DURABILITY AND OPTIMIZATION OF CONNECTING RODS

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OVERALL OBJECTIVES

- Evaluate and compare fatigue performance of forged steel and powder metal connecting rods.
- Perform life predictions of connecting rods and validate by experiments.
- Perform dynamic load analysis and optimization

PROJECT OUTLINE

- Literature Survey on Connecting Rods
  - Load and Stress Analyses
  - Durability and Optimization Aspects
  - Manufacturing Processes and Economic Costs
  - Comparative Studies of Forged Steel & PM Connecting Rods

- Experimental Work
  - Specimen Testing (Material Evaluation)
    - Forged steel
    - Powder metal
    - C-70 steel
  - Testing of Forged Steel and Powder Metal Connecting Rods
    - Manufacturing fixtures
    - Load-control fatigue testing

PROJECT OUTLINE

- Analytical Evaluations
  - Digitizing Connecting Rod Geometry
  - Stress (FEA) Analysis
  - Durability (Fatigue) Analysis and Life Predictions
  - Dynamic Load and Stress (FEA) Analysis
  - Optimization Analysis

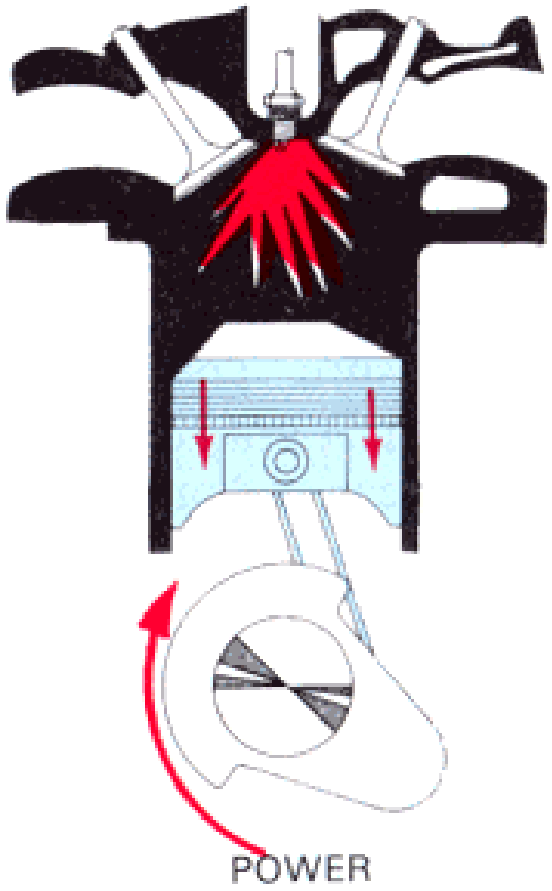
PUBLICATIONS AND PRESENTATIONS

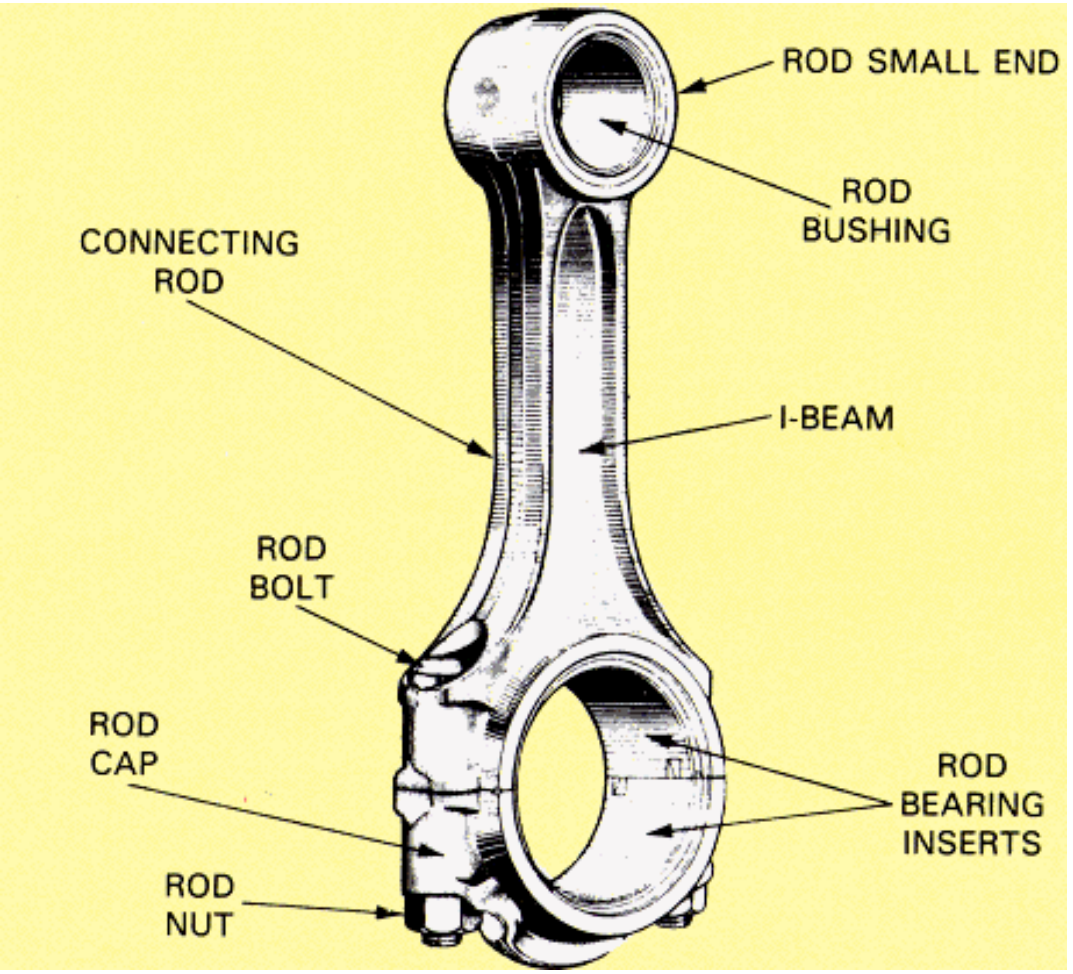
- **Durability and Optimization of Connecting Rods,** *Great Designs in Steel Seminar 2004*, Livonia, MI (February 18th 2:30 PM).

- **A Comparative Study of Fatigue Behavior and Life Predictions of Forged Steel and PM Connecting Rods, *SAE Technical paper 2004-01-1529***, *SAE World Congress 2004*, Innovations in Steel Bar Products and Processing Session (M2), Detroit, MI (March 11th,11:00 AM).

