Introduction to Materials, Testing, and Selection

วัสดุ การทดสอบ และการเลือกใช้

พิเชษฐ์ พินิจ

ทบทวนความเข้าใจจาก

Reviewing for understanding

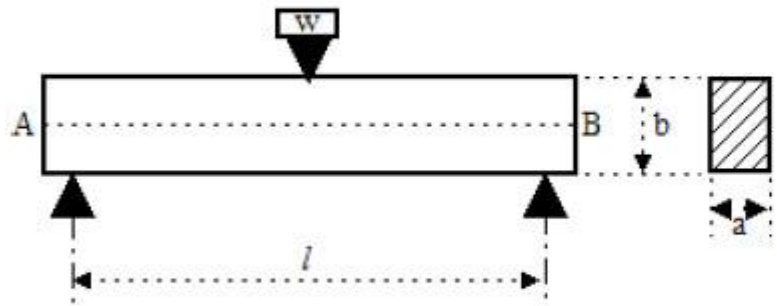
2

แนวคิดรวบยอด

“การออกแบบชิ้นส่วนทางกล”

การออกแบบเพื่อต้านแรงเพื่อป้องกันความเสียหายแบบครากและแตกหัก

ความต้านแรงคราก/สูงสุด



อาศัยฟังก์ชันความเสียหายเพื่อเปรียบเทียบขนาดของความเค้นประสิทธิผล σ_{eff} ที่ได้จากการคำนวณกับความต้านแรง *Strength* ของวัสดุที่ได้จากการทดสอบ

$$f\,(\sigma_{eff}, \mathit{Strength})$$

S_y เสียหายแบบคราก (yielding failure) สำหรับวัสดุเหนียว (ductile materials)

S_u เสียหายแบบแตกร้าว (fracture failure) สำหรับวัสดุเปราะ (brittle materials)

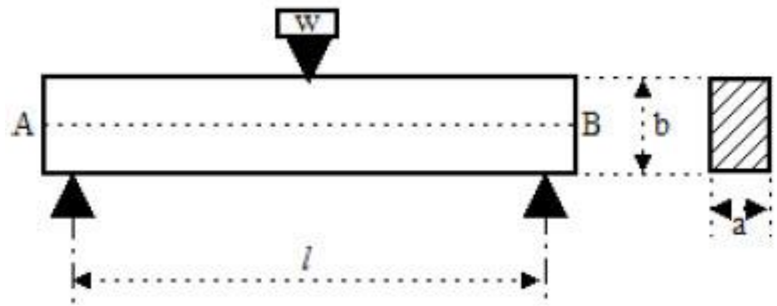
ความเค้นพื้นฐาน ➔ ทฤษฎีความเสียหาย

แนวคิดรวบยอด

“การออกแบบชิ้นส่วนทางกล”

การออกแบบเพื่อต้านแรงเพื่อป้องกันความเสียหายแบบครากและแตกหัก

ความต้านแรงคราก/สูงสุด



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$$f(\sigma_{eff}, Strength)$$

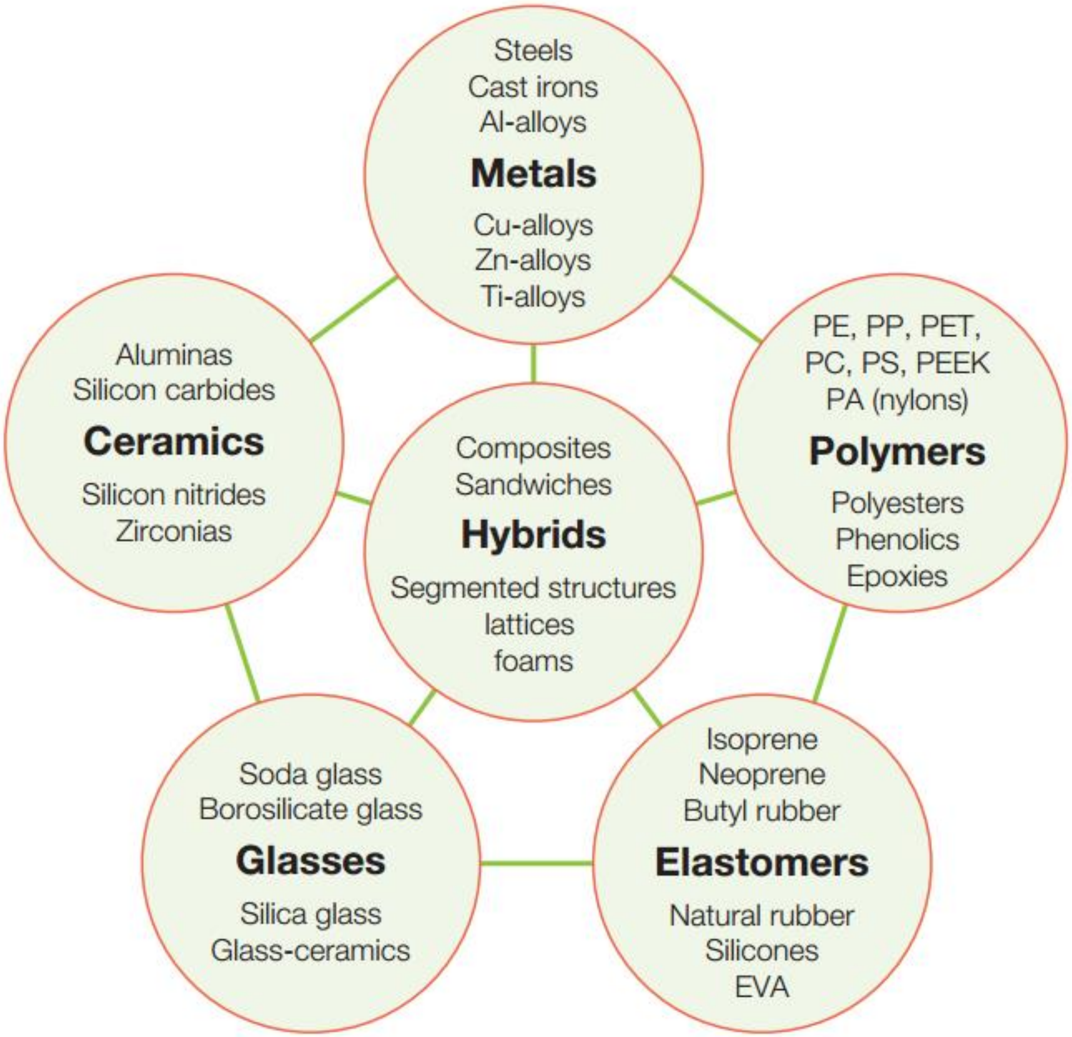
ความเสียหายจะเกิดขึ้นเมื่อ $\sigma_{eff} > Strength$

ความเค้นพื้นฐาน ➔ ทฤษฎีความเสียหาย

สมบัติของวัสดุ-แบบจำลองวัสดุ

$$f\,(\sigma_{\text{eff}}, Strength)$$

ความเสียหายจะเกิดขึ้นเมื่อ $\sigma_{\text{eff}} > Strength$



Michael, F.A. (2011). **Materials Selection in Mechanical Design**, 4th ed., Oxford: Butterworth-Heinemann.

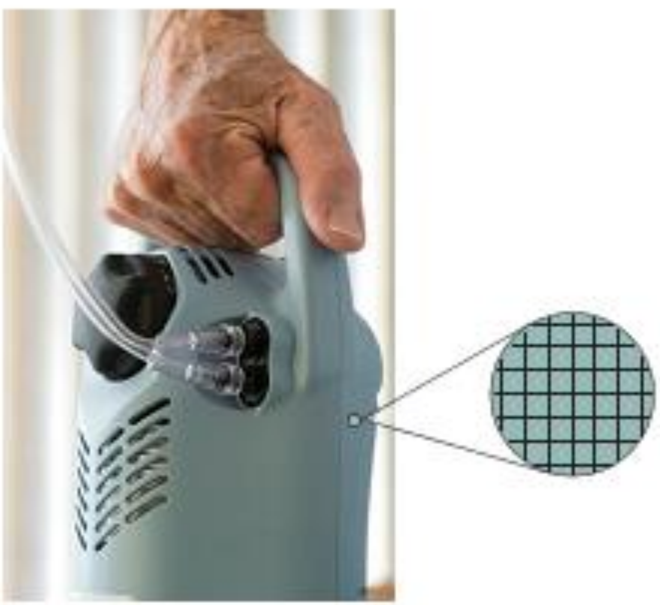
สมบัติของวัสดุ

A crack in a structure, such as this support column, is a type of failure. This crack may be repairable. A structure that fractures completely into two parts would clearly be unacceptable.

While a structure may still be intact, it could be viewed as having failed if there is a permanent deformation. A bicycle that has deformed this much is unlikely to be useful.

Source: Paul, S. S. (2012). **Mechanics of materials**. New Jersey: Pearson Higher Education.

สมบัติของวัสดุ



Source: Paul, S. S. (2012). **Mechanics of materials**. New Jersey: Pearson Higher Education.

