CORROSION ISSUES IN PIPELINES

Dr. V.R. KRISHNAN

इंजीनियर्स इंडिया लिमिटेड
(भारत सरकार का उपक्रम)

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PIPELINE EXTERNAL CORROSION

- **DEGRADATION OF PIPELINES CAN OCCUR DUE TO PERSISTENT ATTACK BY THE ENVIRONMENT**
- **BURRIED PIPELINES ARE LOCATED WITHIN CONTINUOUSLY CHANGING ENVIRONMENTAL CONDITIONS WHICH MAY LEAD TO A CORROSIVE ENVIRONMENT**
- **MANY FACTORS MAY PREVENT OF CONTRIBUTE TO THE INITIATION AND ATTACK ON BURRIED PIPELINES**

PIPE COATINGS

PIPE COATINGS

- A BREAKDOWN OF THE PROTECTIVE COATING WILL RESULT IN PIPELINES METAL BEING EXPOSED TO THE CORROSIVE ENVIRONMENT

- THE MATERIAL USED FOR COATING THE PIPES VARIES OVER THE YEARS AS TEHNOLOGY EVOLVED.

* 40'S - 50's	COAL TAR, WAX, VINYL TAPES
* 60'S	ASPHLTS
* 70'S	FBE
* 50'S	PE TAPES & JACKETS
* 70'S	PP

CATHODIC PROTECTION

- INTRODUCTION OF AN ELECTRICAL CURRENT ON A BURRIED PIPELINE SUCH THAT THE ELECTRODE POTENTIAL OF THE BURRIED PIPE IS LOWERED AND CREATES AN ENVIRONMENT WHERE METAL LOSS IS REDUCED.
- SOIL CONDITIONS SUCH AS MOISTURE CONTENT AND MINEROLOGY INFLUENCE THE EFFECTIVENESS OF THE CATHODIC PROTECTION , AS DOES THE TYPE OF COATING OF THE PIPE
- FOR EXAMPLE, PIPE COATED WITH POLYETHYLENE MATERIAL IS SHIELDED FROM CP MORE THAN PIPES COATED WITH ASPHALTS

SOIL CONDITIONS

- SOIL STRUCTURE AND CONDITION WILL IMPACT THE EFFECTIVENESS OF THE CP
- IT MAY ALSO CONTRIBUTE TO THE CREATION OF CORROSIVE ENVIRONMENT
- FACTORS THAT CONTRIBUTE TO THE CORROSIVE ENVIRONMENT SURROUNDING THE PIPE ARE :
  - SOIL TYPE
  - DRAINAGE
  - CO_2 CONCENTRATION
  - ELECTRICAL CONDUCTIVITY

TEMPERATURE

- THE TEMPERATURE OF THE SOIL AS WELL AS THE TEMPERATURE OF THE PIPE MAY CREATE A FAVOURABLE CONDITION FOR ATTACK ON PIPELINE MATERIALS
- LIQUID AND GAS PIPELINES HAVE SLIGHTLY DIFFERENT OPERATING CHARACTERISTICS BUT BOTH ARE SUSCEPTIBLE
- FOR EXAMPLE WITH GAS LINES, BOTH PIPE AND SURROUNDING GROUND CAN VARY FROM A …… OR > 50 ^{0}C UPON LEADING THE COMPRESSOR STATION DOWN TO 5 O c AT DISTANCES AWAY FROM THE PIPELINES.

STRESSES (RESIDUAL & OTHERS)

- STRESSES IN PIPE MAY LEAD TO PREMATURE DEGRADATION OF THE STRENGTH

- STRESS ACTING UPON A PIPE INCLUDE :

  * RESIDUAL STRESSES FROM MANUFACTURING

  * EXTERNAL STRESS SUCH AS THOSE INCURRED DUE TO PENDING, WELDING, MECHANICAL GOUGES & CORROSION

  * SECONDARYSTRESES DUE TO SOIL SETTLEMENT

PIPE PRESSURE

- CORROSION IN PARTICULAR CRACKING IS RELATED TO PRESSURES EXERTED ON THE PIPE
- AS THE PRESSURE IS INCREASED, THE PARTIAL PRESSURES OF THE CORROSIVE SPECIES INCREASES TO INCREASE THE CORROSIVITY
- THE GROWTH RATE OF CRACKS INCREASE AS THE HOOPS STRESS GENERATED BY THE OPERATING PRESSURE INCREASED

CYCLIC LOADING EFFECTS

- ANY CYCLIC LOADING CONDITIONS EXPERIENCES BY THE PIPELINE MAY INCREASE THE CRACK INITIATION TENDENCY AND CRAK GROWHT RATE
- FOR EXAMPLE IN LONG DISTANCE PIPELINES PIPELINE PRESSURE CONTINUOUSLY FLUCTUATES DUE TO LOADING AND UNLOADING OF PRODUCTS AS WELL AS DUE BY THE COMPRESSOR/PUMP ACTIVITY.
- THIS APPLIES TO BOTH GAS AND OIL LINES BUT IS MORE PRONOUNCED IN LIQUID SYSTEMS.

TYPES OF CORROSION

GENERAL

- **CORROSION IS THE BREAKDOWN OF THE PARENT MATERIAL DUE PRIMARILY TO ELECTROCHEMICAL METHODS WHERE THERE IS AN EXCHANGE OF ELECTRONS BETWEEN TWO MATERIALS OR LOCATIONS**
- **CORROSION HAS THE POTENTIAL TO REDUCE THE PIPELINES DESIGN LIFE BY PREMATURE DEGRADATION**
- **THE RATES OF ATTACK AND SEVERITY OF CORRSION WILL VARY DEPENDING ON THE INFLUENCING FACTORS MENTIONED ABOVE**

TYPES OF CORROSION - CONTD

- THE TYPE OF CORROSION FOUND IN PIPELINES INCLUDE :

- <u>UNIFORM CORROSION</u>

  PROCEEDS APPROXIMATELY AT THE SAME RATE OVER THE WHOLE SURFACE BEING CORRODED AND EXTENT CAN BE PREDICTED AND MEASURED AS MASS LOSS PER UNIT AREA

