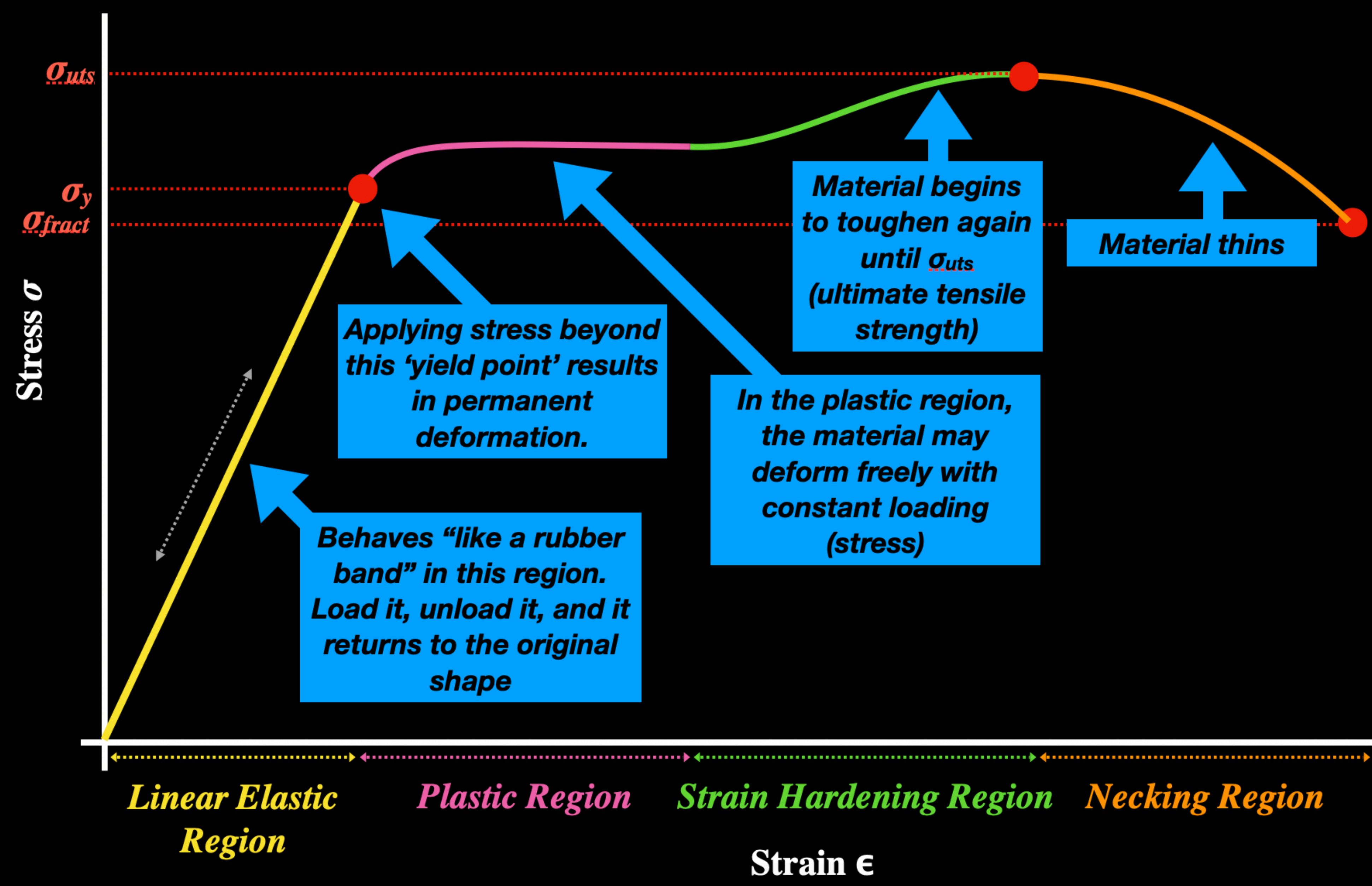
TODAY & TOMORROW

- Today:
  - Materials III: Hardness & Impact Behaviour
- Thursday: Materials IV: Deformation and Shear Stress
  - Gearbox assignment & Mechanical Principles assignment handed out
- (Next week: SolidWorks. SolidWorks videos will be posted to Blackboard. Jim will pop around to your labs for optional help sessions during Tues + Thurs lecture times)

MECHANICAL PRINCIPLES I

- **Assignment due end of week 9**
  - Bring completed assignment to lecture…
    - …or drop it off at my office (slide under the door if necessary)
- Show all work; attach to assignment sheets.
  - If using Excel or similar, include any formulae used
- Covers material through tomorrow’s lecture (all ‘materials’ lectures)
- Assignment will be posted to Blackboard on Wednesday

