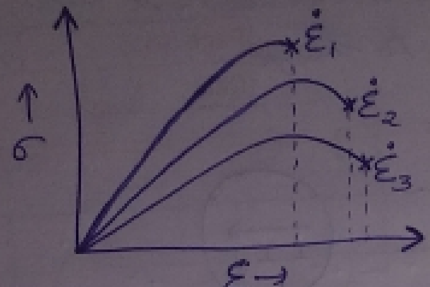


$\boxed{\dot{\varepsilon}_1 > \dot{\varepsilon}_2 > \dot{\varepsilon}_3}$ → because fracture happens earlier in ε_1, so more elongation in specific time

$$\Rightarrow \boxed{\begin{array}{l} \uparrow \text{in } \underbrace{\varepsilon}_{\text{strain rate}} \Rightarrow \overbrace{\sigma}^{\text{strength}} \uparrow,\ \overbrace{d}^{\text{ductility}} \downarrow \\ \uparrow \text{in } \underbrace{T}_{\text{temp.}} \Rightarrow \sigma \downarrow,\ d \uparrow \end{array}}$$

31/1/23

Q) i) In a tension test of metal, fracture occurs at max. load, the conditions at fracture were final area = 100 mm², final length = 60 mm, the initial area = 150 mm² & initial length = 40 mm, determine true strain to fracture using changes in both length and area.

ii) If more ductile metal is tested such that necking occurs, final gauge length is 83 mm, final diameter = 8 mm, initial length = 40 mm, initial diameter = 12.8 mm, determine true strain to fracture using changes in both length and area.

sol. Case i)

a) Using length:

$$\varepsilon = \frac{\Delta L}{L} = \frac{60-40}{40} = \frac{20}{40} = 0.5$$

$$\varepsilon_T = \ln(1+\varepsilon) = \ln(1.5) \Rightarrow \underline{\underline{\varepsilon_T = 0.405}}$$

b) Using area:

$$q = \frac{150-100}{150} = \frac{50}{150} = \frac{1}{3}$$

$$\Rightarrow \varepsilon_f = \frac{q}{1-q} = \frac{\frac{1}{3}}{1-\frac{1}{3}} = \frac{\frac{1}{3}}{\frac{2}{3}} = \frac{1}{2} = 0.5$$

$$\Rightarrow \varepsilon_T = \ln(1+0.5) = \ln(1.5) \Rightarrow \underline{\underline{\varepsilon_T = 0.405}}$$

Case ii)

a) Using length:

$$\varepsilon = \frac{\Delta L}{L} = \frac{83-40}{40} = 1.075 \Rightarrow \varepsilon_T = \ln(1+1.075) \Rightarrow \underline{\underline{\varepsilon_T = 0.73}}$$

b) Using area:

$$q = \frac{\frac{\pi}{4}(12.8)^2 - \frac{\pi}{4}(8)^2}{\frac{\pi}{4}(12.8)^2} = 0.61 \qquad \Rightarrow \varepsilon_f = \frac{0.61}{1-0.61} = 1.56$$

$$\Rightarrow \varepsilon_T = \ln(1+1.56) \Rightarrow \underline{\underline{\varepsilon_T = 0.94}}$$

Q) Find true strain & engineering strain where necking begins for the following material law $\sigma_T = K(\varepsilon_T + \varepsilon_o)^n$ & the eqn is as $\sigma = 500(\varepsilon_T + 0.05)^{0.25}$ at the point where necking begins.

sol. $$\frac{d\sigma_T}{d\varepsilon_T} = \sigma_T \quad \text{— ①}$$

$$\sigma_T = 500(\varepsilon_T + 0.05)^{0.25} \Rightarrow \ln\sigma_T = 0.25\ln(\varepsilon_T + 0.05) + \ln(500)$$

$$\Rightarrow \ln\sigma_T = 0.25\ln\varepsilon_T \ln(0.05) + \ln 500$$

$$\Rightarrow \ln\sigma_T = -0.75\ln\varepsilon_T + \ln 500$$

$$\Rightarrow d\ln\sigma_T = -0.75\, d\ln\varepsilon_T$$

$$\Rightarrow \frac{d\ln\sigma_T}{d\ln\varepsilon_T} = -0.75 \Rightarrow \frac{d\sigma_T}{d\varepsilon_T} = -0.75\left(\frac{\sigma_T}{\varepsilon_T}\right) \quad \text{— ②}$$

