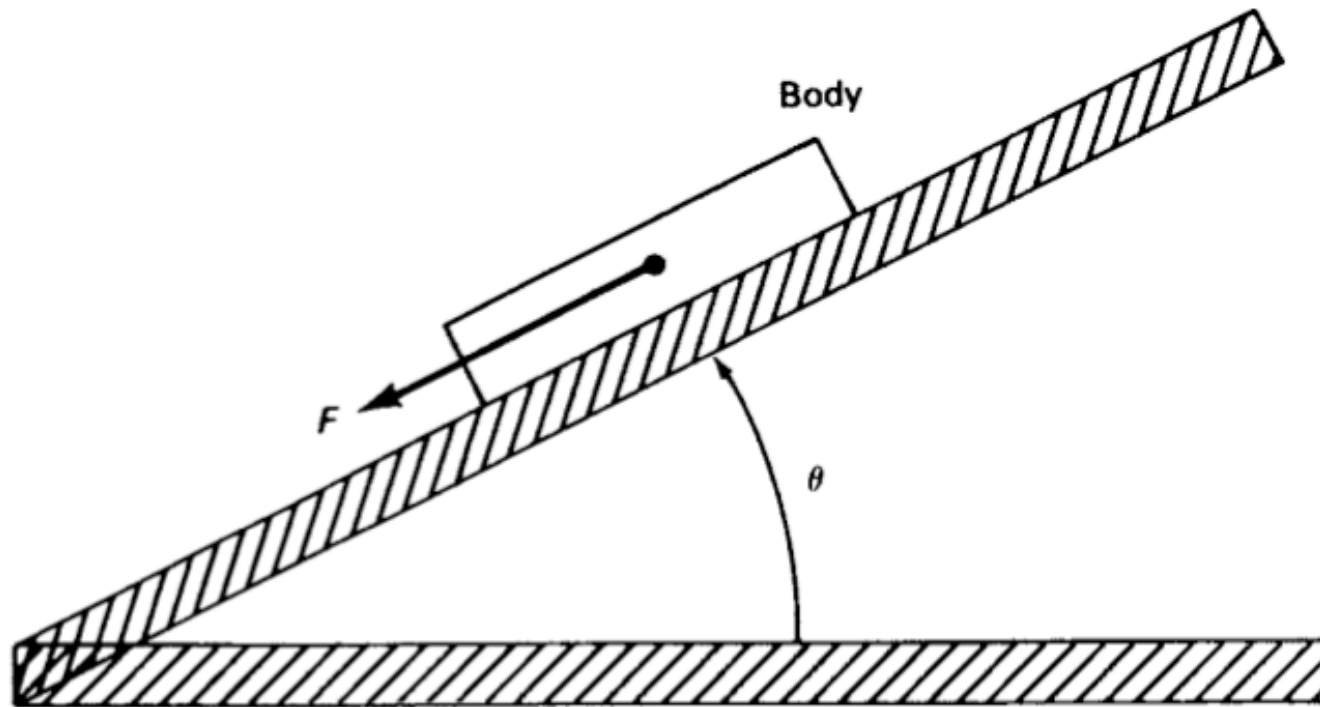
	Indentation hardness	Pyramid hardness "under load"	Shore hardness		Rockwell hardness						Barcol hardness (with device type No. 834-1)	Characteristics of hardness test process
	Ball 5 mm diam.	Quadratic py- ramid sur- faces = 136°	Truncated cone d _{0.05} = 0,79 mm; 35°	with spherical cap R = 0,1 mm; 30°	Scale α	Scale R	Scale L	Scale M	Scale E	Scale K	Truncated cone d _{0.05} = 0,157 mm; 26°	Test specimen
	49 to 961 *)	0,5 to 4,9 *)	0,55 to 8,1	0 to 44,5	589	589	589	981	981	1472	65 to 77	Test force in N
	DIN 53456	none	DIN 53505	DIN 53505	ASTM D 785	ASTM D 785	ASTM D 785	ASTM D 785	ASTM D 785	ASTM D 785	DIN EN 59 ASTM D 2583	Heat
	H.../30	HV... 9/60	Shore A	Shore D	α HR	HRR	HRL	HRM	HRE	HRK	—	Characteristic
	N/mm ²	N/mm ²	—	—	—	—	—	—	—	—	—	Dimension
PA 610	90	80	>	78	80	105	85	55	<	<	<	*) according to material in each case (see table) 1) according to ISO/CD 14529/3 etc.
PA 12	80... 100	80... 85	>	70... 75	75... 85	100... 110	85... 85	50... 65	<	<	<	
PA 612	105... 120	105... 120	>	75... 80	95	>	95	70... 75	<	<	<	
PC	115... 135	115... 130	>	82... 85	95... 100	120... >	97... 105	60... 75	<... 9	<	10... 20	
PC-GF	150... 190	130... 160	>	85... 90	105... 115	>	105... 110	25... 90	25... 30	<	30... 40	
PBTP	50... 135	45... 115	>	70... 80	35... 95	105... >	85... 110	65... 95	10... 15	<	<... 2	
PPD/PS	90... 175	85... 160	>	80... 85	80... 105	105... 120	80... 105	40... 85	<... 15	<	<... 20	
PPD/PS-GF	180... 215	160... 175	>	85... 87	105... 110	120	105... 110	85... 95	20... 35	<	30	
PEI	240... 290	205... 210	>	88... 90	115... 120	125	120	110	55... 65	5... 20	40... 45	
PEI/GF	325	270	>	91	120	125	120	110	70	35	50	
PF (type 12...13) ¹⁾	380... 500	425... 510	>	>	108... >	>	107... >	110... 115	90... 99	<... 81	60... 70	
PF (type 31...85) ¹⁾	275... 365	260... 400	>	>	105... >	>	114... >	103... 114	77... 92	60... 78	54... 61	
UF (type 131;131.5) ¹⁾	440... 460	420... 460	>	>	>	>	>	107... >	100... 105	85... 90	63... 65	
MF (type 150...157)	400... 515	475... 580	>	>	105... >	>	114... >	115... >	95... 112	77... 100	62... 72	
MP (type 180...183) ¹⁾	350... 445	425... 525	>	>	110... >	>	115... >	113... >	97... 103	79... 88	60... 67	
UP-GF (type 802...804) ¹⁾	300... 475	310... 475	>	>	115... >	>	112... >	96... 112	61... 98	45... 83	57... 77	