- <u>PITTING CORROSION</u>

  RESULTS IN PITS IN THE METAL SURFACE DUE TO LOCALISED CORROSION

TYPES OF CORROSION - CONTD

- **INTERGRANULAR CORROSION**

  OCCURS IN OR AROUND A BREAK OR A METALLURGICAL DISCONTINUITY IN THE METAL

- **EROSION CORROSION**

  INVOLVES CONJUCT EROSION AND CORROSION THAT TYPICALLY OCCUR IN FAST FLOWING LIQUIDS THAT HAVE HIGH LEVEL OF TURBULENCE

TYPES OF CORROSION - CONTD

- **ENVIRONMENT –INDUCED CORROSION**

  RESULTS FROM THE JOINT ACTION OF MECHANICAL STRESSES AND CORROSION FOR EXAMPLE STRESS CORROSION CRACKING

- **MICROBIOLLY INDUCED CORROSION**

  RESULTS FROM THE ACTION OF MICROBES THAT COULD BE IN THE OUTSIDE SOIL OR INTRODUCED INTO THE INSIDE FLUID HANDLED

APPEARANCE OF CORROSION

- THE VARIES TYPES OF CORROSION PRODUCE DISTINCT CORROSION PATTERNS
- IT COULD BE THE RESULT OF LOW LEVEL UNIFROM OR PITTING CORROSION OVER A LARGER AREA
- OR
- IT COULD BE A MORE AGGRESSIVE GALVANIC OR MICRO-BIOLOGICALLY INDUCFED CORROISON (MIC)
- CORROSION PATTERNS PRODUCE INCLUDE UNIFORM DEFECTS, PITTED SURFACES, STRIATIONS AND CHANNEL DEFFECTS

CORROSION DETECTION

- USUAL METHOD OF CORROSION DETECTION IS BY USE OF ULTRASONIC TESTING (OR BY USE OF MAGNETIC FLUX LEAKAGE)

- CALIBERATION BLOCKS USED FOR AUTOMATED INSPECTION FORMATS ALLOWS FOR THE CALIBERATION SAMPLE TO BE MORE REPRESENTATIVE OF THE CORRSION BEING INSPECTED .

- USUALLY FLAT BOTOM HOLES (FBH) ARE USED.

CORROSION DETECTION-CONTD

- UTILISATION OF MORE INTRICATE CALIBERATION BLOCKS IS BENEFICIAL WHICH FACILITATES OPERATORS TO HAVE A RANGE OF SIGNAL RESPONSES THAT CAN BE USED TO MACK-UPTHE ACTUAL INSPECTION AND TEST THE CALIBERATION.

- THIS ALLOWS CONFIRMATION OF THE VARIOUS COMPONENTS OF THE SIGNAL BEING EXTRACTED FROM THE DATA SHETS (FIG . 6-8)

CORROSION DETECTION - CONTD

- ITEMS TO CONSIDER WHILE CORROSION MAPPING INCLUDE :
- a) VELOCITY COMPENSATION
- b) IDENTIFICATION OF THE VARIOUS SIGNAL COMPONENTS OBTAINED.
- BOTH OF THESE ARE REQUIRED TO PROVIDE ACCURATE MEASUREMNTS OF REMAINING WALL THICKNESS
- ALLOWANCES FOR ANY OUT-OF-ROUNDNESS ISSUES NEED TO BE PROVIDED.

CRACKING

- MANY TYPES OF CRACKING EXISTS IN THE VARIOUS MATERIALS THAT SUSCEPTBLE TO CRACKING.
- MAIN TYPES OF MECHANICALLY & CHEMICALLY INDUCED CRACKING TO BE CONSIDERED ARE :
- a) FATIGUE CRACKING
- b) SCC
- C) HIC
- d) HOT HYDROGEN ATTACK
- FOR PIPELINES SCC IS THE MAIN MODE.

While designing the pipeline, following needs to be considered.

- The type of material and properties,
- Manufacturing methods,
- Time required for pipe laying,
- Tolerance controls on dimensions of pipes,
- Welding processes and techniques,
- Inspection methods and techniques,
- Acceptance limits of defects, etc.

SPECIFICATION FOR LINE PIPE

- API 5L/2007
- ISO 3183/2007
- NACE MR 0175/ ISO15156

TYPES OF PIPE

- **SEAMLESS PIPE**
- **CONTINUOS WELDED PIPE**
- **ELECTRIC WELDED PIPE**

  - *PSL 1 Electric Welded Pipe:*

    For grades higher than X42, heat treatment of weld seam and entire HAZ

  - *PSL 2 Electric Welded Pipe:*

    Welding with a minimum welder frequency of 100 kHz.

- LONGTITUDINAL SEAM SUBMERGED-ARC WELDED PIPE

  One longitudinal seam produced by automatic submerged –arc welding process

- GAS METAL-ARC WELDED PIPE

  One longitudinal seam produced by continuous gas metal arc welding process

- HELICAL SEAM SUBMERGED ARC WELDED PIPE

  Making of one helical seam

PSL 2

PSL 2 has mandatory requirements for

- *Carbon equivalent ,*
- *Notch toughness,*
- *Max. yield strength and*
- *Max. tensile strength*

MATERIAL REQUIREMENTS

- **Chemical Composition**

  Different grades of steel must contain certain amount of iron and alloying elements (Mn, Cu, Ni, Si, Al etc.) to attain desired mechanical properties.

- **Mechanical Properties**

  - For cold expanded pipe, ratio of body yield strength and body UTS shall not exceed 0.90.

  -The YS shall be the tensile stress required to produce a total elongation of 0.5% of the gage length as determined by extensometer.

CARBON EQUIVALENT FOR PSL 2

- When Carbon content <= 0.12%,

  CE=C+Si/30+Mn/20+Cu/20+Ni/60+Cr/20+Mo/15+V/10+5B

  Max. CE =0.25%

- When Carbon content >= 0.12%,

  CE=C+Mn/6+(Cr+Mo+V)/5+(Ni+Cu)/15

  Max. CE =0.43%

TYPICAL COMPOSITION AND MECH. PROPERTIES (PSL2)

Composition:

GRADE	C (Wt%) max	Mn (Wt%) max	P (Wt%) max	S (Wt%) Max	Ti (Wt%) Max
X46, X52	0.22	1.40	0.025	0.015	0.04
X65	0.22	1.45	0.025	0.015	0.06
X70	0.22	1.65	0.025	0.015	0.06

Mechanical Properties:

GRADE	YS (psi), min	YS (psi), max	UTS (psi), min	UTS (psi), max
X52	52000	77000	66000	110000
X70	70000	90000	82000	110000

MATERIALS USED

- Traditionally, C-Mn steels similar to API 5L grades- X46, X52, X56, X60 and X65 were used.
- Use of X 70 and X80 and higher grades are gaining momentum to reduce the wall thickness and cost.
- Special steel grades are used for more corrosive environments such as sour service and for highly corrosive field production pipelines.
- New higher strength grades require special production methods and controls on chemical composition and toughness properties.