- **Dynamic Load and Optimization Aspects**, to be published.

CONNECTING ROD NOMENCLATURE





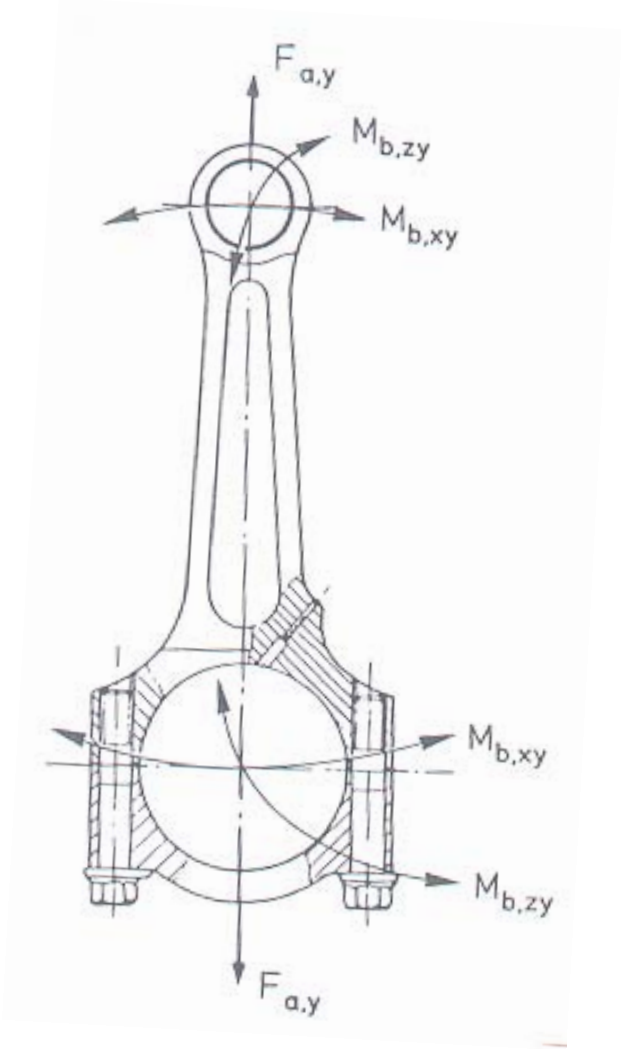
From *"Tension and Compression in Connecting Rods, Schreier 1999"*

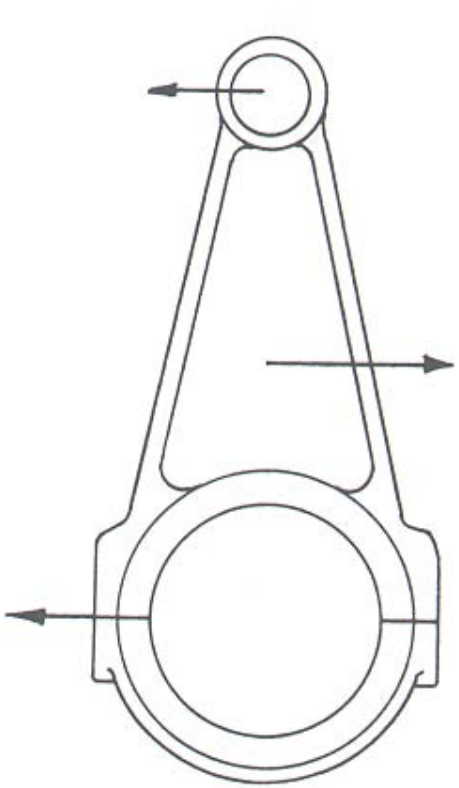
LOADING OF CONNECTING ROD

- **Connecting Rods Are Subjected to:**
  - Inertia forces due to mass
  - Forces generated from the combustion process
  - Forces due to wearing of forging flashes

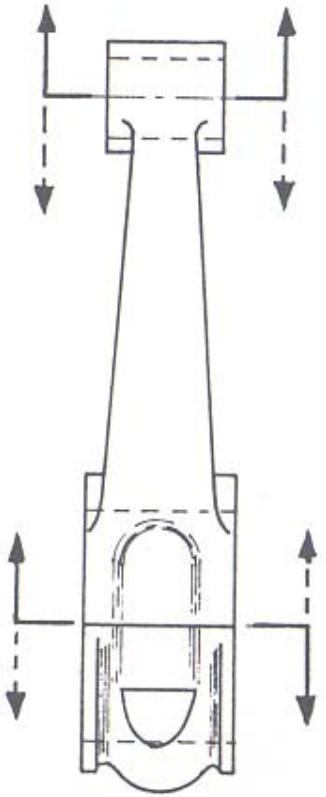
- **These Forces Produce:**
  - Cyclic *axial* force and stress
  - Cyclic *bending* moment and stress (perpendicular to the crankshaft axis)
  - Cyclic *bending* moment and stress (parallel to the crankshaft axis)

LOADING OF CONNECTING ROD (SONSINO, 1996)





