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HYDRAULIC BULGE TEST

Objective: To find out the flow stress behaviour of sheet metal under equi-biaxial stress condition.

Equipments Required:

1. Hydraulic Bulge Test-Rig.
2. Sheet metal blank of diameter 120mm
3. Scriber
4. Micrometer (screwgauge)
5. Depth micrometer
6. Spherometer
7. Flexible scale.

Theory:

The stress-strain relationship of sheet metals are conventionally determined by tensile test, where the specimen is loaded unaxially; but the range of stable uniform strain is restricted to approx 30% of the fracture value. Mostly the stress strain states in actual sheet metal forming processes are biaxial but not uniaxial; so for finding out the biaxial stress-strain relationship of sheet metals 'Hydraulic bulge test' is widely used, which gives flow curves for sheet metals with the extended range of plastic strain upto 70% of fracture value. Another advantage of the process is that the deformation occurs isothermally.

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Methodology:- In 'Hydraulic bulge test' a thin metallic sheet is clamped at its periphery between circular die ring and blank holder and then uniform hydrolic pressure is applied at one side of the sheet. The edge of the dome is prevented from slipping by a lock bead placed in a die ring. It consists of a ridge with small radii on one side and a 'matching groove' on the other. The constant parameter for die set is a die corner radius r_c as it affects the bulged sheet shape and size. Initial thickness of sheet metal is another constant. As pressure is introduced, metal starts to bulge to a hemispherical dome shape. Instantaneous variables of this bulging are the dome height h_d, pressure P, dome appex thickness t, and bulge and dome radius R_d.

Since the bulge diameter is greater than 10 times of the sheet thickness, so the effect of bending of the sheet can be neglected. and the bulged sheets can be treated as membrane in which the stresses are tangential to the middle surface of the wall. and uniformly distributed across its thickness. Such stresses are called membrane stresses and can easily be calculated by appling membrane theory neglecting bending stresses as:-

$$\frac{\sigma_c}{R_c} + \frac{\sigma_r}{R_r} = \frac{P}{t_d} \quad \text{———} \quad (1)$$

where σ_c and σ_r are the principle stresses on the sheet surface along the circumferencial and radial directions. R_c, R_r are the corresponding radii of the curved surface. P is the hydrolic pressure and t_d is the thickness of the bulged dome sheet. For axisymmetric case of the hydrolic bulge test, $\sigma_c = \sigma_r$ and the radius of the bulged dome is $R_d = R_c = R_r$.

$$\sigma_c = \sigma_r = \frac{P R_d}{2 t_d} \quad \text{———} \quad (2)$$

In 'hydraulic bulge test' initially both internal and outer sheet surfaces remain at atmospheric pressure. But once hydraulic pressure is applied the internal sheet surface experiences pressure P. Therefore the average stress σ_n in the sheet metal normal to the sheet surface will be:

$$\sigma_n = \frac{1}{2}(-P + 0)$$

$$= \frac{1}{2}(-P) \quad \text{—} \quad (3).$$

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Now the effective stress $\bar{\sigma}$ can be calculated using 'Von Mises' Plastic flow criterion as [1]:

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\sqrt{[(\sigma_{XX}-\sigma_{YY})^2+(\sigma_{YY}-\sigma_{ZZ})^2+(\sigma_{ZZ}-\sigma_{XX})^2+6(\tau_{XY}^2+\tau_{YZ}^2+\tau_{ZX}^2)}$$

Substituting $\sigma_{XX}=\sigma_c$, $\sigma_{YY}=\sigma_r$, $\sigma_{ZZ}=\sigma_n$, $\tau_{XY}=\tau_{YZ}=\tau_{ZX}=0$ and then simplyfying the equation we get:

$$\bar{\sigma} = \frac{P}{2}\left(\frac{R_d}{t_d}+1\right) \quad — (4)$$

Similarly the strain normal to the sheetsurface can be calculated using 'Volume constancy' condition as:

