Life design
Steel cylinders
Partners involved
Roquet
Labson
Cinme
IFTR
Cenaero

Fatigue state of the art for NON welded parts

Morrow and Juvinal approach

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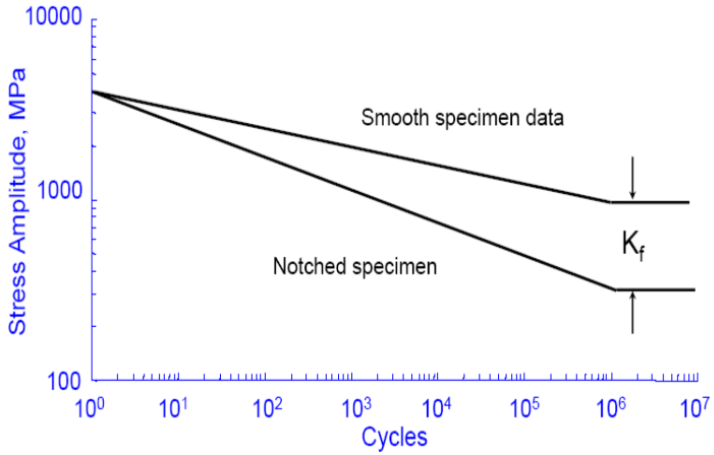
Notched SN Curve



Stress concentrations are not very important at short lives

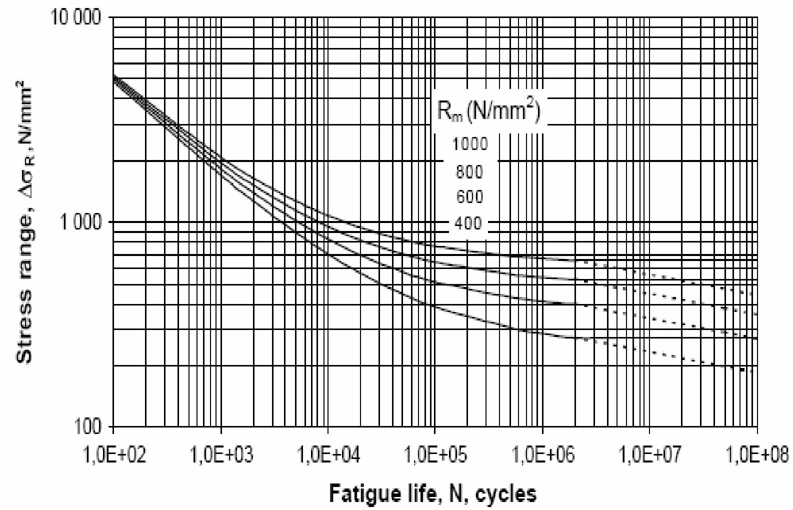


Figure 18-15: Fatigue design curves for unwelded ferritic and austenitic forged and rolled steels (mean stress = 0)

1.- It exist a so called " material S-N curve, obtained empirically testing smooth specimen This curve is ad equated to be used to use with F.E.M stresses

2.- S-N curves for real pieces are obtained applying a coefficient Kf to this "material curve" which affects to the long life's zone basically

3.- Slope of the S-N curve depends of the stress concentration

4.- S-N curves a highly dependent on the ultimate strength of the material

5.- Standards recommends S-N curves corresponding to a reliability of 99,99 %, no information about the 50 % reliability curve

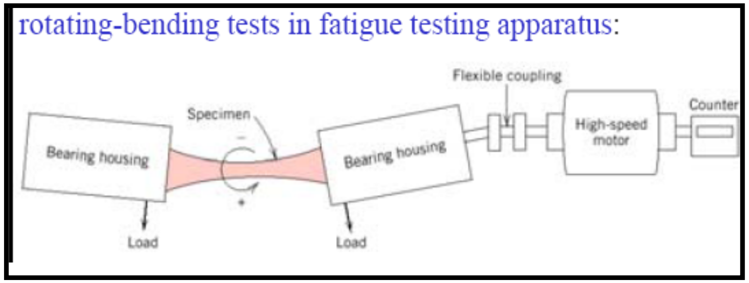
ROQUET - COORDINADOR

State of the art

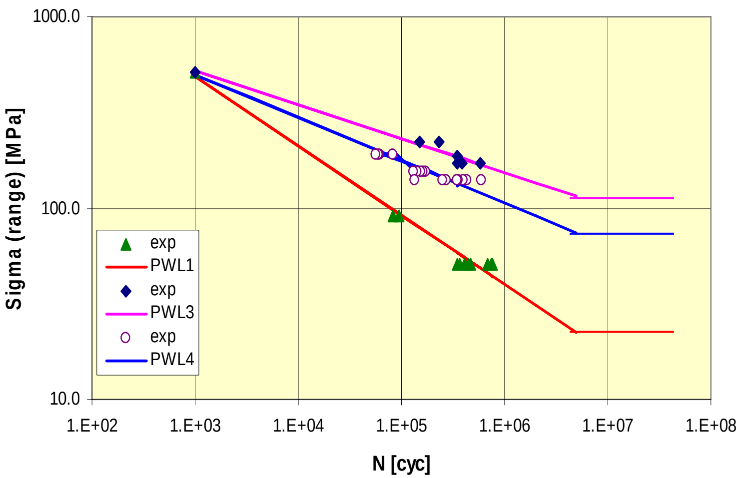
Morrow and Juvinal approach

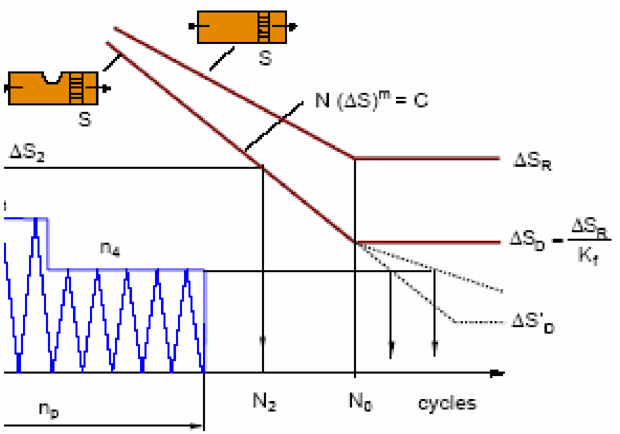
There are an impressive amount of literature presenting the approach of a “material curve “ corresponding to smooth specimens and a curve corrected for parts including the concept of stress concentration factor

Considerable part of this works referees to tests done in a bending machine were fatigue are related to a flexion phenomena



This flexion results are extrapolated to traction loads giving slopes of 18 for smooth specimens and 4,3 for a stress concentration factor of 3.
To have slopes of 3 we need to consider stress concentration factors between 6 and 7.

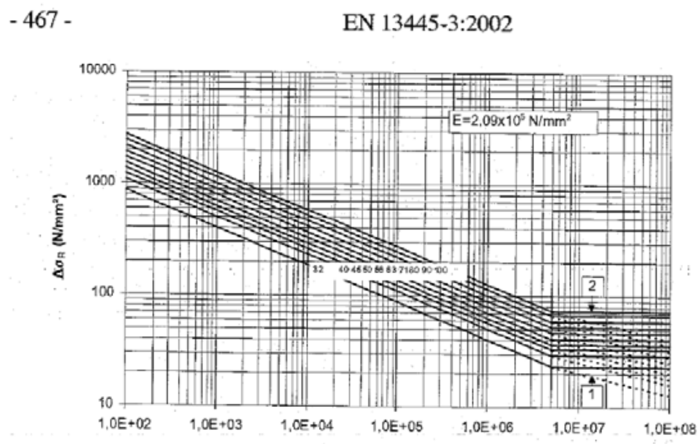




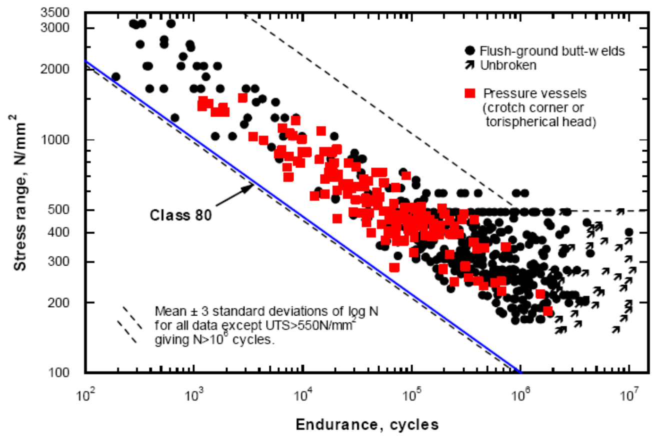
Morrow and Juvinal approach ,with a pivoting point corresponding to stress near Su

Fatigue state of the art

m=3 approach ,



ISO standard for WELDED components recommends m=3
Curves are no limited for high stresses
Eurocode III for welded components also



Maddox in a report issued in 2001 , as an assessment of the standard 13445, stated that for NON welded material , the standard underestimates the resistance, he proposes to use S-N curves of slope 3 and class 83, as per welded material

$$L_{10} = \left(\frac{C}{P}\right)^m \text{ or } C = P L_{10}{}^{1/m}$$

Where L = basic rated life (millions of re
C = basic dynamic load rating
P = equivalent dynamic bearing l
m = exponent in the life equation,
m = 3 for ball bearings
m = 3.3 for other bearings.