สมบัติของวัสดุ

Basic Design-Limiting Material Properties

Table 3.1 Basic Design-Limiting Material Properties and Their Usual SI Units*

Class	Property	Symbol and Units
General	Density	ρ (kg/m^3 or Mg/m^3)
	Price	C_m (\$/kg)
Mechanical	Elastic moduli (Young's, shear, bulk)	E, G, K (GPa)
	Yield strength	σ_y (MPa)
	Tensile (ultimate) strength	σ_{ts} (MPa)
	Compressive strength	σ_c (MPa)
	Failure strength	σ_f (MPa)
	Hardness	H *(Vickers)*
	Elongation	ε (–)
	Fatigue endurance limit	σ_e (MPa)
	Fracture toughness	K_{1c} (MPa.m$^{1/2}$)
	Toughness	G_{1c} (kJ/m^2)
	Loss coefficient (damping capacity)	η (–)
	Wear rate (Archard) constant	K_AMPa^{-1}
Thermal	Melting point	T_m (°C or K)
	Glass temperature	T_g (°C or K)
	Maximum service temperature	T_{max} (°C or K)
	Minimum service temperature	T_{min} (°C or K)
	Thermal conductivity	λ (W/m.K)
	Specific heat	C_p (J/kg.K)
	Thermal expansion coefficient	α (K^{-1})
	Thermal shock resistance	ΔT_s (°C or K)
Electrical	Electrical resistivity	ρ_e (Ω.m or $\mu\Omega$.cm)
	Dielectric constant	ε_r (–)
	Breakdown potential	V_b (10^6 V/m)
	Power factor	P (–)
Optical	Refractive index	n (–)
Eco-properties	Embodied energy	H_m (MJ/kg)
	Carbon footprint	CO_2 (kg/kg)

** Conversion factors from metric to imperial and cgs units appear inside the back and front covers of this book.*

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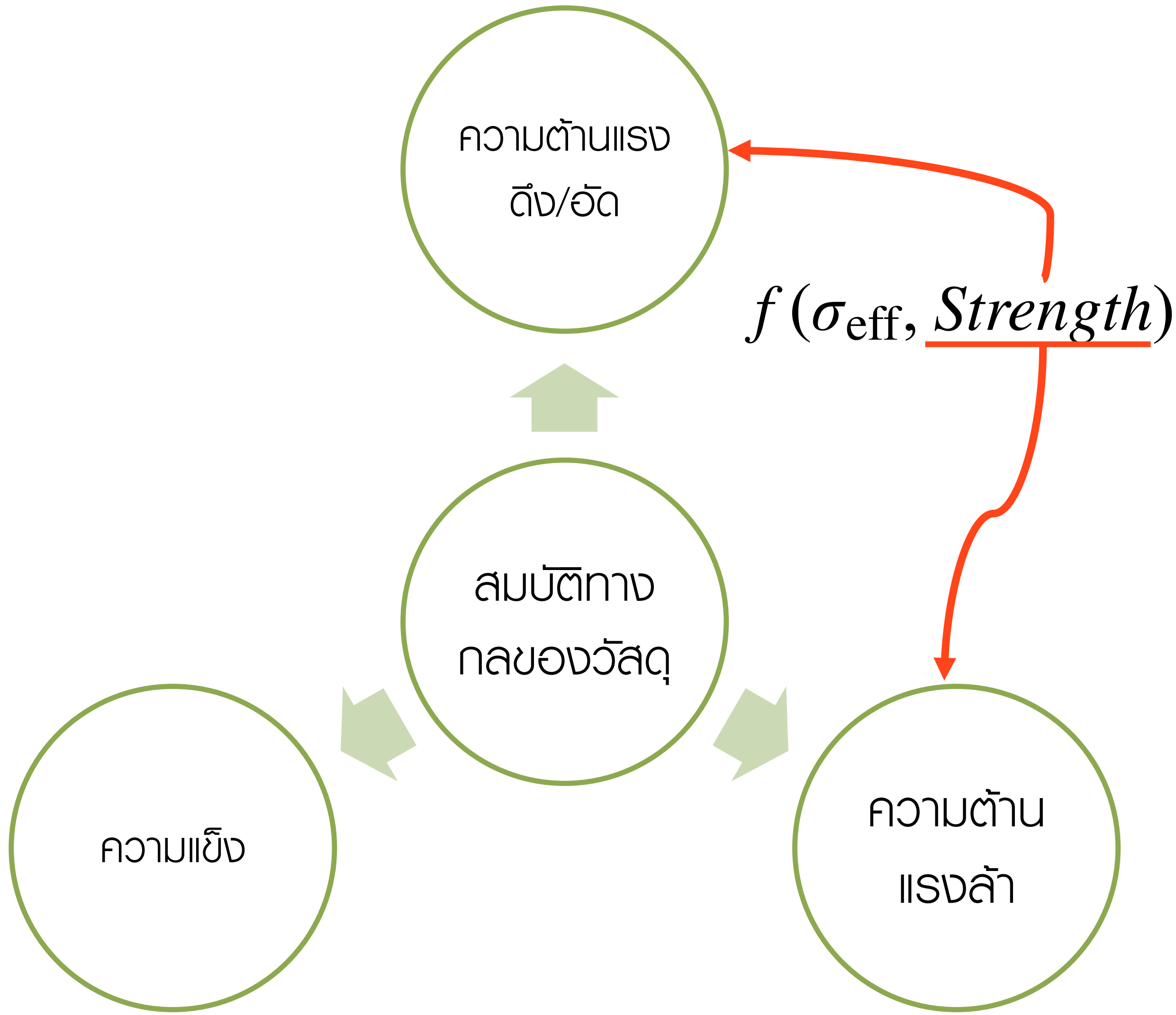
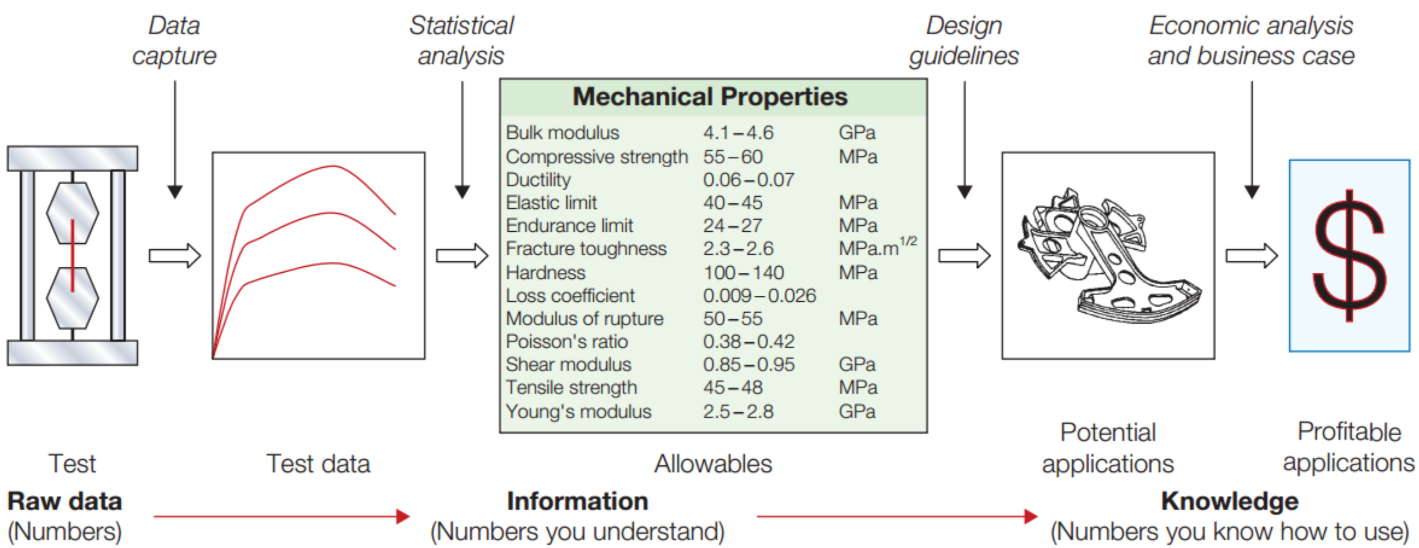
สมบัติทางกลพื้นฐานของโลหะ



สมบัติทางกลของวัสดุ



Types of material information. We are interested here in the types found in the center of this schematic: structured data for design “allowables” and the characteristics of a material that relate to its ability to be formed, joined, and finished; records of experience with its use; and design guidelines for its use.

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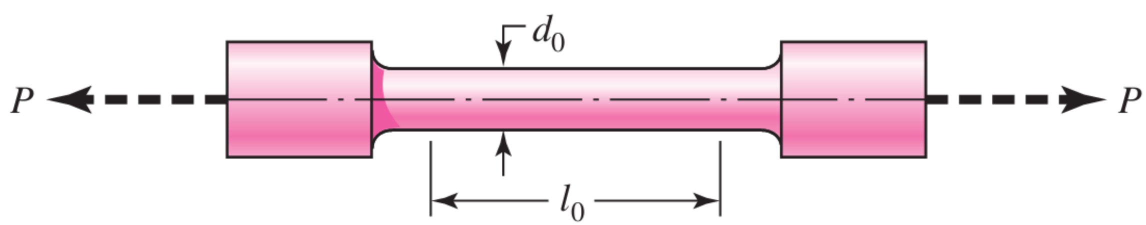
ความต้านแรง (ดึง/อัด)

Strength

การทดสอบหา

“ความต้านแรง (strength)”

เป็นการทดสอบหาความต้านทานแรงดึง/กดในวัสดุ
โดยเฉพาะวัสดุที่เป็นโลหะ

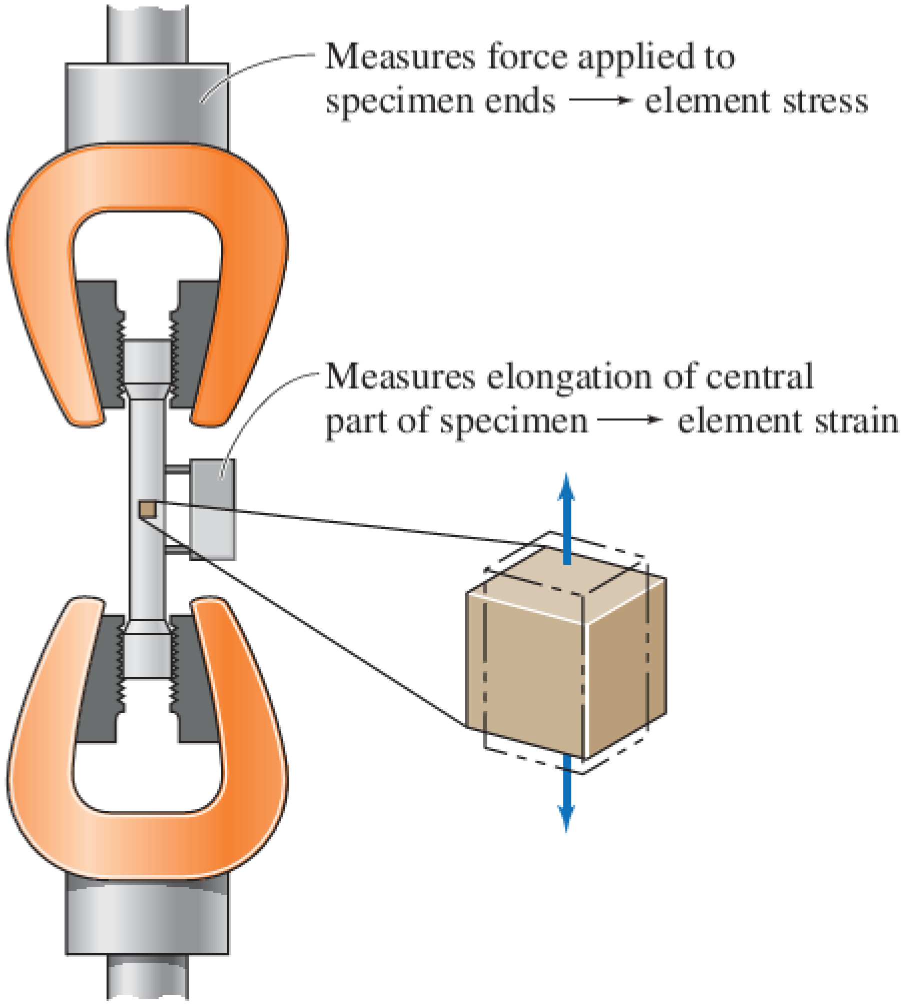


A typical tension-test specimen. Some of the standard dimensions used for d_0 are 2.5, 6.25, and 12.5 mm and 0.505 in, but other sections and sizes are in use. Common gauge lengths l_0 used are 10, 25, and 50 mm and 1 and 2 in.