$$\epsilon_{XX}+\epsilon_{YY}+\epsilon_{ZZ}=0$$

$$\epsilon_{XX}+\epsilon_{YY}=-\epsilon_{ZZ}$$

Substituting $\epsilon_{XX}=\epsilon_c$, $\epsilon_{YY}=\epsilon_r$ and $\epsilon_{ZZ}=\epsilon_t$ in the above equation we get;

$$\epsilon_c+\epsilon_r+\epsilon_t=0$$

$$\epsilon_c+\epsilon_r=-\epsilon_t \quad — (5)$$

Now similar to the effective stress; effective strain can also be calculated as:

$$\bar{\epsilon} = -\epsilon_t = -\ln\left(\frac{t_d}{t_0}\right) \quad — (6)$$

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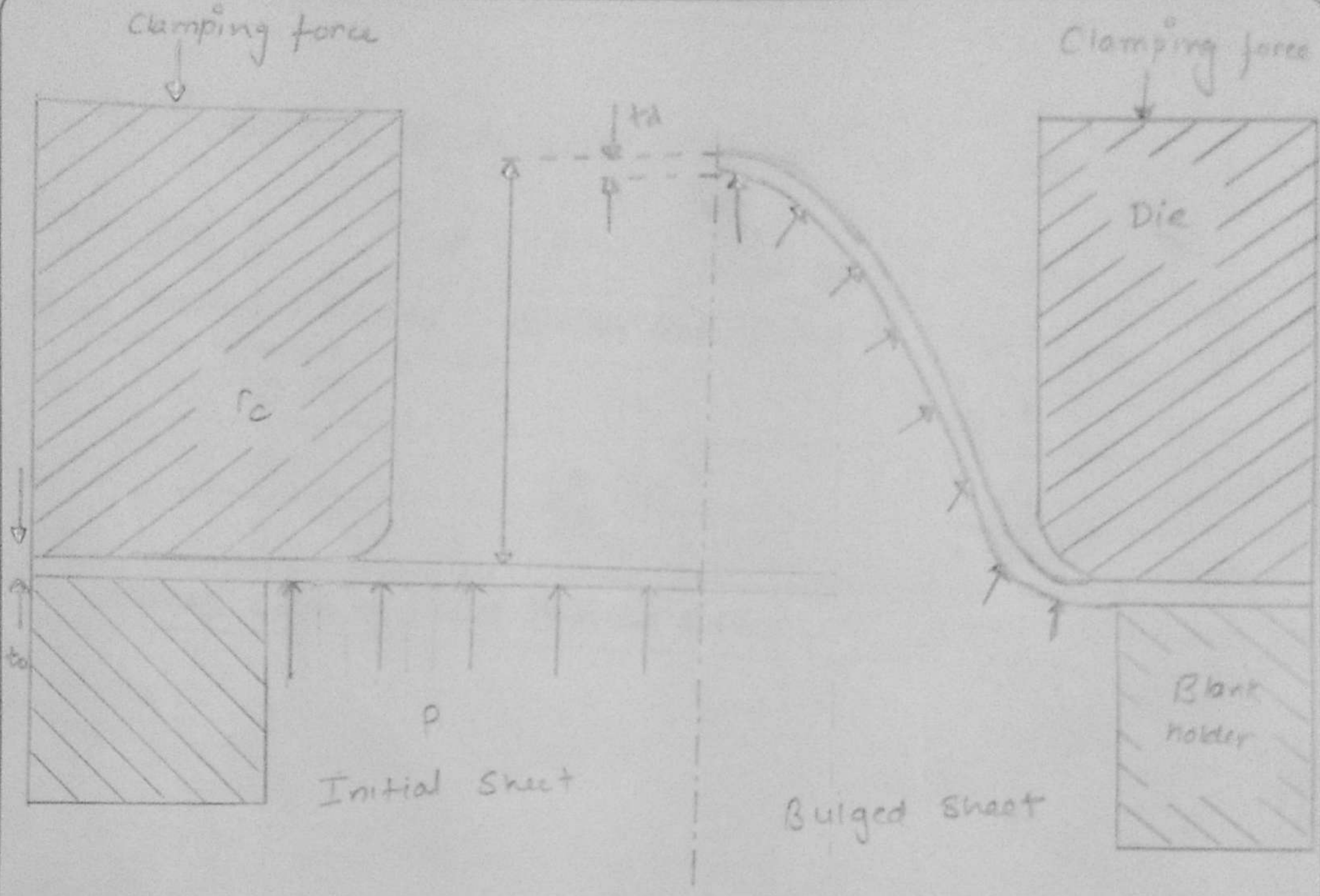