Durezza alla penetrazione (“Indentation hardness”)

$$H_p \approx 10E^{3/4}$$

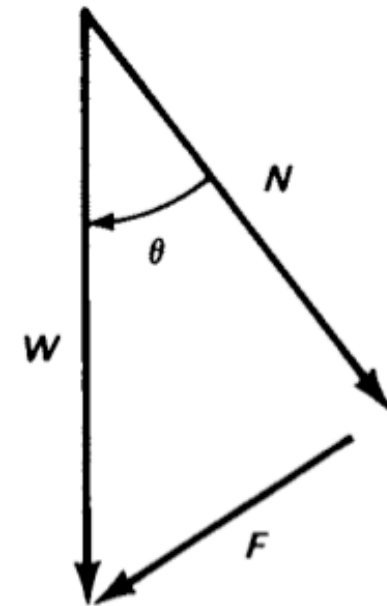


Abrasion e attrito



(a)

$$\tan \theta = F/N = \mu_s$$



(b)

Inclined plane used to determine the static coefficient of friction (μ_s). (a) Tilting a flat surface through the smallest angle, θ , needed to initiate movement of the body down the plane. (b) Relationship of the friction angle to the principal applied forces. F , friction force; N , load; W , weight of body. Source: Ref 2

Abrasion e attrito

ASTM D 1894-90, "Standard Test Method for Static and Kinetic Coefficients of Friction of

Plastic Film and Sheeting", describes the determination of μ_s and μ_k of plastic film and sheeting using a variety of test assemblies. In each case, the force required to move a sled across a plane is measured. A test speed of 150 ± 30 mm/min (0.5 ± 0.1 ft/min) is specified. Both the force required to initiate motion and the average force required to sustain motion are recorded and used to calculate μ_s and μ_k . While this test is written for the evaluation of plastic film, it can be used to evaluate other materials, such as coated metals and paper.