Classical formula for roller bearings life assessment recommends m=3, and 3,3

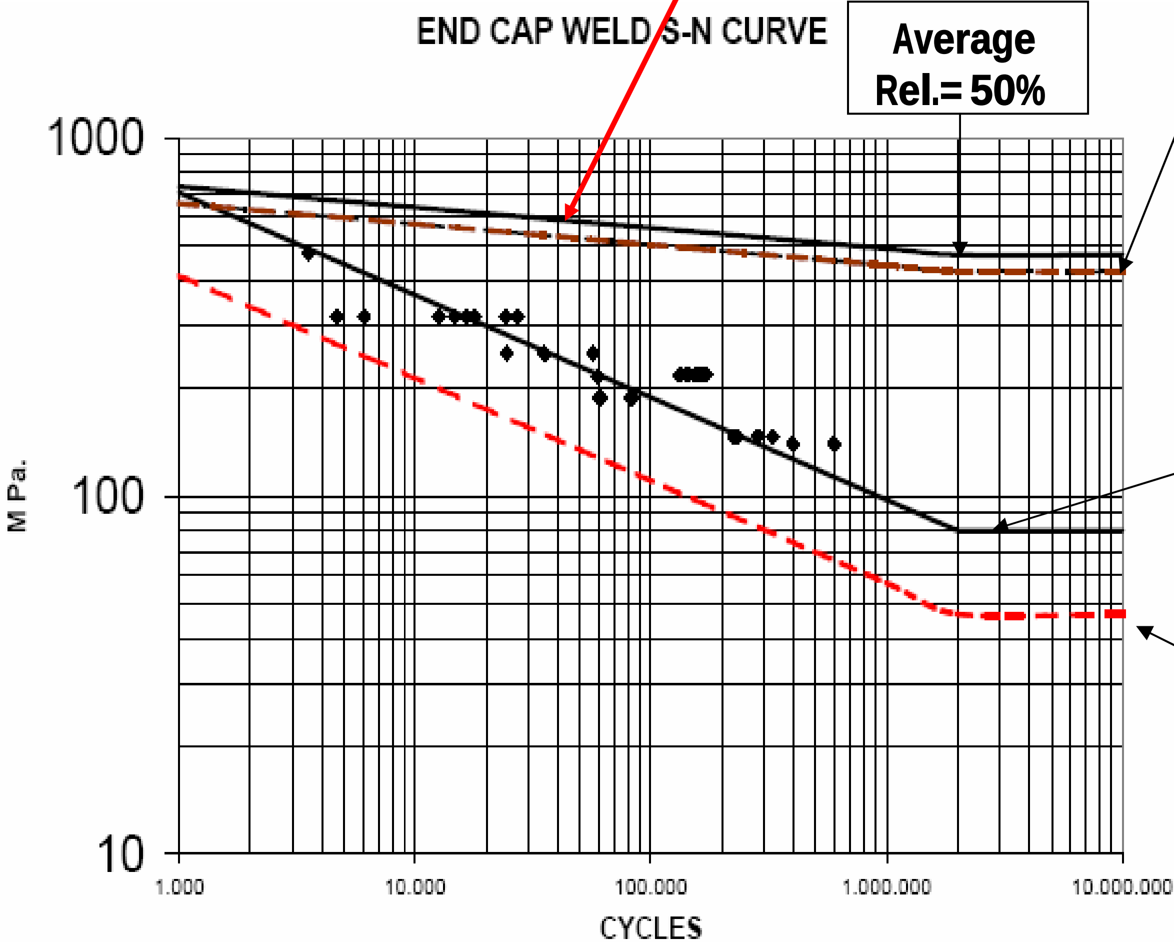
S-N curves 1ers approach

Morrow and Juvinal approach

Local stresses

Guarantied life
Rel 100%

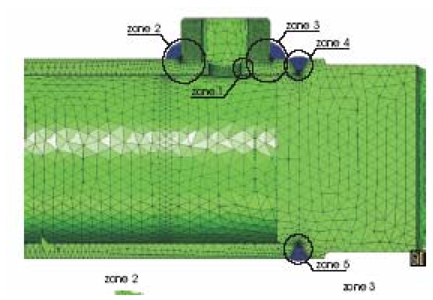
Average
Rel.= 50%



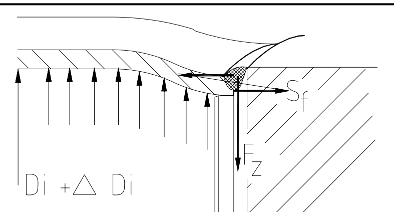
Average
Rel.= 50%

Guarantied life
Rel 100%

F.E.M.

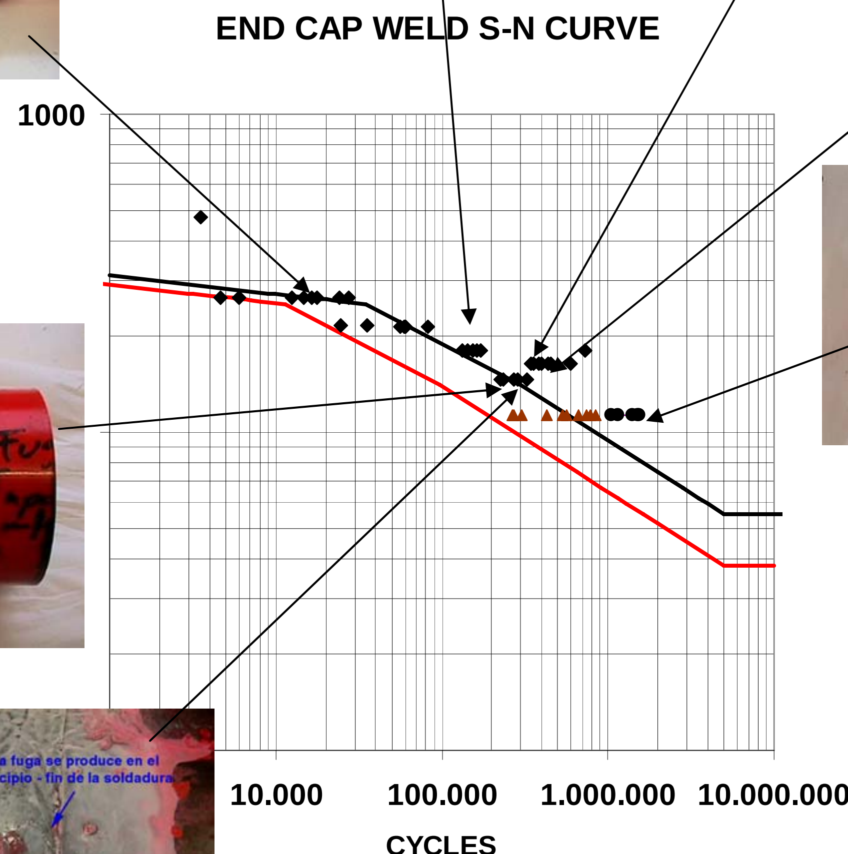


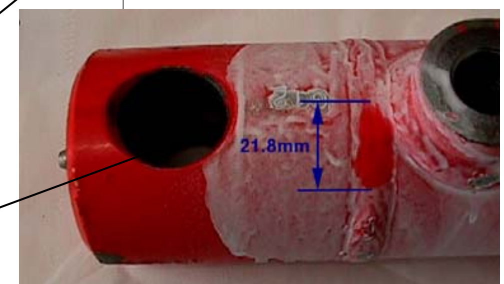
Nominal stresses



$$\sigma_A = \frac{M_A}{W} = \frac{12}{\alpha\, D_i\, s^2}\;\frac{P\, l^2\, D_i\, \alpha}{54}$$