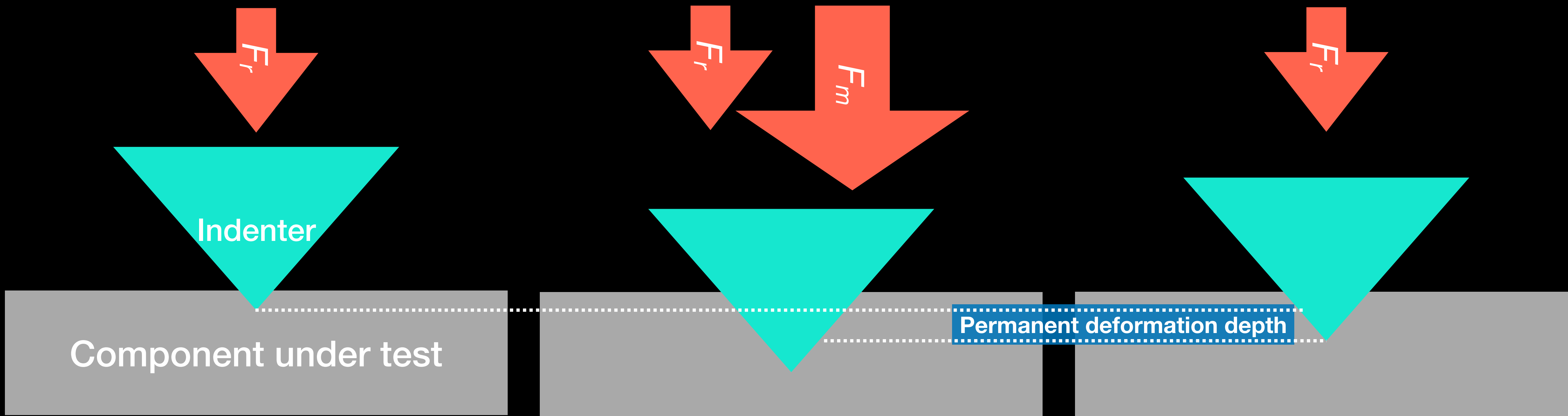
STRESS STRAIN DIAGRAM



HARDNESS

- Hardness: how difficult a material is to penetrate with a pointed tool.
  - It is difficult to conduct tensile tests (or similar):
    - Expensive equipment
    - Time-consuming
    - Destructive
  - We can use hardness tests as a way to more easily arrive at a material's ultimate strength.
- Hardness tests can be conducted at a very small scale (examining only a tiny portion of a material) up through very large-scale tests that use a large pointed tool to deform the material.
  - These large-scale tests are typically used in mechatronics engineering applications.
    - "Macro-hardness tests"
  - Two types dominate hardness testing in engineering:
    - Rockwell & Brinell hardness

ROCKWELL HARDNESS



1) The indenter is brought into contact with the component under test with an "Initial Force" specified according to the indenter material; this provides a precise known starting position.

2) Applied force is increased (with addition of a "Major Force," an amount specified by the indenter material).

3) Major Force is released. The resulting permanent deformation depth is measured. This depth is then input into an equation whose variables depend on the indenter material.

- Advantage: easily tested by a single apparatus that can be completely automated.
  - Very popular for the testing of parts on a production line.
- Disadvantage: tests only a small area (may give an incomplete picture)
  - Also, there are many different Rockwell Hardness scales that depend on the indenter used! Things can get confusing, particularly in assemblies with many different materials.

ROCKWELL HARDNESS

- Rockwell scales: A, B, C, etc.
  - A scale indenter: diamond cone (60 kg load)
  - B scale indenter: ~1.6 mm diameter ball (100 kg load)
  - C scale indenter: diamond cone (150 kg load)
- Key takeaway: Rockwell Hardness tests are relative to other tests on the same scale only.

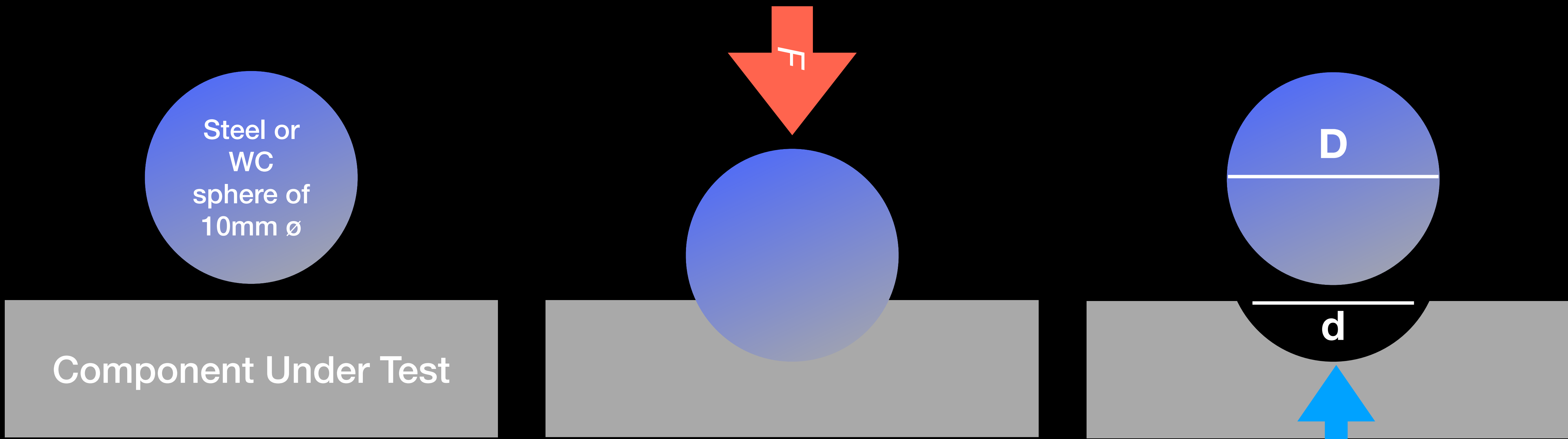
Rockwell Hardness Scales

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

BRINELL HARDNESS

- A good approach to use when avg. hardness is desired (due to a much larger indenter than is used in Rockwell hardness testing)
- This test is a bit more difficult/slow to automate (it usually requires manual measurement of the indentation).
  - Like Rockwell, it is largely non-destructive.
- Hardness Hb equals the load applied to the sphere divided by the (spherical!) surface area of the resulting indentation.