MATERIALS RELATED CONSIDERATIONS

- Newer materials are to be produced through advanced steel melting, tertiary refining and controlled rolling processes to obtain highest quality levels.
- Typically, Basic open hearth furnace or an LD convertor process in used with special ladle fluxing and vacuum degassing would be required to achieve low levels of C, S, P, Mn, Si and dissolved gases and non-metallic inclusions.
- Additional steps such as Calcium treatment are to be utilized for inclusion shape control for sour services.

- For all materials used for pipelines, the upper limit of the UTS must be specified in order to restrict the spring back and residual stresses.
- The ratio yield strength/ UTS must not exceed 0.90, in order to ensure ductile behavior.
- The residual stress levels should be controlled in order to derive full utility of the strength of the material.
- The weld metal chosen should have mechanical properties matching the base metal
- Base metal and weld metal should have sufficiently high impact properties to ensure freedom from brittle fracture in service.
- For sour service, compliance to NACE requirements must be ensured by testing.

- Recently, bainitic steels with ultra low carbon and additions of alloying elements such as Mn, Nb, B, Ti, with special online accelerated cooling and controlled rolling steps, are being increasingly used.

- The need to use faster laying techniques require faster welding techniques which by itself put many restrictions on the material quality, welding processes and manufacturing tolerances, NDT etc.

- Newer materials such as Duplex stainless steels, High Nickel alloy clad carbon steels, heat traced pipelines etc. are being introduced to tackle corrosive fluids.

CHEMICAL COMPOSITION REQUIREMENTS FOR SEAMLESS PIPES & FITTINGS (SOUR SERVICE)

A 106 Gr. B / API 5L Gr. B

ELEMENT	LIMITS
C	0.20 % max..
Si	0.10%-0.35%
S	0.01% max
P	0.02% max.
Note: The unspecified elements Mn. Cu, Ni, Cr, Mo, V etc. shall be as per the limits of A 106 Gr. B.	

(FOR LINE PIPES/PRESSURE VESSELS/HEAT EXCHANGERS/STORAGE VESSELS) ASTM A 516 Gr. 60/A 234 Gr. WPB (Welded)/API 5L Gr B(SAW)/API 5LX52/60(SAW)

ELEMENT	LIMITS
C	0.20% max.
Si	0.15%-0.35%
S	0.003% max.
P	0.020% max.
N	0.01% max.
Ca/S	2-3
Al/N	2 min
B	0.002% max.

INSPECTION & TESTING

- TESTING OF CHEMICAL COMPOSITION
  Heat analyses and Sampling methods
- TESTING OF MECHANICAL PROPERTIES
  - Tensile tests
  - Flattening tests
  - Bend tests
  - Fracture toughness tests
  - Hydrostatic tests
- DIMENSIONAL TESTING
- SURFACE INSPECTION
- NONDESTRUCTIVE TESTING

COATINGS

DESIRABLE CHARACTERISTICS OF COATING

- EFFECTIVE ELECTRICAL INSULATOR
- EFFECTIVE MOISTURE BARRIER
- ABILITY TO RESIST DEVELOPMENT OF HOLIDAYS
- GOOD ADHESION TO PIPE SURFACE
- RESISTANCE TO DISBONDING
- EASE OF REPAIR
- NONTOXIC INTERACTION WITH ENVIRONMENT
- GOOD HARDNESS/ABRASION RESISTANCE
- GOOD PENETRATION RESISTANCE
- GOOD SOIL STRESSING RESISTANCE
- APPLICABILITY

COATING STANDARDS

- CSAZ 245.20-06 – External fusion bond epoxy coating for steel pipe (double layer)
- ISO/FDIS 21809-2:2007(E) – External coatings for buried or submerged pipelines used in pipeline transportation systems- Fusion bonded epoxy coatings (single layer)
- DIN 30670 – Polyethylene coatings for steel pipes and fittings
- NACE RP 0169-96 SECTION 5
- AWWA C203-02 – Coal tar protective coatings and linings for steel water pipelines