Building up S-N curves 2nd approach

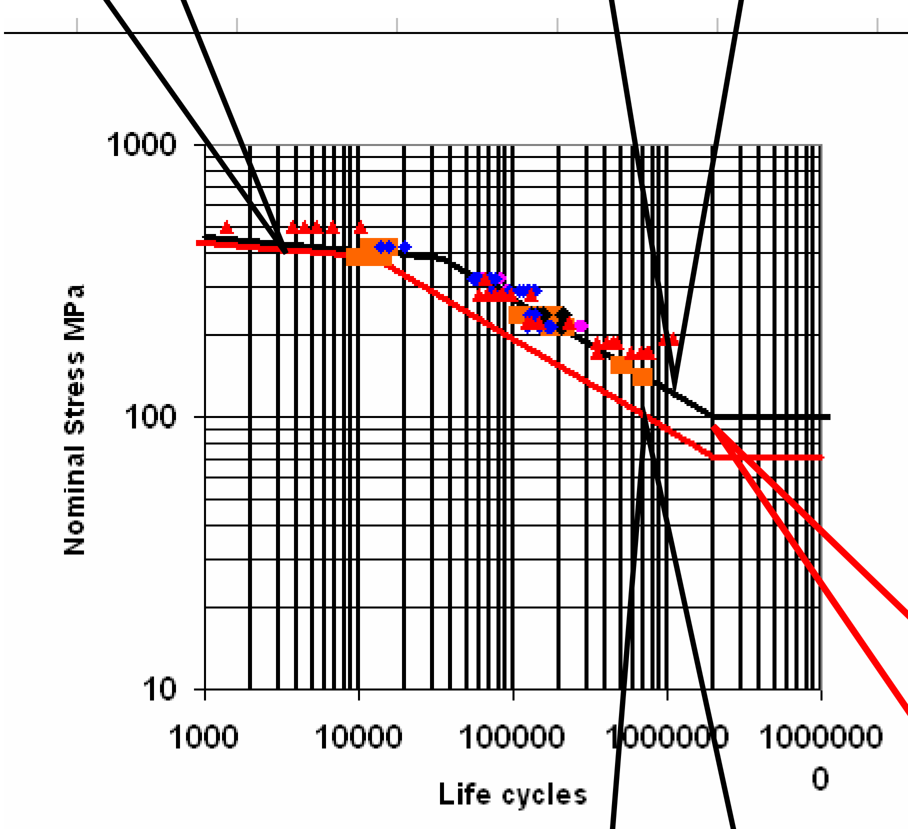




PROPOSAL

upper limit of validity

A 50% reliability curve is determined from the experimental results



a- S-N curves of slope of **3**, different for every different failure mode (Nominal stresses)

b.- S-N curves for **different reliability** to be capable to predict a reliability of expected life

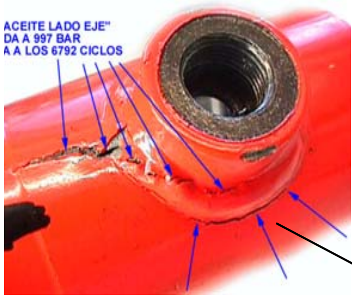
c.- Curves S-N with an **upper limit** of validity

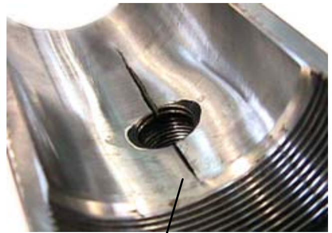
d.- Local stress curve **same slope** as nominal stress curve

A 99,9% reliability curve is considered

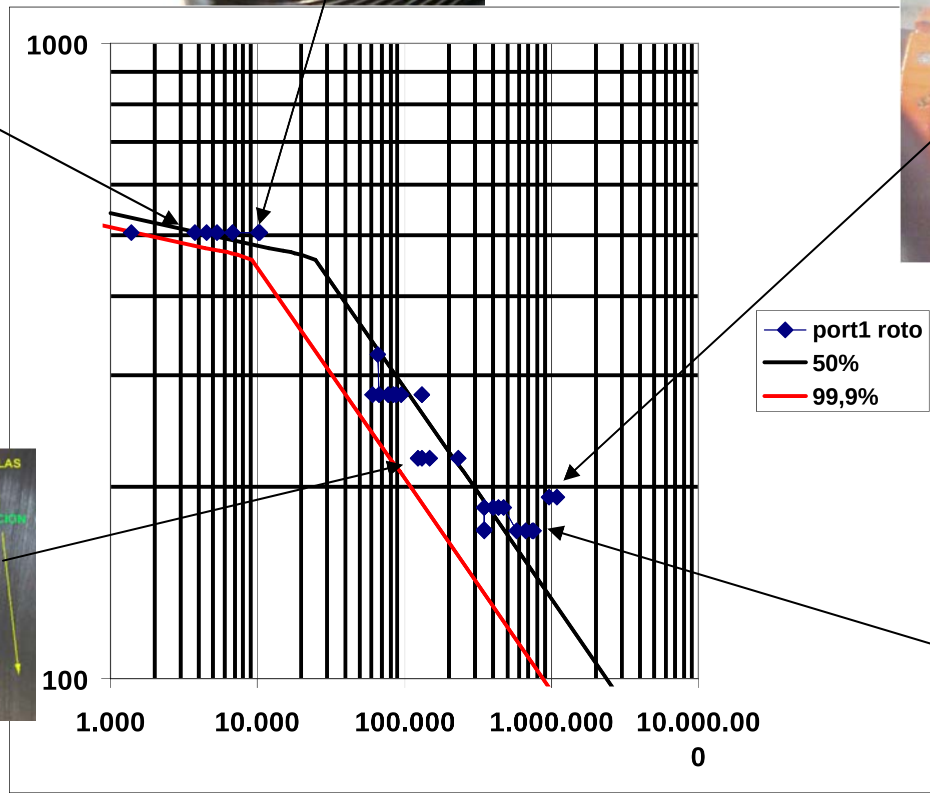
Curves are classified by “classes” (stress corresponding to 2.000.000 cycles)

Port failure in full cylinder test



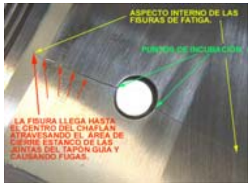


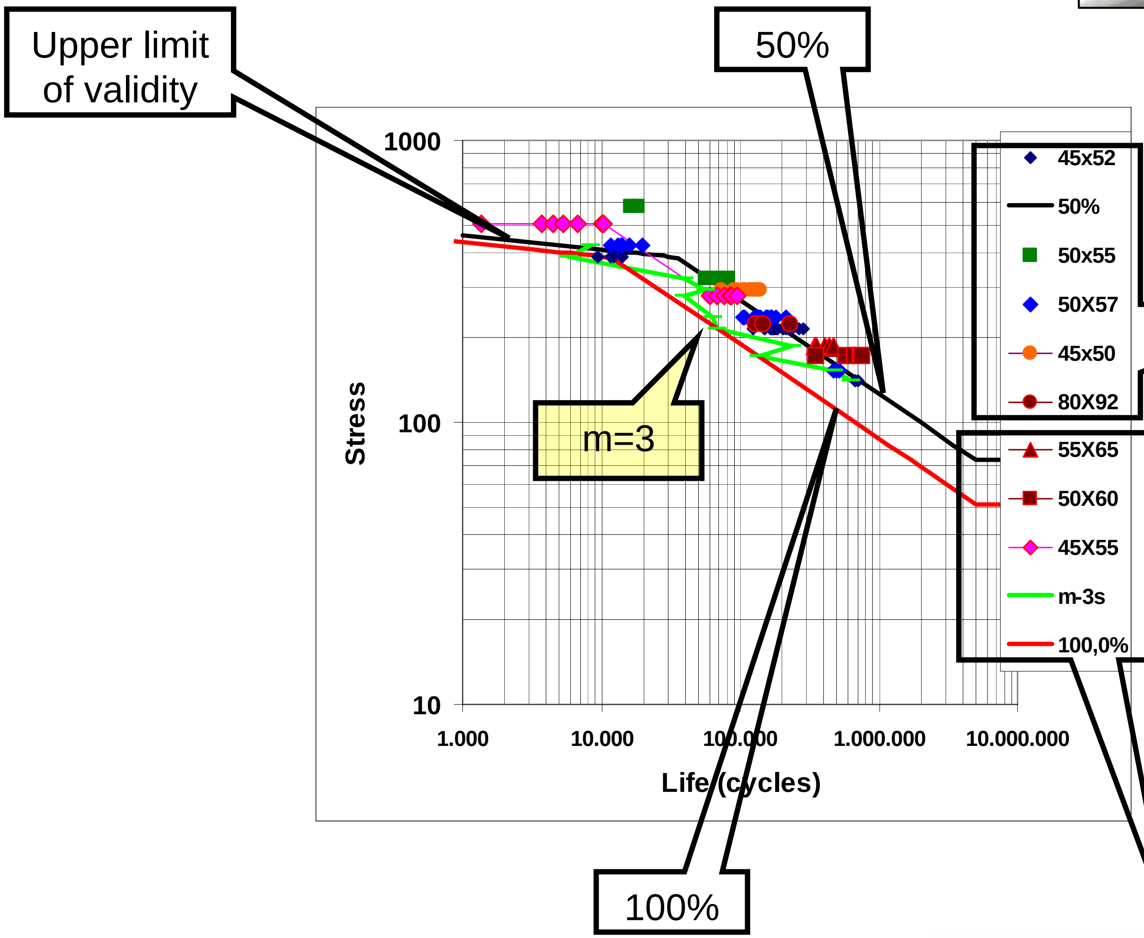
Results (life v.s. nominal stresses) plotted
Trying to find a best-fit line in a double logarithmic plot



Considering a slope of the S-N curve :m=3 with an upper limit. 99,9 curve corresponds to a scattering of Vx = 0,21

Port failure in complete cylinders
Pressure test at constant maximum pressure
Rod port is always the first to fail.