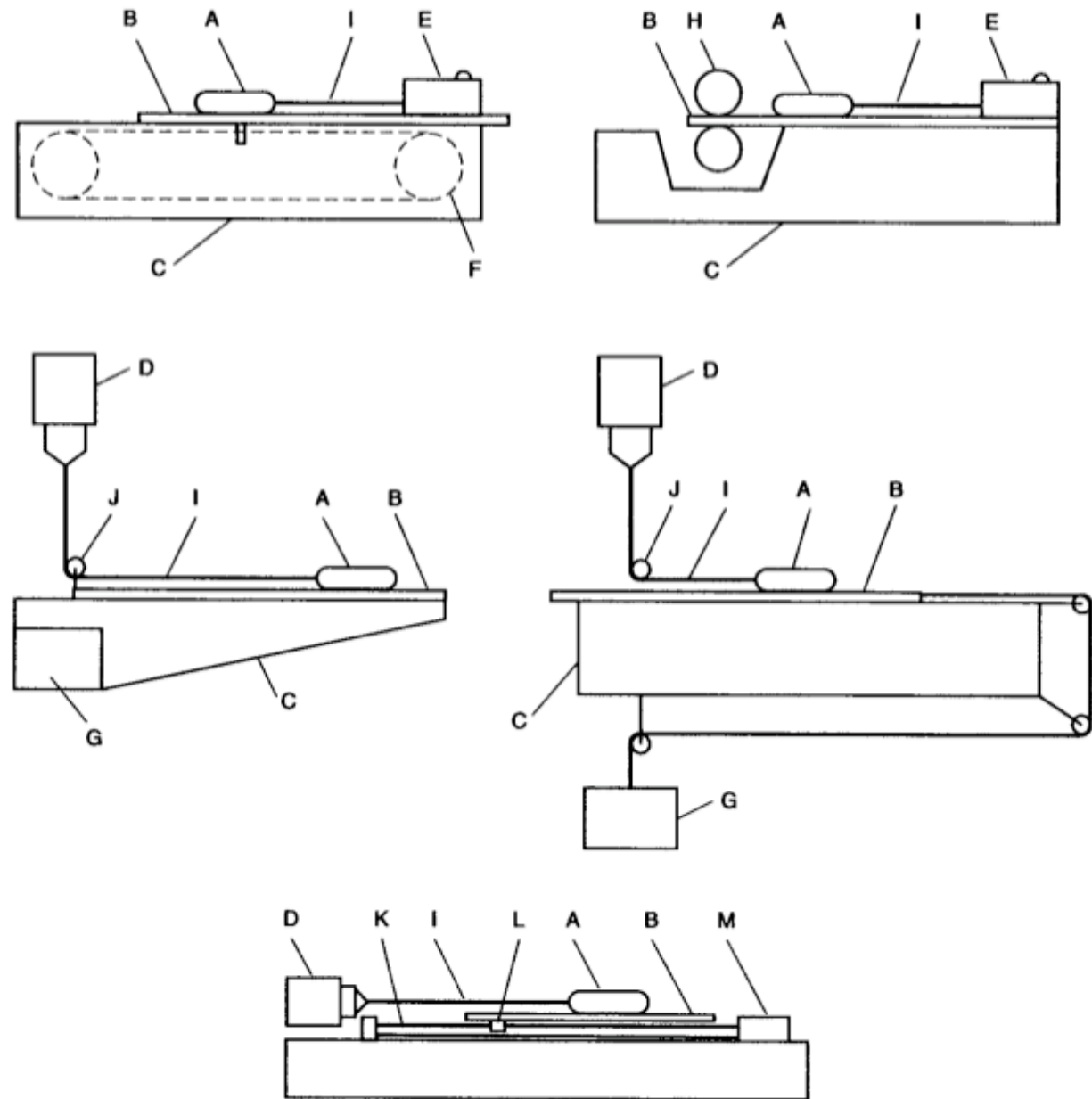


Fig. 3 Different assemblies used for the determination of coefficients of friction by ASTM D 1894. A, sled; B, plane; C, supporting base; D, gage; E, spring gage; F, constant-speed chain drive; G, constant-speed tensile tester crosshead; H, constant-speed drive rolls; I, nylon monofilament; J, low-friction pulley; K, worm screw; L, half nut; M, hysteresis, synchronous motor. Source: Ref 19

Abrasione e attrito

ASTM D 3028-90, "Standard Test Method for Kinetic Coefficient of Friction of Plastic Solids", uses a variable-speed frictionometer to measure kinetic coefficients of friction.

Three types of test specimens can be used: 20.0 ± 0.1 mm diameter rigid fixed specimens that weigh 5.0 ± 0.1 g, 100.0 ± 0.1 mm diameter rigid moving specimens, or film or sheeting mounted on a 100 mm diameter mounting wheel.

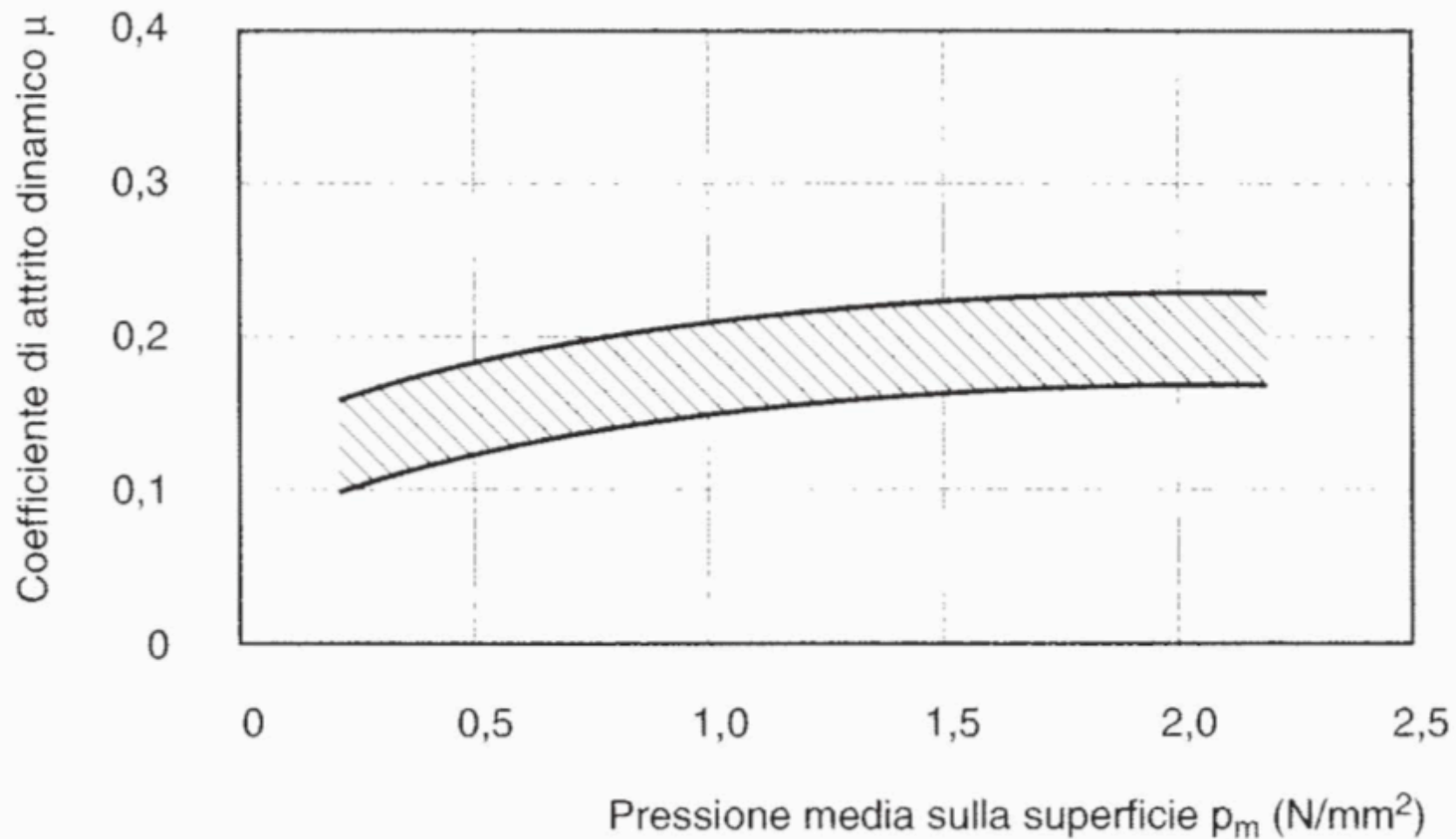
Two procedures are described.