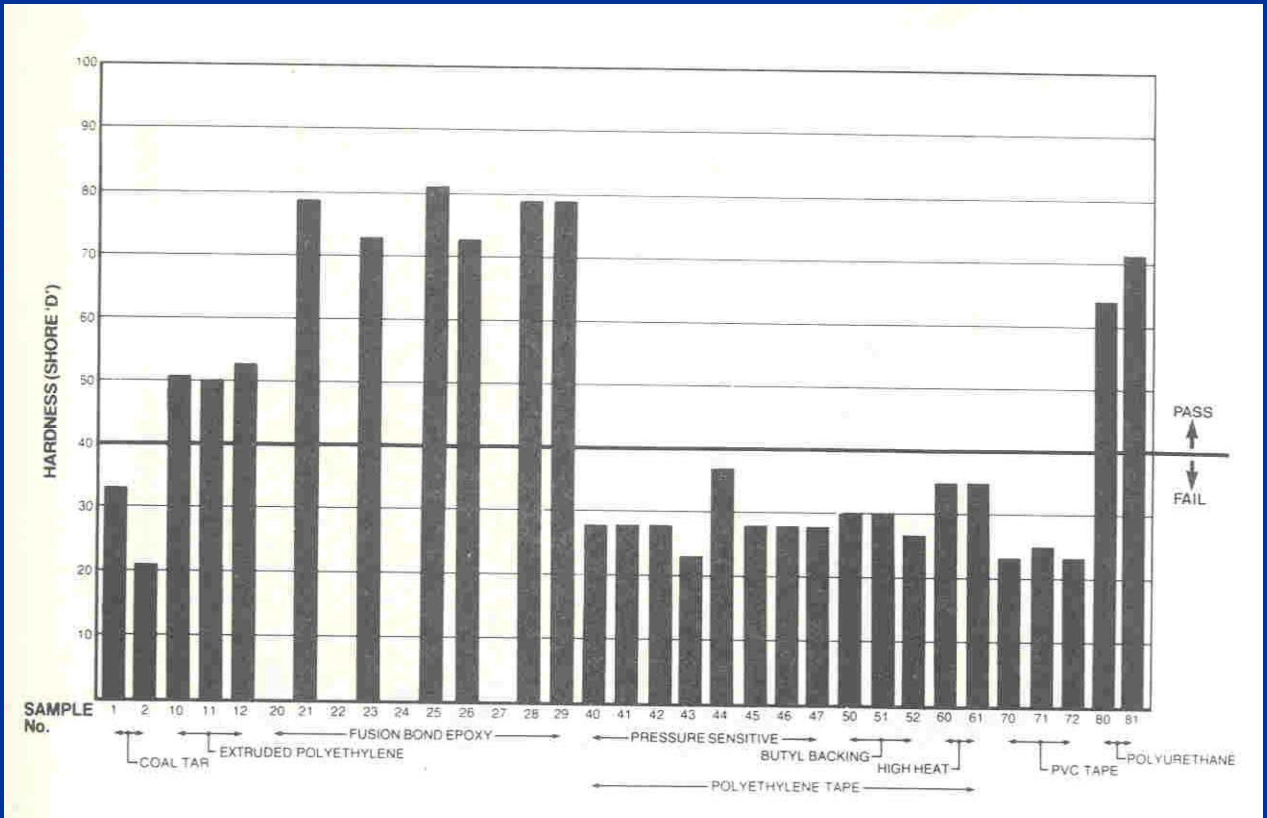
TYPES OF PIPELINE COATINGS

- COAL TAR ENAMEL (CTE)
- FUSION BONDED EPOXY (FBE), SINGLE AND DUAL LAYER
- 3 LAYER POLYETHELYNE (3LPE)
- 3 LAYER POLYPROPYLENE (3LPP)

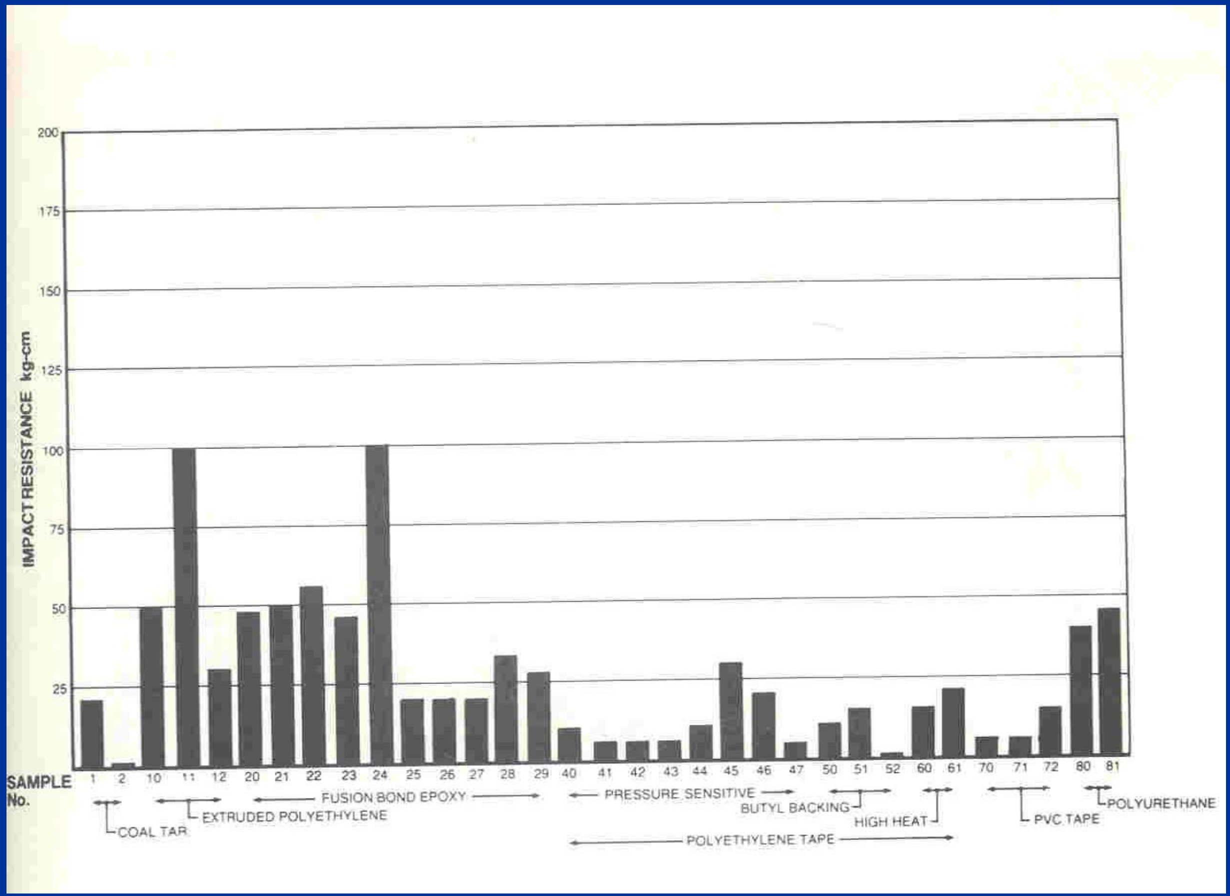
COATING CHARACTERISTICS & LIMITATIONS

PIPE COATING	CHARACTERICTICS	LIMITATIONS
CTE	-Low current requirement -Good resistance to cathodic disbondment - Good adhesion to steel	-Limited manufacturers -Limited applicators -Health and air quality concerns
FBE	- Low current requirement -Excellent resistance to cathodic disbondment - Excellent adhesion to steel -Excellent resistance to hydrocarbons	-High moisture absorption -Lower impact and abrasion resistance -High application temp
3LPE	-Lowest current requirement -Highest resistance to cathodic disbondment -Excellent adhesion to steel -Excellent resistance to hydrocarbons -High impact and abrasion resistance	-Limited applicators -Higher initial cost -Possible shielding of CP current

