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« THE DISK PRESSURE TEST »

A POWERFUL MECHANICAL INVESTIGATION METHOD

L'ESSAI DE DISQUE SOUS PRESSION

UNE PUISSANTE MÉTHODE D'INVESTIGATION MÉCANIQUE

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-I- Purpose of the test

CHARACTERIZATION OF BRITTLENESS EITHER INTRINSIC OR INDUCED (EMBRITTLEMENTS) IN A WIDE RANGE OF EXPERIMENTAL CONDITIONS.

-II- Main advantages

- ONLY ONE KIND OF SPECIMEN CAN BE USED FOR INVESTIGATIONS
  - AT TEMPERATURES BETWEEN - 196 AND + 1000°C
  - AT STRAIN RATES BETWEEN 0.2 AND 2×10^{8} s^{-1} (50.000 TO 0.005 $BAR.MN^{-1}$)
  - AT FREQUENCIES BETWEEN 0.1 TO 0.005 HZ DURING LOW CYCLE FATIGUE
  - OF MATERIALS PERMEABILITY TO GASES
  - OF SPECIFIC PARAMETERS E.G. WELDING
- THE OPERATION IS LITTLE TIME DEMANDING, SIMPLE AND ITS COST LOW.

-III- Principle

- DETERMINATION OF THE BURSTING, RUPTURE OR CRACKING PRESSURE OF CLAMPED DISKS, UNDER A FLUID PRESSURE.
- COMPARISON OF THE RUPTURES ACHIEVED UNDER EMBRITTLING (E) AND REFERENCE NON-EMBRITTLING CONDITIONS (REF).
- COMPUTATION OF 3 EMBRITTLEMENT CONDITIONS :

$I_1 = \frac{\overline{P_{REF}}}{\overline{P_E}}$	$I_2 = \frac{\overline{P_{REF}}}{P_{E\ mini}}$	$I_3 = \frac{P_{REF\ Maxi}}{P_{E\ mini}}$

WITH

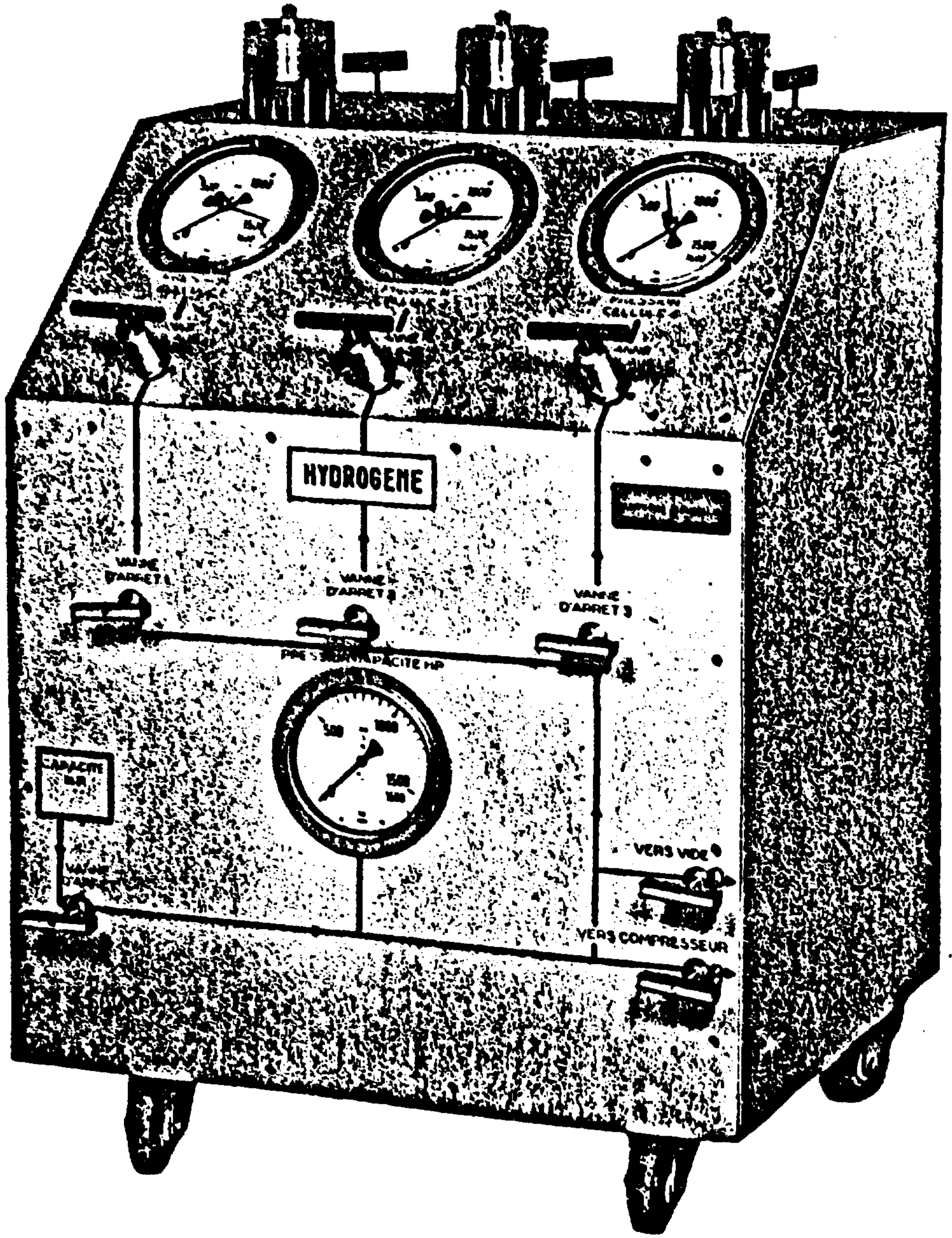
- $\overline{P_{REF}}$: AVERAGE REFERENCE RUPTURE PRESSURE
- P_{REF} Maxi : MAXIMUM REFERENCE RUPTURE PRESSURE
- $\overline{P_E}$: AVERAGE RUPTURE PRESSURE UNDER BRITTLE CONDITIONS
- P_E mini : MINIMUM RUPTURE PRESSURE UNDER BRITTLE CONDITIONS

AN EFFECT GIVES VALUES LARGER THAN 1. GENERALLY 2 IS CONSIDERED A LANDMARK ABOVE WHICH THE EFFECTS APPEAR DANGEROUS. SOMETIMES VALUES WELL IN EXCESS OF 10 CAN BE ACHIEVED.

- COMPARISON OF THE INDEXES BETWEEN THEMSELVES AND A THRESHOLD VALUE.

WHENCE ONE CONCLUDES TO THE POSSIBILITY OF USING OR NOT, MATERIALS UNDER SPECIFIC CONDITIONS, AND THE REPRODUCIBILITY OF THE MATERIAL↔FLUID INTERACTION.

- OBSERVATION OF THE MACROSCOPIC RUPTURE (FIG.2.) MODE AND INDICATIONS ON MATERIALS RESIDUAL DUCTILITY. THEY ARE SUPPLEMENTED BY LIGHT AND ELECTRON MICROSCOPY.