BRINELL HARDNESS



F is expressed in kgf (1 kgf is equal to 9.80665 N.)

$$BHN = \frac{2P}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

Diameter of spherical depression is measured.

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BRINELL HARDNESS

Relationship between Brinell Hardness and ultimate strength of a material is (roughly) linear.

$$S_u = 3.4\, H_b \,\mathrm{MPa}$$

Approximation for steels

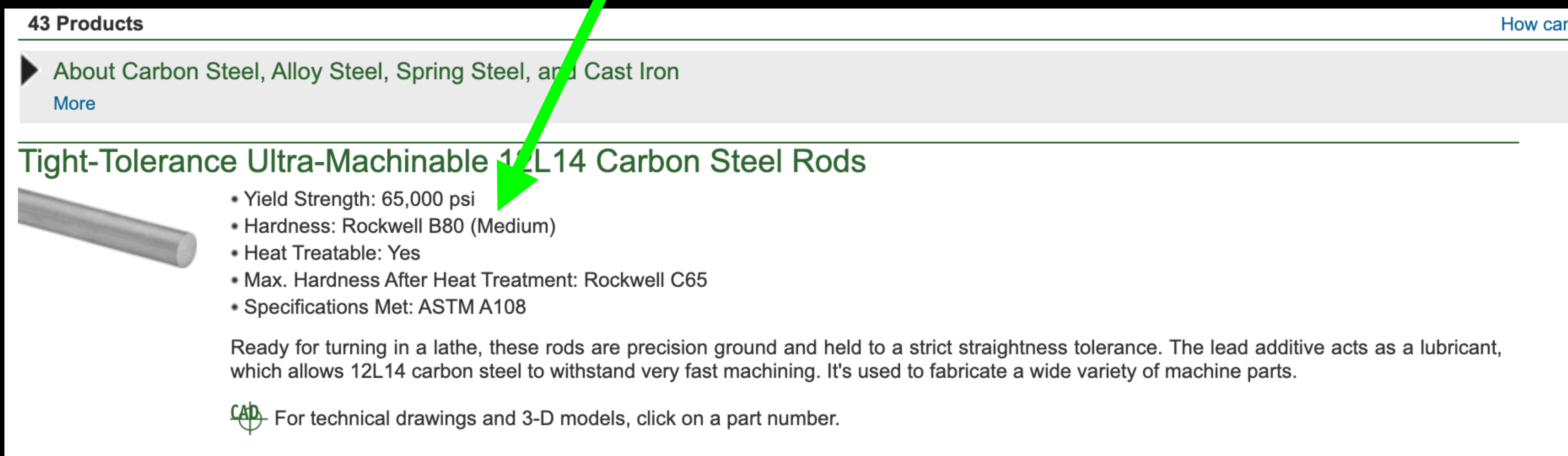
$$S_u = 1.58\, H_b - 86 \,\mathrm{MPa}$$

Approximation for cast irons*

*D. E. Krause, "Gray Iron—A Unique Engineering Material," ASTM Special Publication 455, 1969, pp. 3–29, as reported in Charles F. Walton (ed.), Iron Castings Handbook, Iron Founders Society, Inc., Cleveland, 1971, pp. 204, 205.

MATERIAL HARDNESS

Rockwell B80: B scale (soft metals: aluminium, soft steel, etc.)



43 Products

How can

About Carbon Steel, Alloy Steel, Spring Steel, and Cast Iron

More

Tight-Tolerance Ultra-Machinable 12L14 Carbon Steel Rods

- Yield Strength: 65,000 psi
- Hardness: Rockwell B80 (Medium)
- Heat Treatable: Yes
- Max. Hardness After Heat Treatment: Rockwell C65
- Specifications Met: ASTM A108

Ready for turning in a lathe, these rods are precision ground and held to a strict straightness tolerance. The lead additive acts as a lubricant, which allows 12L14 carbon steel to withstand very fast machining. It's used to fabricate a wide variety of machine parts.

CAD For technical drawings and 3-D models, click on a part number.

https://www.mcmaster.com/metals/steel/tight-tolerance-ultra-machinable-12l14-carbon-steel-rods/

MATERIAL HARDNESS

Rockwell C60: C scale (Hard steels)

Hardened Undersized High-Speed M2 Tool Steel Rods

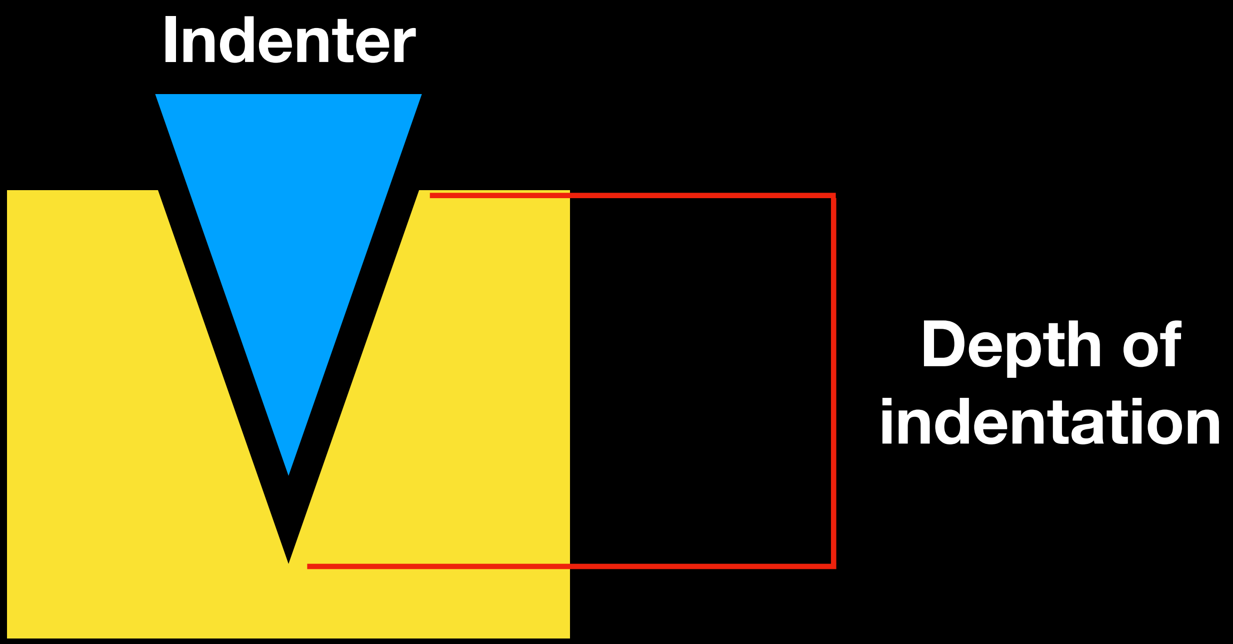
- Yield Strength: Not Rated
- Hardness: Rockwell C60 (Very Hard)