Shigley, J.S., Mischke, C.R., and Budynas, R.G. (2008). **Mechanical Engineering Design**, 8th ed., New York: McGraw-Hill.

การทดสอบหา

“ความต้านแรง (strength)”

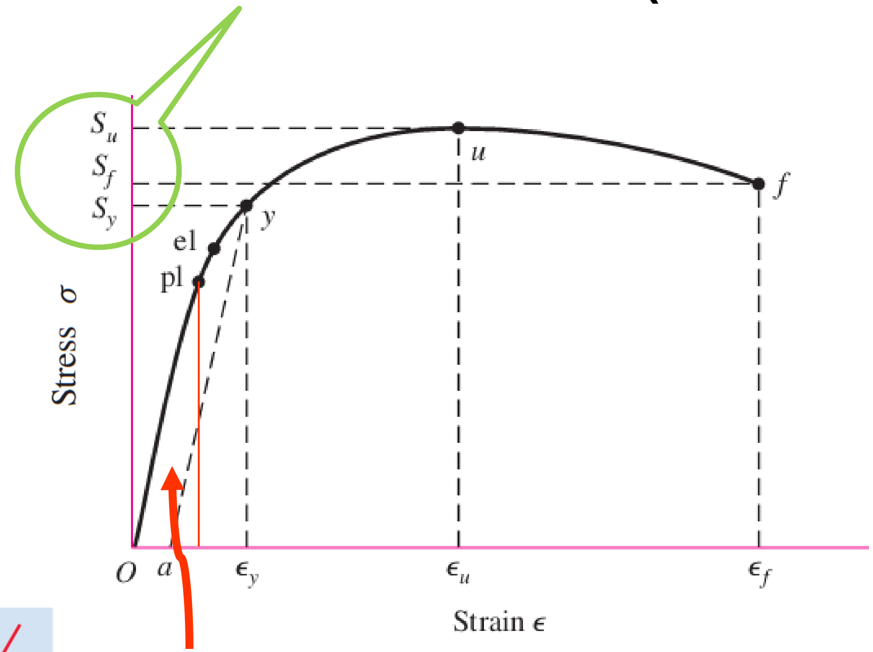


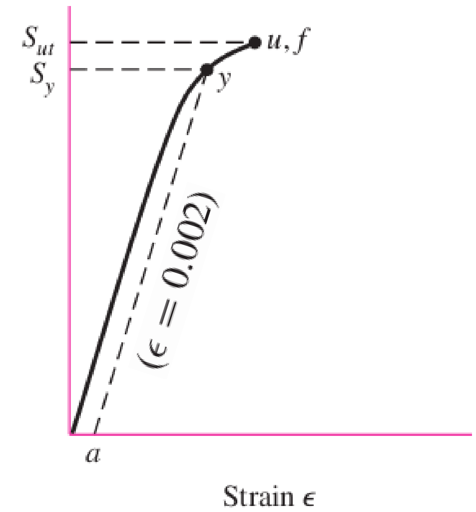
Source: Paul, S. S. (2012). **Mechanics of materials**. New Jersey: Pearson Higher Education.

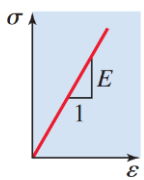
Source: https://www.youtube.com/watch?v=5QaqwmZ7Sic

การทดสอบหา

“ความต้านแรง (strength)”





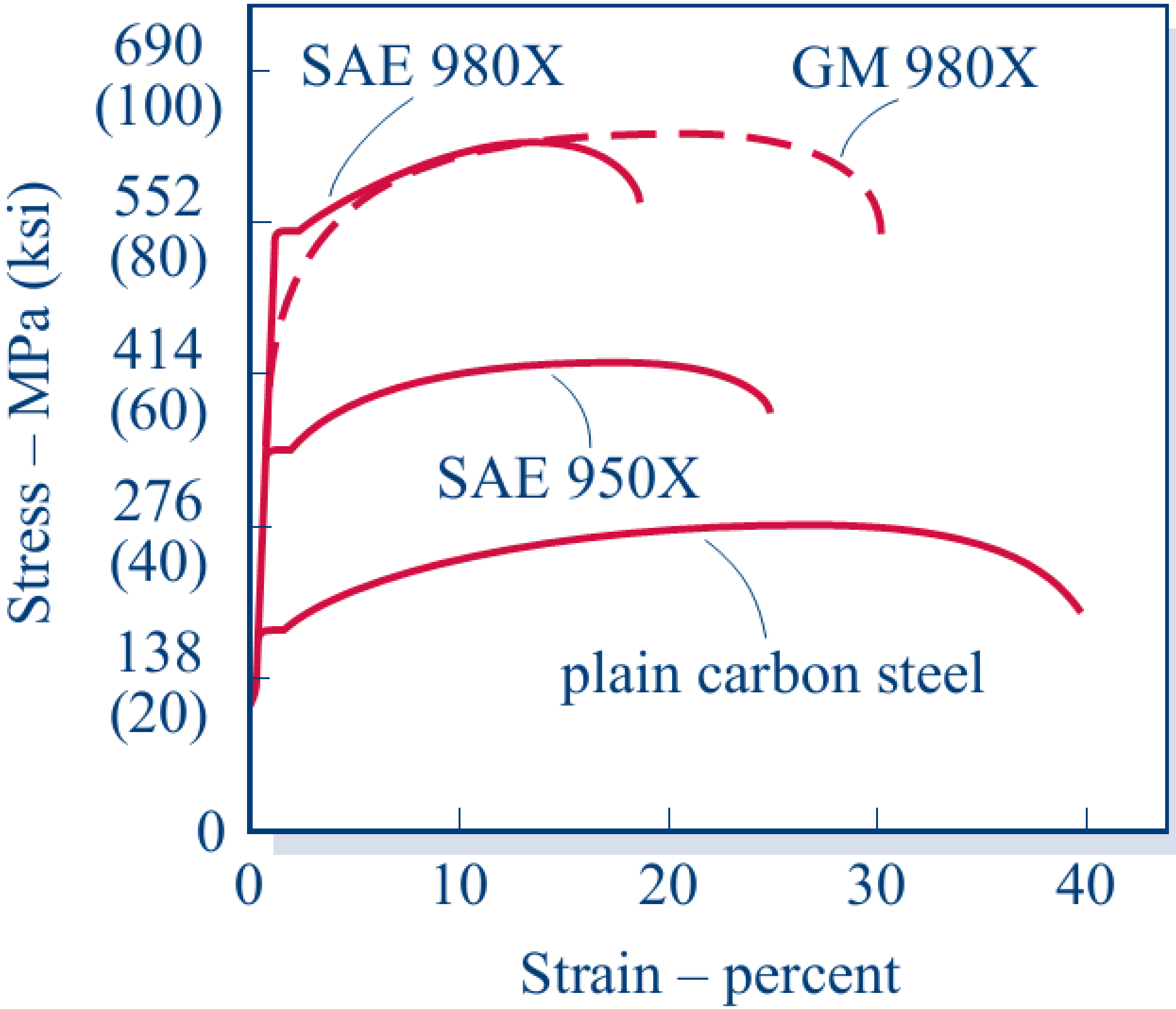


ช่วงยืดหยุ่นเราได้

$$E = \frac{\sigma}{\epsilon}$$

การทดสอบหา

“ความต้านแรง (strength)”



“ความแข็งแรง (strength)”

การทดสอบ

Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels [The strengths listed are estimated ASTM minimum values in the size range 18 to 32 mm ($\frac{3}{4}$ to $1\frac{1}{4}$ in). These strengths are suitable for use with the design factor defined in Sec. 1–10, provided the materials conform to ASTM A6 or A568 requirements or are required in the purchase specifications. Remember that a numbering system is not a specification.] *Source:* 1986 SAE Handbook, p. 2.15.

1	2	3	4	5	6	7	8
UNS No.	SAE and/or AISI No.	Processing	Tensile Strength, MPa (kpsi)	Yield Strength, MPa (kpsi)	Elongation in 2 in, %	Reduction in Area, %	Brinell Hardness
G10060	1006	HR	300 (43)	170 (24)	30	55	86
		CD	330 (48)	280 (41)	20	45	95
G10100	1010	HR	320 (47)	180 (26)	28	50	95
		CD	370 (53)	300 (44)	20	40	105
G10150	1015	HR	340 (50)	190 (27.5)	28	50	101
		CD	390 (56)	320 (47)	18	40	111
G10180	1018	HR	400 (58)	220 (32)	25	50	116
		CD	440 (64)	370 (54)	15	40	126
G10200	1020	HR	380 (55)	210 (30)	25	50	111
		CD	470 (68)	390 (57)	15	40	131
G10300	1030	HR	470 (68)	260 (37.5)	20	42	137
		CD	520 (76)	440 (64)	12	35	149
G10350	1035	HR	500 (72)	270 (39.5)	18	40	143
		CD	550 (80)	460 (67)	12	35	163
G10400	1040	HR	520 (76)	290 (42)	18	40	149
		CD	590 (85)	490 (71)	12	35	170
G10450	1045	HR	570 (82)	310 (45)	16	40	163
		CD	630 (91)	530 (77)	12	35	179
G10500	1050	HR	620 (90)	340 (49.5)	15	35	179
		CD	690 (100)	580 (84)	10	30	197
G10600	1060	HR	680 (98)	370 (54)	12	30	201
G10800	1080	HR	770 (112)	420 (61.5)	10	25	229
G10950	1095	HR	830 (120)	460 (66)	10	25	248

Shigley, J.S., Mischke, C.R., and Budynas, R.G. (2008). **Mechanical Engineering Design**, 8th ed., New York: McGraw-Hill.