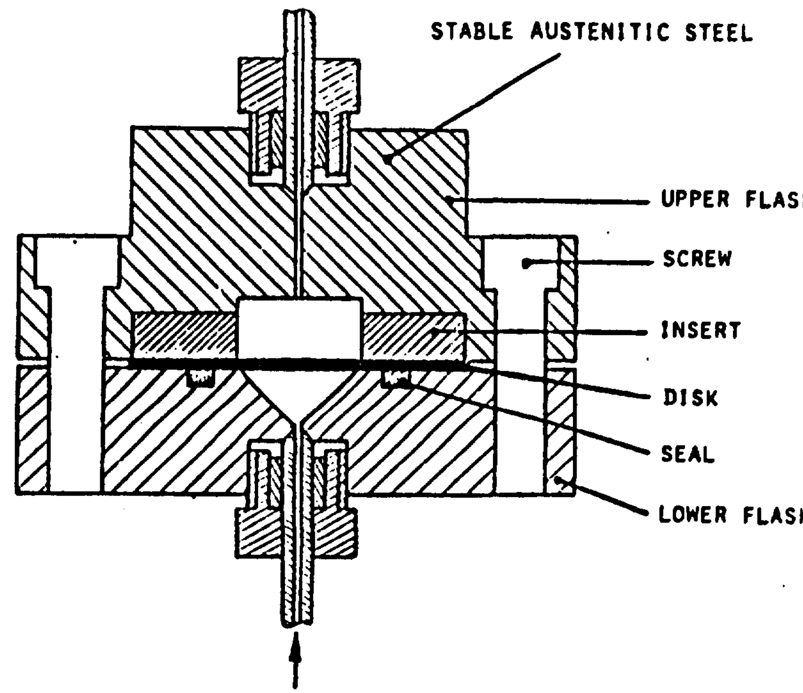
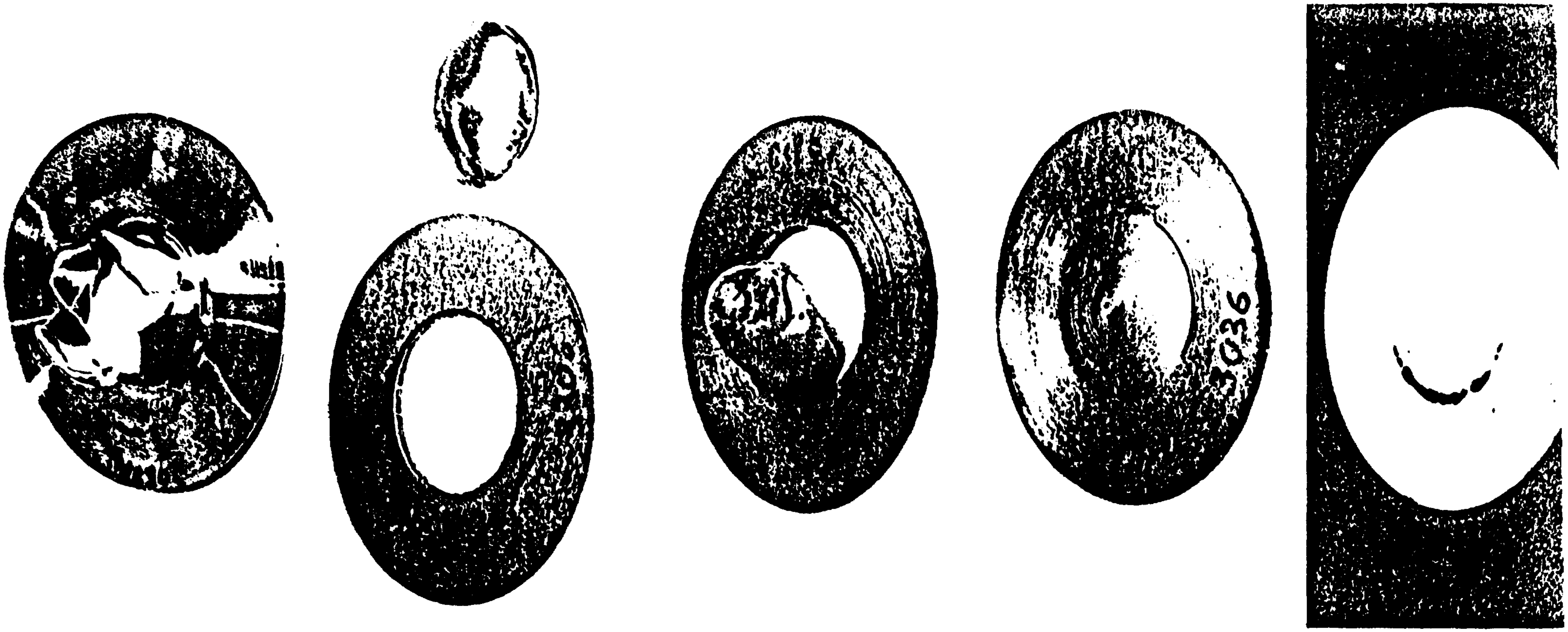


FIGURE 1 - BF 58 BASIC CELL



A
"FLOWER"
E.G. : 316 SS/HE, H_2

B2
CENTRAL CAP
OUTSTRIPPING
4330 / HE

C3
PARTIAL CAP
OUTSTRIPPING
LS 4330 / H_2

D21
REDUCED BULGE
CRACKING AT THE
ANCHORAGE
INCONEL 718 / H_2

E
"FLAT DISK"
HS 4330 / H_2

FIGURE 2 - TYPICAL ASPECTS OF FAILED DISKS : PLASTIC DEFORMATION (DUCTILITY) BEFORE RUPTURE ↓/ BRITTLENESS OR EMBRITTLEMENT INCREASES FROM **A** (VERY DUCTILE BEHAVIOR) TO **E**.

-IV- Test sensitivity

THE EXPLANATION OF ITS VERY HIGH SENSITIVITY HAS BEEN DERIVED FROM TWO COMPLEMENTARY APPROACHES :

- INSTRUMENTATION AND DIRECT MEASUREMENT OF CHARACTERISTIC VALUES
- MODELIZATION MEANS OF FINITE ELEMENTS

- INSTRUMENTATION.

  - MEANS OF PRESSURE-LOADING AND UNLOADING CYCLES, DETERMINATION OF THE PRESSURE AT THE ONSET OF PLASTIC FLOW : π_0.
  - DRAWING OF THE PRESSURE-CENTRAL DEFLECTION CURVES.
  - GAUGE-DETERMINATION OF STRAINS AT VARIOUS SITES OF THE DISK SURFACE.

- MODELIZATION MEANS OF FINITE ELEMENTS (FIG.3.).