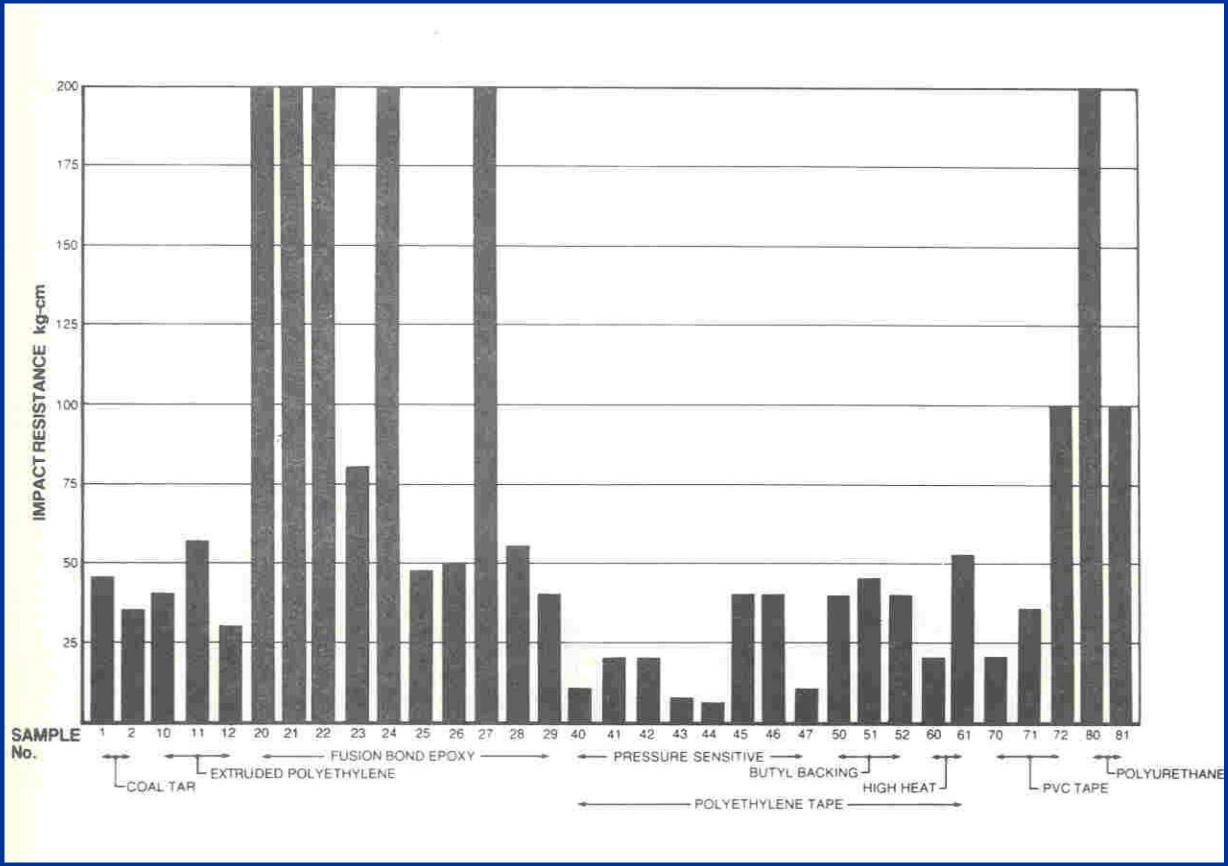
HARDNESS COMPARISON CURVE



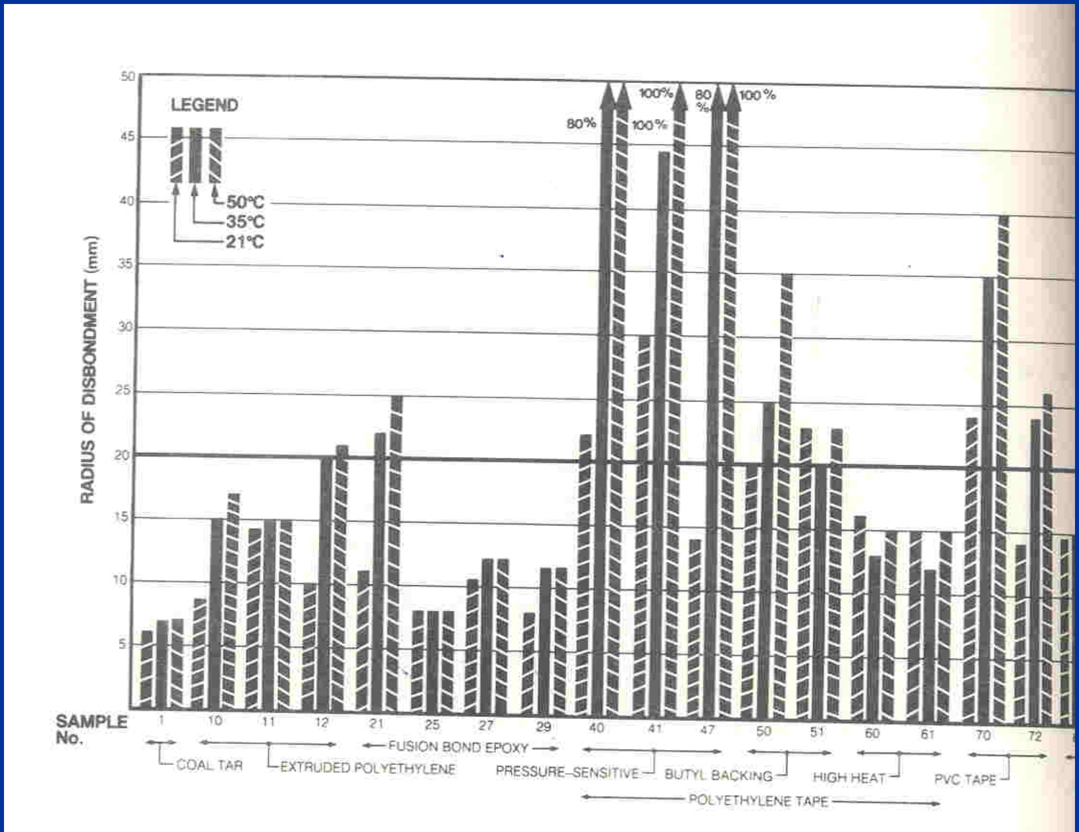
IMPACT RESISTANCE COMPARISON CURVE AT -50 DEGREE CENTIGRATE



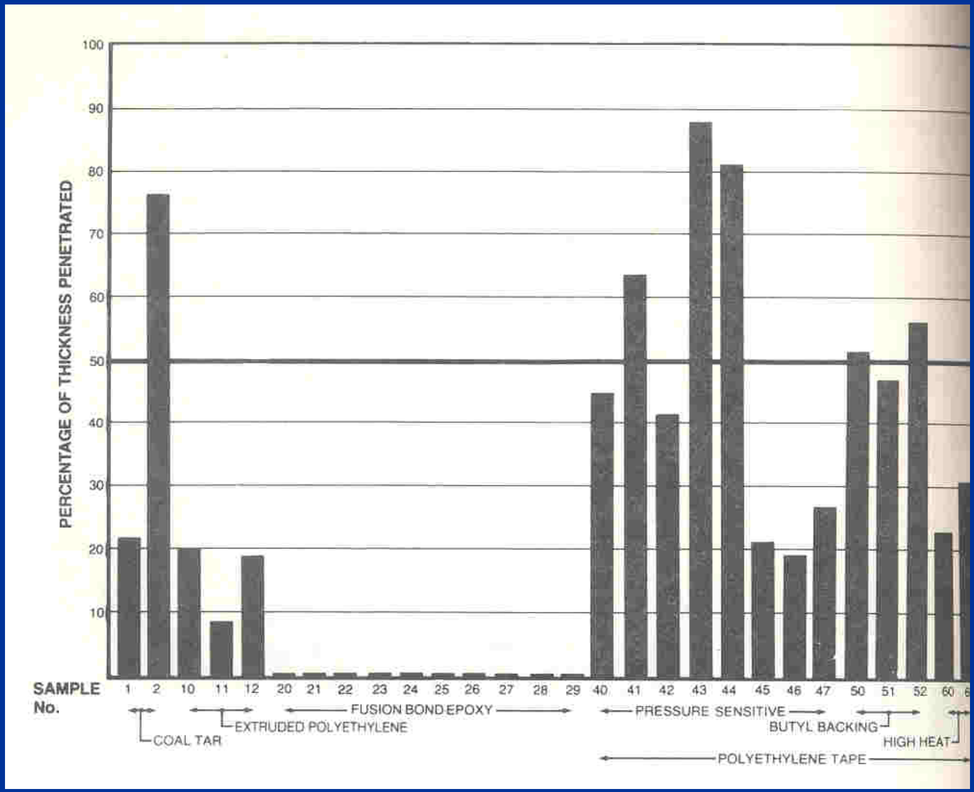
IMPACT RESISTANCE COMPARISON CURVE AT 20 DEGREE CENTIGRATE



CATHODIC DISBONDMENT COMPARISON CURVE



PENETRATION COMPARISON CURVE



WATER ABSORPTION COMPARISON CURVE