From ① & ②, $\sigma_T = -0.75\dfrac{\sigma_T}{\varepsilon_T} \Rightarrow \varepsilon_T = -0.75$

$$\Rightarrow d\ln\sigma_T = 0.25\, d\ln(\varepsilon_T + 0.05)$$

$$\Rightarrow \frac{d\ln\sigma_T}{d\ln(\varepsilon_T + 0.05)} = 0.25 \Rightarrow \frac{\frac{d\sigma_T}{\sigma_T}}{\frac{d\varepsilon_T}{\varepsilon_T + 0.05}} = 0.25$$

$$\Rightarrow \frac{d\sigma_T}{d\varepsilon_T} = 0.25\left[\frac{\sigma_T}{(\varepsilon_T + 0.05)}\right] \quad \text{— ②}$$

From ① & ②,
$$\cancel{\sigma_T} = 0.25\left[\frac{\cancel{\sigma_T}}{(\varepsilon_T + 0.05)}\right] \Rightarrow \varepsilon_T + 0.05 = 0.25$$
$$\Rightarrow \varepsilon_T = 0.2$$

$$\varepsilon_T = \ln(1+\varepsilon) \Rightarrow 0.2 = \ln(1+\varepsilon)$$
$$\Rightarrow \varepsilon = e^{0.2} - 1 = 0.22 \Rightarrow \varepsilon = 0.22$$

1/3/23

Q) A 13mm diameter tensile specimen has 50mm gauge length, the load corresponding to 0.2% off set, the load is 6800kg & max. load is 8400kg, fracture occurs at 7300kg, gauge length at fracture is 65mm. Calculate standard properties of material from tension test.

sol. $A_o = \frac{\pi}{4}(13)^2 = 132.7 \times 10^{-6} m^2$

$A_f = \frac{\pi}{4}(8)^2 = 50.3 \times 10^{-6} m^2$

$\underbrace{UTS}_{\text{Ultimate Tensile Strength}} = \frac{P_{max}}{A_o} = \frac{mg}{A_o} = \frac{8400 \times 9.8}{132.7 \times 10^{-6}}$

$= \frac{8400 \times 9.8 \times 10^6}{132.7} = \frac{84 \times 9.8 \times 10^6}{132.7} = 620$

$\Rightarrow UTS = 620 MPa$

$\boxed{\text{Area reduction} = \frac{A_o - A_f}{A_o} = \frac{132.7 - 50.3}{132.7} = 62\%}$

$\underbrace{YS}_{\text{Yield strength}} = \frac{P_{(0.2)}}{A_o} = \frac{6800 \times 9.8}{132.7 \times 10^{-6}} = 502 \Rightarrow YS = 502 MPa$

Fracture stress $= \frac{\overbrace{P_f}^{\text{load at fracture point}}}{A_o} = \frac{7300 \times 9.8}{132.7 \times 10^{-6}} = 539 \Rightarrow$ Fracture stress $= 539 MPa$

$\underbrace{\varepsilon}_{\text{strain}} = \frac{L_f - L_o}{L_o} = \frac{65 - 50}{50} = \frac{15}{50} = 0.3 \Rightarrow \varepsilon = 0.3$

$\Rightarrow$ Elongation = 30%.

Hardness test:

$\hookrightarrow$ resistance to permanent deformation by indentation. (indentation $\to$ penetration; $\to$ for metallurgist)

Hardness test is cheaper and not time consuming. So this test is widely used to compare 2 materials.