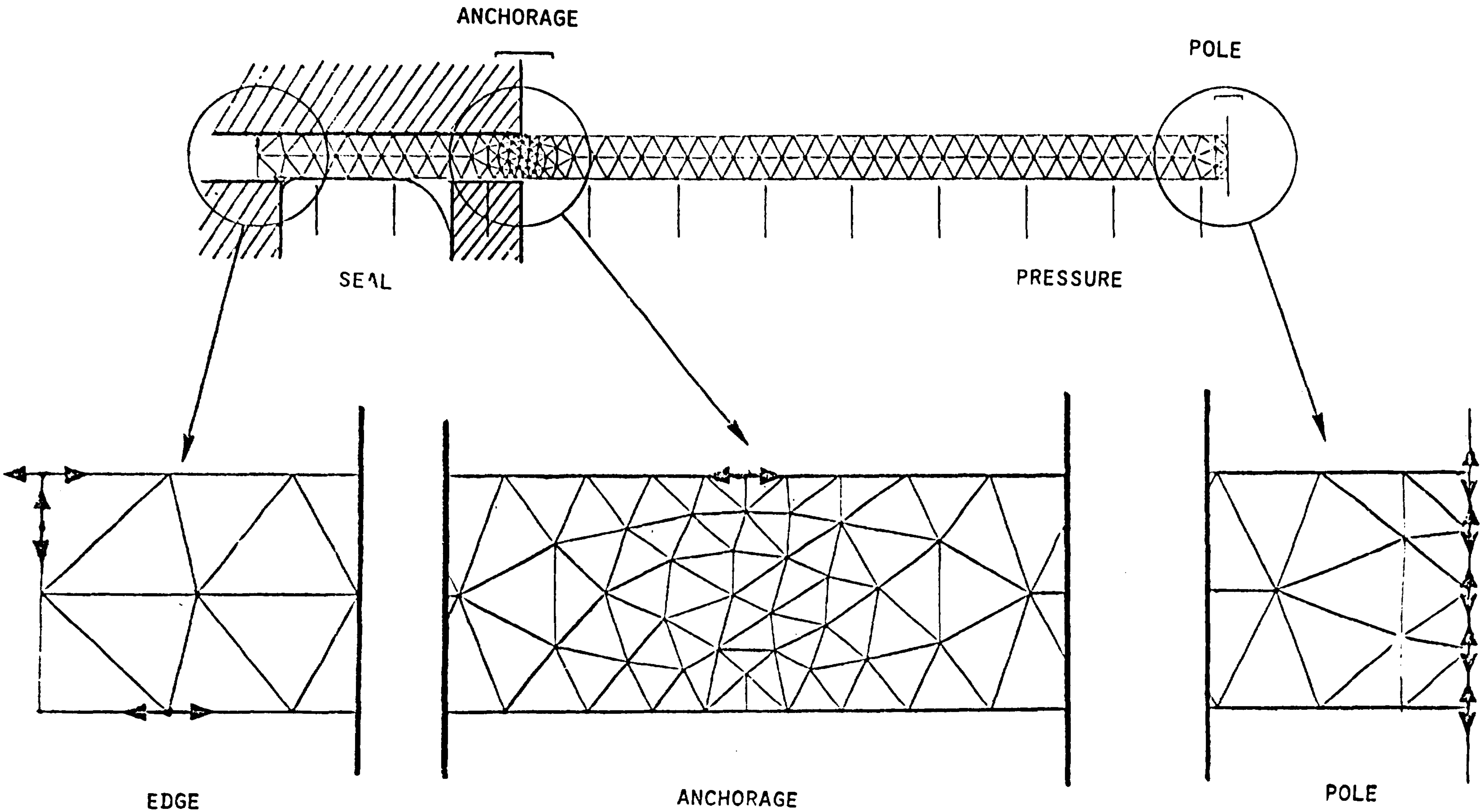
  - WITH THE SAME MESHING, IT HAS BEEN CARRIED OUT ON 4 ALLOYS WITH TYPICALLY DIFFERENT MECHANICAL BEHAVIORS

MATERIAL	NATURE	E MPa	ν	σ_0 MPa	N	σ_{Y0} MPa	UTS★ MPa	E %★
35 Ni-Cr-Mo 16	HS Steel	200,000	0.3	3 450	0.143	1 170	1 800	5
20 Cr-Ni-Mo 10	MS Steel	210,000	0.3	930	0.104	350	700	25
304 L	Metastable γ-SS	210,000	0.3	★★	★★	240	600	50
0.2 % V - U	Uranium	150,000	0.21	1 450	0.211	150	900	20

★ DO NOT CONTRIBUTE TO THE COMPUTATION.

★★ CURVE ENTERED POINT BY POINT.

FIGURE 3 - MESHING.



-V- Mechanical results

A - COMPARISON : CENTRAL DEFLECTION W_0 / STATE OF PLASTIFICATION / EQUIVALENT STRESS $\overline{\sigma}$ AT THE UPSTREAM POLE (FIG. 4, 5).

4 STAGES ARE CONSIDERED :

- STAGE I : ELASTIC BEHAVIOR TYPICAL OF A THICK PLATE : THE STRESSES ARE SYMETRIC ON EACH SIDE OF A NEUTRAL FIBER.
- STAGE II : PSEUDO-SYMETRIC ELASTO-PLASTIC BEHAVIOR : AREAS IN TENSION AT THE ANCHORAGE UPSTREAM AND THE DOWNSTREAM POLE GO ON SPREADING.
- STAGE III : ELASTO-PLASTIC BEHAVIOR : PROGRESSIVE DISAPPEARANCE OF THE AREA IN COMPRESSION AT THE POLE UPSTREAM.
- STAGE IV : GENERAL PLASTIFICATION IN TENSION.

B - KINDS OF STRESSING MODES :

PRESENTLY WE ARE CONSIDERING THE LARGER PRESSURES, NAMELY STAGE IV.

- POLE : PLANE STRESS CONDITION, RATHER SIMILAR TO THAT IN A PRESSURIZED THIN SPHERE.
- ANCHORAGE : PLANE STRAIN CONDITION BECAUSE OF THE VERY REDUCED METAL SLIP UNDER THE ANCHORAGE. THIS HELPS TO PROMOTE BRITTLE FAILURE.
- HYDROSTATIC COMPONENT : IN TENSION AND HIGH, ENHANCES THE INGRESS OF INTERSTITIALS.