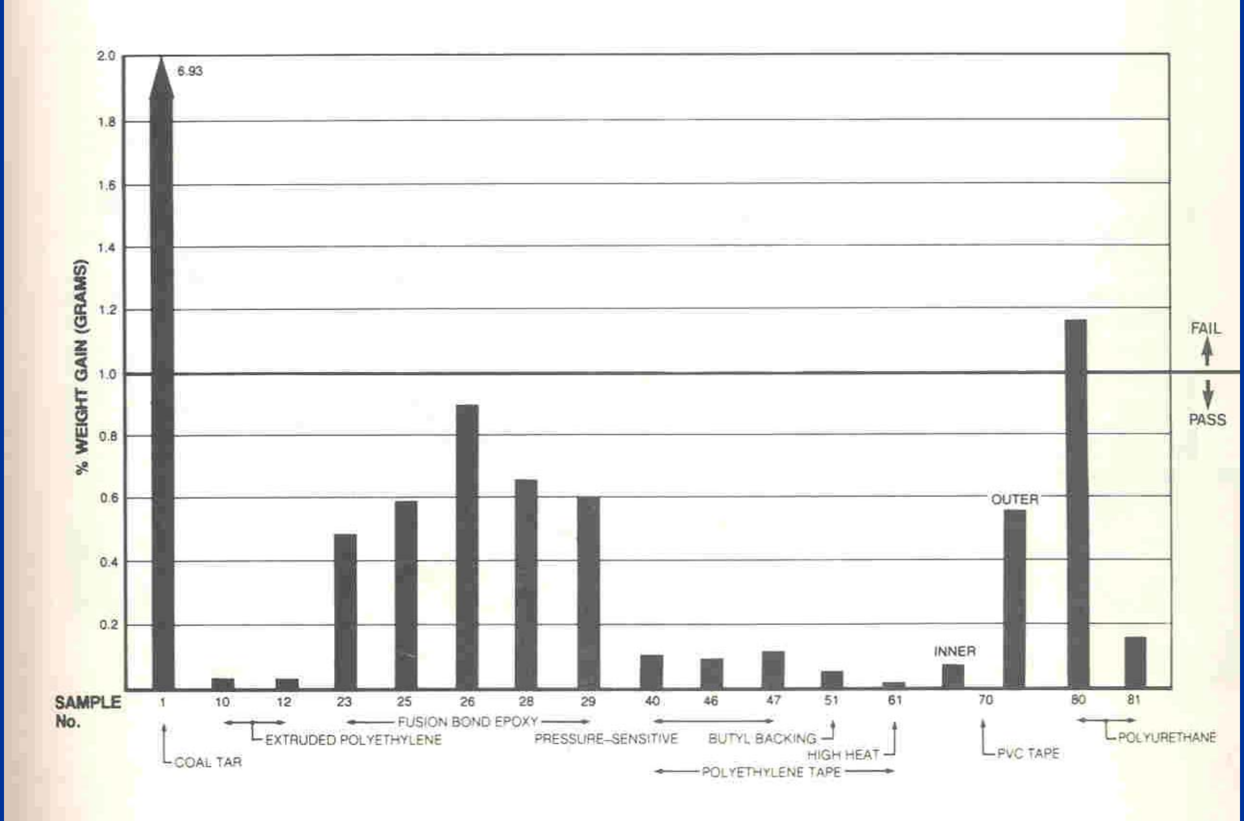


Fig 1: An example of general deep pitting corrosion with some pits joining to form larger pits and interconnected pitting.

Fig 2: Image presenting the trend towards channel style corrosion. The channels were initially small pits that joined together and continued to grow. This type of corrosion pattern can result in defects with significant depth and length.