These rods, also known as drill blanks, have an undersized diameter for machining your own jobbers'-length drill bits. They're hardened for increased abrasion and impact resistance. M2 tool steel offers a nice balance of wear resistance and machinability. It has a high molybdenum content, which allows it to maintain sharp cutting edges even at elevated temperatures.

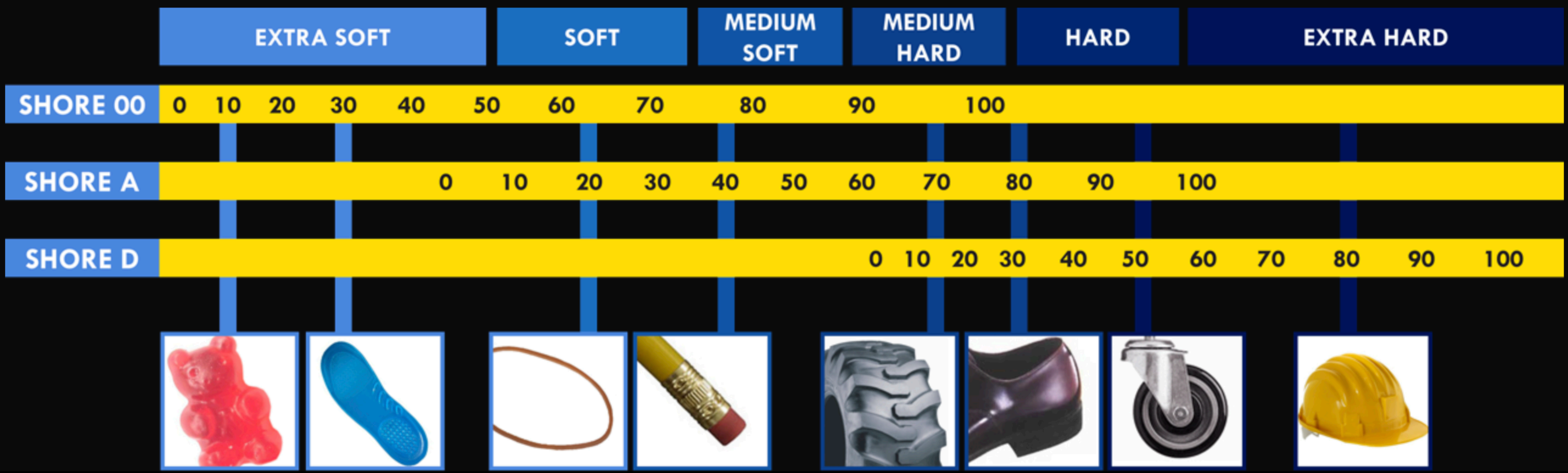
https://www.mcmaster.com/metals/tool-steel/hardened-undersized-high-speed-m2-tool-steel-rods-9/

HARDNESS OF "SOFT" MATERIALS

- For rubbers, polymers, and other 'soft' materials, the Shore Hardness scales are used.
  - There are multiple different shapes of indenters (A, C, D, B, M, E, O, OO, DO, OOO, OOO-S); no need to know all of these… OO, A, and D are by far the most common. Scales are unrelated and overlap.
  - A: Flattened cone-shaped indenter (35 degree), diameter of 1.40 mm, spring force of 8.05 N; OO = 1.20 mm sphere, 1.111 N spring force (for very soft materials).
  - D: Cone shaped indenter (30 degree), 1.40 mm diameter, spring force: 44.45 N
- Tests examine indentation depth after 15 seconds of indenter application.
  - If the indenter presses 2.54 mm into a material, then the durometer reads 0; if the indenter presses 0 mm into a material, the durometer reads 100.



SHORE DUROMETER



SHORE DUROMETER

Durometer: from 30A to 70A (using the Durometer A scale)

251 Products

Multipurpose Neoprene Rubber Sheets and Strips

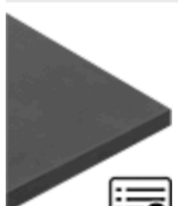
Neoprene is also known as chloroprene. It offers good oil and abrasion resistance. Softer durometer rubber has better conformability; harder durometer rubber is more wear resistant.

Crisscross texture rubber provides a nonslip gripping surface on both sides.

Buffed texture rubber is rough on one side to accept adhesive and smooth on the other.