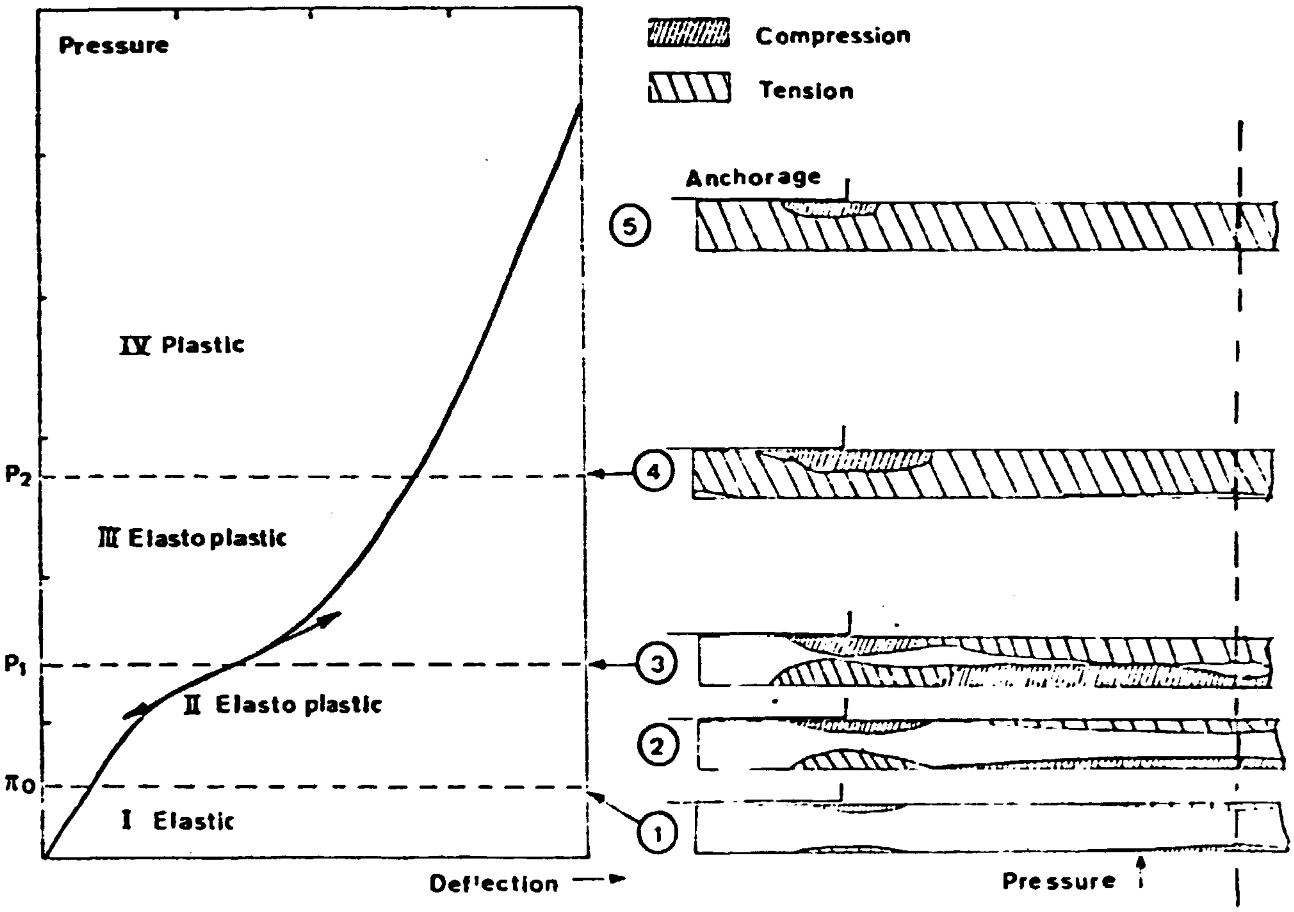


FIGURE 4 - RELATIONSHIP BETWEEN THE SPREADING OF PLASTICITY AND W_0 AS A FUNCTION OF PRESSURE.

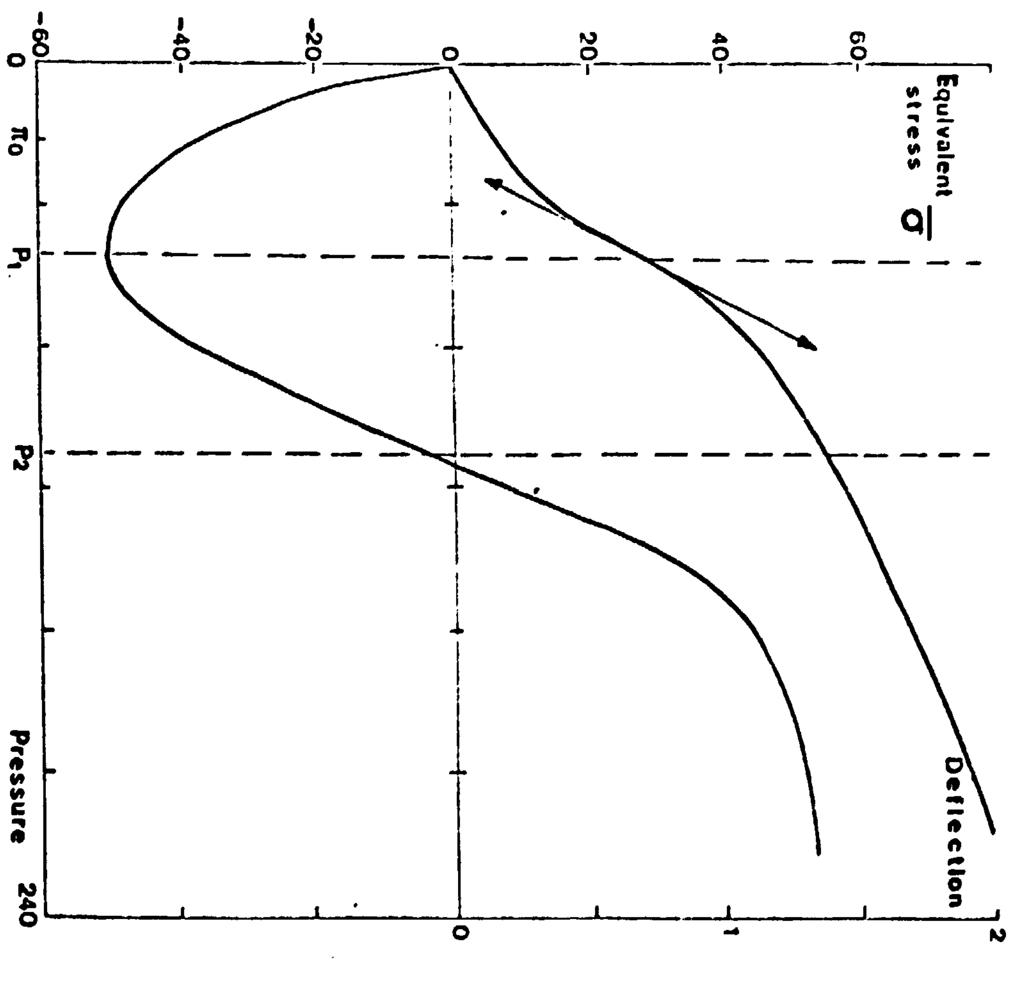


FIGURE 5 - RELATIONSHIP BETWEEN $\bar{\sigma}$, W_0 AND P.

C - <u>DEFORMATION ENERGY</u> (FIG. 6) : HIGHER AT THE ANCHORAGE THAN AT THE POLE. EXPLAINS THE MAJORITY OF THE FAILURES AT THE ANCHORAGE.

D - <u>STRAIN RATES</u> (FIG. 7) : REMARKABLY, AT ODDS WITH A TENSILE TEST, THEY TEND TOWARDS A CONSTANT VALUE AT THE END OF THE TEST.