การทดสอบหา

“ความต้านแรงเฉือน (shear strength)”

$$G = \frac{\tau}{\gamma}$$

สมบัติของวัสดุ “E, G, and ν”

$$G = \frac{E}{2(1+\nu)}$$

TABLE F.2. Modulus of Elasticity, Shear Modulus of Elasticity, and Poisson's Ratio

Material	Modulus of Elasticity (E)		Shear Modulus of Elasticity (G)		Poisson's Ratio (ν)
	10^3 ksi	GPa	10^3 ksi	GPa	
Aluminum Alloys	10.0–11.4	70–79	3.8–4.3	26–30	0.33
Alloy 2014-T6	10.6	73	4.0	27	0.33
Alloy 6061-T6	10.0	70	3.8	26	0.33
Brass					
Red Brass (85% Cu, 15% Zn)					
Cold-rolled	15	100	5.6	37	0.34
Annealed	15	100	5.6	37	0.34
Cast Iron					
Gray, ASTM-A48	10	70	4.1	29	0.22
Malleable, ASTM-47	24	165	9.4	65	0.27
Steel					
Structural, ASTM-A36	29	200	11.2	78	0.29
Stainless, AISI 302					
Cold-rolled	28	195	10.8	75	0.30
Annealed	28	195	10.8	75	0.30
High-strength, low alloy, ASTM-A242	29	200	11.2	78	0.29
Quenched & tempered, ASTM-A514	29	200	11.2	78	0.29
Titanium					
Alloy (6% Al, 4% V)	16.5	115	6.2	43	0.33
Concrete[1]					0.1–0.2
Medium Strength	3.6	25	—	—	—
High Strength	4.5	31	—	—	—
Glass	8.7	60	—	—	0.2–0.3
Plastics					
Nylon, type 6/6 (molding cpd.)	0.4	2.8	—	—	0.4
Polycarbonate	0.35	2.4	—	—	—
Vinyl, rigid PVC	0.4	2.8	—	—	—
Wood[2]					
Douglas Fir	1.75	12	—	—	—
Southern Pine	1.75	12	—	—	—

[1]Concrete properties are for compression.
[2]Timber properties are for loading parallel to the grain.

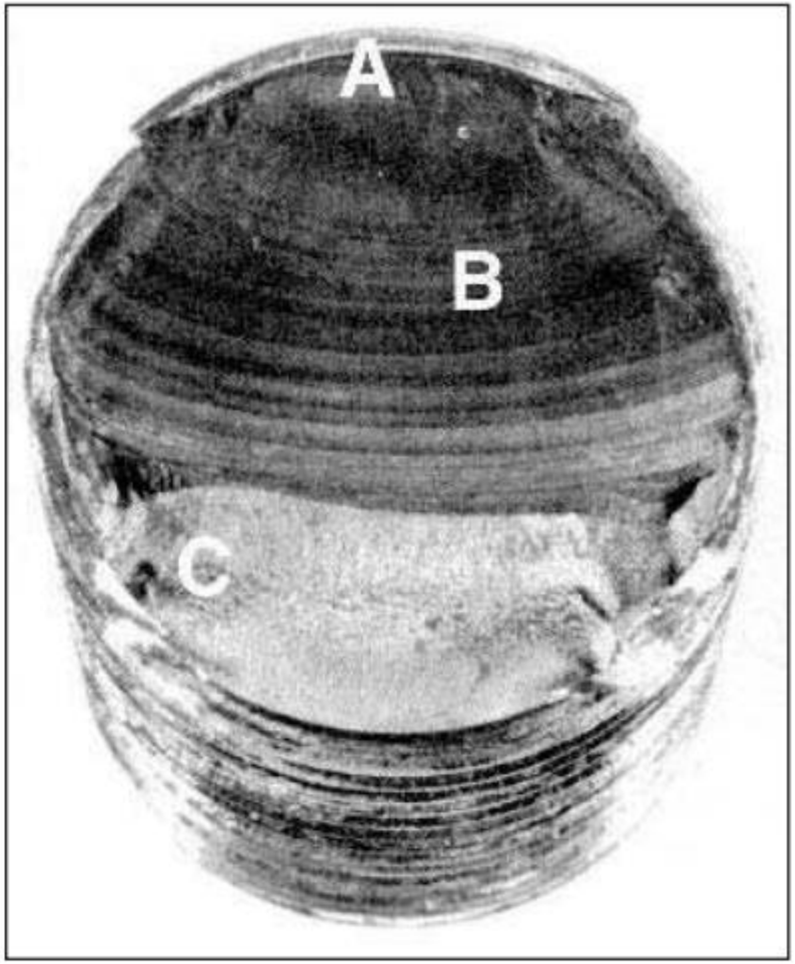
ความต้านแรงล้า

Fatigue Strength

การทดสอบหา

“ความล้าของวัสดุ ”

Fatigue failure of a bolt due to repeated unidirectional bending. The failure started at the thread root at *A*, propagated across most of the cross section shown by the beach marks at *B*, before final fast fracture at *C*. *(From* ASM Handbook, Vol. 12: Fractography, *ASM International, Materials Park, OH 44073-0002, fig 50, p. 120. Reprinted by permission of ASM International ®, www.asminternational.org.)*



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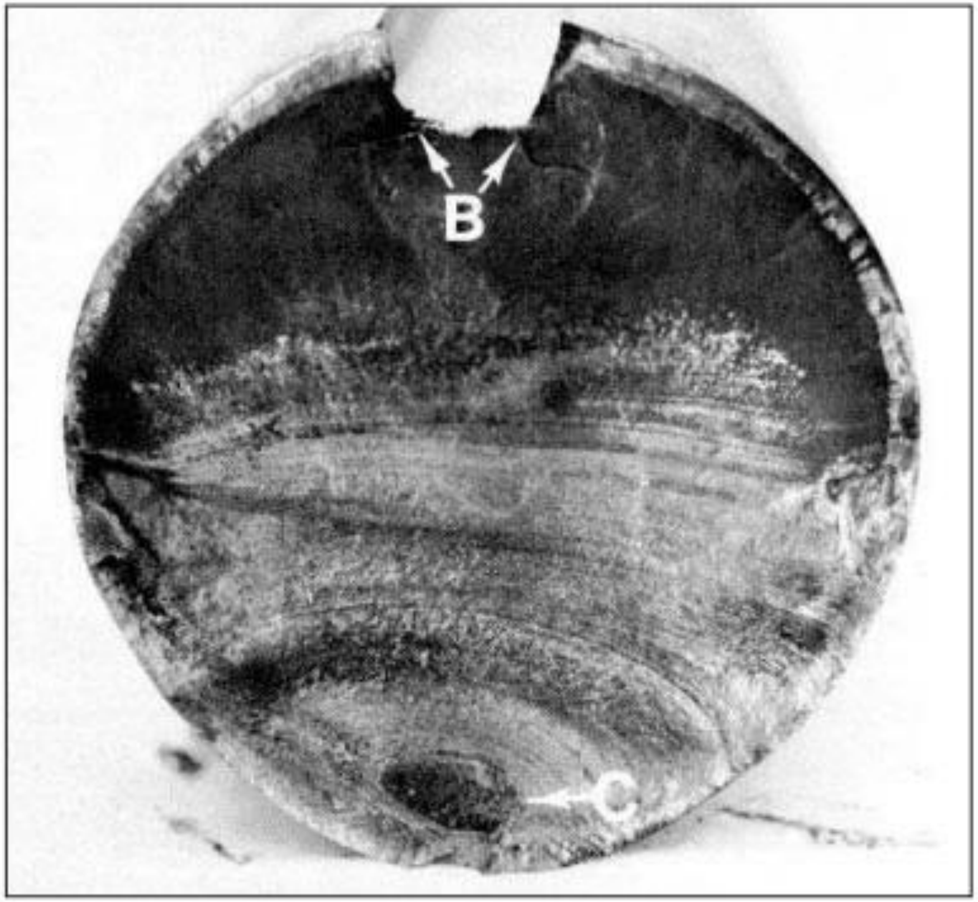
การทดสอบหา

“ความล้าของวัสดุ ”

Fatigue fracture of an AISI 4320 drive shaft. The fatigue failure initiated at the end of the keyway at points *B* and progressed to final rupture at *C*. The final rupture zone is small, indicating that loads were low. *(From ASM Handbook, Vol. 11: Failure Analysis and Prevention, ASM International, Materials Park, OH 44073-0002, fig 18, p. 111. Reprinted by permission of ASM International®, www.asminternational.org.)*



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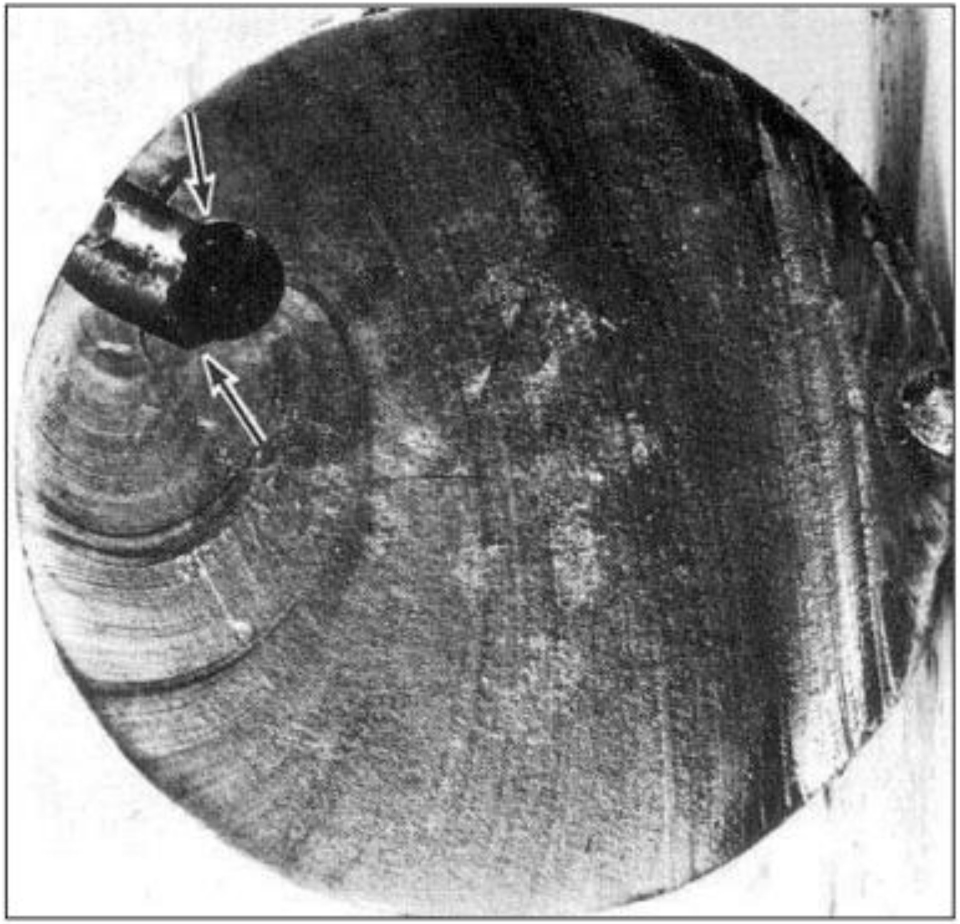
การทดสอบหา