(a) Bending Perpendicular to the Crankshaft Axis due to Inertia Forces



(b) Bending Parallel to the Crankshaft Axis due to Crankshaft Bending

CONNECTING RODS

Conventional forged steel

- Sedan, 150 HP @ 5700 RPM
- Weight: 0.93 lb

Powder metal

- Minivan, 150 HP @ 5200 RPM
- Weight: 1.2 lb

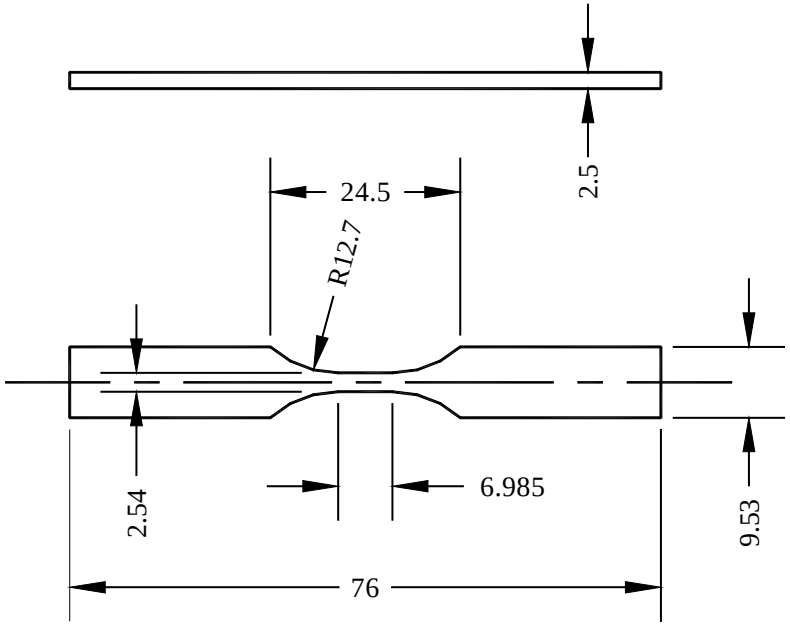
SPECIMEN TESTING

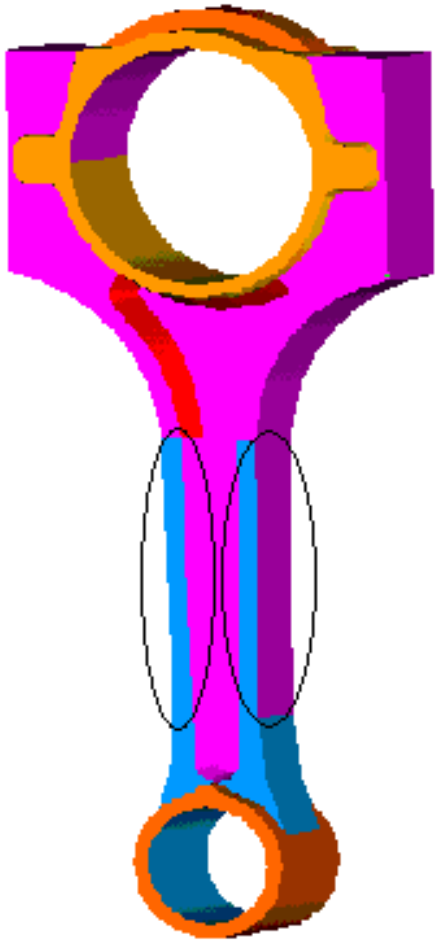
Specimen Testing

- Strain-controlled tensile tests
- Strain-controlled fatigue tests
- Based on ASTM standards and recommended practices
- Flat specimens from forged steel and powder metal connecting rods

Instron closed-loop servo-controlled hydraulic axial load frame and digital servo controller are utilized for the tests.

SPECIMEN GEOMETRY





Flat plate specimen configuration and dimensions according to ASTM Standard E606

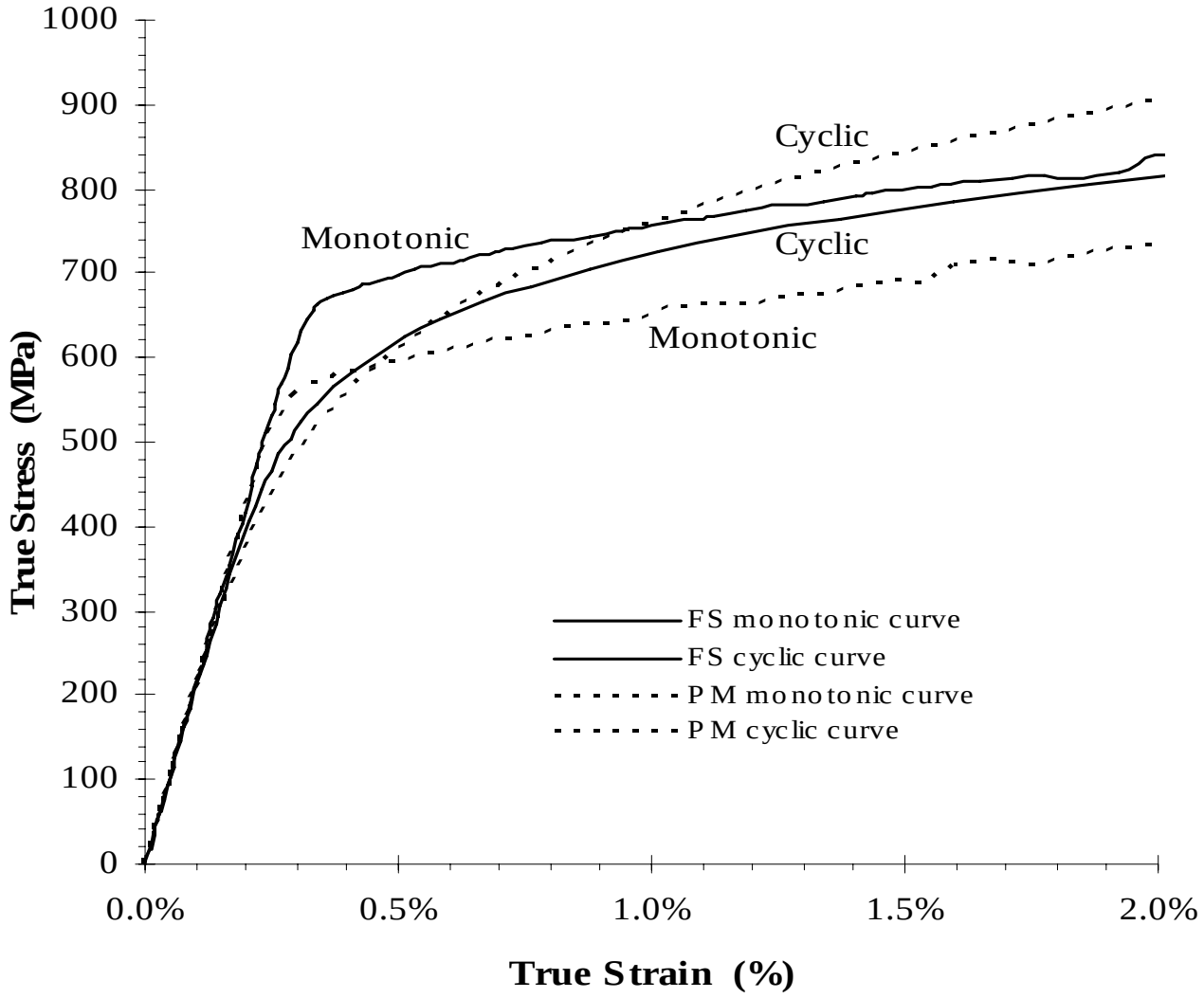
(All dimensions in mm)

COMPARISON OF MATERIAL MECHANICAL PROPERTIES

	Forged Steel	Powder Metal
YS (MPa)	700	588
YS Ratio	*1*	*0.84*
UTS (MPa)	938	866
UTS Ratio	*1*	*0.92*
YS' (MPa)	620	609
YS' Ratio	*1*	*0.98*
S_f (at $N_f = 10^6$)	423	334
S_f Ratio	*1*	*0.79*