Rubber **with material certification** comes with a traceable lot number and cure date.

Sheets



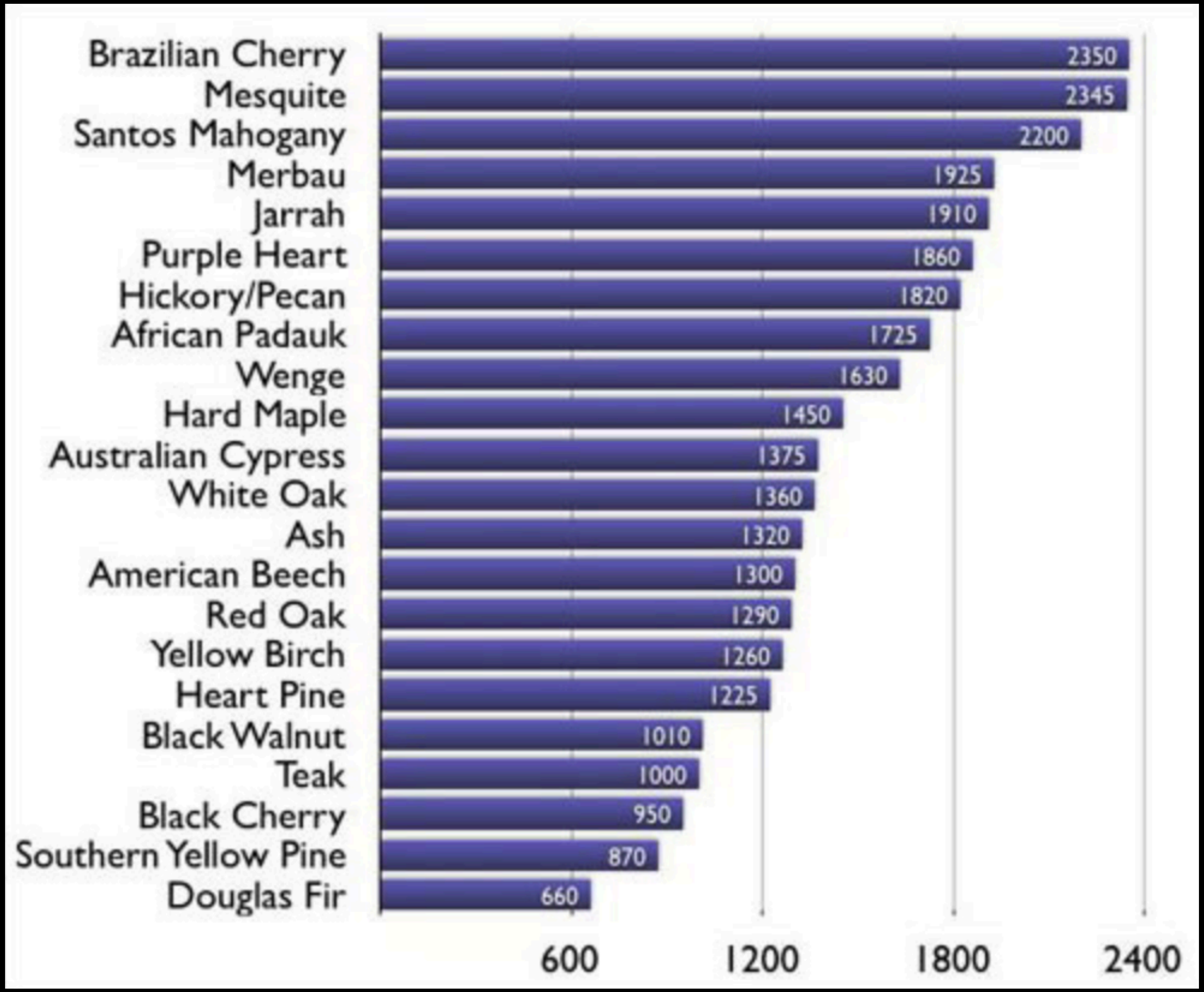
- Color: Black
- Temperature Range: -30° to 200° F
- Tensile Strength: 900 psi
- For Use Outdoors: Yes

Thick.	Thick. Tolerance	Choose a Durometer	6" × 6"	Each	12" × 12"	Each	12" × 24"	Each
Material Certification with Traceable Lot Number and Cure Date								
1/64"	-0.010" to +0.010"	50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N11	$5.92	1370N31	$9.28	1370N51	$12.61
1/32"	-0.010" to +0.010"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N12	6.21	1370N32	10.41	1370N52	13.76
1/16"	-0.016" to +0.016"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N13	6.75	1370N33	11.73	1370N53	15.83
3/32"	-0.016" to +0.016"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N14	7.65	1370N34	13.49	1370N54	19.93
1/8"	-0.020" to +0.020"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N15	9.12	1370N35	16.55	1370N55	24.92
3/16"	-0.031" to +0.031"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N16	10.84	1370N36	20.77	1370N56	32.58
1/4"	-0.031" to +0.031"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N17	13.60	1370N37	27.33	1370N57	41.86
3/8"	-0.047" to +0.047"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N18	17.37	1370N38	34.40	1370N58	58.47
1/2"	-0.047" to +0.047"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N19	21.92	1370N39	43.33	1370N59	74.01
3/4"	-0.094" to +0.094"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N21	31.29	1370N41	65.48	1370N61	111.36
1"	-0.100" to +0.100"	30A (Soft), 40A (Medium Soft), 50A (Medium), 60A (Medium Hard), 70A (Hard)	1370N22	39.78	1370N42	86.83	1370N62	148.48

https://www.mcmaster.com/rubber/rubber/multipurpose-neoprene-rubber-sheets-and-strips/