“ความล้าของวัสดุ ”

Fatigue fracture surface of an AISI 8640 pin. Sharp corners of the mismatched grease holes provided stress concentrations that initiated two fatigue cracks indicated by the arrows. *(From ASM Handbook, Vol. 12: Fractography, ASM International, Materials Park, OH 44073-0002, fig 520, p. 331. Reprinted by permission of ASM International®, www.asminternational.org.)*



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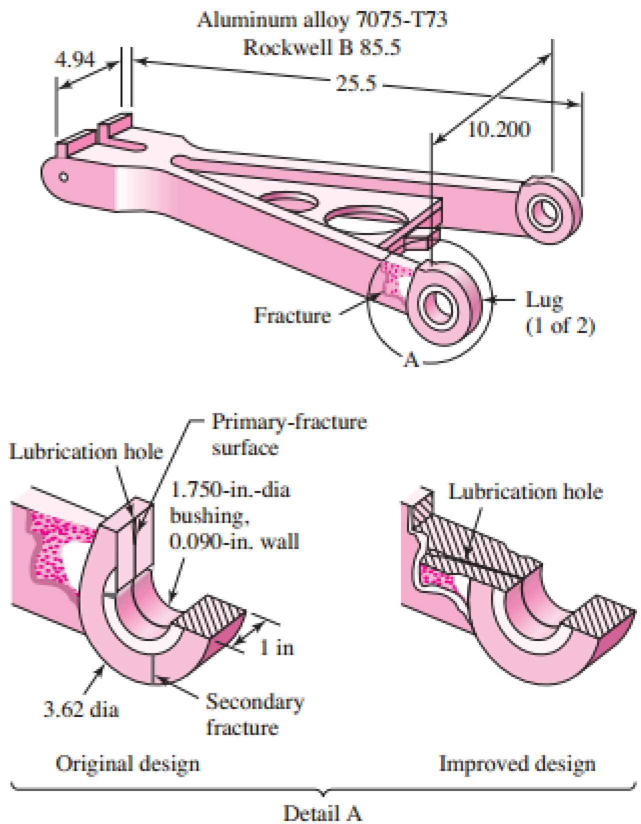
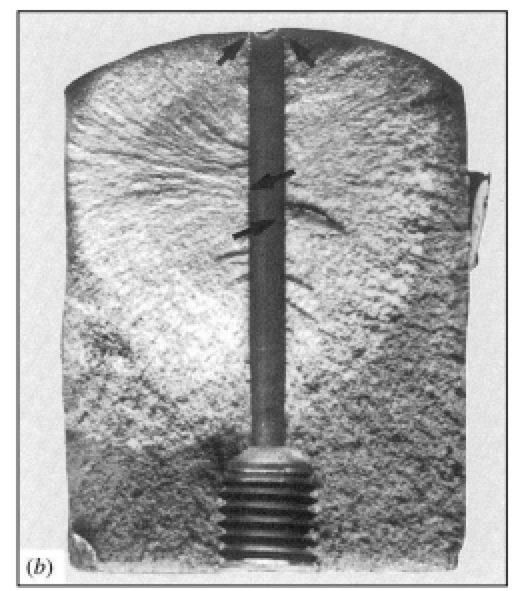
การทดสอบหา

“ความล้าของวัสดุ ”

Aluminum alloy *7075-T73* landing-gear torque-arm assembly redesign to eliminate fatigue fracture at a lubrication hole. (*a*) Arm configuration, original and improved design (dimensions given in inches). (*b*) Fracture surface where arrows indicate multiple crack origins. *(From ASM* Handbook, Vol. 11: Failure Analysis and Prevention, *ASM International, Materials Park, OH 44073-0002, fig 23, p. 114. Reprinted by permission of ASM International ®, www.asminternational.org.)*





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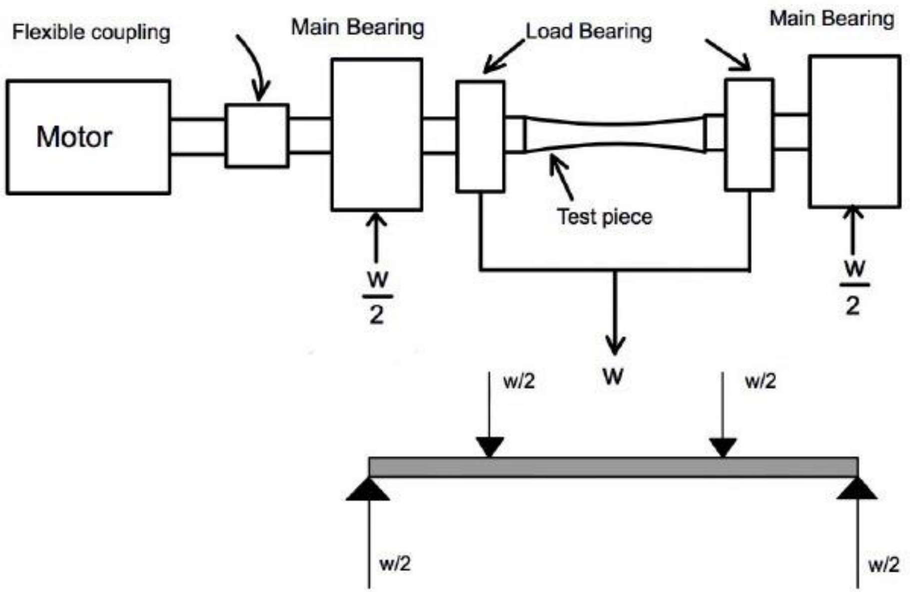
การทดสอบหา

“ความล้าของวัสดุ”



Source: http://kstestmc.blogspot.com/p/fatigue-test.html

การทดสอบหา

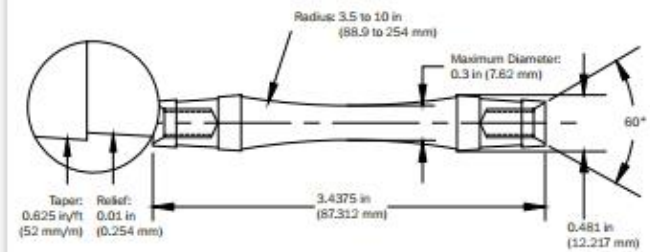
“ความล้าของวัสดุ”

R.R. Moore | Rotating Beam Fatigue Testing System

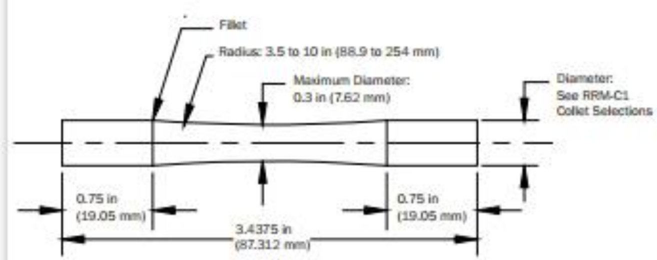
Specifications

		RRM-A1	RRM-A2
Bending Moment Capacity	in-lb	20 - 200	-
	kg-cm	-	25 - 230
Capacity Increments	in-lb	0.2	-
	kg-cm	-	0.254
Rotational Speed[1]	RPM	500 - 10,000	500 - 10,000
Load Weight Set[2]	lb	(8) 10, (1) 5, (2) 2, (1) 1, (1) 0.5, (2) 0.2, (1) 0.1	-
	kg	-	(7) 5, (2) 2, (1) 1, (1) 0.5, (1) 0.2, (2) 0.1, (2) 0.05
Mimimum Effective Weight[3]	lb	10	-
	kg	-	5
Machine Weight[4]	lb	90	90
	kg	41	41
Shipping Weight[5]	lb	240	240
	kg	110	110
Nominal Shipping Dimensions[5] (h × d × w)	in	39 × 13 × 20	39 × 13 × 20
	mm	990 × 330 × 510	990 × 330 × 510
Power Requirement[6]	V	100 -120	100 - 120
	Hz	50/60	50/60

Notes:
1. Speed regulation accuracy ±2%
2. Includes open-end wrench and allen wrenches for machine operation
3. Of yoke and weight pan
4. Does not include loading weights
5. Does not include optional stand (RRM-D1) but does include standard weight set
6. Transformer can be optionally supplied to step down 200 V to 240 V power



Tapered-end specimen



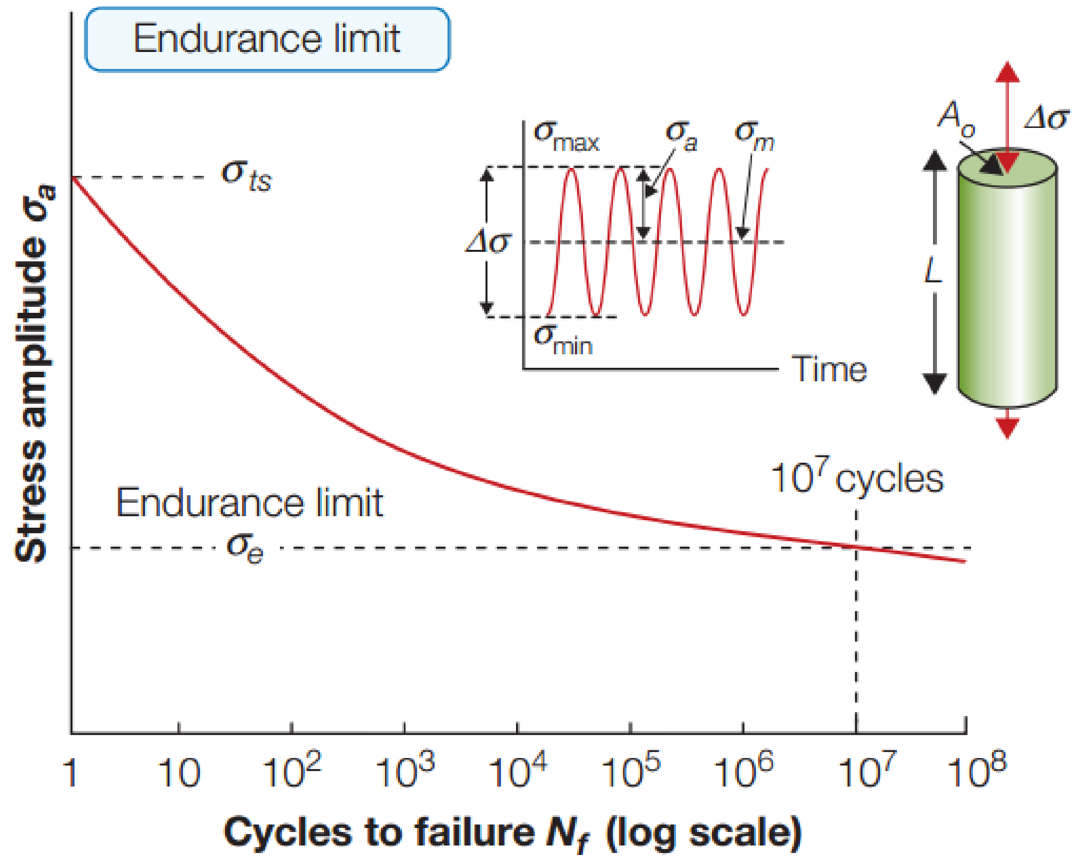
Straight shank specimen

การทดสอบหา

“ความล้าของวัสดุ ”

การทดสอบหา

“ความล้าของวัสดุ”



The endurance limit, σ_e, is the cyclic stress that causes failure in $N_f = 10^7$ cycles.