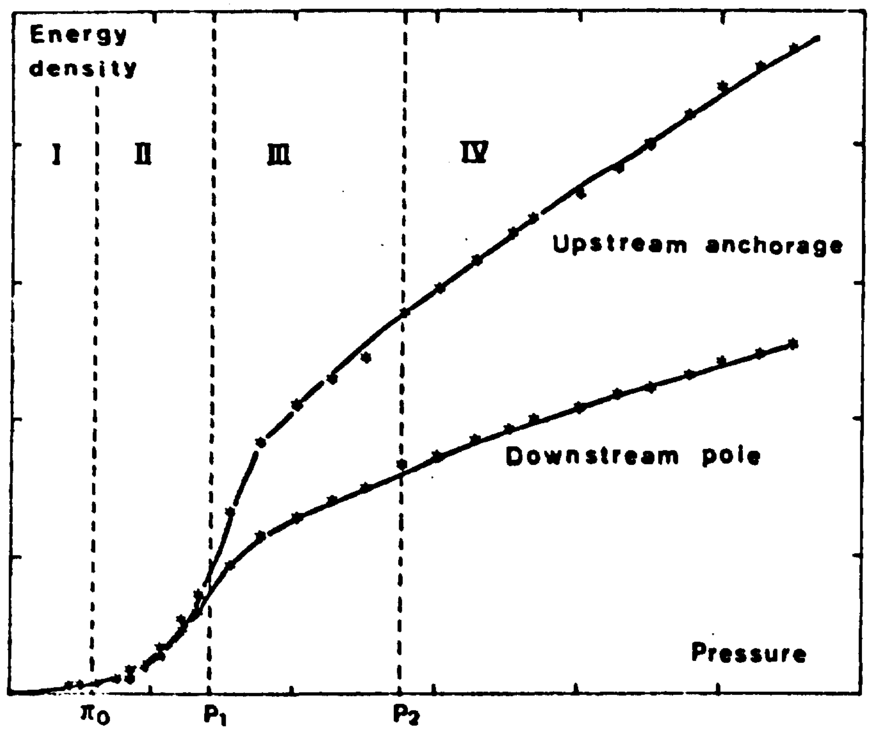


FIGURE 6 - DW = F (P)

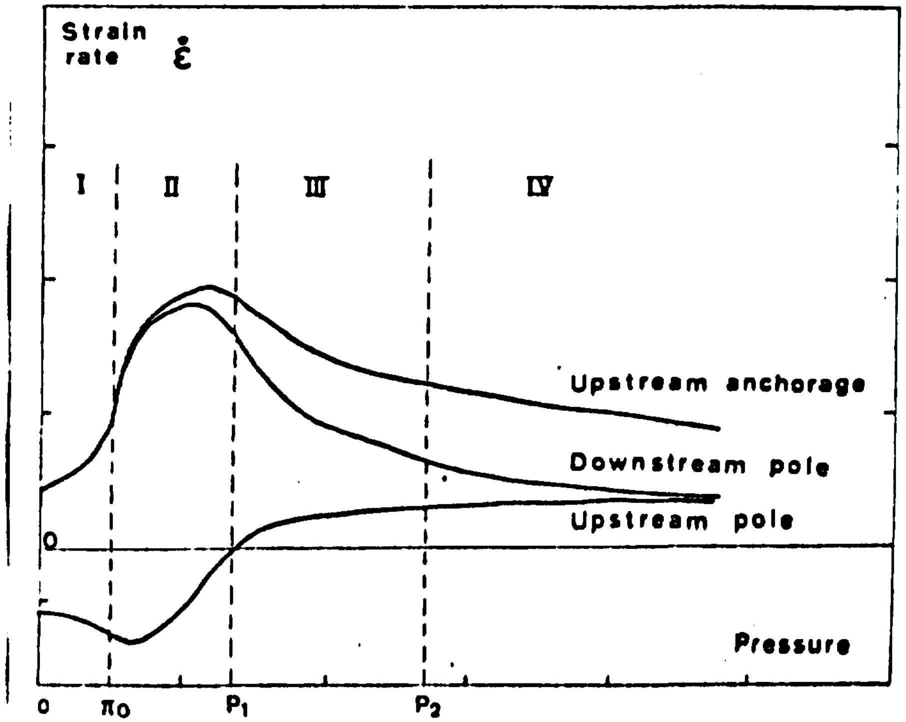


FIGURE 7 - $\dot{\varepsilon} = F(P)$

E - <u>TYPICAL PRESSURE RATIOS</u> . THE RATIOS BETWEEN THE RUPTURE PRESSURES AND π_0 (AT THE ONSET OF PLASTIC FLOW) ARE VERY HIGH : 10 IN CASE OF HS STEELS TO MORE THAN 300 IN CASE OF AUSTENITIC STEELS.

IN CASE OF A TENSILE TEST THE RATIO UTS/σ_Y SELDOM EXCEEDS 3.

FOR FRACTURE TOUGHNESS TESTS THE RATIO K_{1C} / K_{1TH} SELDOM EXCEEDS 4.

ACCORDINGLY PLASTIFICATION AND EMBRITTLEMENT PHENOMENA TAKE PLACE EARLIER DURING THE DPT.

IT IS EMPHASIZED HOW EMBRITTLEMENT CAN REDUCE A MATERIAL ABILITY TO RESIST CRACK GROWTH, BY LOCALIZED PLASTIC STRAIN.

-VI- Instances of experimental embrittlement data

A - TYPICAL INFLUENCE OF THE PRESSURE INCREASE RATE ($\Delta P / \Delta T$ OR $\dot{\varepsilon}$)

THERE ARE 4 AREAS :

I - WHERE IT DECREASES AS $\dot{\varepsilon}$ INCREASES.

II - A MINIMUM (FIG.8) OR A PLATEAU, WHERE H DRAGGING BY DISLOCATIONS IS MAXIMUM.

III - WHERE IT DECREASES AS $\dot{\varepsilon}$ INCREASES, BUT H TRANSPORT BY CLASSICAL DIFFUSION PROGRESSIVELY TAKES OVER ...

IV - ... THE RESULTING EFFECT

THE TIMES SEPARATING THESE ZONES ARE RELATED TO VARIOUS FACTORS SUCH AS H DIFFUSIVITY AND MATERIAL SENSITIVITY TO HE CONDITIONS.

B - INFLUENCE OF TEMPERATURE : CASE OF TZM MOLYBDENUM ALLOY (FIG. 9).

C - INFLUENCE OF MECHANICAL PROPERTIES :

- ON HYDROGEN GAS EMBRITTLEMENT (HGE). SEE ALSO THE EFFECT OF H_2 PRESSURE (FIG. 10).
- ON THE RELATIONSHIP BETWEEN HGE. HE BY DISSOLVED H AND BLISTERING OF CATHODICALLY CHARGED STEELS (FIG. 11).

D - LOW-CYCLE FATIGUE IN THE PRESENCE OF FLUIDS (FIG. 12).

E - ANOMALOUS BEHAVIOR :

- PALLADIUM HARDENING, THEN HE AS $\Delta P / \Delta T$ DECREASES AND H ABSORPTION INCREASES (FIG. 13

F - OTHER INSTANCES :

- STRAIN AGING AT 200°C, DUE TO RESIDUAL O IN COLD WORKED TANTALUM THIN DISKS (FIG. 14).
- DUCTILE TO BRITTLE TRANSITION IN XC 18 S FERRO-PEARLITIC LS STEEL. CENTER-NOTCHED DISKS (FIG. 15).
- STRESS CORROSION CRACKING OF 10 WT % MO URANIUM STAINLESS URANIUM ALLOY BY HUMIDITY (1) IN AIR DOWNSTREAM (2) IN COMPRESSED HE UPSTREAM (FIG. 16).