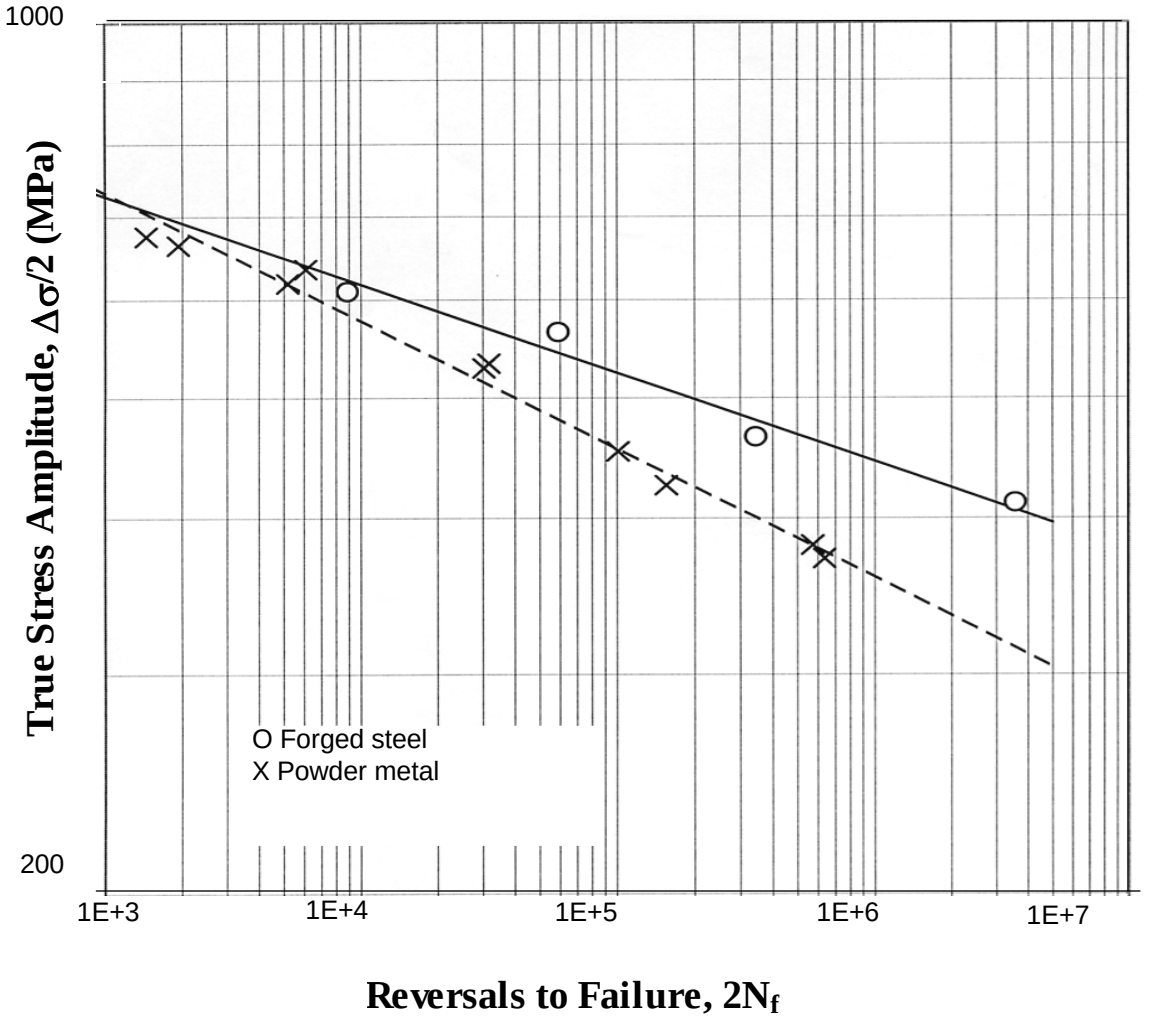
* Base of comparison is Forged Steel.

MATERIAL CYCLIC & MONOTONIC STRESS-STRAIN BEHAVIORS



MATERIAL STRESS-LIFE COMPARISON

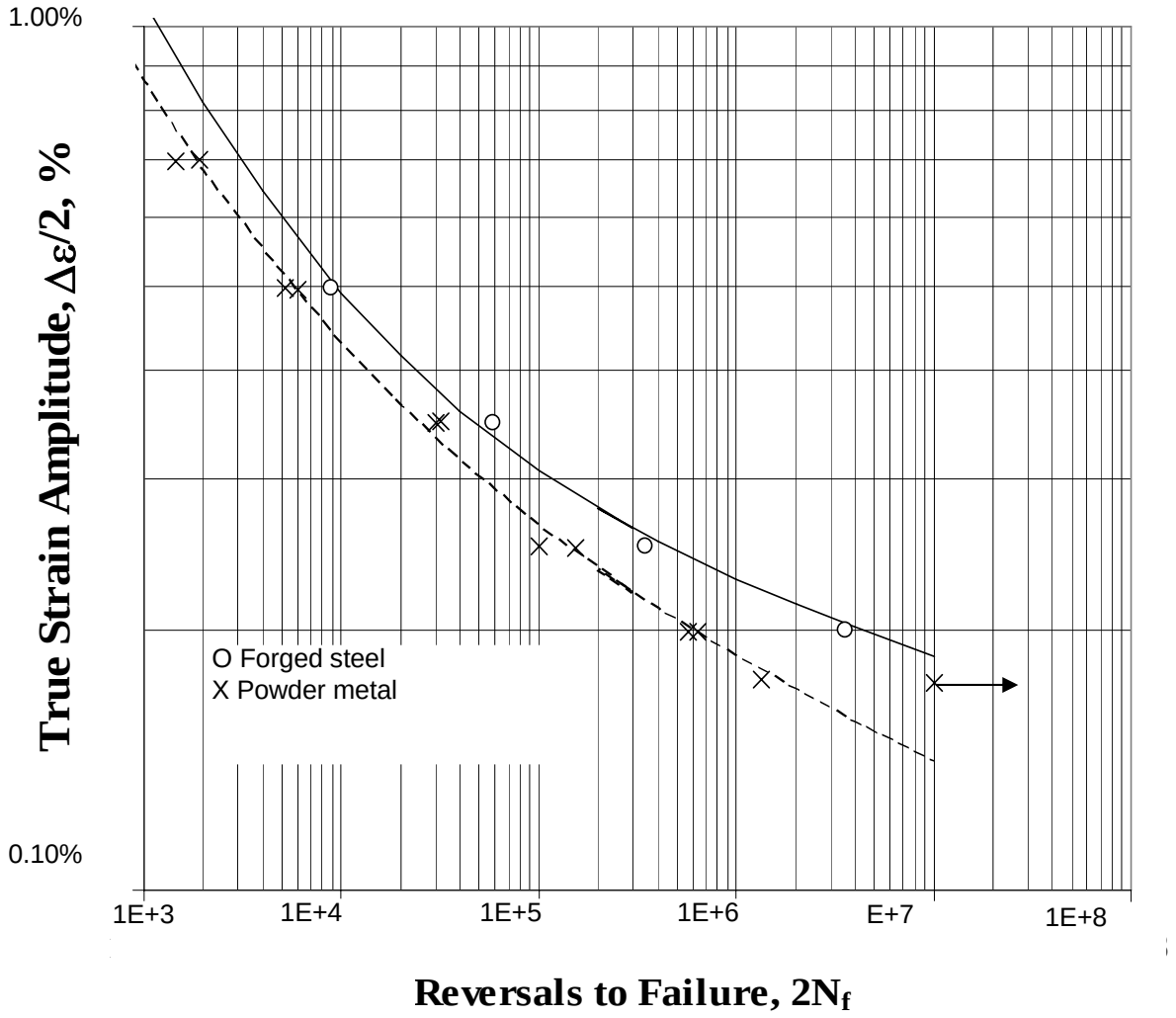
- Better overall S-N fatigue resistance of the forged steel
- Long-life fatigue life of forged steel more than an order of magnitude longer than powder metal