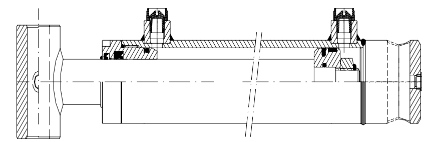
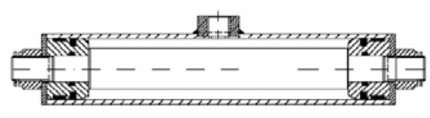
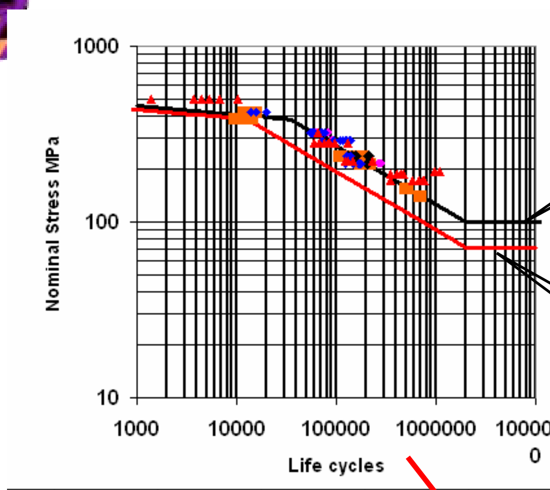


Figure presents the S-N curve for cylinder ports
Obtained from test until failure of full cylinders and specific samples



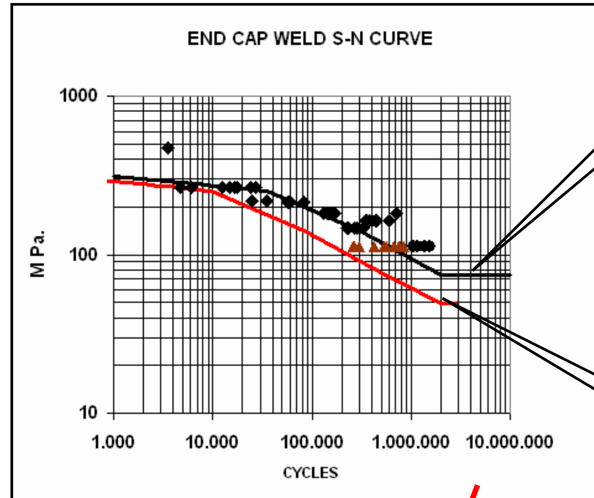
Cylinder life prediction by empirical S-N curves



C 100
50%

N/Nm=2,7 (*)

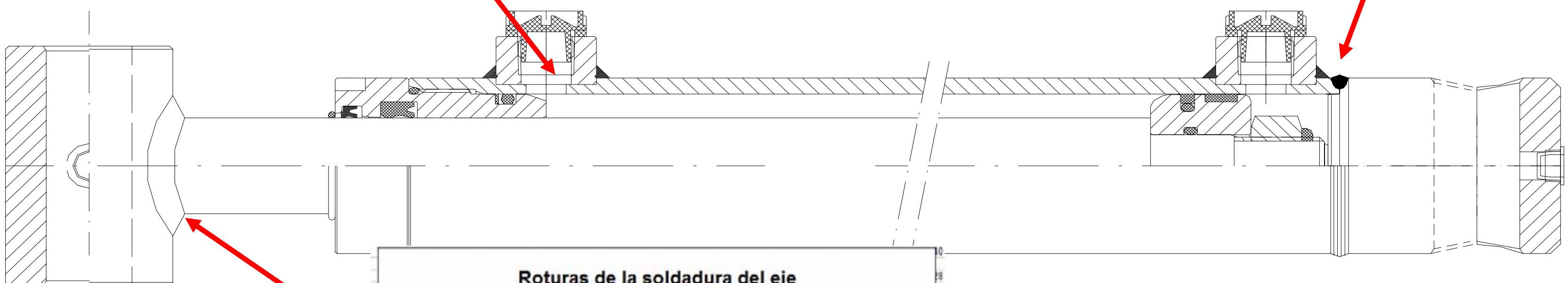
C 70
99,9%

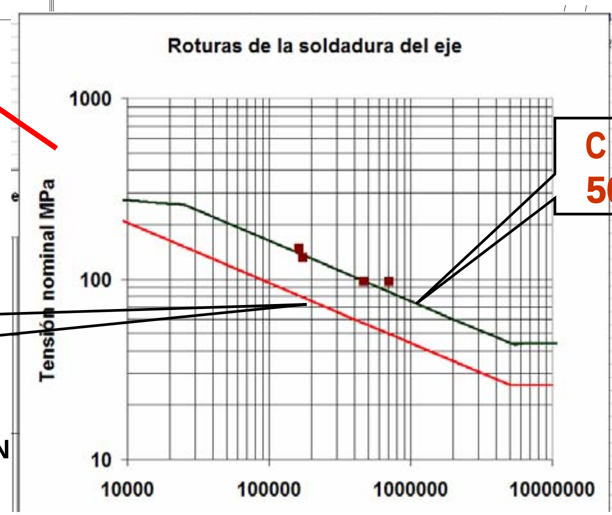


C 75
50%

N/Nm=3,1

C 50
99,9%





C 60
50%

C 35
99,9%

N/Nm=5

* Scattering depends on
-How good is the nominal stress formula choose
-Quantity of experimental results

June 2007

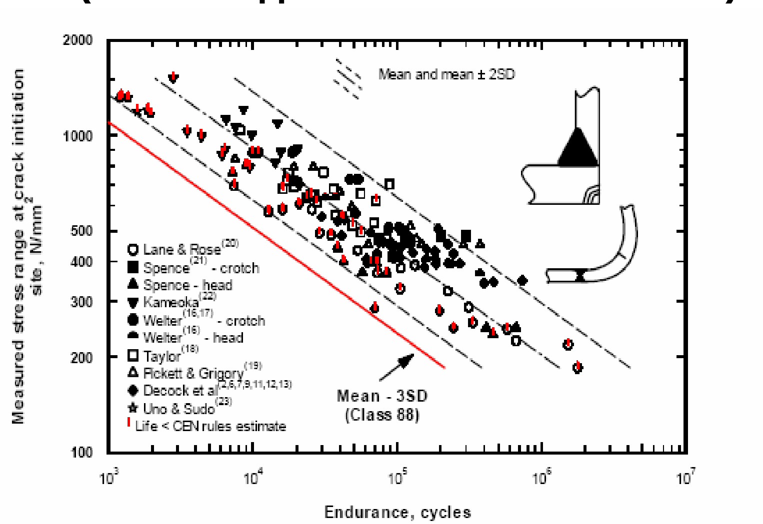
ROQUET - COORDIN

are S-N curves INDEPENDENT of the steel ultimate strength ?

state of the art

-Typically the slope and position of the S-N curves has been considered highly dependent of the material strength (so ISO 13445

-On 2001 a report of a research leadered by J.S. Maddox pointed out the fact that the recommendations of the ISO standard for non welded material could be wrong, and that a common S-N curve of slope 3 could be used for all materials independent of their strength -(a limited upper value was not considered)