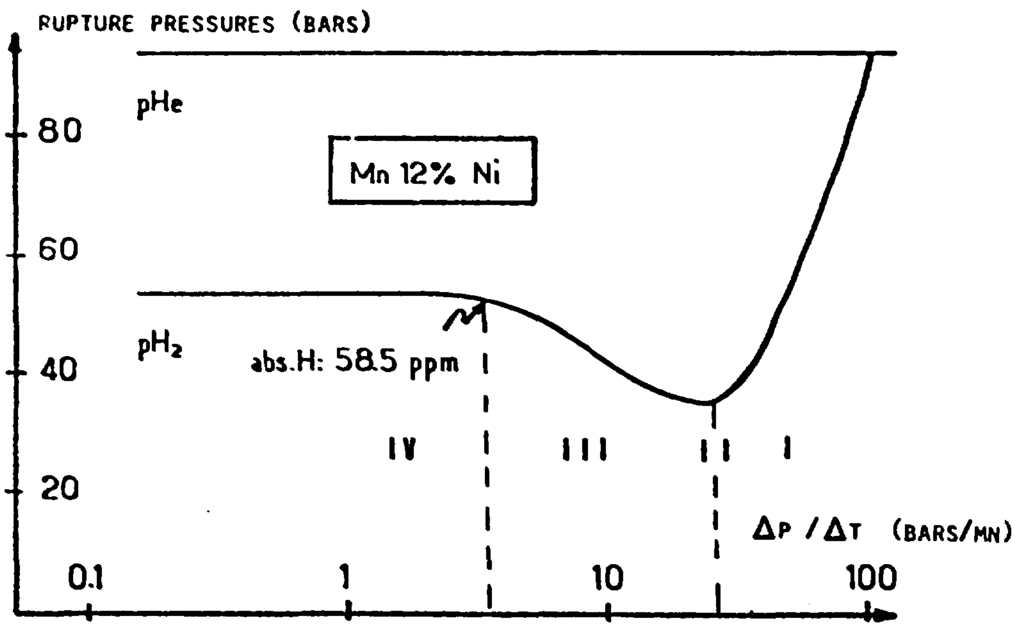


FIGURE 8 - INFLUENCE OF $\Delta P / \Delta T$ ON HYDROGEN GAS EMBRITTLEMENT (HGE) OF 12 % NI FCC MN ALLOY.

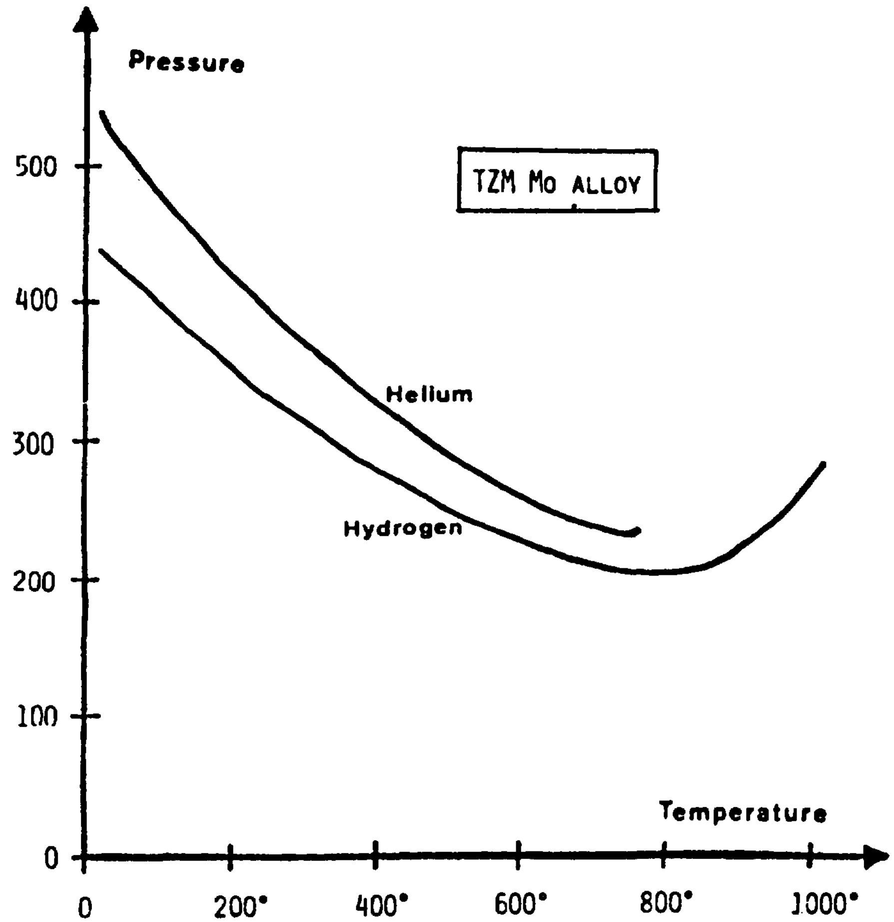


FIGURE 9 - INFLUENCE OF TEMPERATURE ON HGE OF TZM MO ALLOY AT $\Delta P / \Delta T$ = 100 BAR/MN.

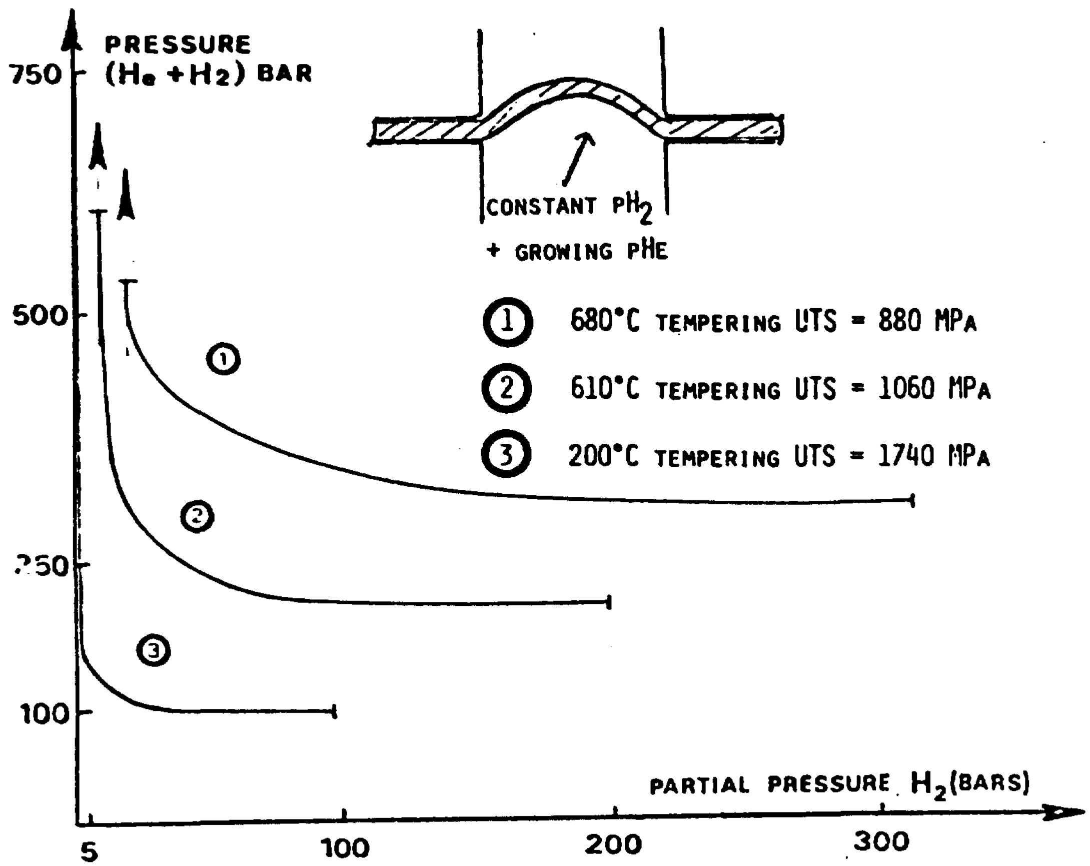


FIGURE 10 INFLUENCE OF H_2 GAS PRESSURE ON HGE OF 4330 STEEL HEAT TREATED TO VARIOUS STRENGTH LEVELS.