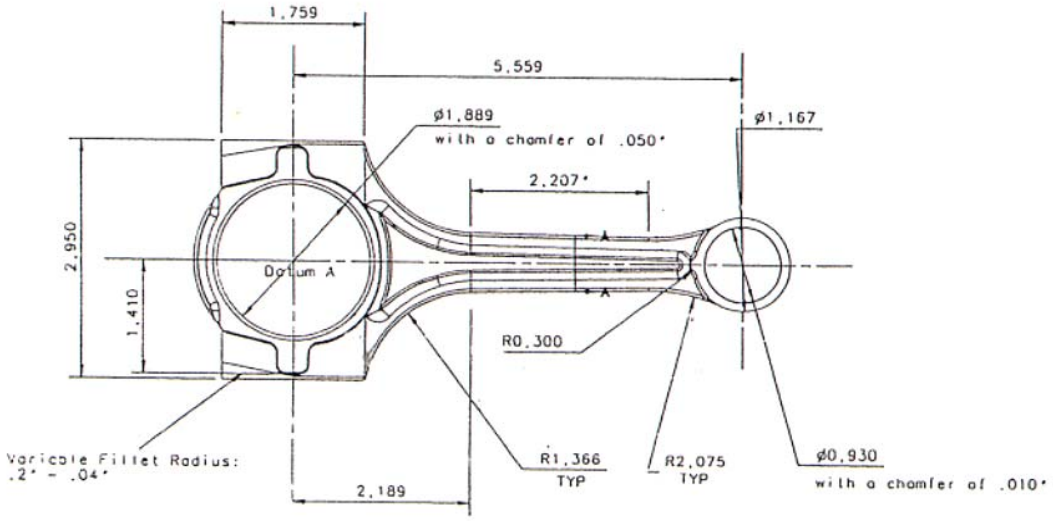
MATERIAL
TOTAL STRAIN-LIFE COMPARISON

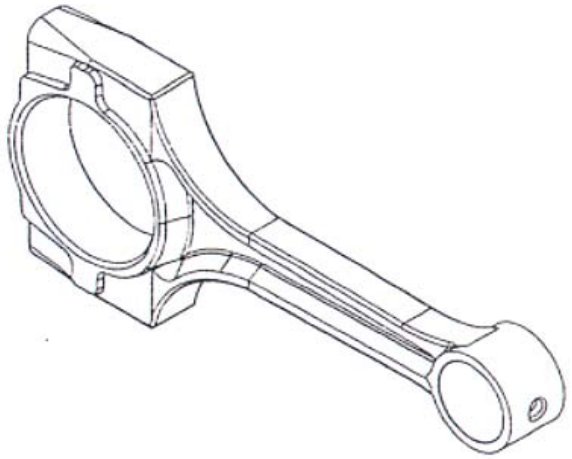
- For a connecting rod, subjected to many millions of cycles, high cycle regime is of primary interest

- In the high cycle regime, forged steel results in about a factor of seven longer life than the powder metal material.