WOOD HARDNESS

- Wood is heterogeneous: different behaviour with grain, tangential to grain, etc.
  - Janka Scale: How much force (kN) is needed to press a steel ball, 11.27 mm in diameter halfway into a piece of wood.
  - Many caveats due to heterogeneity: wood dimensions, wood location on tree, knot content, moisture content, etc. are all controlled.



https://www.builddirect.com/learning-center/wp-content/uploads/2010/03/Janka_Chart.jpg

OTHER HARDNESS TESTS

- Vickers
  - Pyramidal indentation
  - Wide dynamic range
  - Developed in 1921 as easier alternative to Brinell
  - Pyramidal indenter's dimensions are measured
- Mohs Hardness Scale
  - Used by ceramics engineers, geologists, mineralogists
  - A material at a given Mohs number will scratch all materials with lower numbers.
- Knoop Hardness Scale
  - Used for measuring brittle, thin materials
  - Diamond micro-indentations are made

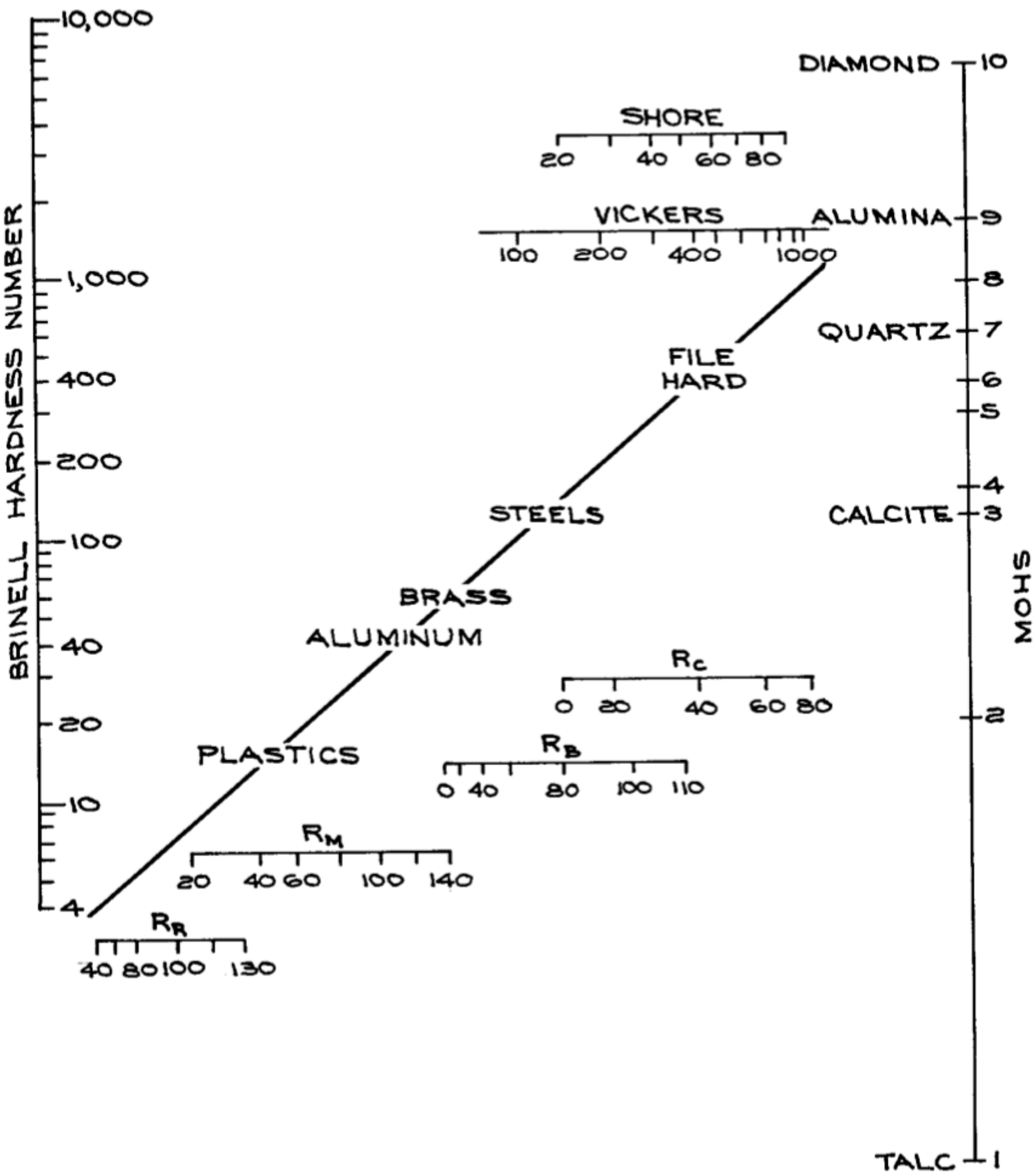
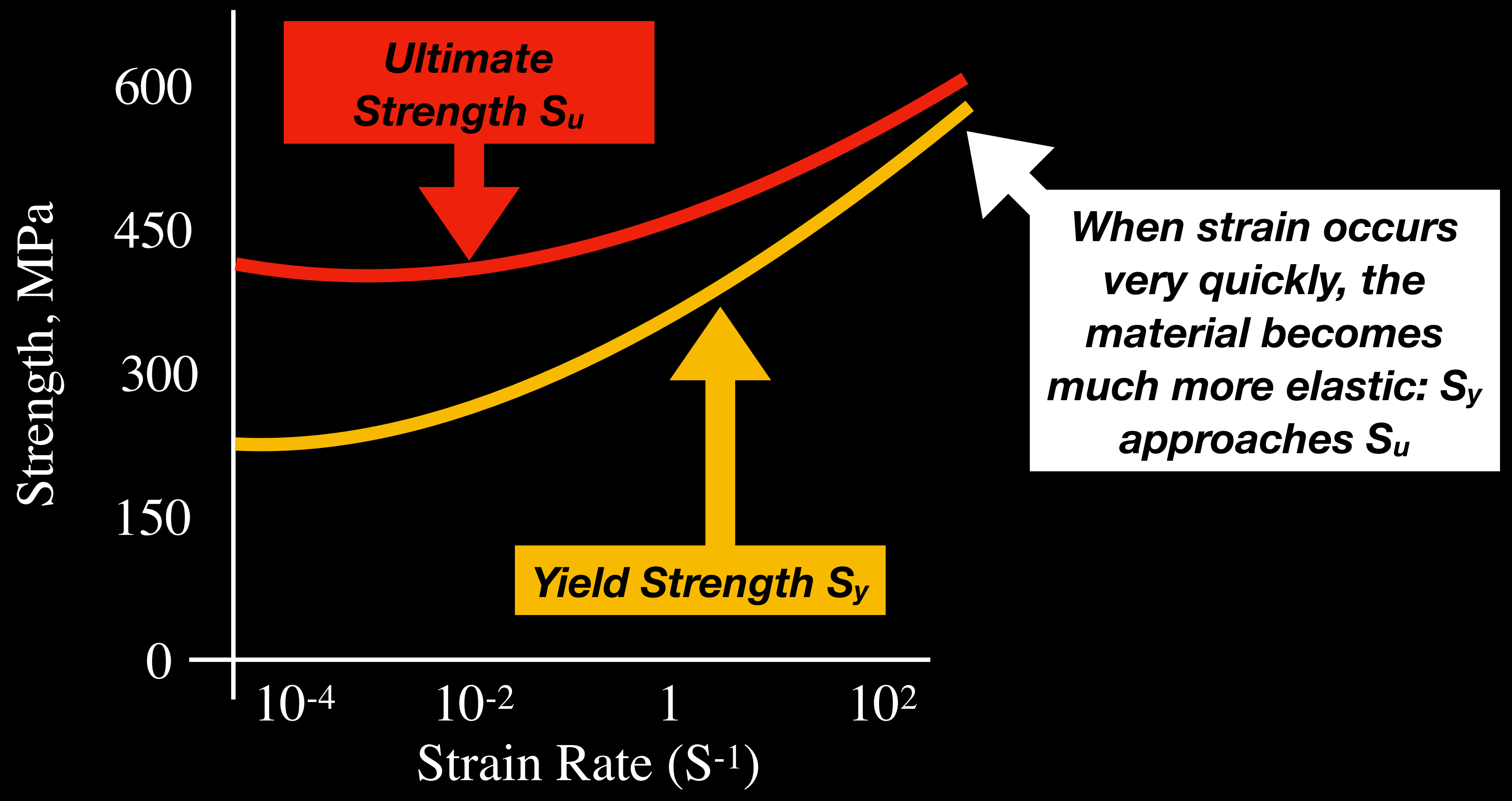