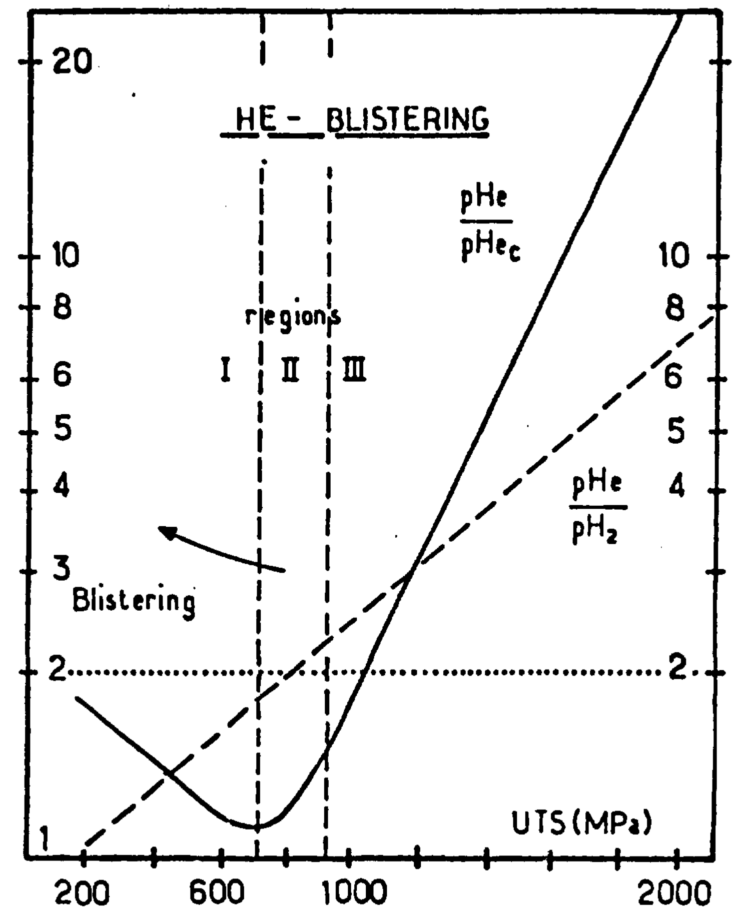


FIGURE 11 - RELATIONSHIP BETWEEN HGE. HE BY DISSOLVED H AND BLISTERING OF CATHODICALLY CHARGED STEELS WITH VARIOUS STRENGTH LEVELS.

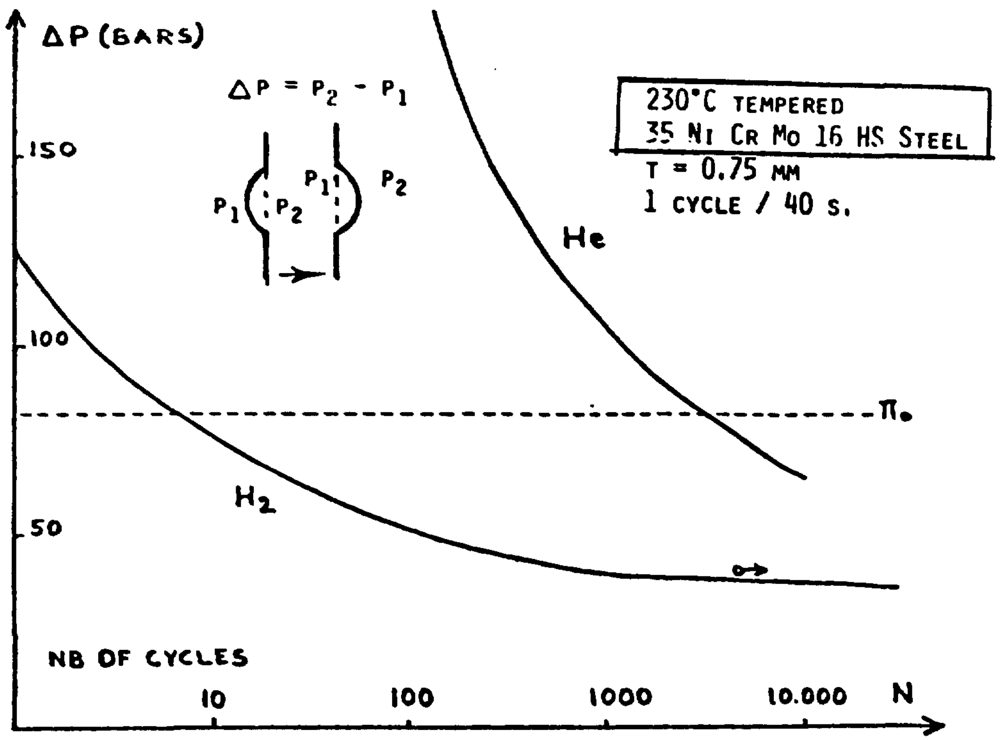


FIGURE 12 - LOW-CYCLE FATIGUE. SYMETRICAL DEVICE.