DIGITIZED MODEL OF FS CONNECTING ROD

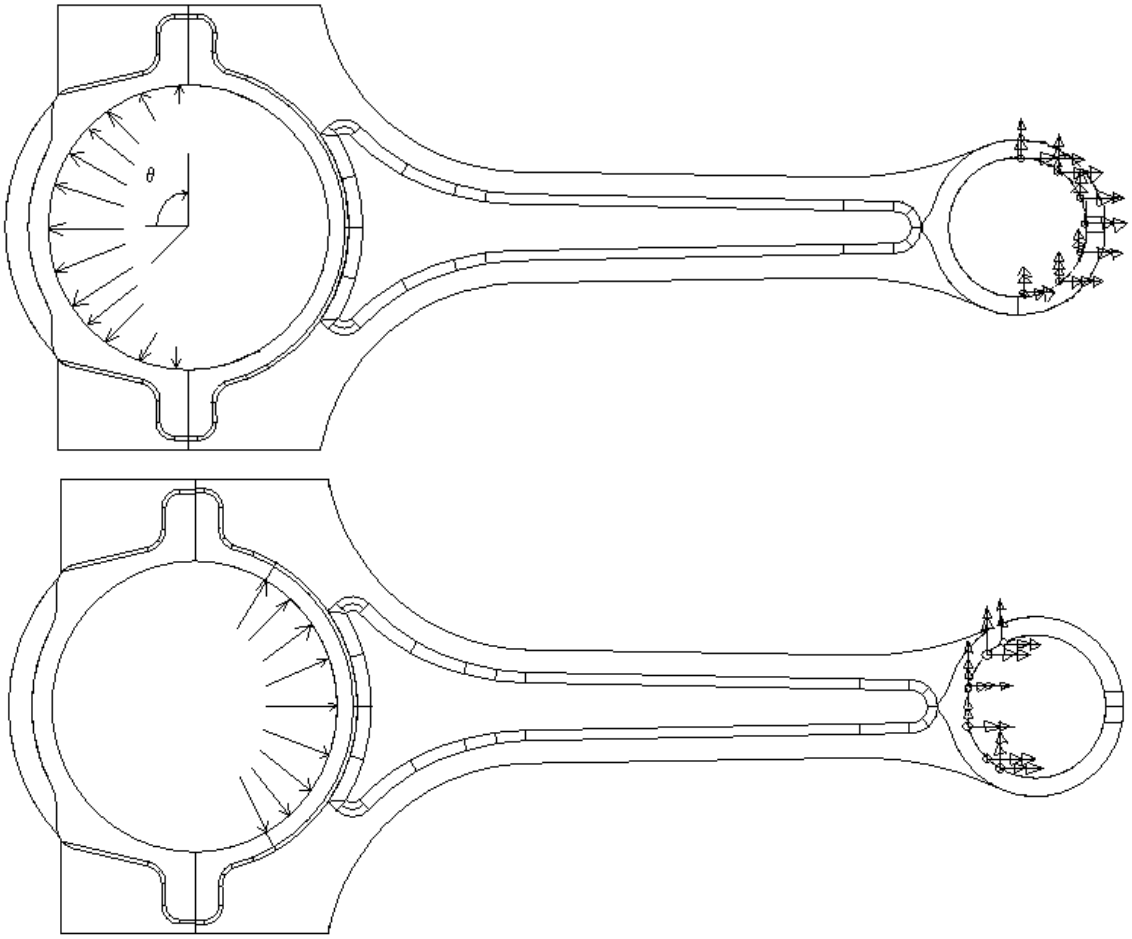




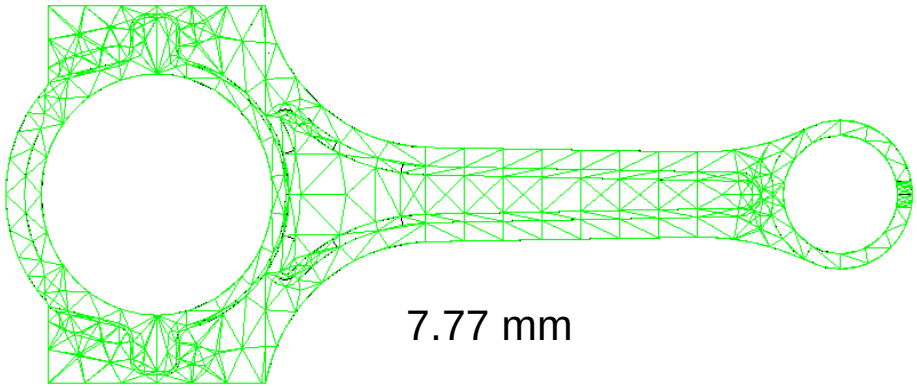
BOUNDARY CONDITIONS FOR STRESS (FEA) ANALYSIS

- Tension and compression loads applied as pressure on bearing surfaces.
- In tension cosine function over 180 deg, in compression uniform distribution over 120 deg (Webster 1983).
- Four cases considered:

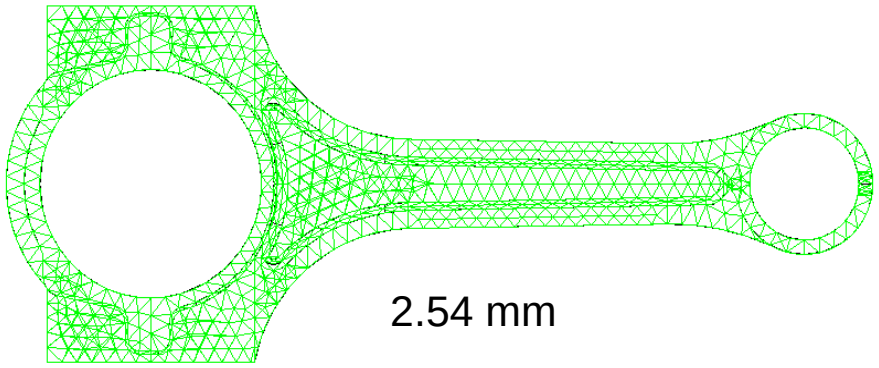
Crank end	Pin end
tension	restrained
compression	restrained
restrained	tension
restrained	compression