Figure 1.13 Approximate relation of Brinell (BHN), Rockwell (R_R, R_M, R_B, R_C), Vickers (VHN), Shore, and Mohs hardness scales.

"Building Scientific Apparatus" 4th Edition, Moore et al.

IMPACT BEHAVIOUR

- The preceding studies examined material behaviour under static (slowly applied) stresses.
  - If the stress applied at a rate slower than 1/3rd of the fundamental vibrational frequency of the material, the load is said to be static.
  - Faster than this, and this suddenly applied stress is said to be dynamic.
- The stress-strain relationship changes under impact conditions.

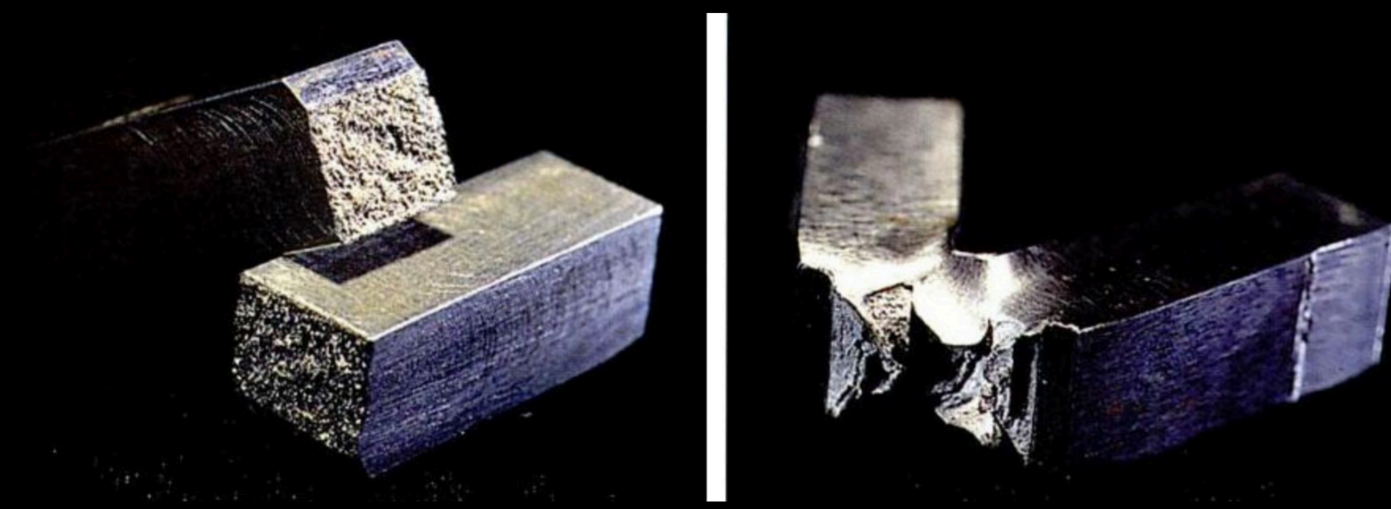


Graph from 2-8, Shipley's Mechanical Engineering Design

IMPACT TESTING

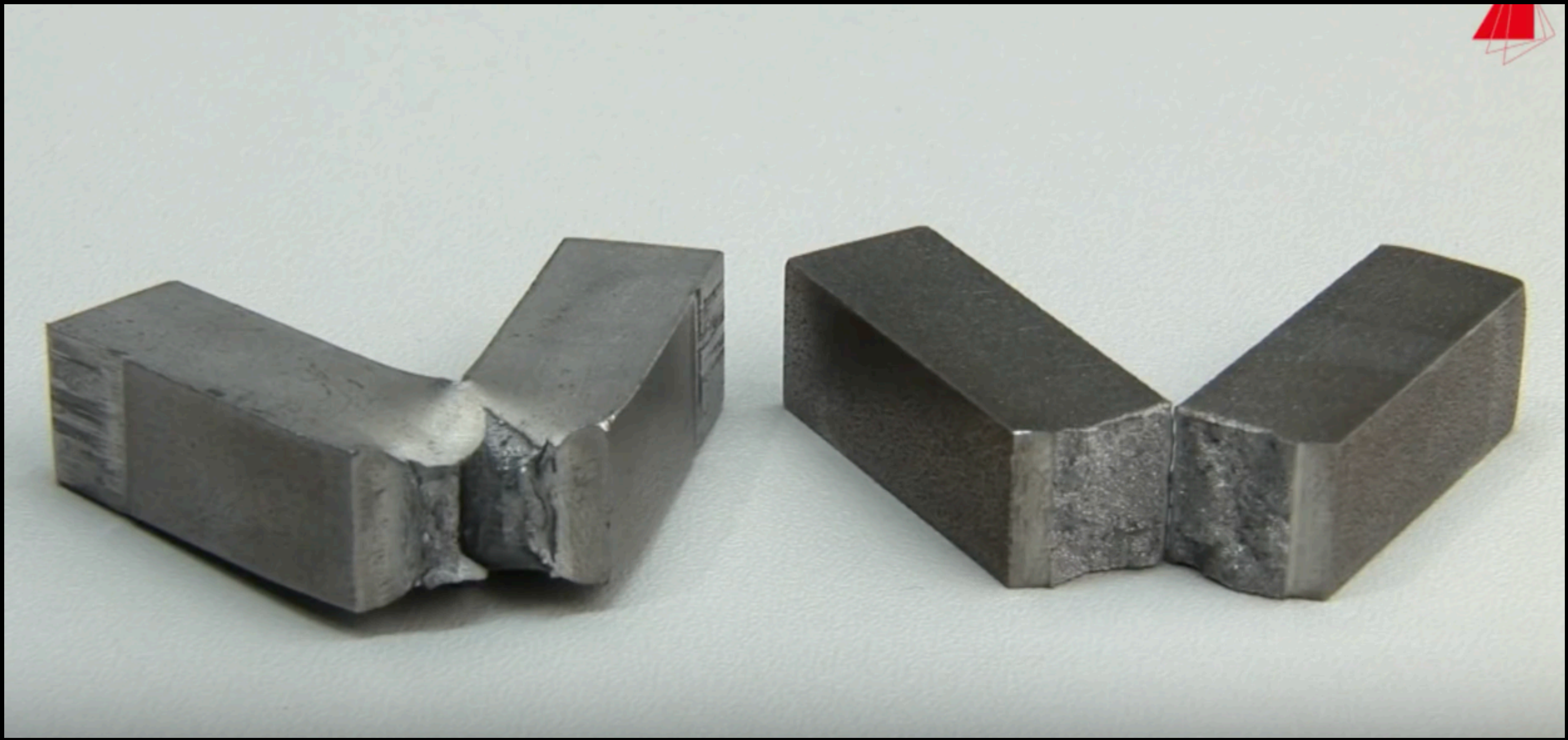
- In the Charpy Test, a swinging pendulum apparatus is usually used to test a material's impact behaviour.
  - A pendulum is raised to a known height and is released, swinging against a material.
  - The material is prepared with a v-shaped groove of specified dimensions.
- The distance that the pendulum bounces back (or follows through) from the material shows how much energy is absorbed the material in an impact.
  - More bounce-back/follow-through = less energy absorbed; more brittle material.
- The material's failure mode can be examined for empirical evidence of ductility/brittleness.
  - *Used to forensically analyse Titanic steel!*
- This test is quite sensitive to temperature and dimension errors (in the v-groove); more modern fracture analysis approaches have come to dominate high-consequence applications (alternatively, use many samples of a Charpy test… expensive, though)
- For more information: https://www.tf.uni-kiel.de/matwis/amat/iss/kap_3/backbone/r3_2_2.html

Brittle: No elastic deformation. Clean granular break.



Ductile: evidence of elastic deformation prior to fracture

VIDEO: CHARPY TEST



https://www.youtube.com/watch?v=tpGhqQvftAo