In procedure A, coefficients of friction are measured at velocities of 0.25, 0.50, 1.0, 2.0, and 3.0 m/s. The test is performed as rapidly as possible to minimize wear effects.

Testing performed by **procedure B** is intended to show the effects of time, velocity, and wear on coefficient of friction. A velocity is selected (1.0 m/s is suggested as a default), and readings are taken every 30 s until they reach a constant value.

The **relationship between wear and friction** is an important consideration when selecting a friction test. Several ways in which wear may affect friction are illustrated in Fig. 4. Figure 4(a) shows how friction force varies with time when a system experiences no wear. The friction is essentially constant. Figure 4(b) shows a system where the friction force increases with time and finally reaches a steady state. This type of behavior may be seen in a system where both surfaces experience heavy wear: The coefficient of friction is low for the original surfaces, but it rises and stabilizes as new surfaces are exposed. Figure 4(c) shows a system that experiences a variety of wear events. Friction changes as the wear processes change. This type of behavior may be observed in a system where retained wear debris can either increase or decrease friction. If a system will wear, and the friction of worn surfaces is of interest, friction should be measured in a test that produces wear. ASTM D 3028-90, described previously, has that capability, as do several of the wear tests described subsequently.

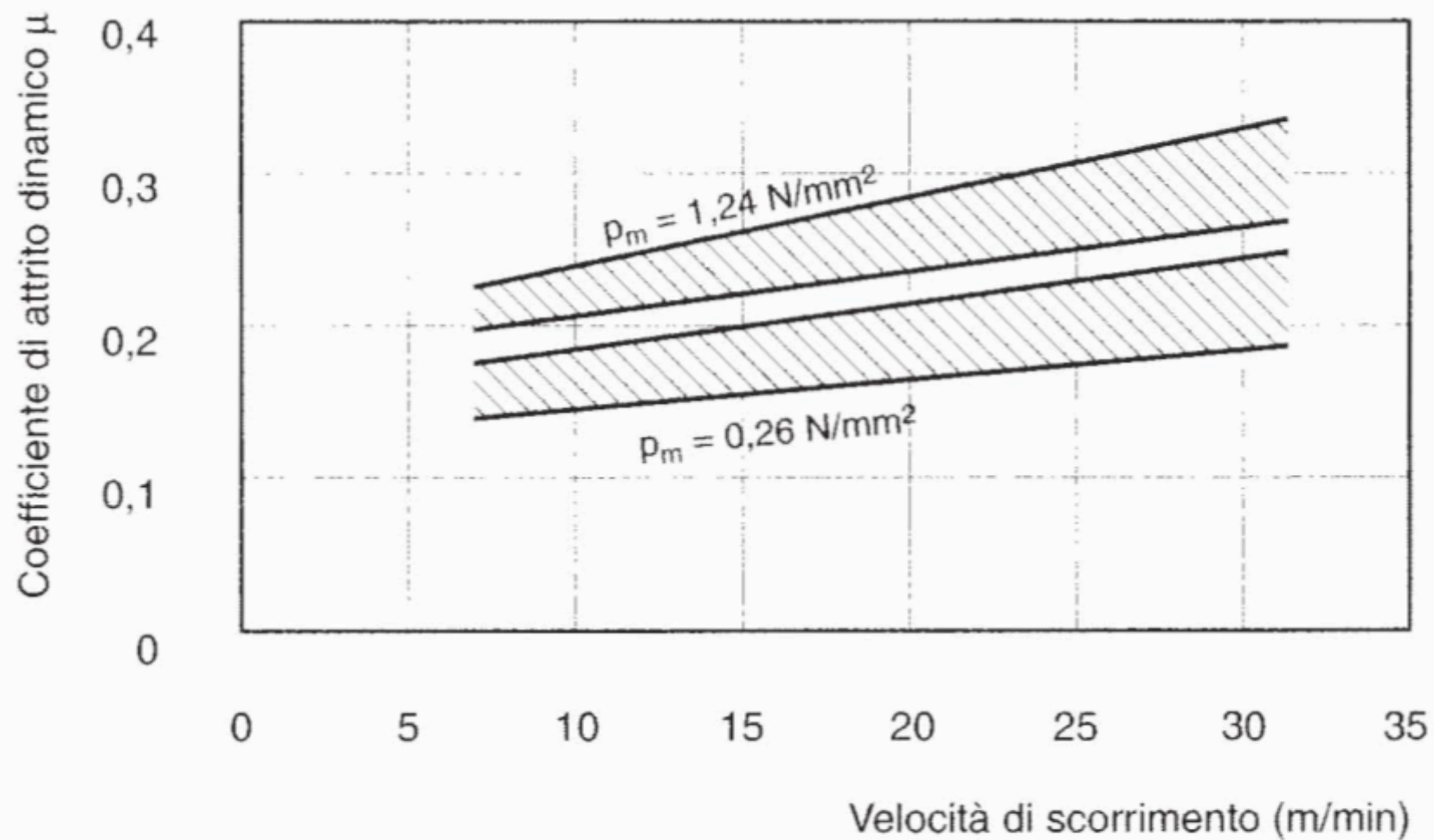
Abrasion e attrito



Dipendenza del coefficiente di attrito dinamico μ dalla pressione media sulla superficie p_m per PE-HD-UHMW.

Velocità di scorrimento $v = 10 \text{ m/min}$

Abrasion e attrito



- Dipendenza del coefficiente di attrito dinamico dalla velocità di scorrimento per PE-HD-UHMW.

Abrasion e attrito

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Figure 4(b) shows a system where the friction force increases with time and finally reaches a steady state. This type of behavior may be seen in a system where both surfaces experience heavy wear: The coefficient of friction is low for the original surfaces, but it rises and stabilizes as new surfaces are exposed.

Figure 4(c) shows a system that experiences a variety of wear events. Friction changes as the wear processes change. This type of behavior may be observed in a system where retained wear debris can either increase or decrease friction.

If a system will wear, and the friction of worn surfaces is of interest, friction should be measured in a test that produces wear.

ASTM D 3028-90, described previously, has that capability.

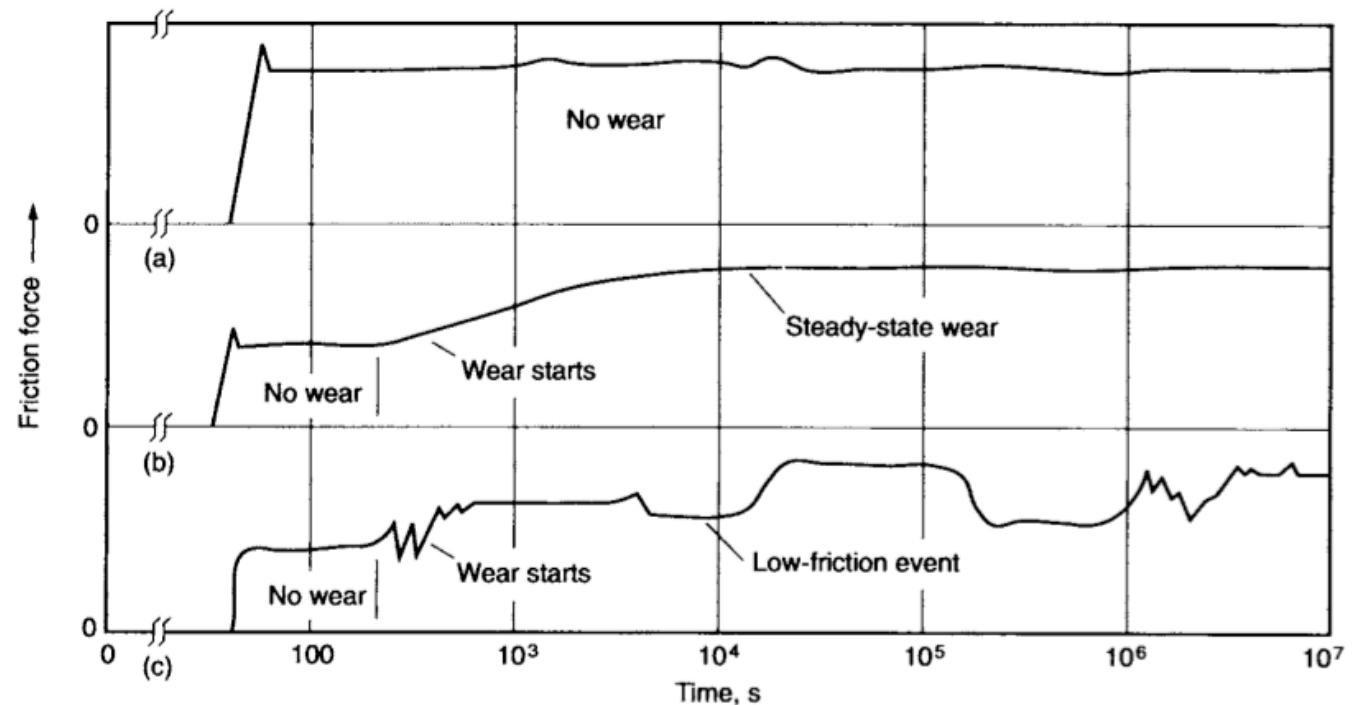


Fig. 4 The effect of system wear on friction force. (a) System that does not experience any wear. (b) System where friction force increases with time until reaching a steady-state condition. (c) System where friction force varies with each event in the wear process. Source: Ref 18