Classification of hardness test:

i) Nature
- static $\rightarrow$ Rockwell (micro), Vickers, Brinell, Knoop hardness test
- dynamic $\rightarrow$ Shore hardness test
- scratch $\rightarrow$ Moh's hardness test

ii) Type of loading
- macro $\Rightarrow$ load $> 1 kgf$
- micro $\Rightarrow$ load $= 1 gmf - 1 kgf$
- nano $\Rightarrow$ load $< 0.1 mN$

3/2/23

$\rightarrow$ Scratch hardness is used for comparison purpose. For eg., Moh's hardness has a scale of 1-10, 1 being the softest & 10 being the hardest.

$\rightarrow$ Every hardness test has an indentor & load.

$\rightarrow$ We can calculate hardness by $\Rightarrow$ i) depth of indentation

ii) area of indentation

Page No.:
Date: / /

→ compressive or shear loading can be used for hardness test.

→ Tensile loading is not used because brittle materials break.

→ For composite material, the composition is different at different places, so we get different values of hardness based on the point of application of load, so usually 10 readings are taken and avg. is calculated.

→ Sample should be a polished one. If surface is irregular, indentation will not be proper.

→ Time of loading should 15 – 120 sec, not more than 30 sec generally.

→ The geometry of the indentator plays an important role in hardness test.

→ Time of loading should be more for material because it deforms easily & it takes time for it to respond to indentation.

→ $\boxed{\text{Hardness} \propto \dfrac{1}{\text{depth of indentation}}}$

Rockwell hardness test :

Has 4 scales A, B, C & D depending upon load & indenter.

$$\left.\begin{array}{l} A \rightarrow 60\,kgf \\ B \rightarrow 100\,kgf \\ C \rightarrow 150\,kgf \\ D \rightarrow 100\,kgf \end{array}\right\} \rightarrow \text{scale based on load}$$

widely used ← {B, C}

Indentors → diamond cone indentor ⇒ A, B, D — also known as Brale indentor (tip radius 0.2 mm, apperture = 120°)

Indentors → steel ball indentor ⇒ ($\frac{1}{16}$ inch hardened steel ball for C)

Load → major ⇒ 50 / 90 / 140 kgf

Load → minor ⇒ 10 kgf load so that material does not behave abnormally when major load is applied due to sudden impact.
So minor load applied before applying major load.

6/3/23 points moves in anti-clockwise direction in Rockwell test when load is applied.

When load is removed, the pointer moves back in clockwise direction due to elastic recovery of material.

If we get –ve reading, that means the sample is overpenetrated because the material is too soft / indenter & load are not suitable for that material.

If we get hardness value as 70, then we represent it as 70 HR_C or HR_C 70. Here 'C' refers to the 'C' scale.

→ for soft material, pointer makes more than 1 rotation around the scale.

$$\boxed{H = h - 500t}$$

→ constant ⇒ A, C, D = 100
B = 130

Depth of indentation = difference in indentation of major & minor load
↓
For Rockwell hardness test

Superficial Rockwell scale → minor load = 3 kgf
major load = 15, 30, 45 kgf

variation of Rockwell test
⇓
for thin & soft materials

For hardness value 70, 70 N_{30} ⇒ diamond cone
70 T_{30} ⇒ steel ball
↳ scale

Rules for hardness test

i) $T = 10t$
T → thickness of specimen
t → depth of indentation

ii) The spacing b/w indenter should be 3–5 times indenter

30 HR_C ⇒ softer material , 70 HR_C ⇒ harder material

Brinell hardness test:

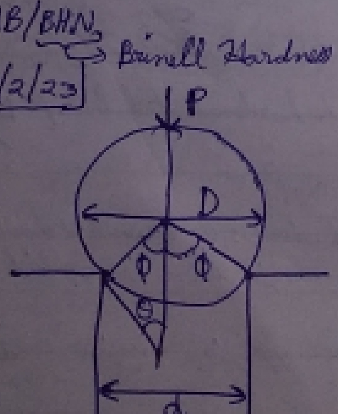
i) This is the oldest method for hardness.
ii) 10 mm hardened steel ball indenter is used.
iii) Upto 3000 kgf load can be used.
iv) Area of indentation is used to calculate hardness.

v) $H = \dfrac{P}{\text{surface area of indentation}}$ ⇒ $\boxed{H = \dfrac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}}$

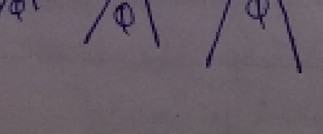
P → load
D → diameter of indentor
d → diameter of indentation in sample

H → HB/BHN → Brinell Hardness Number

7/2/23



We can change the load or diameter, but it has to be geometrically similar i.e., ϕ should be same. For different angle, we get different hardness values.