<u>Fig 3:</u> Examples of corrosion striations. This style of corrosion looks like scratch marks and requires special consideration when being inspected using ultrasonic methods, since the striated corrosion surface profile affects the reflected ultrasound signal.

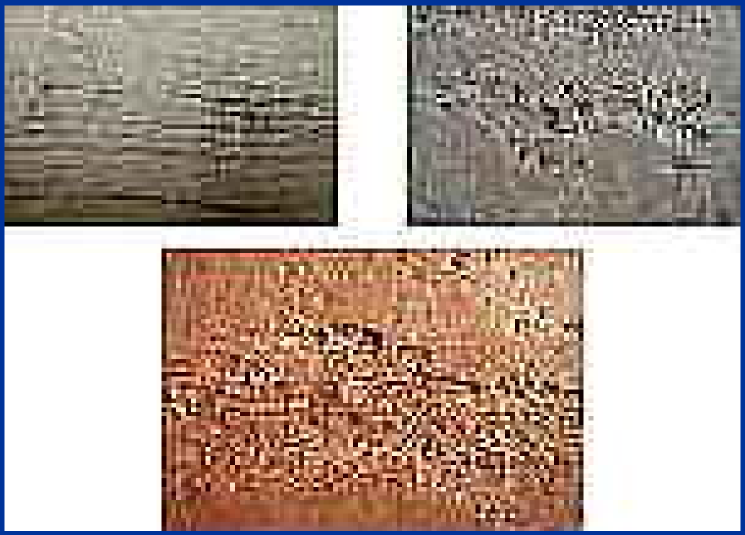


Fig 4: General corrosion patterns range from the image on the left (with little or no good wall) to the image on the right (with only minor corrosion throughout the surface).

Fig 5: Example of a typical step wedge and SDH. In this example the step wedge and SDH are from the Eclipse Thin Wall (ETW) calibration block.

Fig 6: Flat bottom holes of various depths and diameters are useful for identifying transducer limitations. Additional fixed known angle hole targets (cone shaped) can also be used.

Fig 7: Actual pipe corrosion sample and the associated machined replica pattern in a calibration sample.

Fig 8: Calibration sample showing three replicas of the same corrosion feature. Each corrosion replica has been machined to a different predefined depth to provide TOF measurement variation.

Fig 9: Photomicrograph of a SCC crack in pipeline steel.

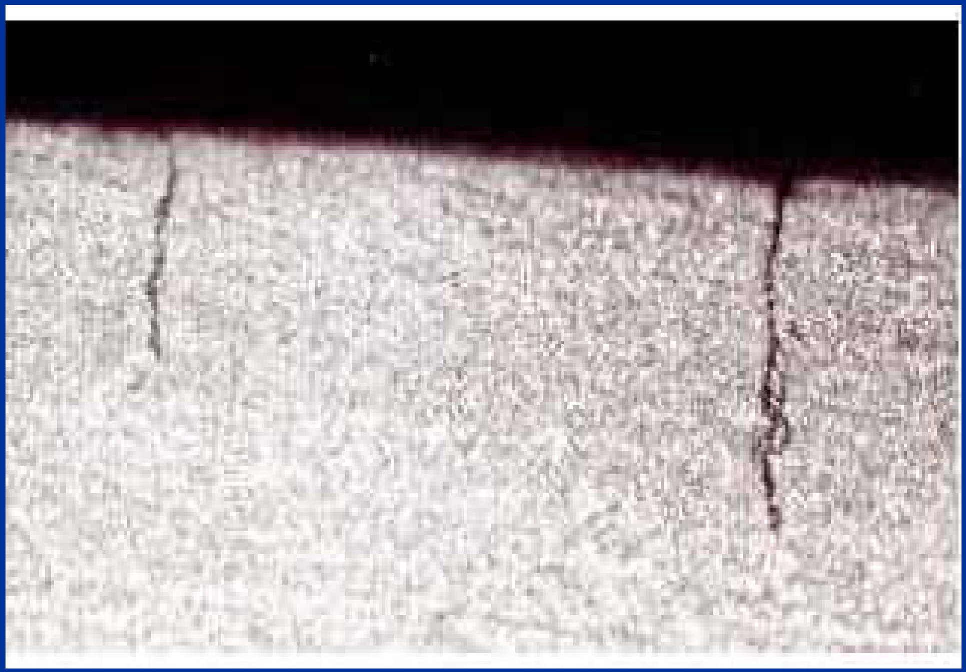


Fig 11: Photograph of a SCC crack at the weld fusion line (toe crack). Branching nature that may occur at the crack tip can clearly be seen in this profile.

Fig 10: Photomicrograph of a SCC in a weld. The two indications shown are located adjacent to one another and both occur within the weld material.

Fig 12: Example of an isolated SCC.

Fig 13: Example of a SCC colony.

Fig 14: Toe crack with adjacent SCC colony. The weld is located along the top edge of the photograph, above the toe crack. The toe crack shown is 15cm in length and over 3mm deep.

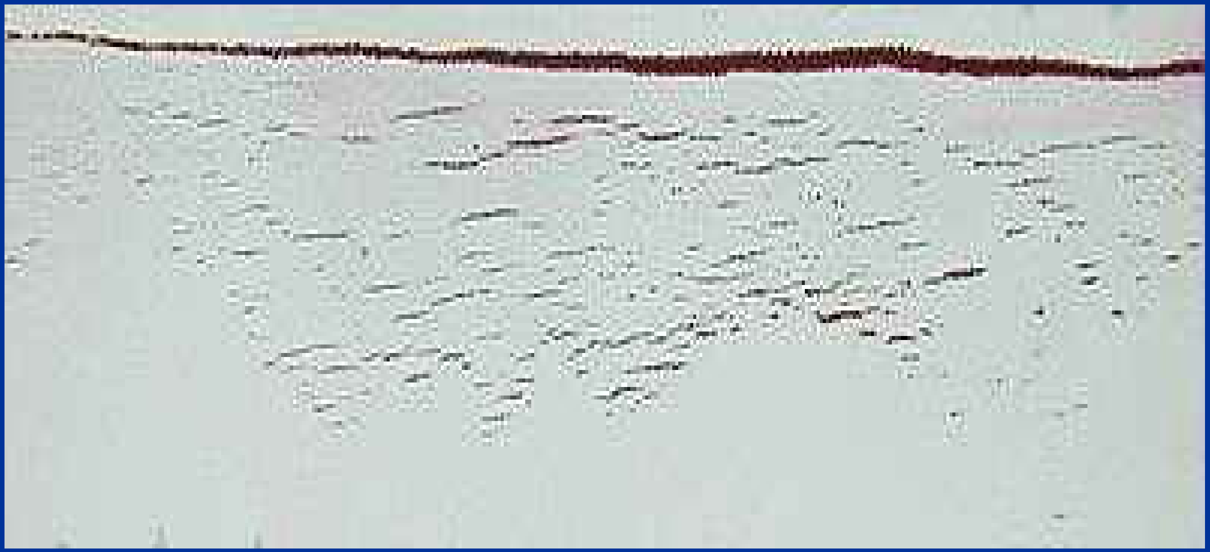


Fig 15: Machined notches used to simulate single and co-parallel cracks.