Abrasione e attrito

A concern with all wear tests, regardless of the test apparatus used, is the actual measurement of wear. Common wear measurements include weight loss, volume loss, displacement scar width or depth, and indirect measures such as the time required to wear through a coating or the load required to cause a change in reflectance.

Weight loss is straightforward, but it may not account for material displacement, and it should not be used to compare materials with different densities.

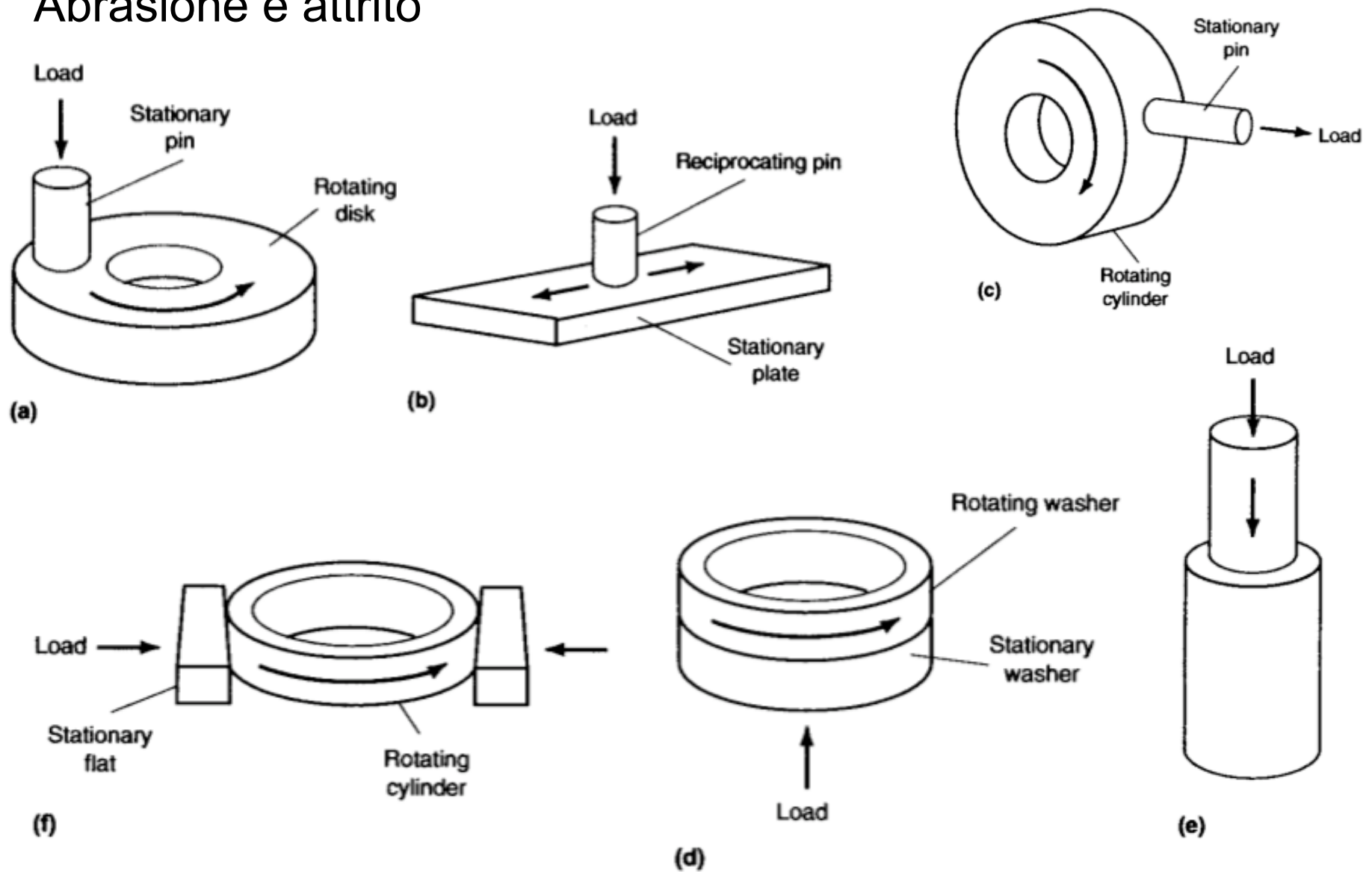
Volume loss can be calculated from weight loss or estimated based on wear geometry.