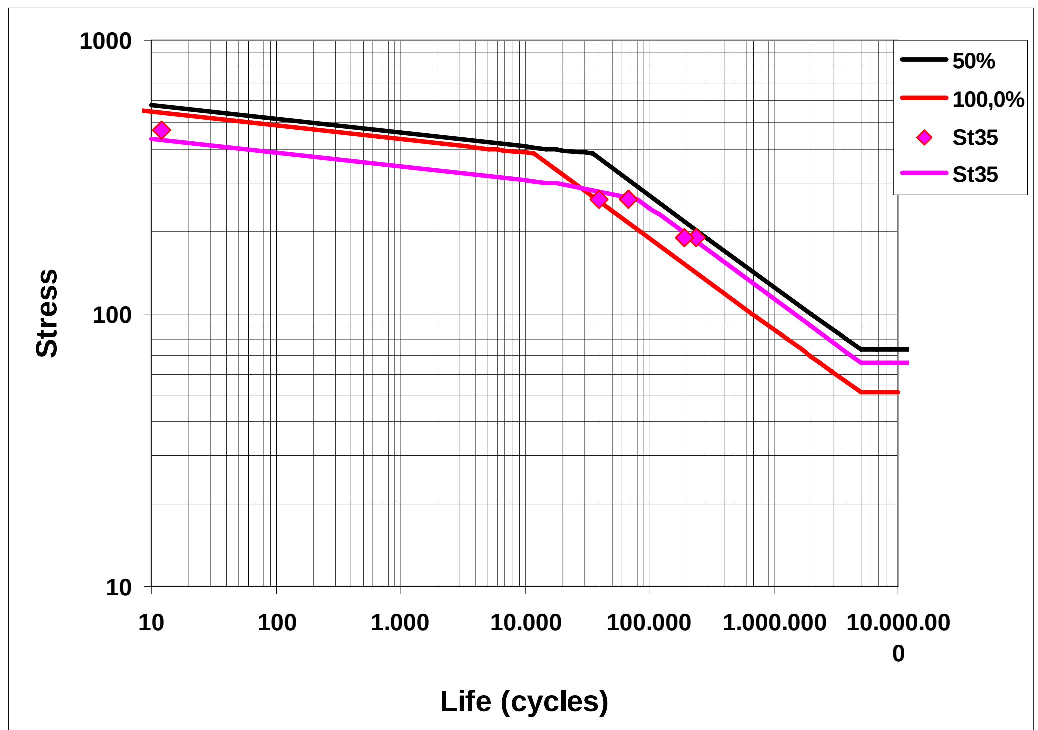


Conclusions of the project

-The Maddox assumption that the S-N curves are common for different steel strength may be considered basically correct for long life´s

-For short life´s the upper limit are smaller, (neither Maddox neither standards considers this upper limit)

-so designs for short life´s specifications may be not possible for steels of lower stress limit and perfectly possible for long life´s specifications

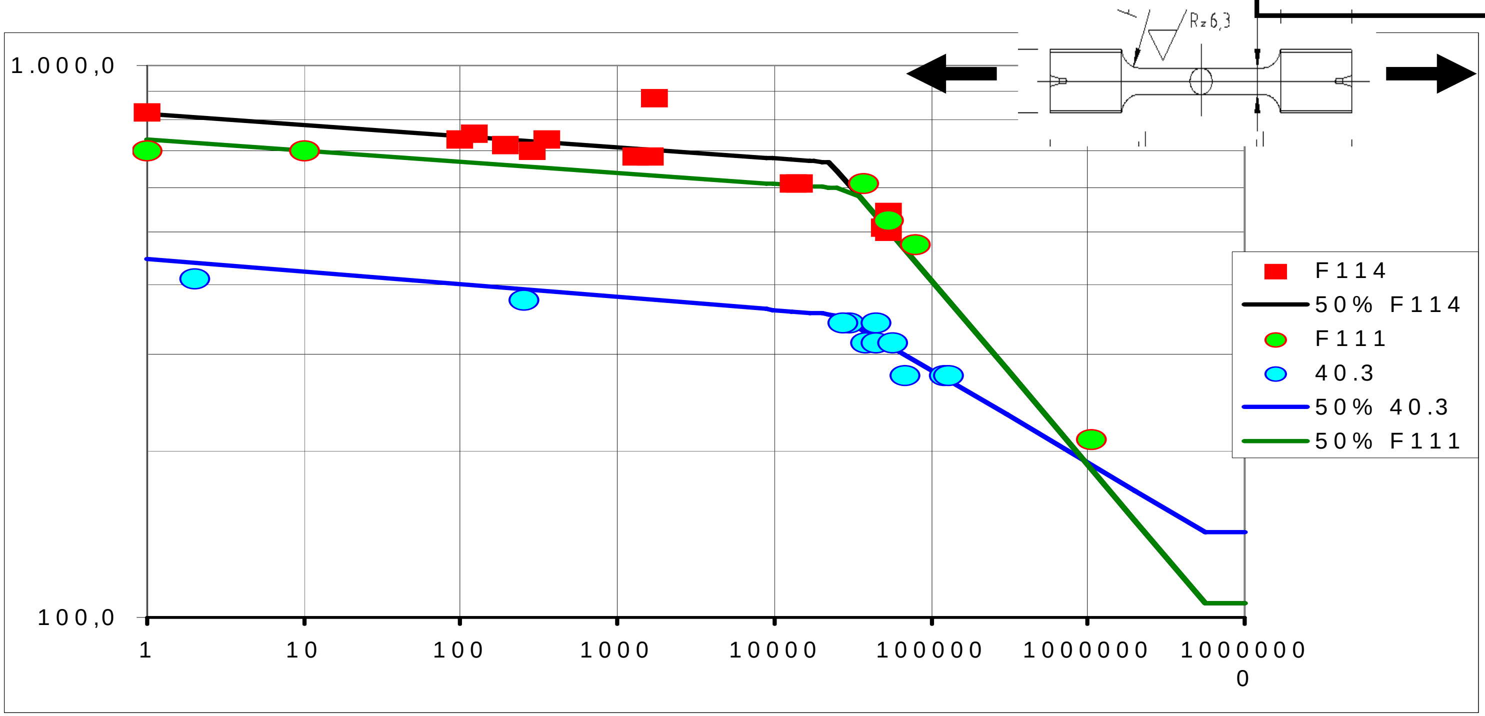


ROQUET - COORDINADOR

Do specimens S-N curve conform the current "state of the art" (Extrapolation from flexion load)
Do the specimen curve conform with the "local stresses" S-N curve?
are specimen S-N curves INDEPENDENT of the steel ultimate strength ?

S-N curves for steels are of slope 3
S-N curves of ductile cast iron are of slope 6 / 7
S-N curves for long life's , of carbon steels of different strength may be considered similar
Limit of validity of S-N curves of steels of different strength, are different

TRACTION



ROQUET - COORDINADOR

Life design

Cast iron cylinders

Partners involved

Roquet

Labson

Cinme

Cast iron- Fatigue: State of the art

$$n_{eq} = n_i \left(\frac{\Delta P_i}{P_{max.}} \right)^{8,62}$$

EN 13445-6:2002 (E)
Issue 1 (2002-05)

In part 13445 – 6 assumes that m=8,62

EN 13445-6:2002/prA1:2002

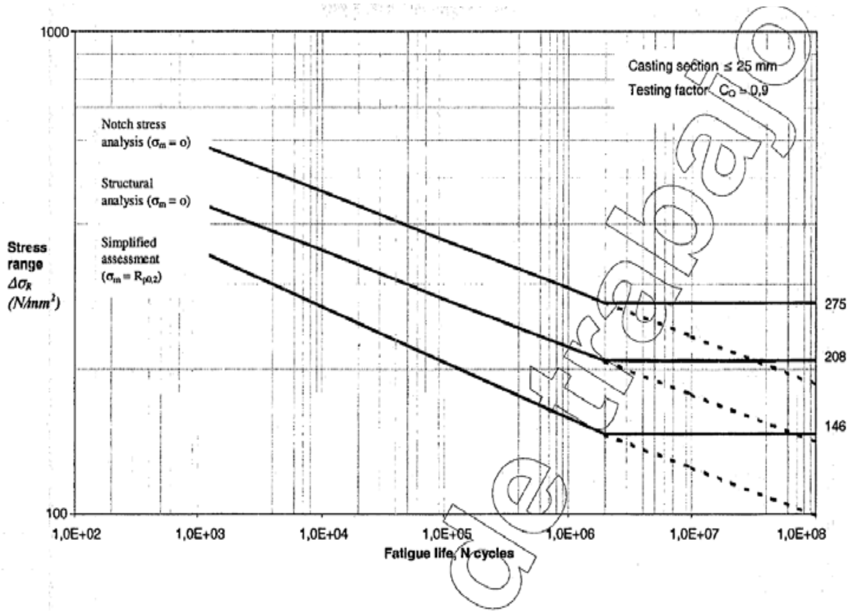


Figure D.1 – Fatigue design curves for spheroidal graphite cast iron grade EN-GJS-400-18RTLT

In part 13445 – 6 issue 1 (2002) assumes that The F.E.M determines the real local stresses , including the stress concentration factor which use to be 3.