⇒ angle is same but size is different

So, if we change diameter, we should change load also such that :- $\boxed{\frac{P}{D^2} = \text{constant} = K}$, K = load factor

$0.25 < \frac{d}{D} < 0.5 \rightarrow$ for metals, Ideal value = 0.375

$\rightarrow$ geometrical similarity will be maintained for this condition

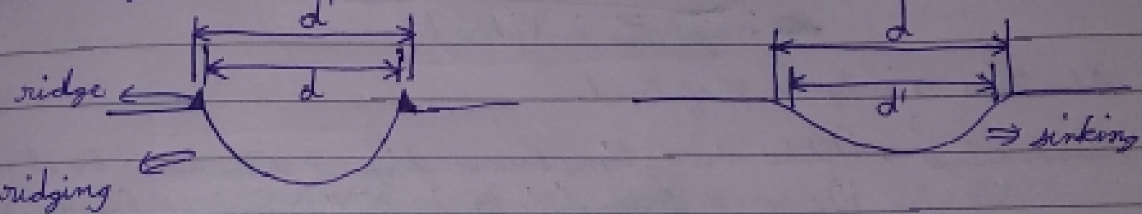
Ridging $\Rightarrow$ flow of material is more & material pile up at edges.

Sinking $\Rightarrow$ material flows inside.

underestimated diameter {d' > d

d' < d} $\rightarrow$ overestimated diameter

irregularities



Tungsten carbide ball can be used for BHN 400 - 850.

WC [10mm dia hardened ball]

Loads $\Rightarrow$ 3000, 1000, 500

Diameter $\Rightarrow$ 10, 5, 2

In Rockwell test, dial gauge is used which is a live case i.e, we cannot recheck the hardness, we have to perform the test again.

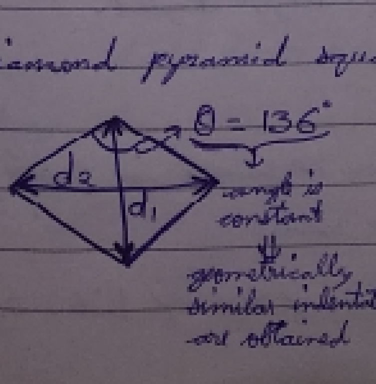
for Brinell test

Advantages $\rightarrow$ i) Recheck hardness.
ii) Heterogenous component can also be used as sample.

Disadvantages $\rightarrow$ i) dependent on load.
ii) thin material can't be used.

Vicker's hardness test:

i) Diamond pyramid square base indenter is used.



ii) If we change the load also, we get same hardness value because size of rhombus will be adjusted according to load.
i.e., Vicker's test is independant of load.

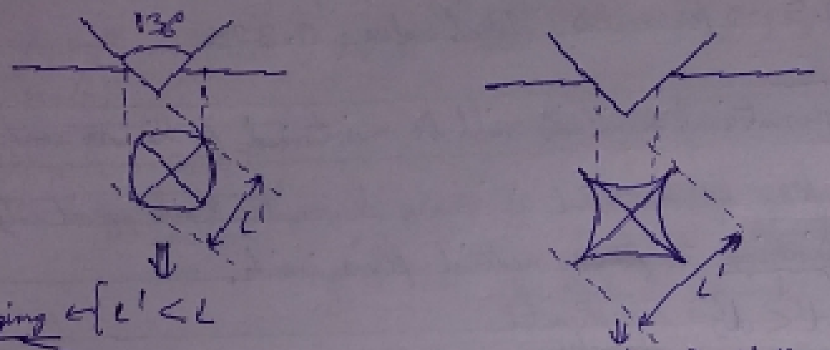
iii) $\underbrace{\text{VHN}}_{\text{Vicker's Hardness Number}} / \text{DPH} = \frac{2P\sin(\theta/2)}{L^2} = \frac{1.854P}{L^2}$ } → where $L = \frac{d_1+d_2}{2}$