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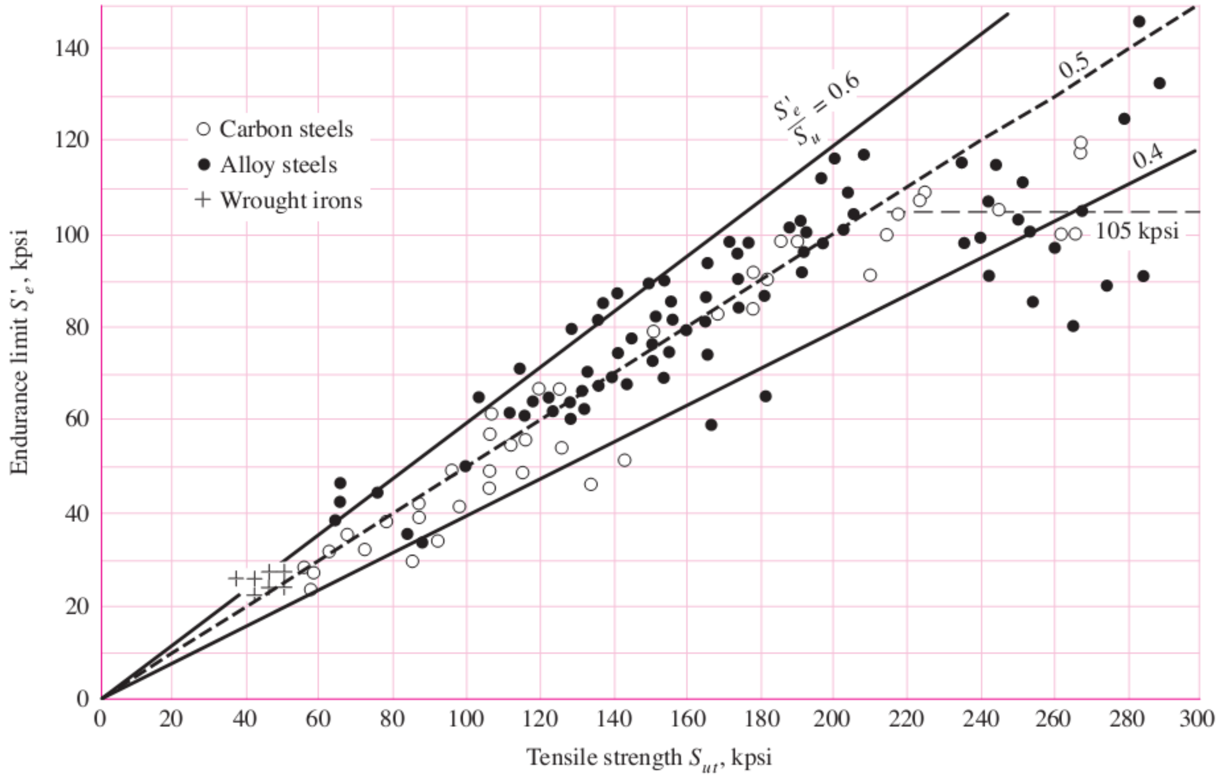
การทดสอบหา

“ความล้าของวัสดุ”

$$S'_e = \begin{cases} 0.5S_{ut} & S_{ut} \leq 200 \text{ kpsi } (1400 \text{ MPa}) \\ 100 \text{ kpsi} & S_{ut} > 200 \text{ kpsi} \\ 700 \text{ MPa} & S_{ut} > 1400 \text{ MPa} \end{cases}$$



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การทดสอบหา

"ความล้าของวัสดุ"

Mechanical Properties of Three Non-Steel Metals

(a) Typical Properties of Gray Cast Iron

[The American Society for Testing and Materials (ASTM) numbering system for gray cast iron is such that the numbers correspond to the *minimum tensile strength* in kpsi. Thus an ASTM No. 20 cast iron has a minimum tensile strength of 20 kpsi. Note particularly that the tabulations are *typical* of several heats.]

ASTM Number	Tensile Strength S_{ut}, kpsi	Compressive Strength S_{uc}, kpsi	Shear Modulus of Rupture S_{su}, kpsi	Modulus of Elasticity, Mpsi: Tension†	Modulus of Elasticity, Mpsi: Torsion	Endurance Limit* S_e, kpsi	Brinell Hardness H_B	Fatigue Stress-Concentration Factor K_f
20	22	83	26	9.6–14	3.9–5.6	10	156	1.00
25	26	97	32	11.5–14.8	4.6–6.0	11.5	174	1.05
30	31	109	40	13–16.4	5.2–6.6	14	201	1.10
35	36.5	124	48.5	14.5–17.2	5.8–6.9	16	212	1.15
40	42.5	140	57	16–20	6.4–7.8	18.5	235	1.25
50	52.5	164	73	18.8–22.8	7.2–8.0	21.5	262	1.35
60	62.5	187.5	88.5	20.4–23.5	7.8–8.5	24.5	302	1.50

*Polished or machined specimens.

†The modulus of elasticity of cast iron in compression corresponds closely to the upper value in the range given for tension and is a more constant value than that for tension.

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การทดสอบหา

“ความล้าของวัสดุ”

Mechanical Properties of Three Non-Steel Metals *(Continued)*

(b) Mechanical Properties of Some Aluminum Alloys

[These *are typical* properties for sizes of about $\frac{1}{2}$ in; similar properties can be obtained by using proper purchase specifications. The values given for fatigue strength correspond to $50(10^7)$ cycles of completely reversed stress. Alluminum alloys do not have an endurance limit. Yield strengths were obtained by the 0.2 percent offset method.]

Aluminum Association Number	Temper	Strength Yield, S_y, MPa (kpsi)	Strength Tensile, S_u, MPa (kpsi)	Fatigue, S_f, MPa (kpsi)	Elongation in 2 in, %	Brinell Hardness H_B
Wrought:						
2017	O	70 (10)	179 (26)	90 (13)	22	45
2024	O	76 (11)	186 (27)	90 (13)	22	47
	T3	345 (50)	482 (70)	138 (20)	16	120
3003	H12	117 (17)	131 (19)	55 (8)	20	35
	H16	165 (24)	179 (26)	65 (9.5)	14	47
3004	H34	186 (27)	234 (34)	103 (15)	12	63
	H38	234 (34)	276 (40)	110 (16)	6	77
5052	H32	186 (27)	234 (34)	117 (17)	18	62
	H36	234 (34)	269 (39)	124 (18)	10	74
Cast:						
319.0*	T6	165 (24)	248 (36)	69 (10)	2.0	80
333.0†	T5	172 (25)	234 (34)	83 (12)	1.0	100
	T6	207 (30)	289 (42)	103 (15)	1.5	105
335.0*	T6	172 (25)	241 (35)	62 (9)	3.0	80
	T7	248 (36)	262 (38)	62 (9)	0.5	85

*Sand casting.

†Permanent-mold casting.

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ความแข็ง

Hardness

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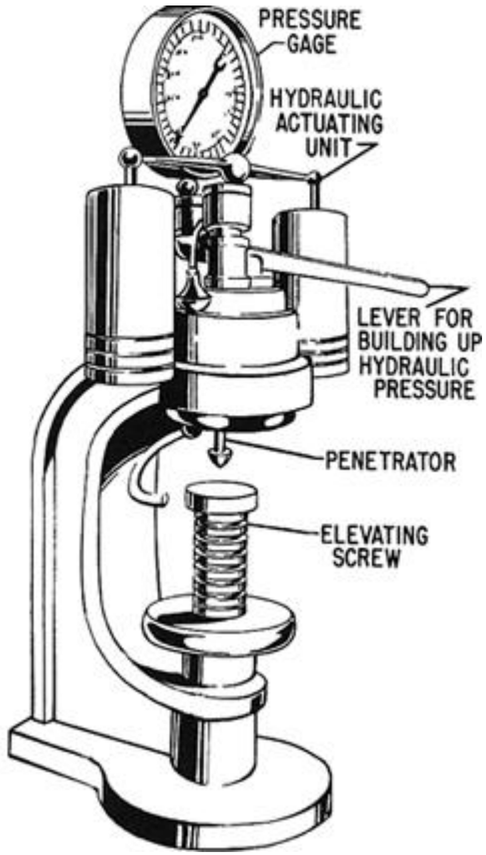
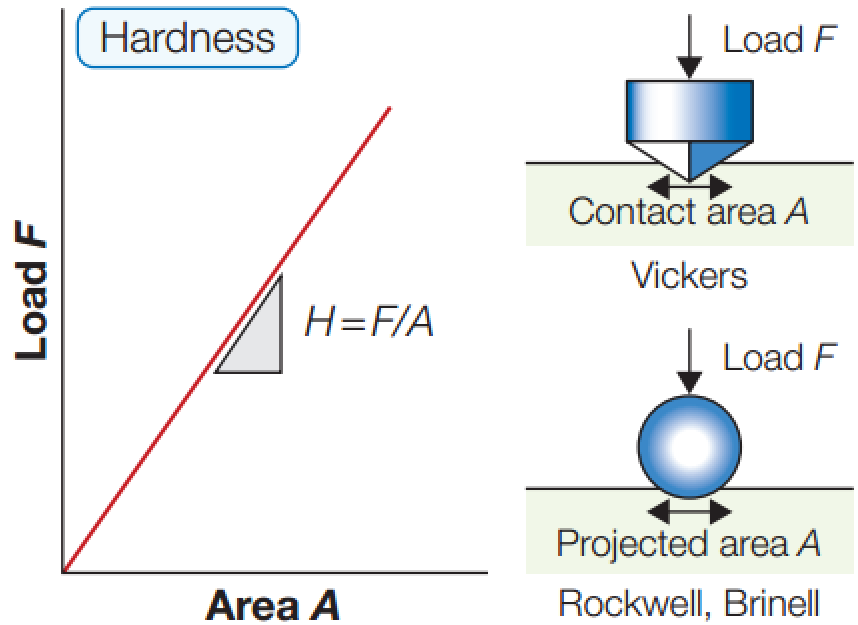
“ความแข็งของวัสดุ”





Hardness is measured as the load, *F*, divided by the projected area of contact, *A*, when a diamond-shaped indenter is forced into the surface.