Fig. Geometry of 'Bulge test'; Initial (left) and Instantaneous (Right)

Initial thickness of the sheet blank t_0 =

TABLE No.- 1

least count = 0.01 mm

Sr. No.	Main Scale Reading	Circular Scale Reading	Total Value
1.	0	32	0.32 mm
2.	0	31	0.31 mm
3.	0	31	0.31 mm
Average value of initial thickness of sheet t_0 =			0.313 mm

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TABLE No.-2

Sr. No.	P (kgf/cm²)	Depth micrometer reading H_i (mm)	Dome height $h_d = H_0 - H_i$ (mm)	Quarter circumference C/4 (mm)	Spherometer reading h' (mm)	Radius of bulged dome $R_d = \frac{a_1^2}{6h'} + \frac{h'}{2}$
1	0	12.45	0	4.71	0	∞
2	10	5.49	6.96	4.75	1.95	137.727
3	20	3.03	9.42	4.80	2.61	103.476
4	30	0.10	12.35	4.90	3.26	83.429
5	40	−2.96	15.41	4.95	3.95	69.485
6	50	−7.11	19.56	5.00	5.01	55.732
7	60	—— FRACTURED ——				
8	70					

Length between two legs of spherometer (a_1) = 40 mm

Diameter of circle market on the sheet = 60 mm

Initial depth micrometer reading (H_0) = 12.45 mm

TABLE No. - 3

Sr No.	h_d (mm)	R_d (mm)	ε_r	$C/4$ (cm)	ε_c	$\varepsilon_t = -\varepsilon_r - \varepsilon_c$	t_d (mm)	$\sigma_c = \sigma_r = \frac{PR_d}{2t_d}$ (kg/cm²)	$\bar{\sigma} = \frac{P}{2}\left(\frac{R_d}{t_d} + 1\right)$ (kg/cm²)	$\bar{\varepsilon} = -\varepsilon_t = -\ln\left(\frac{t_d}{t_o}\right)$
1	0	∞	–	4.71	–	–	–	–	–	–
2	6.96	137.72	–	4.75	8.45	–	–	–	–	–
3	9.42	103.47	-0.206	4.80	10.47	-0.27553	0.237	4355.05	4365.05	0.27553
4	12.35	83.42	-0.215	4.90	20.61	-0.19439	0.257	4856.16	4871.16	0.19439
5	15.41	69.48	-0.182	4.95	10.15	-0.17185	0.263	5274.00	5294.00	0.17185
6	19.56	55.73	-0.22	5.00	20.20	-0.19980	0.256	5442.578	5467.57	0.19980
7	——— FRACTURED ———									
8										

Discussion on Defects: The Hydraulic bulge test would be defectless, if the sheet metal has smooth surfaces has constant thickness through out the surface area and does not have any sharp scratch mark on surface; because these factors cause defects. But mostly sheet metal are non-isotropic in nature, which causes Earing deffect. So to avoid this defect 'ridge impression' & matching grove were made on lock bead & die respectively. One more defect generally appears on bulged sheet blank at flank region is Wrinkling. This occurs due to insufficient clamping force. To avoid this defect, all bolts should be tightened by same sufficient torque by using 'adjustable torque wrench'.

Conclusions:

1) The bulged dome shape has been found very near to Hemisphere

2) Due to equi-biaxial stress state maximum achievable strain before necking/bursting was much larger.

Precautions: Since the measured thickness and bulge radius values are used as parameters to calulculate flow stress curve in test, so measurement & caluculation accuracy of these parameters directly affect accuracy of curve. Therefore operator must follow few precautions

1) Before clamping sheet blank, place it on blank holder plate such that marked circle on sheet blank must be concentric with bulging die internal periphery.