Presents 3 different S.N curves to be used with one tipe of ductile cast iron depending of the method to calculate the Stresses,
Slopes 8,6 - 10

D.7 Determination of the stress concentration factor

Stress concentration factors shall be determined by finite element analysis for the different possible constructions in castings. However, practice shows that, with minimum radii taken into account according to this standard, the maximum stress concentration factor is not exceeding 3.

When no finite element analysis is made, a lump stress concentration factor of 3 shall be taken into account in all fatigue calculations.

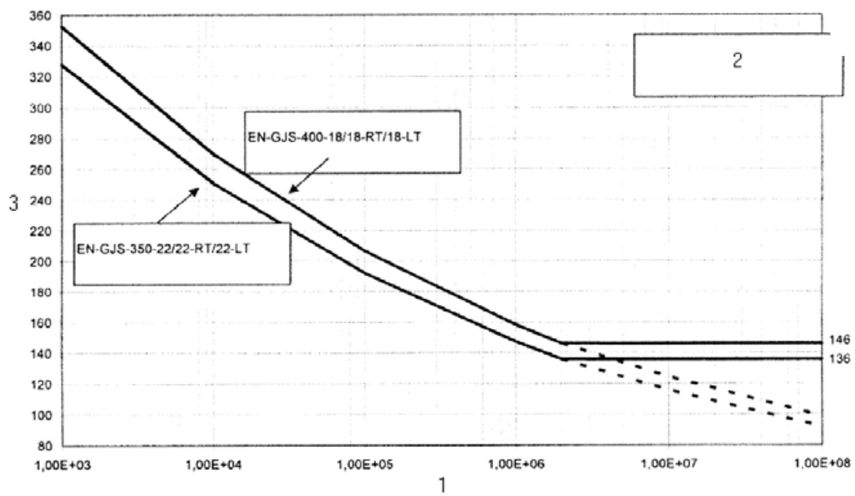
Cast iron- State of the art

EN 13445-6:2002/prA1:2002

NOTE The fatigue design curves have been derived from data obtained from notched and un-notched test pieces of spheroidal graphite cast iron grade EN-GJS-400-18 for axial and bending fatigue tests, tested under load control or, for applied strains exceeding yield (low cycle fatigue), under strain control. The allowable stresses have been derived from the average results with a safety factor of 5 for fatigue life and 1,3 for stress range. These fatigue design curves are valid for a probability of survival $P_s \geq$ 97,7%.

Curves obtained by experimental results on test pieces

EN 13445-6:2002 (E)
Issue 10 (2004-05)



Key
1 Fatigue life, *N*, cycles
2 Testing factor C_Q = 0,9
3 Stress range, $\Delta\sigma_R$, N/mm²

Figure D.1 — Fatigue design curves for spheroidal graphite cast iron grade EN-GJS-400-18RT/LT and EN-GJS-350-22 RT/LT at ambient temperature

In part 13445 – 6 issue 10 (2004) Disappears the distinction according the method of determining the stresses and presents 2 curves for 2 different grades of ductile cast iron, GJS 400-18, GJS-350RT22

slopes 8,6 and 9,2

Reliability 97,7%

EN 13445-6:2002 (E)
Issue 23 (2006-12)

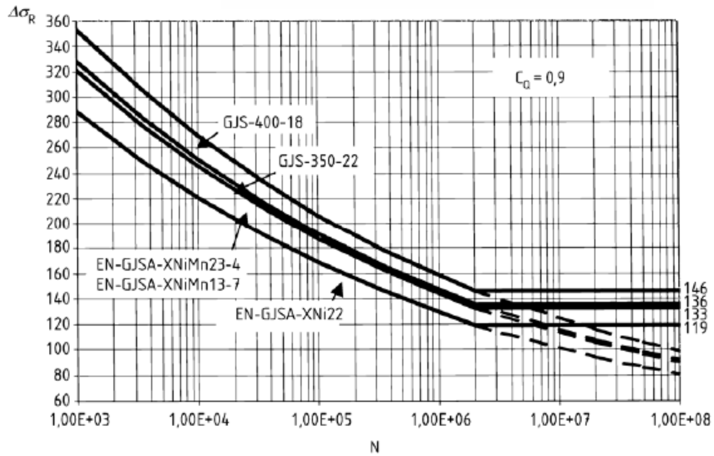


Figure D.1 — Fatigue design curves for ferritic and austenitic spheroidal graphite cast iron grades at ambient temperature - Simplified assessment

In 2006, standard includes 5 materials
Also presents the curves for
"Simplified assessment" .. Slope 8,6
" Detailed assessment" - Slope 10 (¿?)

EN 13445-6:2002 (E)
Issue 23 (2006-12)

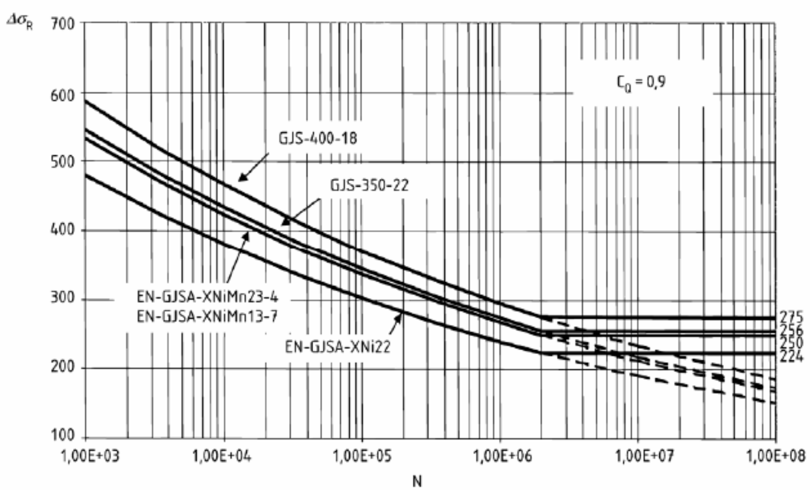


Figure D.2 — Fatigue design curves for ferritic and austenitic spheroidal graphite cast iron grades at ambient temperature - Detailed assessment

Cast iron- State of the art

par **Isabelle CHANTIER – DE LIMA**

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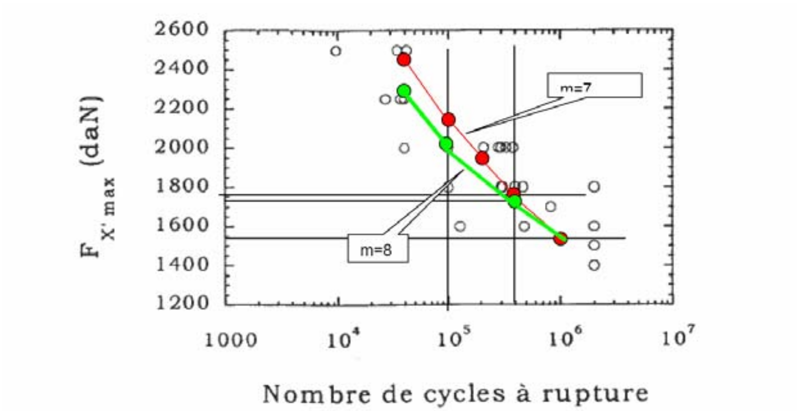


17. Diagramme S-N pour les bras de suspensions sollicités sui direction X' (R_X=0.1).

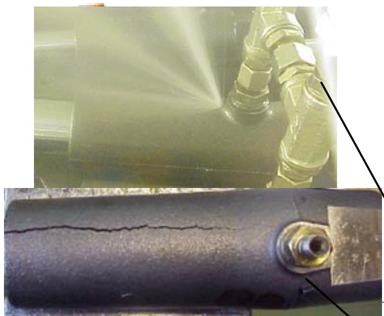
There are few works published about fatigue on cast iron pieces.
One the most interesting are that of "Chantier" and the professor Bobet and Billaron.
They approaches the fatigue problem due to surface defects.
They do not presents the S.N curves in the "classical " way, but the resulting slope of the experimental results presented are 7/8. They studied ductile cast iron.