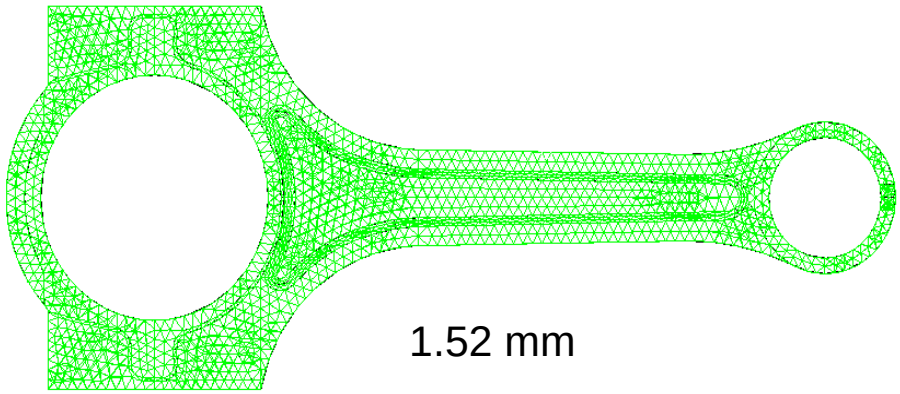
MESH DETAILS



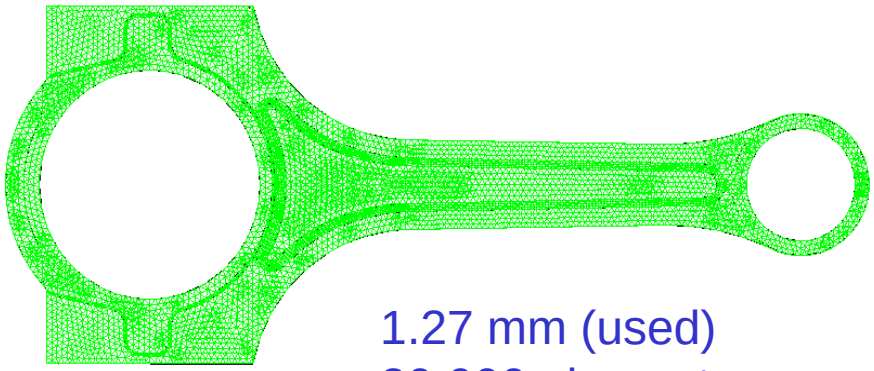
7.77 mm



2.54 mm

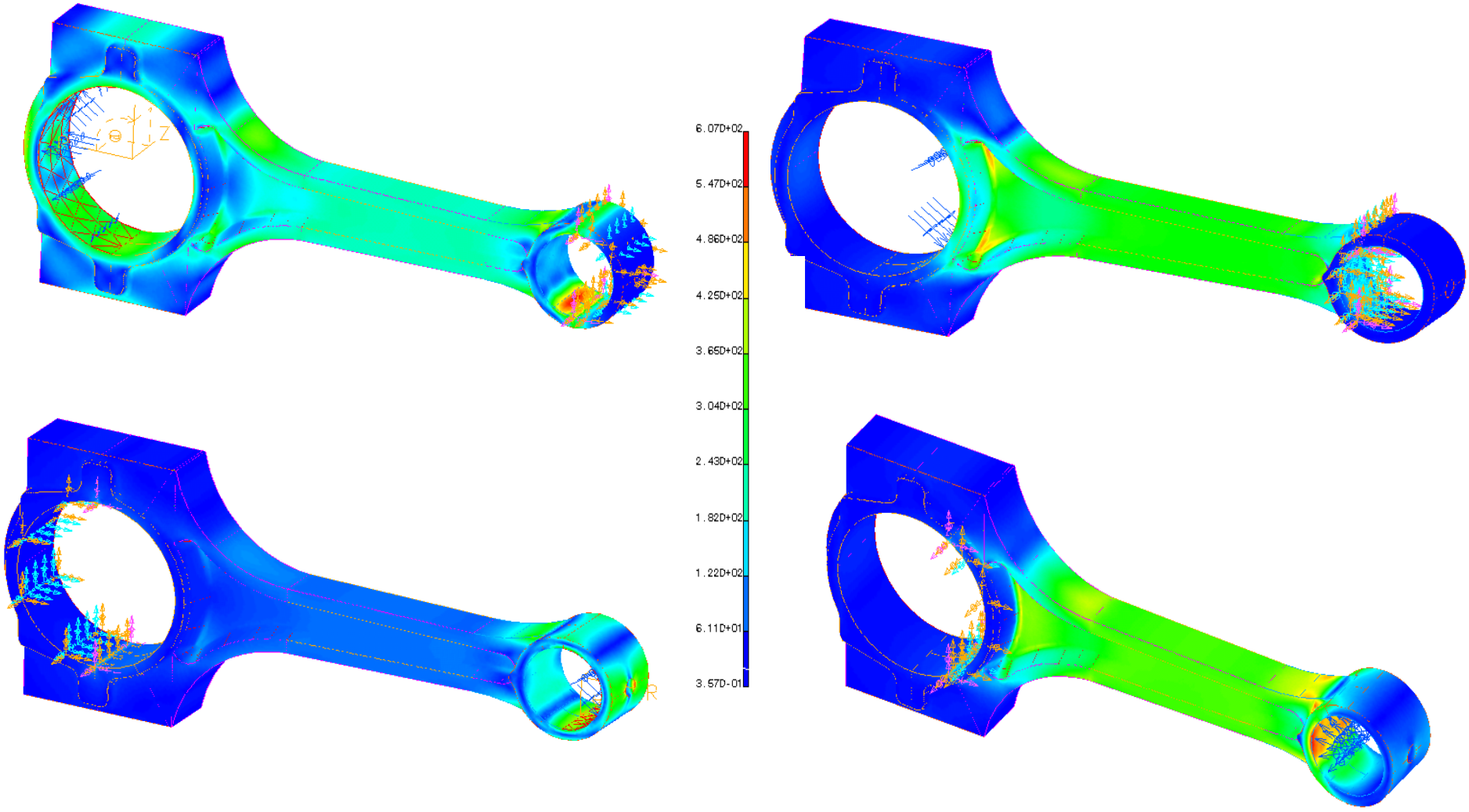


1.52 mm

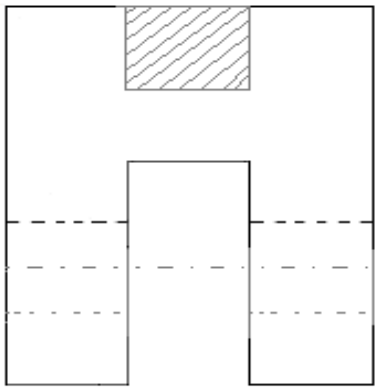


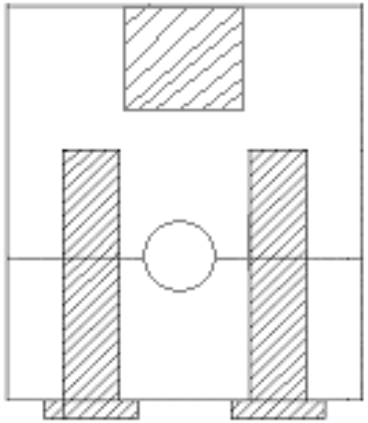
1.27 mm (used)
80,000 elements
130,000 nodes

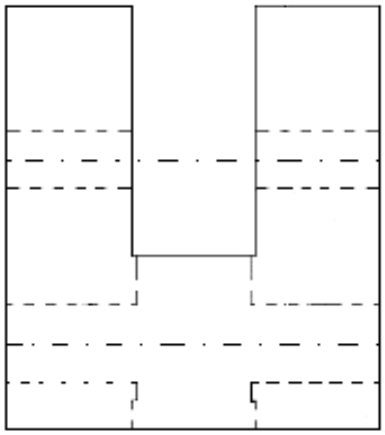
CONTOURS OF VM STRESS FOR FS CONNECTING ROD (P_{max} = 26.7 kN or 6 kip)