2) For clamping the sheet blank, all the bolts must be tightened by same ~~torque~~; in order to achieve uniform strain during bulging

3) Manually applied hydraulic pressure should be such that strain rate is constant during bulging.

Applications: Hydraulic bulge test is widely used for.

1) Flow stress (or) behaviour at plastic stage of sheet metals

2) Working hardening behaviour of sheet materials

3) Planner & Normal anisotropy of sheet metals etc...

Questions:

1) What is 'Plane stress' and 'Plane strain'?

A material is said to be under plane stress if the stress vector is zero across a particular surface when that situation occurs over an entire element of a structure, the stress analysis is considerably simplified.

Plane strain is defined to be a state of strain in which the strain normal to surface and shear strain along other orgothogonal planes is zero.

2) What is Principal stress and Principal strain?

Principal stress is the maximum normal stress a body can have at its some point. It represents purely normal stress.

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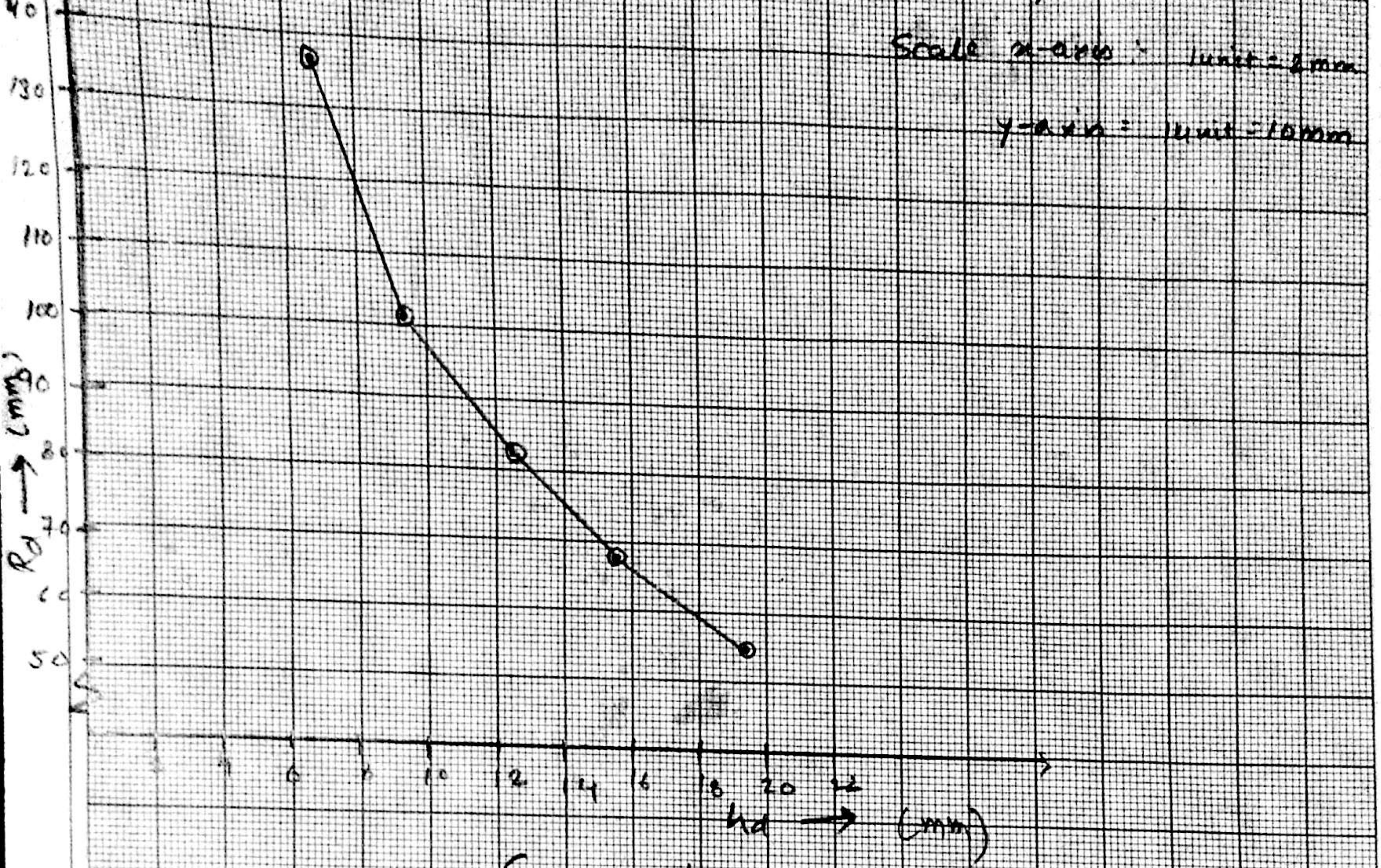
The maximum and minimum normal strain possible for a specific point on a structural element is called principal strain. Shear strain is zero at orientation where principal strain occurs.