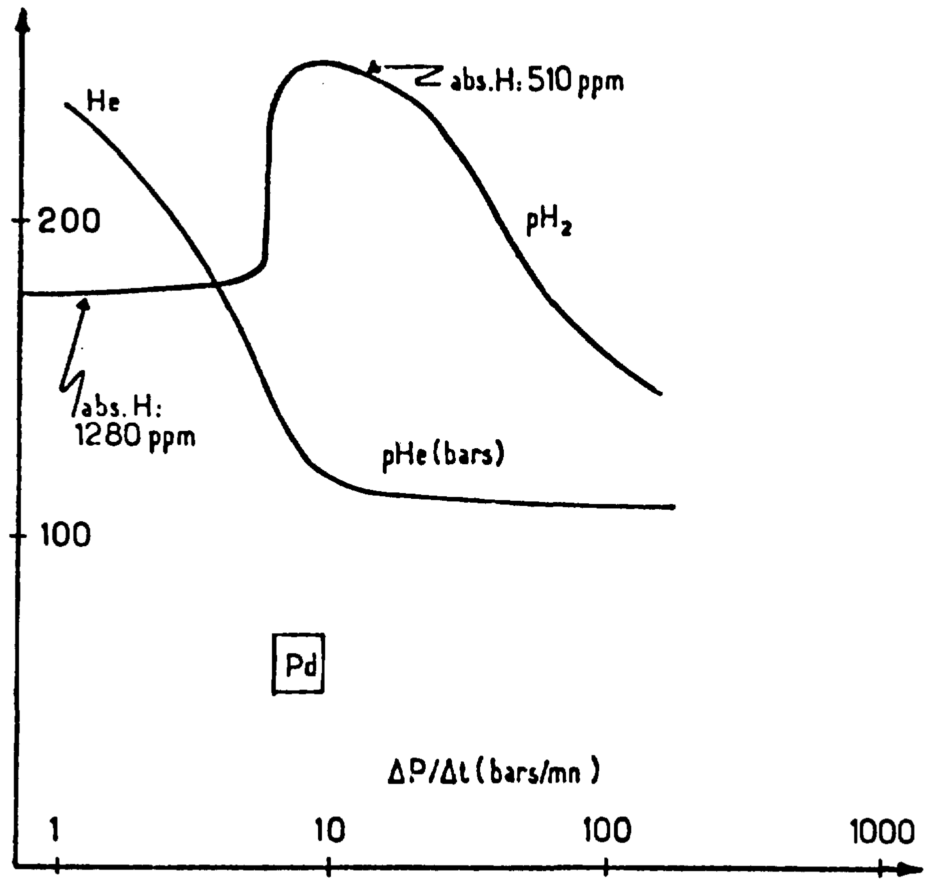


FIGURE 13 - H STRENGTHENING (RIGHT) AND HGE DUE TO H UPTAKE BY PD DISKS STRAINED BY H_2 GAS PRESSURE.

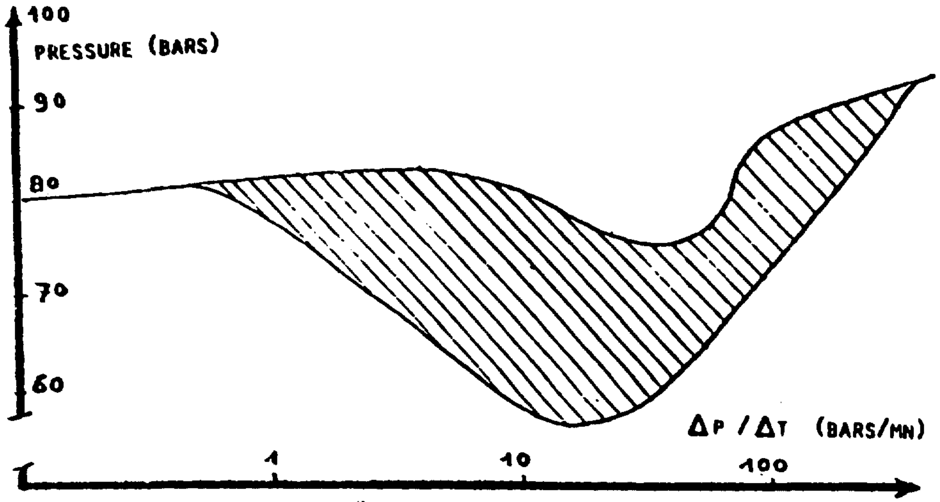


FIGURE 14 - STRAIN AGING AT 200°C IN COLD WORKED TA THIN DISKS.

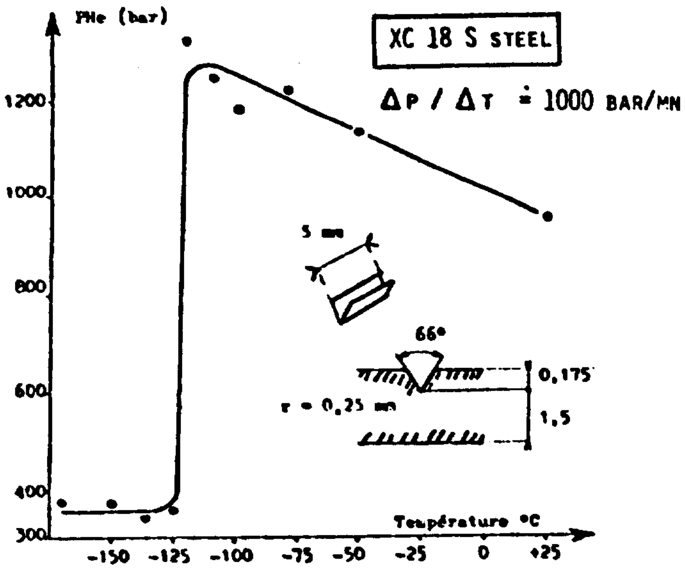


FIGURE 15 - DUCTILE TO BRITTLE TRANSITION IN AN 0.18 % C FERRO-PEARLITIC LOW-STRENGTH STEEL. CENTER-NOTCHED DISKS.

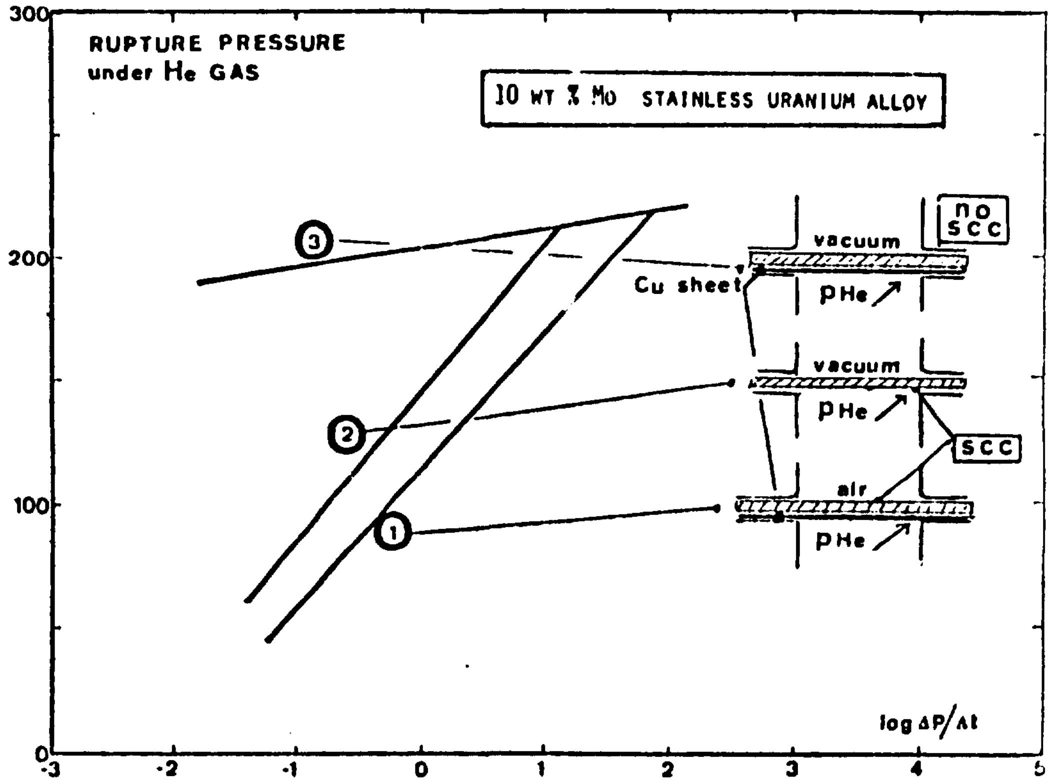


FIGURE 16 - SCC IN 10 % Mo U ALLOY DUE TO (1) AMBIENT AIR MOISTURE DOWNSTREAM (2) RESIDUAL HUMIDITY IN PRESSURIZED He UPSTREAM.