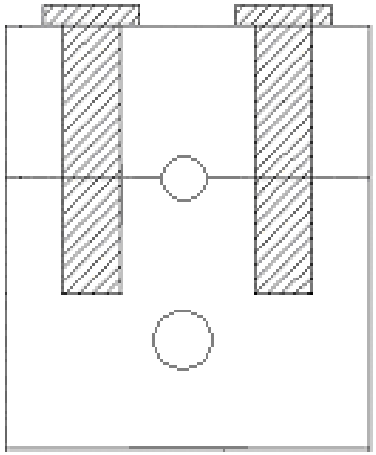


CONNECTING ROD TEST FIXTURES







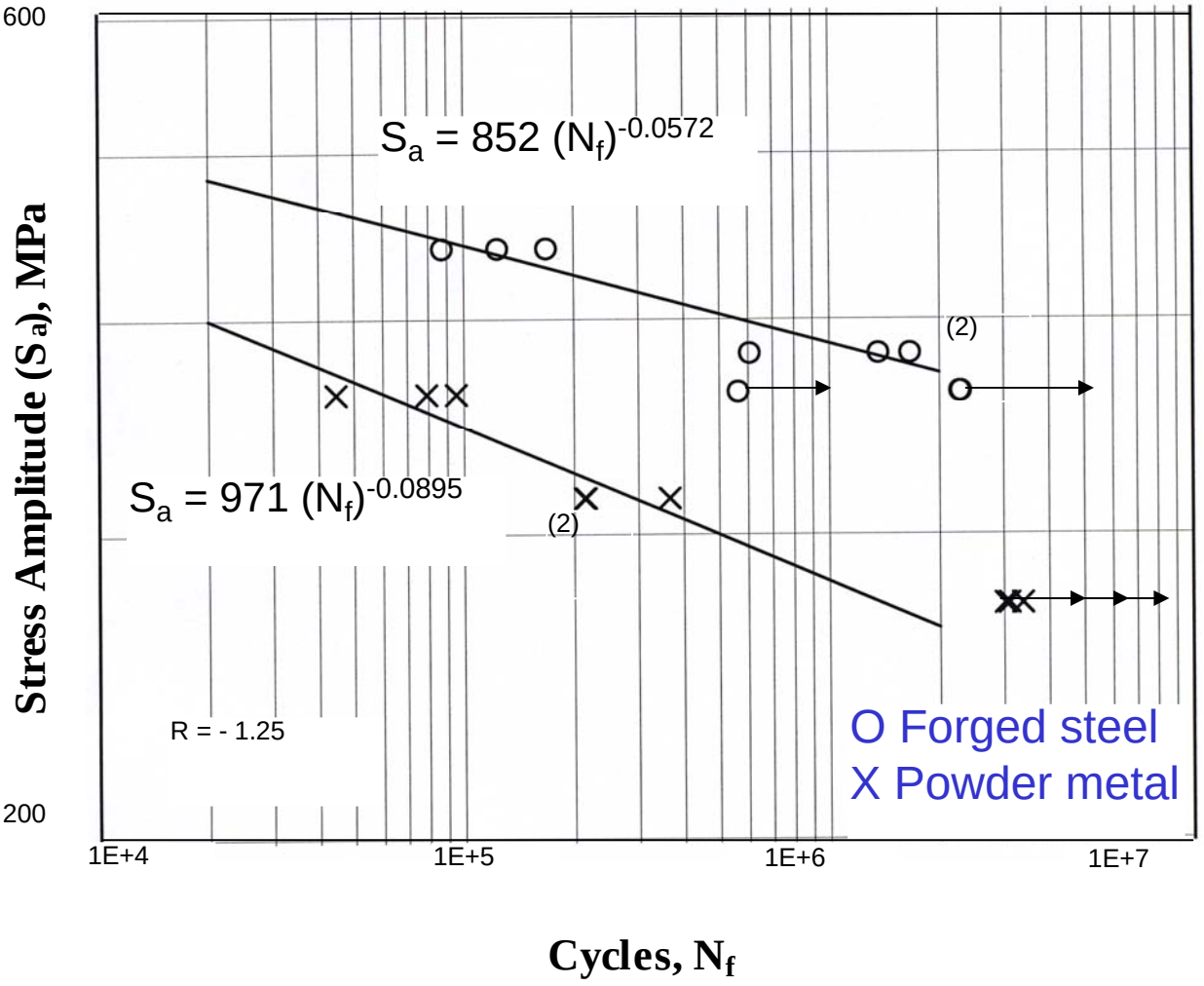


CONNECTING ROD TEST CONDITIONS

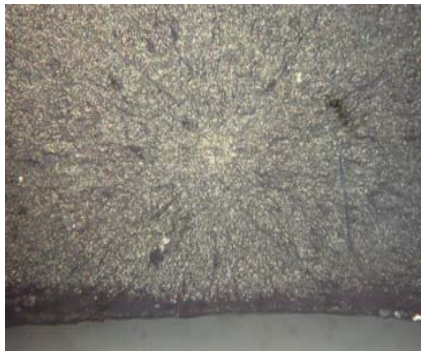
- **Load-controlled axial tests**
- **Load ratio P_{min}/ P_{max} = - 1.25**
- **Test frequency 2-5 Hz**
- **Life range 4 X 10^4 – 4 X 10^6 Cycles**

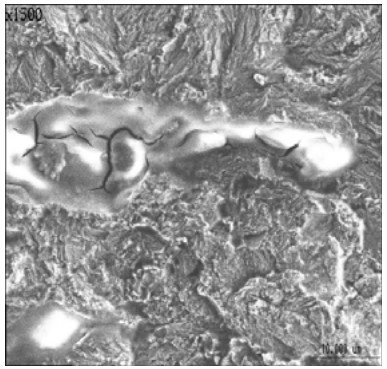
COMPONENT TEST RESULTS & STRESS-LIFE COMPARISONS

- Forged steel connecting rod fatigue strength is 387 MPa, while for PM connecting rod it is 282 MPa.
- About two orders of magnitude longer life for the forged steel connecting rod.

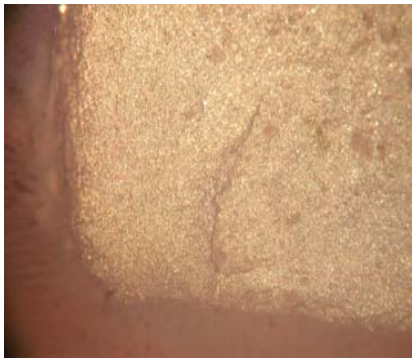


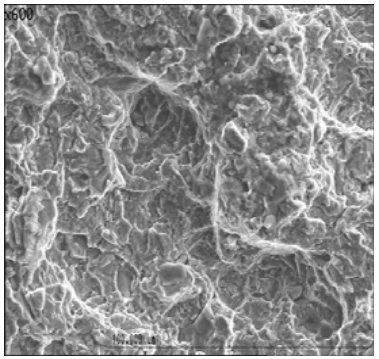
FRACTURE SURFACES





FORGED
STEEL





PM

FS FRACTURE SURFACES