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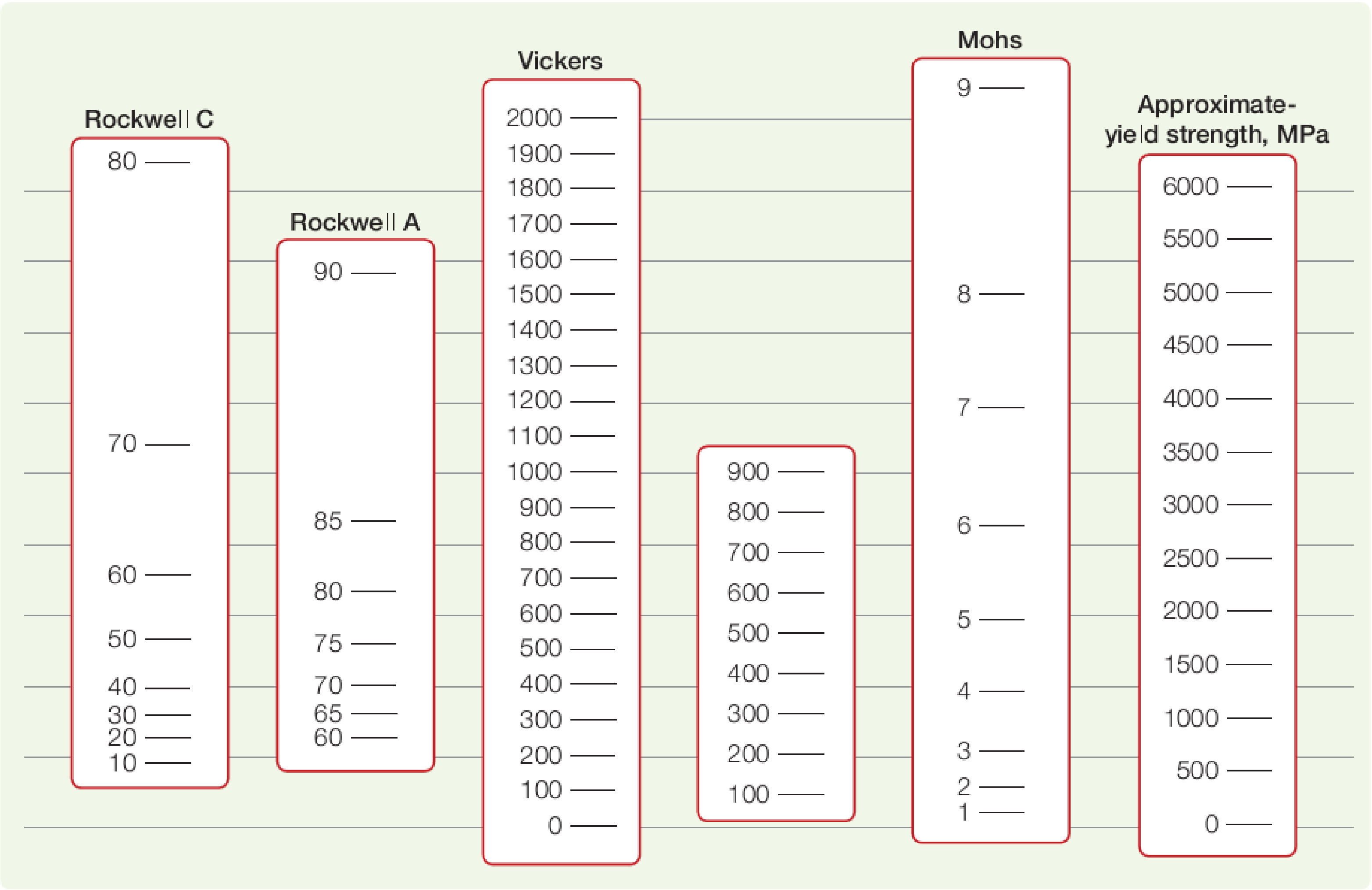
“ความแข็งของวัสดุ”



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“ความแข็งของวัสดุ”

For *steels*, the relationship between the minimum ultimate strength and the Brinell hardness number for $200 \le H_B \le 450$ is found to be

$$S_u = \begin{cases} 0.495 H_B & \text{kpsi} \\ 3.41 H_B & \text{MPa} \end{cases}$$

Similar relationships for *cast iron* can be derived from data supplied by Krause.[5] Data from 72 tests of gray iron produced by one foundry and poured in two sizes of test bars are reported in graph form. The minimum strength, as defined by the ASTM, is found from these data to be

$$S_u = \begin{cases} 0.23 H_B - 12.5 \text{ kpsi} \\ 1.58 H_B - 86 \text{ MPa} \end{cases}$$

Walton[6] shows a chart from which the SAE minimum strength can be obtained. The result is

$$S_u = 0.2375 H_B - 16 \text{ kpsi}$$

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“ความแข็งของวัสดุ”

Mechanical Properties of Three Non-Steel Metals

(a) Typical Properties of Gray Cast Iron

[The American Society for Testing and Materials (ASTM) numbering system for gray cast iron is such that the numbers correspond to the *minimum tensile strength* in kpsi. Thus an ASTM No. 20 cast iron has a minimum tensile strength of 20 kpsi. Note particularly that the tabulations are *typical* of several heats.]

ASTM Number	Tensile Strength S_{ut}, kpsi	Compressive Strength S_{uc}, kpsi	Shear Modulus of Rupture S_{su}, kpsi	Modulus of Elasticity, Mpsi Tension†	Modulus of Elasticity, Mpsi Torsion	Endurance Limit* S_e, kpsi	Brinell Hardness H_B	Fatigue Stress-Concentration Factor K_f
20	22	83	26	9.6–14	3.9–5.6	10	156	1.00
25	26	97	32	11.5–14.8	4.6–6.0	11.5	174	1.05
30	31	109	40	13–16.4	5.2–6.6	14	201	1.10
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*Polished or machined specimens.

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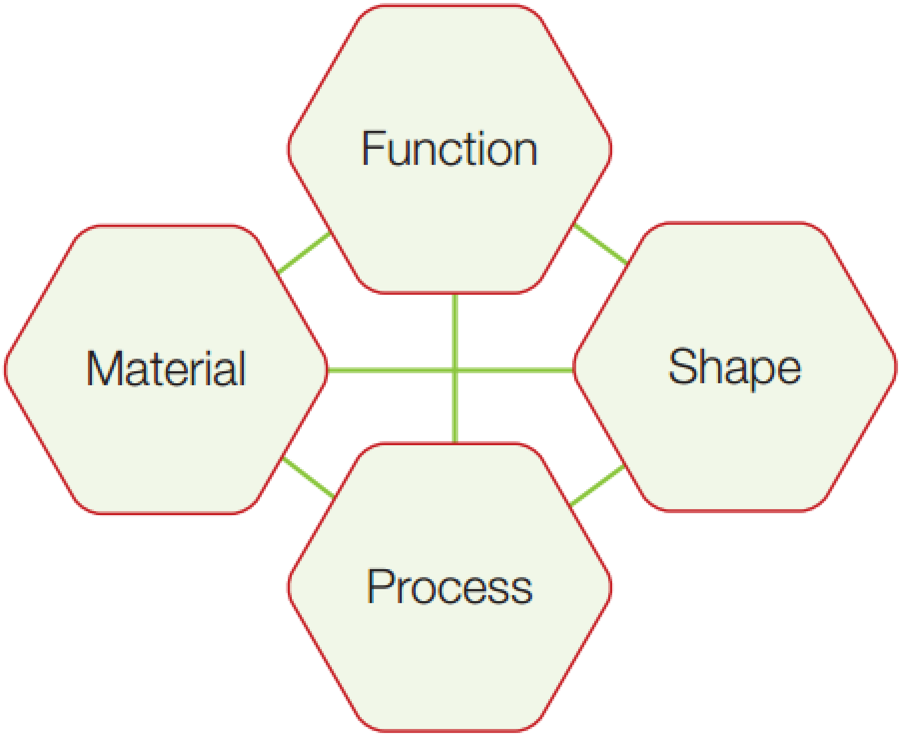
การเลือกใช้

Selection

ความสัมพันธ์ระหว่าง

“องค์ประกอบในการเลือกใช้วัสดุ”