Displacement scar width and depth are related to volume and can be easily measured, but the results of different types of tests are not comparable.

Indirect measures are typically limited in scope and applicability and do not easily provide fundamental wear parameters.

Ideally, the wear measurement method should reflect the actual service performance of the system. It should be repeatable and as objective as possible.

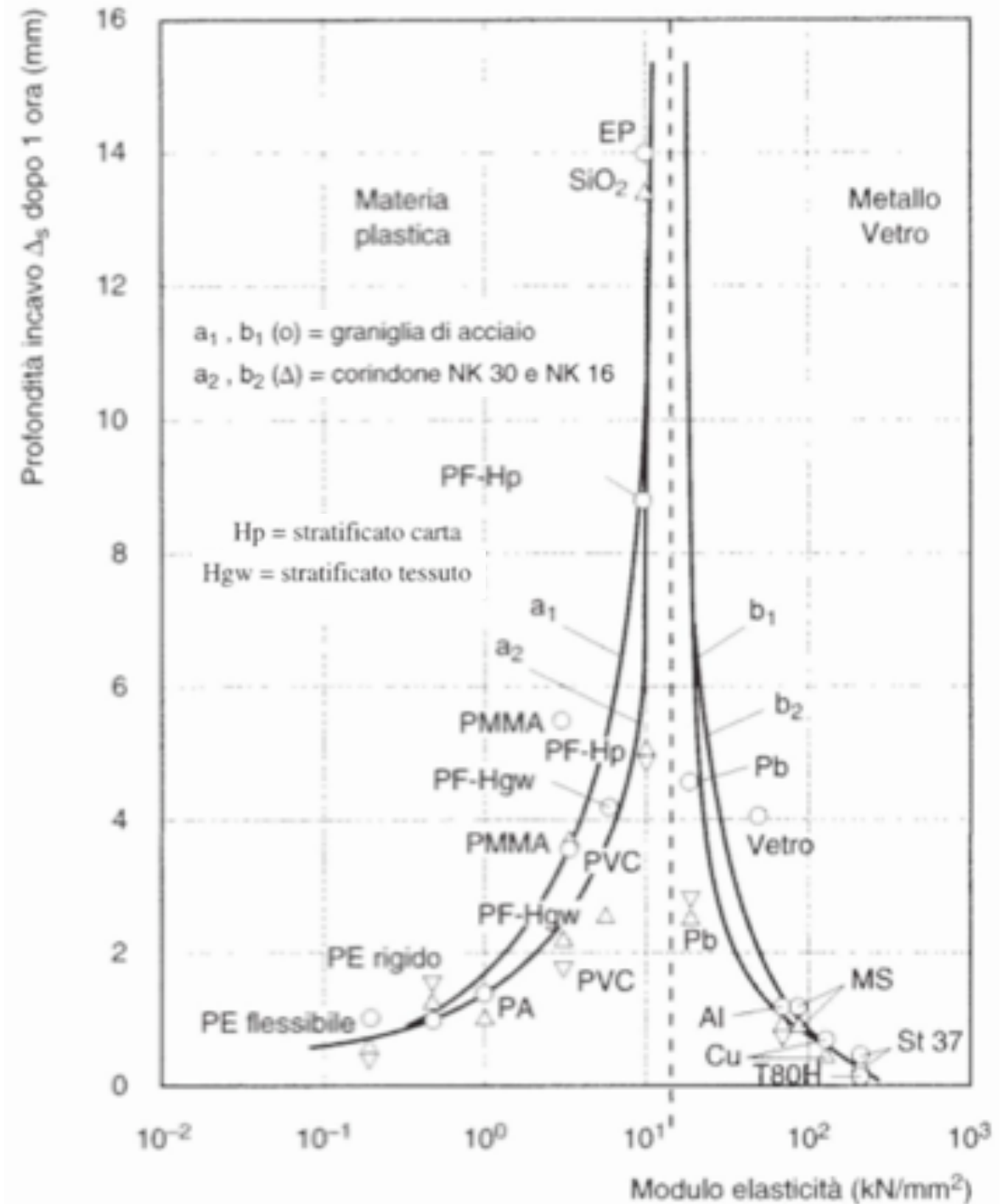
Abrasione e attrito



Examples of test geometries that may be used for sliding friction and wear tests. (a) Pin-on-disk. (b) Pin-on-flat (reciprocating). (c) Pin-on-cylinder. (d) Thrust washer. (e) Pin-into-bushing. (f) Rectangular flats on rotating cylinder.

Abrasione e attrito

La figura indica che sia i materiali flessibili con basso modulo di elasticità sia quelli con un elevato modulo E possono essere resistenti all' usura.



Abrasione e attrito

ASTM D 1242-87, “Standard Test Methods for Resistance of Plastic Materials to Abrasion”, outlines two tests that are suitable for flat plastic surfaces.

Method A calls for loose abrasive (No. 80 TP aluminum oxide grit is suggested) that is applied to the test surface under controlled conditions. The results are expressed as volume loss, calculated from test specimen weight loss and density.