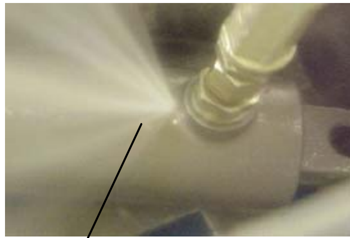
A probabilistic approach to predict the very high-cycle fatigue behaviour of spheroidal graphite cast iron structures

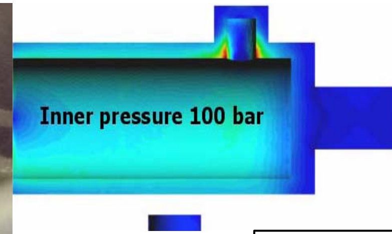
I. CHANTIER, V. BOBET,[1] R. BILLARDON and F. HILD*

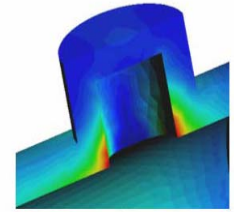
LMT-Cachan, ENS de Cachan, CNRS, Université Paris 6, 61 avenue du Président Wilson, F-94235 Cachan Cedex, France, [1]Renault Technocentre, Direction de la Recherche, Service 64230, 1 avenue du Golf, F-78288 Guyancourt, Cedex, France

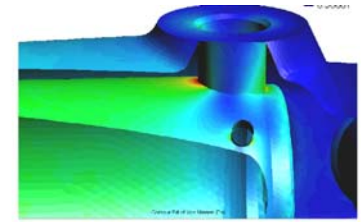
Received in final form 14 June 1999

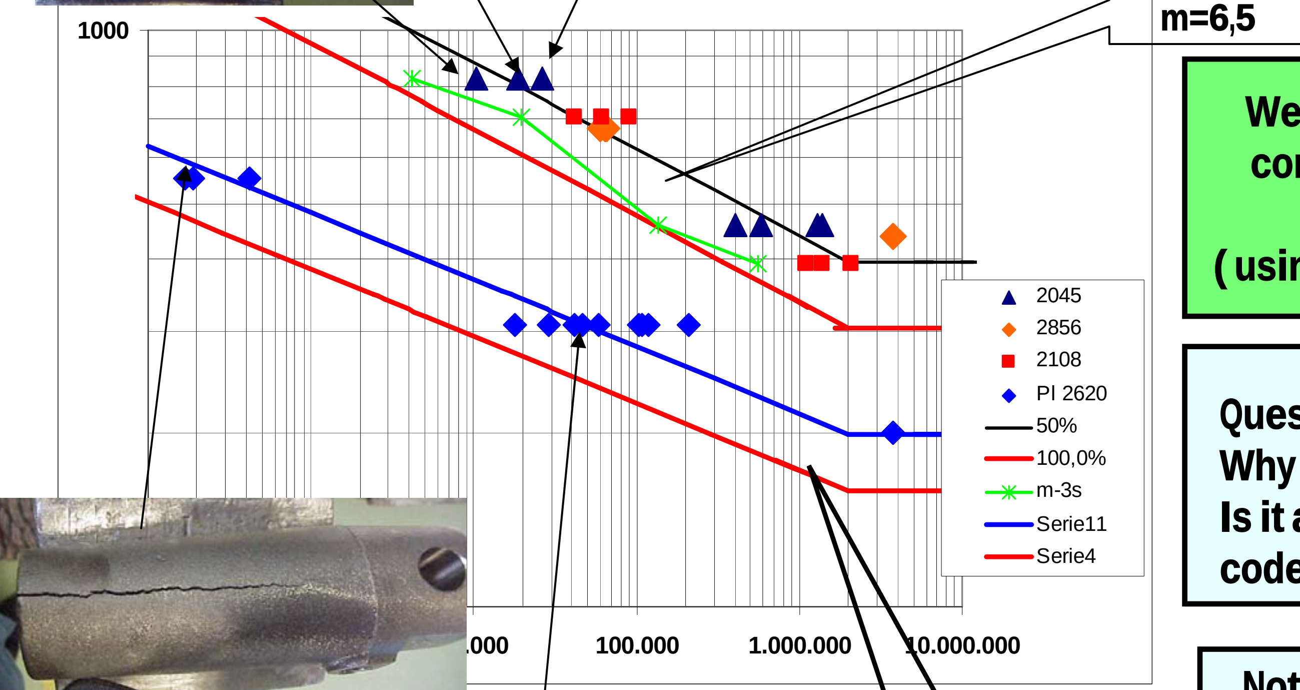


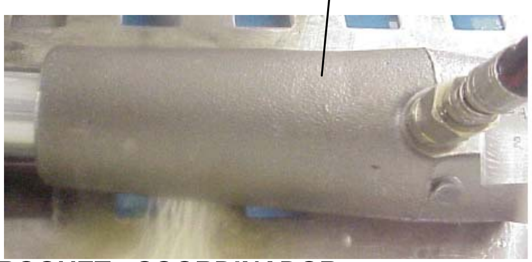


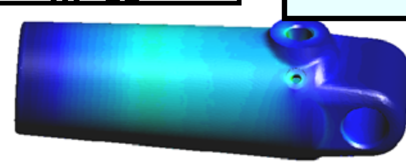












We may assume that there is a common S-N curve for similar geometries in cast iron (using the same computer code?)

Question:
Why so high stress values?
Is it a question of the FEM computer code?, material ?, geometry?

Note the standard ISO 13445-6 Admits 3 different S-N curves for cast iron depending , the way the stresses are calculated

ProHipp

Crack Propagation

Partners involved

Roquet

Cenaero

Crack propagation
State of the art

FRACTURE MECHANICS (LEFM) METHOD

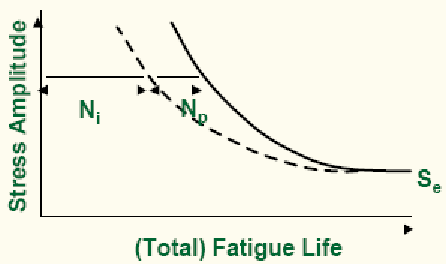
APPLICATIONS

- To measure crack growth from an initial existing flaw.
- To estimate safe life in conjunction with NDT/NDI.
- In situations where propagation life dominates total life ...

$$\frac{da}{dn} = C \cdot \Delta K^{n}$$ Paris law: widely used

Material	C: da/dN (m/cycle) ΔK in MPa√m	C: da/dN (in/cycle) ΔK in ksi√in	m
Ferritic-Pearlitic Steels	6.9×10^{-12}	3.6×10^{-10}	3.0
Martensitic Steels	1.35×10^{-10}	6.6×10^{-9}	2.25
Austenitic Stainless Steels	5.6×10^{-12}	3.0×10^{-10}	3.25
Ni-Mo-V Steels	1.8×10^{-19}	----	3.0

INITIATION LIFE VS. PROPAGATION LIFE



N_i – Crack initiation period
N_p – Crack propagation period

¿ Do crack propagation dominates the cylinder life ? (so it is of application the fracture mechanics approach)

¿When a crack in detected in a routine inspection, do it means that the cylinder must be replaced ?

¿ Is it possible to predict the remaining life?

$$\frac{da}{dN} = C(\Delta K)^m$$

$$\Delta K = G\,\Delta\sigma\sqrt{\pi\,a} \qquad G \approx 1 \div 1{,}2 \approx 1{,}12$$

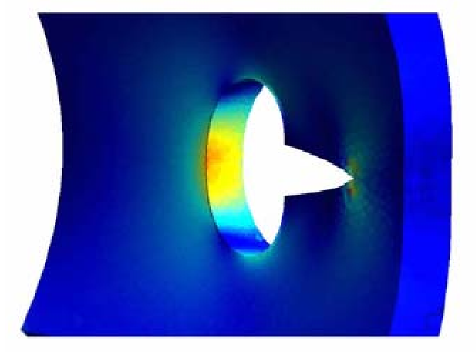
$$N_f = \frac{2}{(m-2)C(G\Delta\sigma\sqrt{\pi})}\left(\frac{1}{a_o^{(m-2)/2}} - \frac{1}{a_f^{(m-2)/2}}\right)$$

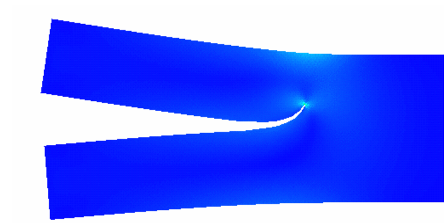
ROQUET - COORDINADOR

PREDICTION OF LABORATORY EXPECTED LIFE (MECANICHAL)

CRACK PROPAGATION (X.F.EM.)