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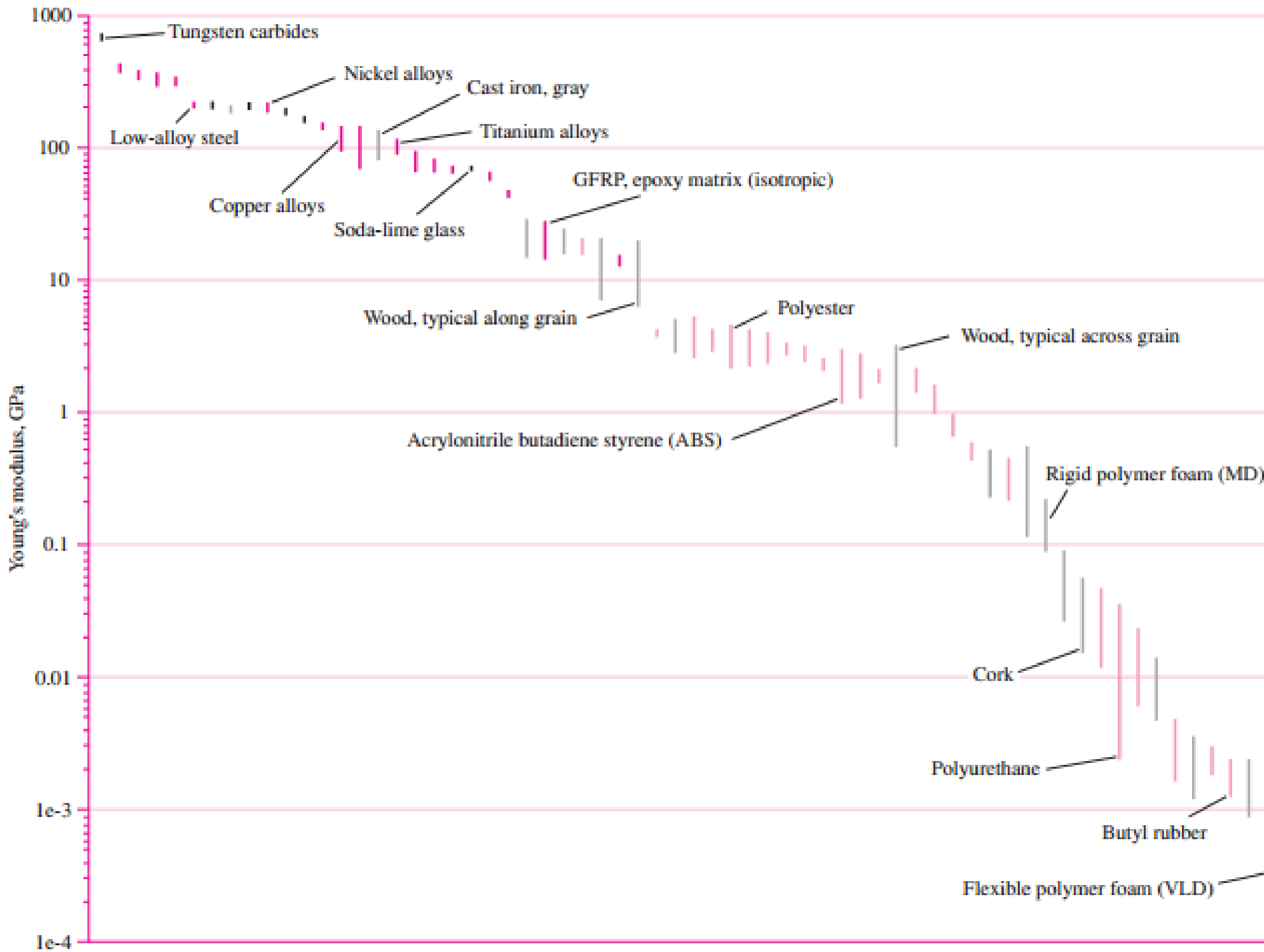
การเลือกใช้ "วัสดุ"

Young's modulus *E* for various materials. *(Figure courtesy of Prof. Mike Ashby, Granta Design, Cambridge, U.K.)*



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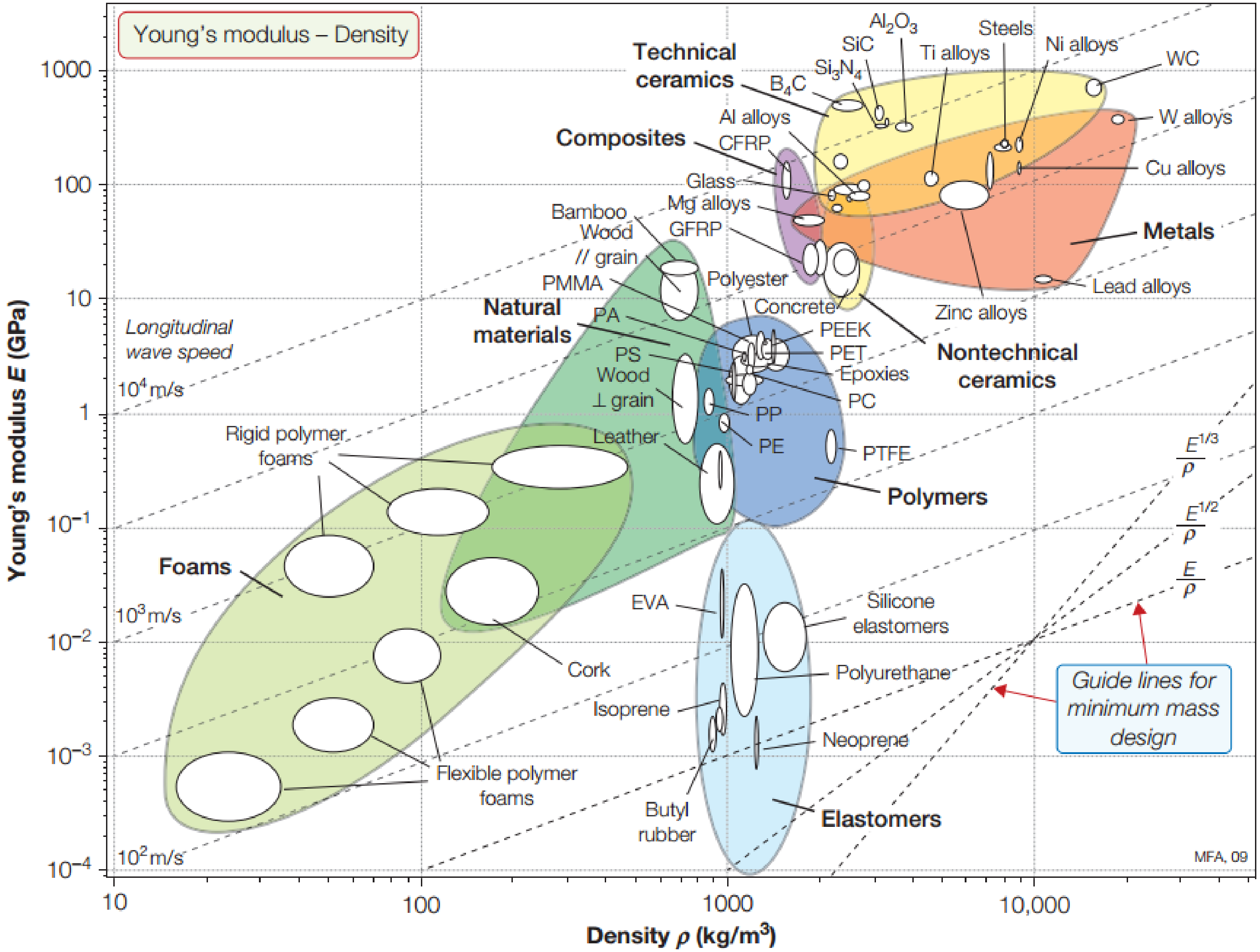

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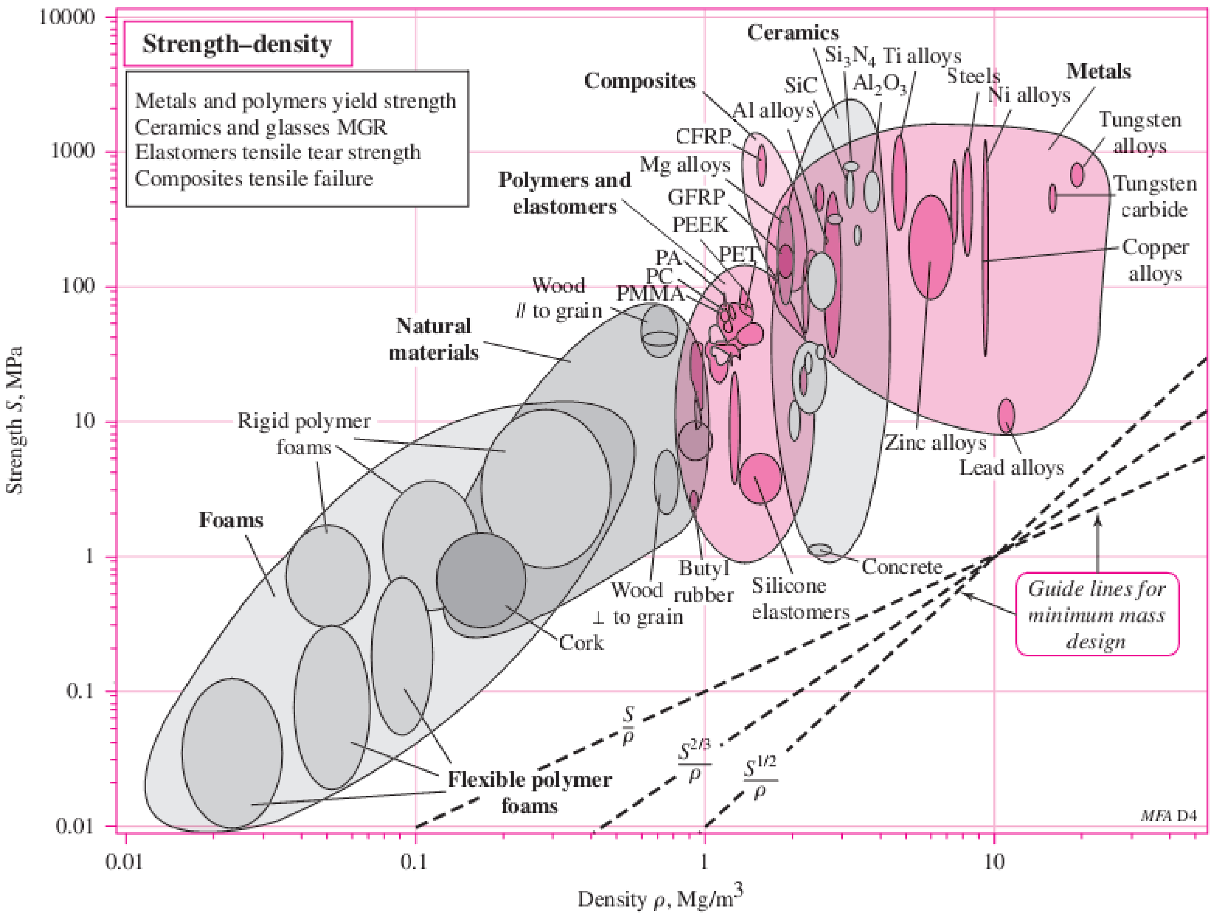
การเลือกใช้

“วัสดุ”

Strength S versus density ρ for various materials. For *metals*, S is the 0.2 percent offset yield strength. For *polymers*, S is the 1 percent yield strength. For *ceramics and glasses*, S is the compressive crushing strength. For *composites*, S is the tensile strength. For *elastomers*, S is the tear strength. *(Figure courtesy of Prof. Mike Ashby, Granta Design, Cambridge, U.K.)*



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