Fig 16: Example of machined notches at the weld edge in a pipe coupon. Single and co-parallel notches along with notches at known angles are introduced and used to evaluate propagation angles of toe cracks.

Fig 17: Light corrosion and significant SCC can be seen in both images. The lower image has channel style corrosion with a high population of SCC indications.

Fig 18: A cross sectional view of corrosion and cracking. This profile illustrates that when the combined depth of the corrosion and cracking is considered a significant percentage of the total wall thickness may be lost.

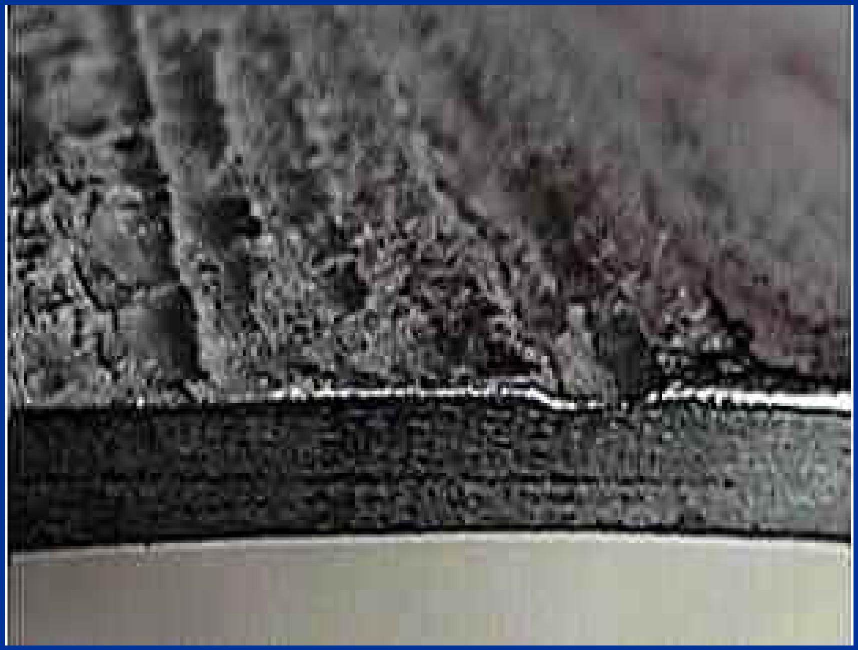


Fig 19: Cracking may occur following corrosion paths as this photograph shows. Consequently, cracks may occur at varied angles relative to the pipe axis.

<u>Fig 20:</u> Replication of a corrosion sample. The image on the left is the original corrosion feature while the corrosion replica is shown on the right.

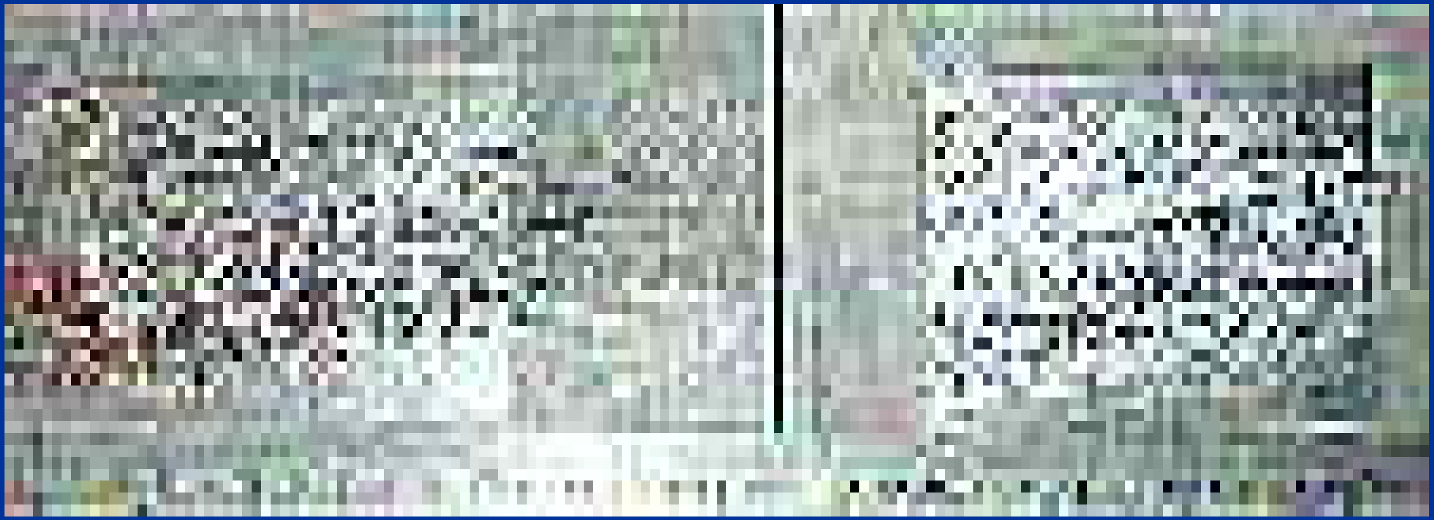


Fig 21: Machined replica of a corrosion feature with introduced notch targets. The notch targets are used for ultrasonic equipment calibration in same side sizing applications.

Fig 22: Velocity test coupons that were machined from pipe material for material property studies.

Fig 23: Round notch (left) or machined notches (right) can be used for calibration. Accurate depth measurements for the notches may be obtained by using rubber replicas and optical measurement devices.

Thank You

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