Method B calls for a “bonded abrasive abrading machine” that is capable of testing multiple specimens. The grade of abrasive material, load, and length of time can all be varied as needed. A standard zinc calibration specimen is included with each run of test specimens. Volume loss is calculated and reported, along with the weight loss of the zinc standard run at the same time.

Abrasione e attrito

	Bakelite-Method ISO	DIN	ASTM	
No.:	Bakelite-Method	53754	D 1242	not comparable
Test specimens:	50 x 50 x 4 mm	2 Round disks 130 mm dia. or octagonals with 50 mm edge length, thickness 0.3 - 5 mm	Method A: 76 x 51 mm Method B: 115 x 45 mm Thickness not prescribed	
Load:	1000 g	5,4 ± 2 N	A: 5000 g B: 1500 g	
Friction surface:	Bar (120 x 10 x 4 mm) on plate (50 x 50 x 4 mm)	Abrasive grain on aluminium oxide	Al ₂ O ₃ grain size No. 80, approx. 0.2 mm or other abrasive grain	
RPM:	Step 4 (40 %)	55 ± 6 min ⁻¹	Test specimen 32.5, Disk 23.5	
Medium:	Dry	Dry	Dry	
Evaluation:	Abrasion after 100,000 strokes (see drawing)	Abrasion amounts by weight for the reference material (m _{SB}) in mg per 100 revolutions are calculated for each pair of grinding discs according to the following equations: $m_{SB} = \frac{m_{1B} - m_{2B}}{50} \cdot 100$ $m_s = m_1 - m_2$	A: cm ³ per 1000 rev. B: cm ³ per X rev. with abrasive grain of Y quality	

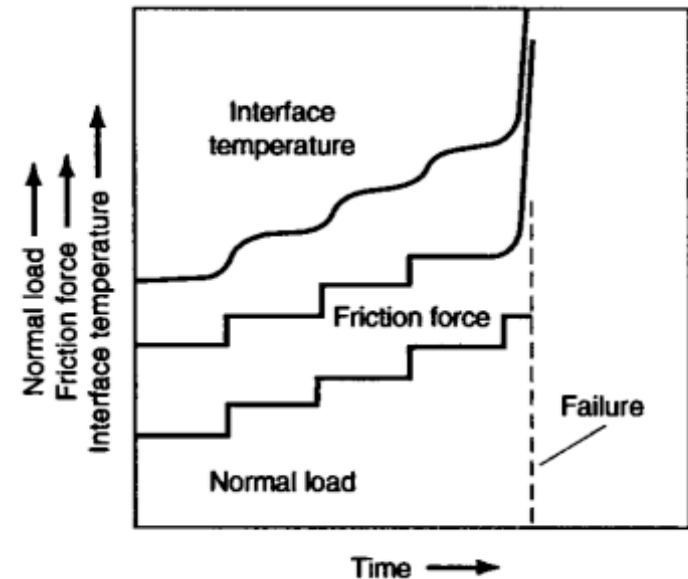
PV Limit

The concept of PVlimit (where P is contact pressure and V is velocity) is important for plastics used in sliding applications. It has been shown experimentally that if PV does not exceed a limiting value for a given system, the operation is basically satisfactory, and only acceptable amounts of wear will occur. The PVlimit may be established using any wear test apparatus that is capable of changing load pressure and velocity, although different apparatuses will provide different PV limits to some extent. Also, the relevance of the PV limit to a given application depends on how closely the test apparatus resembles the application.

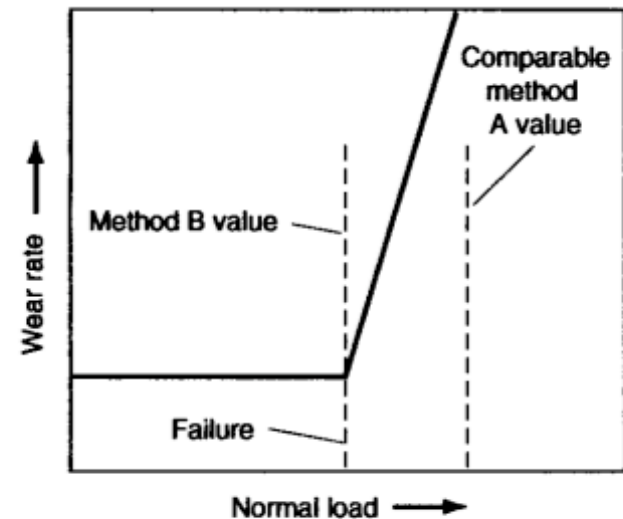
In general, acetal, polyethylene, and polyamides are used for low-PVservice, PTFE is used for moderate-PVservice, and polyphenylene sulfide, polyamide-imide, and polyimide are used for high-temperature and/or high-PV service.

$$p \cdot v = \frac{F \cdot v}{l \cdot d} \text{ in } \frac{\text{N} \cdot \text{mm}}{\text{mm}^2 \cdot \text{min}}$$

F = carico sul cuscinetto
v = velocità di scorrimento
l = lunghezza cuscinetto
d = diametro cuscinetto



(a)



(b)

... Schematic representation of friction, interface temperature, and wear rate changes during the determination of contact pressure and velocity (PV) limit by (a) constant velocity and incremental load increases or (b) wear rate vs. load at constant velocity.