3) What is strain rate ?

Strain rate is the change in strain of a material with respect to time. The strain rate at some point with in the material measures the rate at which the distances of adjacent parts of material change with time in the neighbour hood of that point.

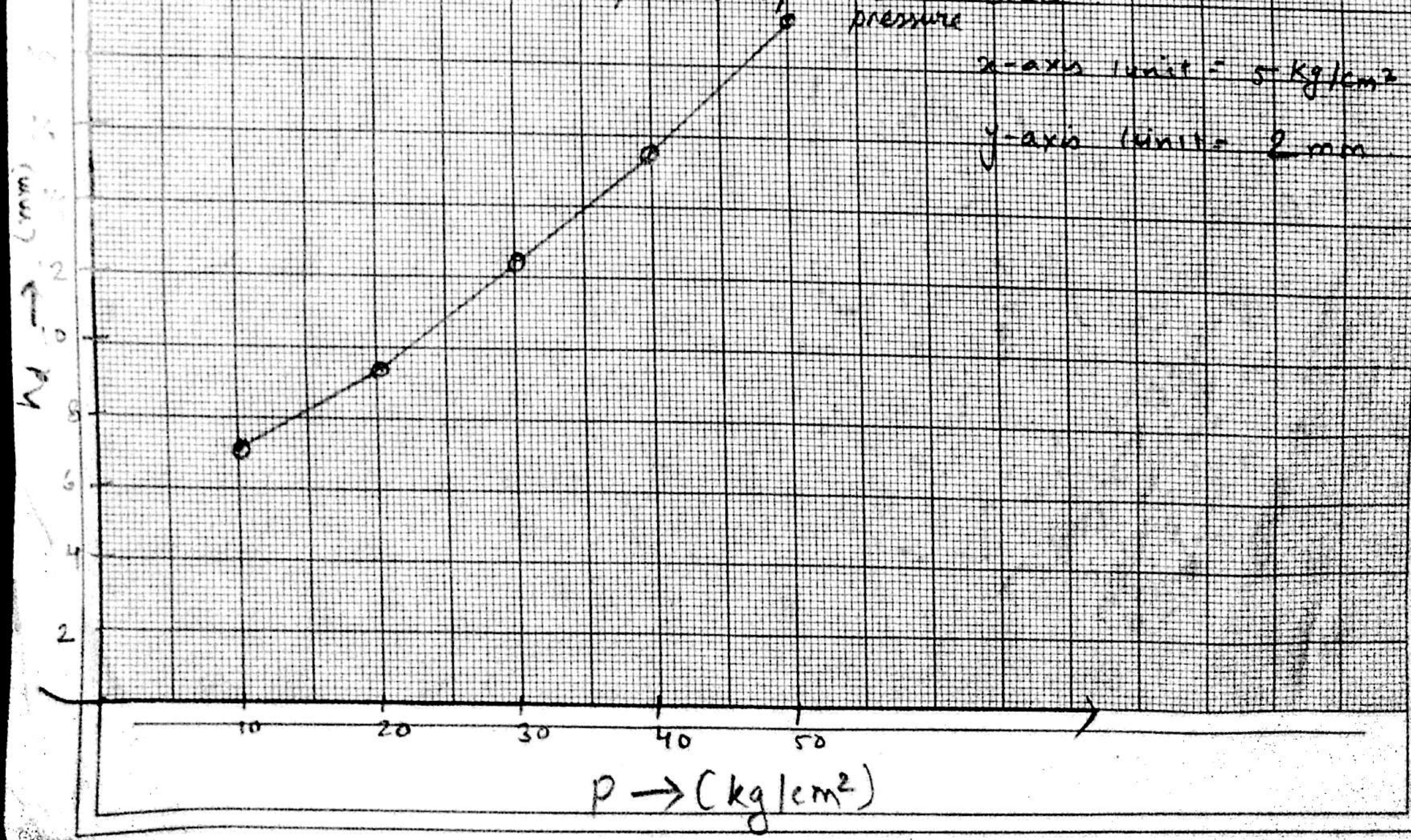
Graph - 2

Dome bulge radius Vs Dome height



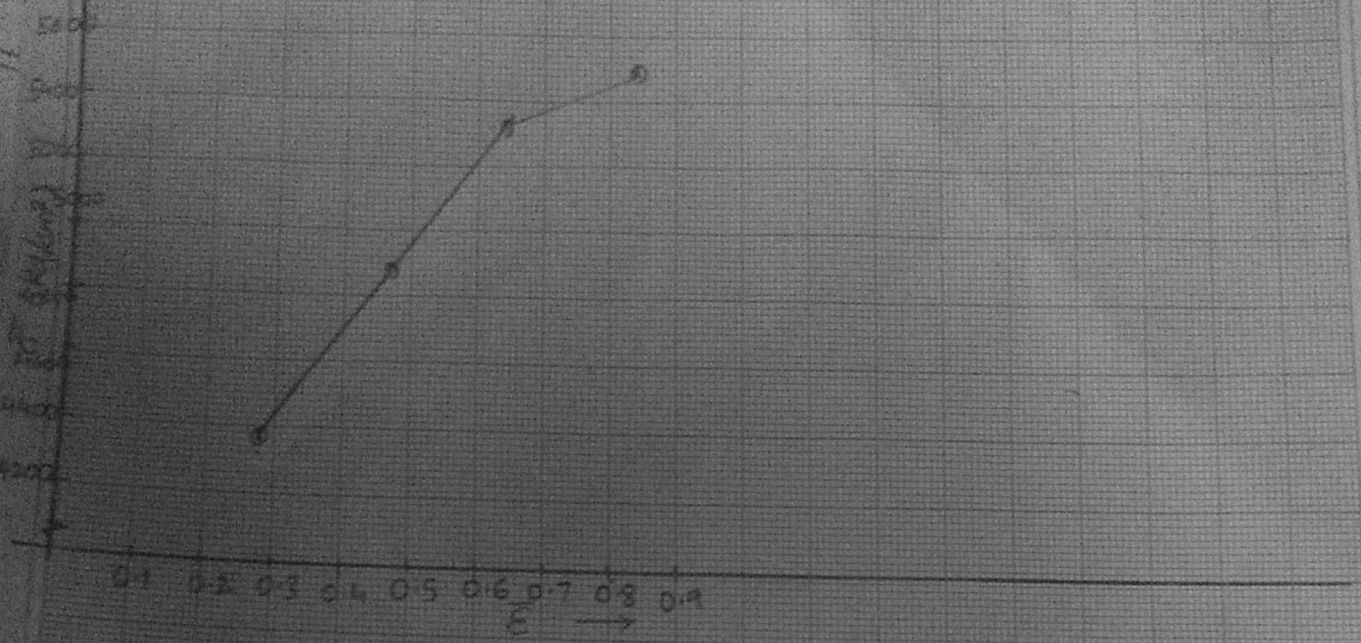
Graph - 1

Dome height Vs hydraulic pressure



Effective stress vs Effective Strain

Scale
X-axis 1cm = 0.1
Y-axis 1cm = 200kg/cm²



Dome apex thickness vs Dome height