DPH → Diamond Pyramid Hardness

8/2/23

iv) Vicker's Hardness Test gives values of 5 DPH - 1500 DPH.

v) Load range → 1 Kg - 120 Kg.



Ridging ← { $L' < L$

$L' > L$ } → sinking

irregularities in Vicker's test

Advantages → independent of load.

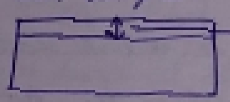
Disadvantages → i) takes more time because diagonal system has to be set manually.
ii) error or difficulty in finding ends of diagonal.

Micro indentation test:

i) Minimum depth of indentation = 0.0125 mm.
⇒ thickness of specimen = $T = 10t$ = 0.125 mm.

ii) Load range → 5 - 1000 gm.

iii) For thin samples.

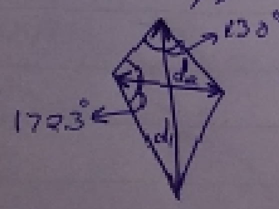


→ In case of case carburised material, hardness gradient is found using micro indentation test.

Vicker's micro hardness test → same as macro test but with less load.

Knoop's hardness test:

i) Diamond pyramid rhombus base indenter is used.



$d_1 : d_2 = 7 : 1$

ii) $\underbrace{\text{KHN}}_{\text{Knoop's hardness number}} / \text{HK} = \frac{P}{CL^2}$ where L is length of longest diagonal.

iii) If load < 300gm, there is elastic recovery of sample in Knoop's test, so for load < 300gm Vicker's test should be used.

iv) Knoop's test only gives 15% of indentation of that of Vicker's test.

Page No.:
Date: / /

So Knoop's test can be used to get many reading with same sample because indentation is less.

Dynamic hardness test:

Indenter falls from certain height, makes indentation & rebounds back to some height.

Rebound height is more ⇒ Hardness is more } because energy spent for indentation is less, so energy for rebound will be more.

9/2/23 Shore hardness:

i) Small pointed indenter (hammer) is made to fall within glass tube from standard height 250mm.

ii) Top height of rebound = measure of hardness. Expressed as number.

iii) Device – Scleroscope.

iv) Hammer tapered at one end, (cyl. metal plug 2.4gm).
Hammer – 6mm dia, 19mm height.
Tapered end fitted with polished diamond.

v) Tip of diamond is 0.254mm radius.

vi) Standard hammer falls from standard height, instantaneous load acts at point of impact (3500MPa).

vii) Specimen should be at least 1Kg to prevent inertia effect shock of striking.

Advantages — i) very fast.

ii) instrument is portable.

iii) impression is invisible, so non-destructive testing i.e., specimen can be used afterwards also.

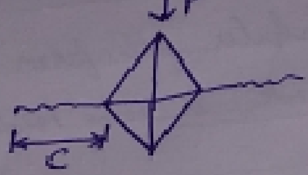
Indentation fracture toughness:

$\hookrightarrow$ resistance to crack propagation

i) more fracture toughness ⇒ more resistance to crack propagation

ii) Mostly used for ceramic coating

iii) Parameters → load (P) & crack length (C) ⟹



iv) Fracture toughness is fixed material property.

v) $K_{IC} = Y\sigma(\pi a)^{0.5}$, Y = dimensionless constant, a = crack length

Unit → $MPa\sqrt{m}$

Evans & Wilshaw eqn → $\boxed{K_c = 0.079\left(\frac{P}{a^{3/2}}\right)\log\left(\frac{4.5a}{c}\right)}$

here P = load applied (N)

$0.6 \le \frac{c}{a} < 4.5$