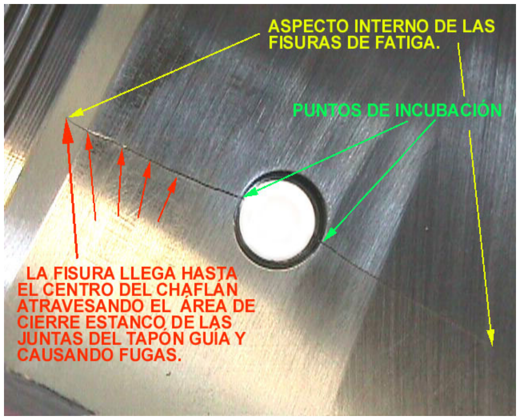
Continuously remeshing method

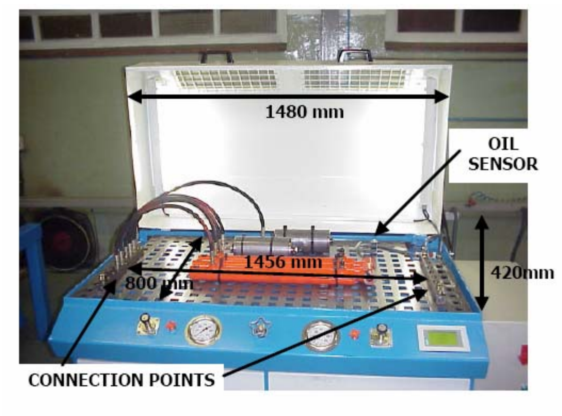




CENAERO

INTENSIVE EXPERIMENTAL RESULTS

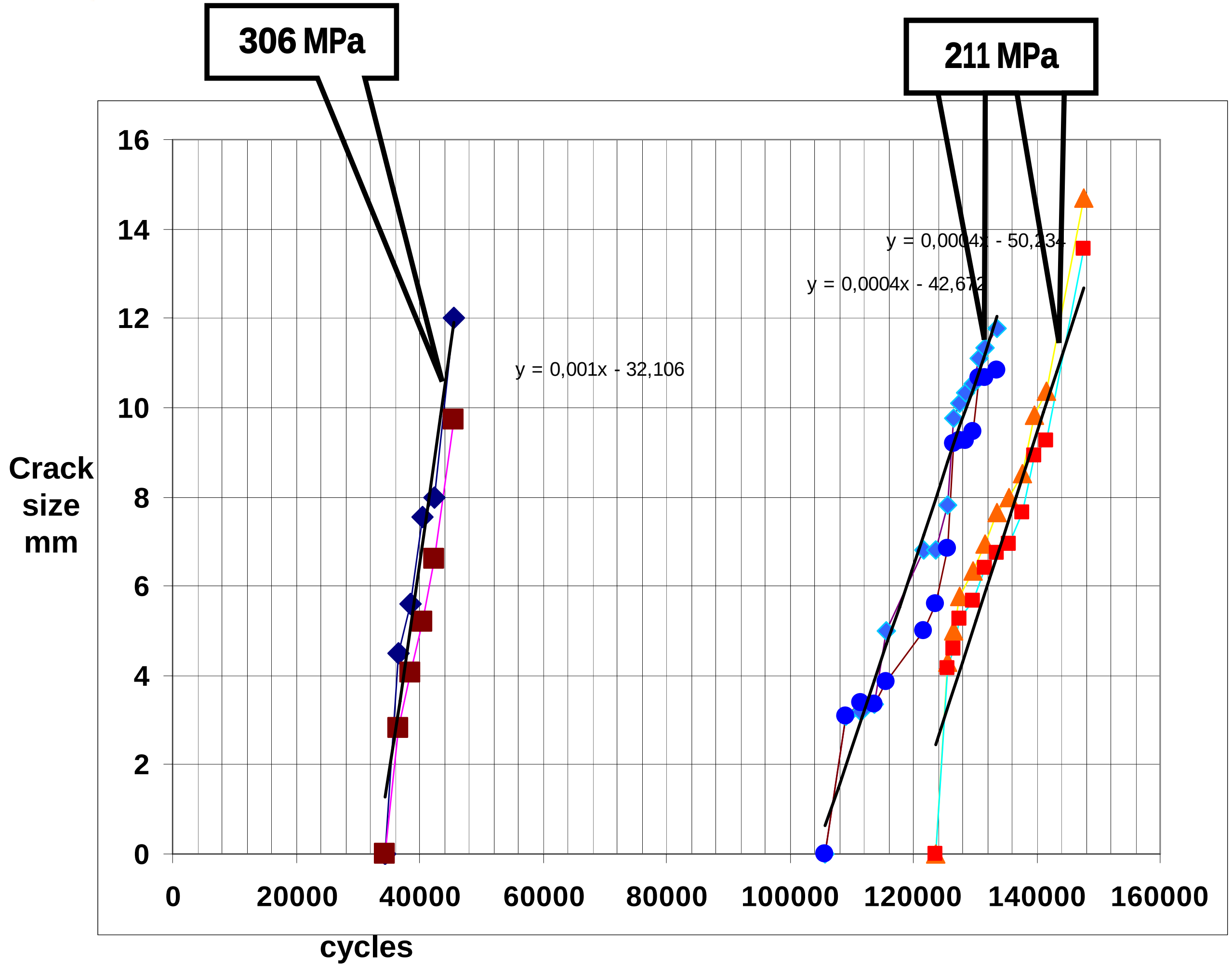


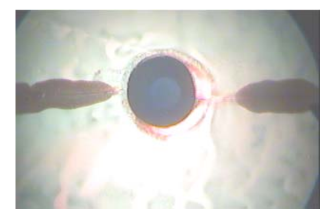


Theoretical and experimental failure modes fits

ROQUET

How relatively long is the crack development size ??





Pending of the analysis of the rest of samples: the crack propagation time is aprox 25 – 30 % of the total life

Protection against corrosion

Partners involved

Hef

Roquet

Labson

Chrome layer substitution

Cylinder rods

Technically will succeed

Some socioeconomic aspects to be considered

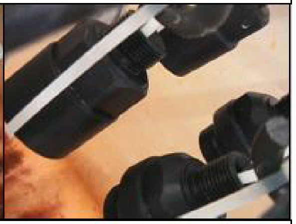
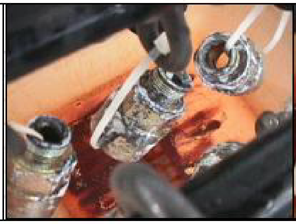
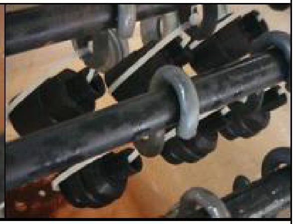
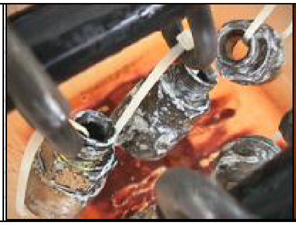
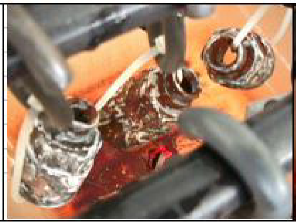
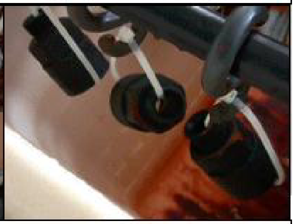
Hand levers

Substitution of bicromated eternal layer with Cr*6 , by an oxinitrurated layer

Substitution of Chrome plating, or cadmium layer by oxinitrurated layer

Advantages when some hardness treatment are involved

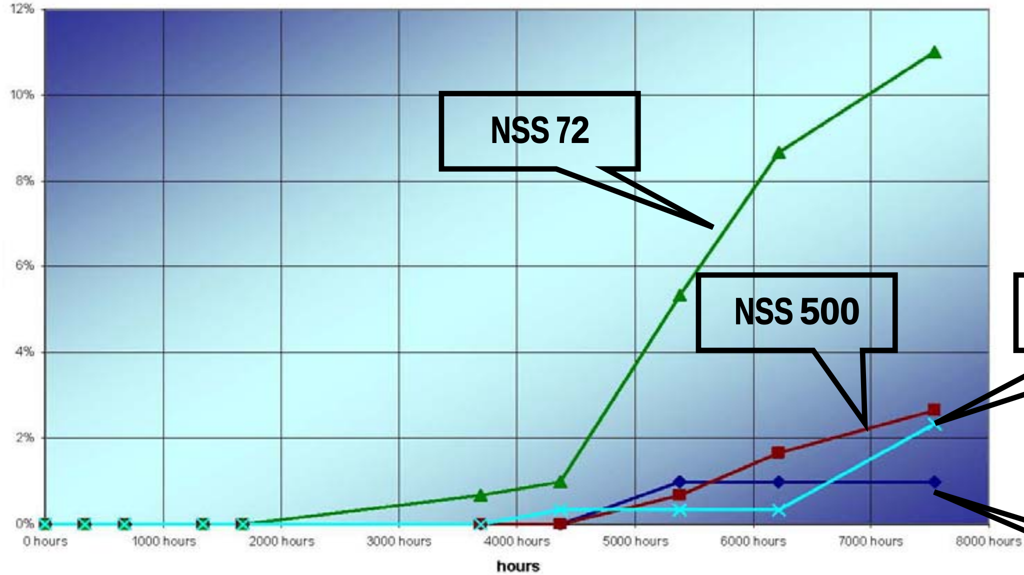
Chrome substitution

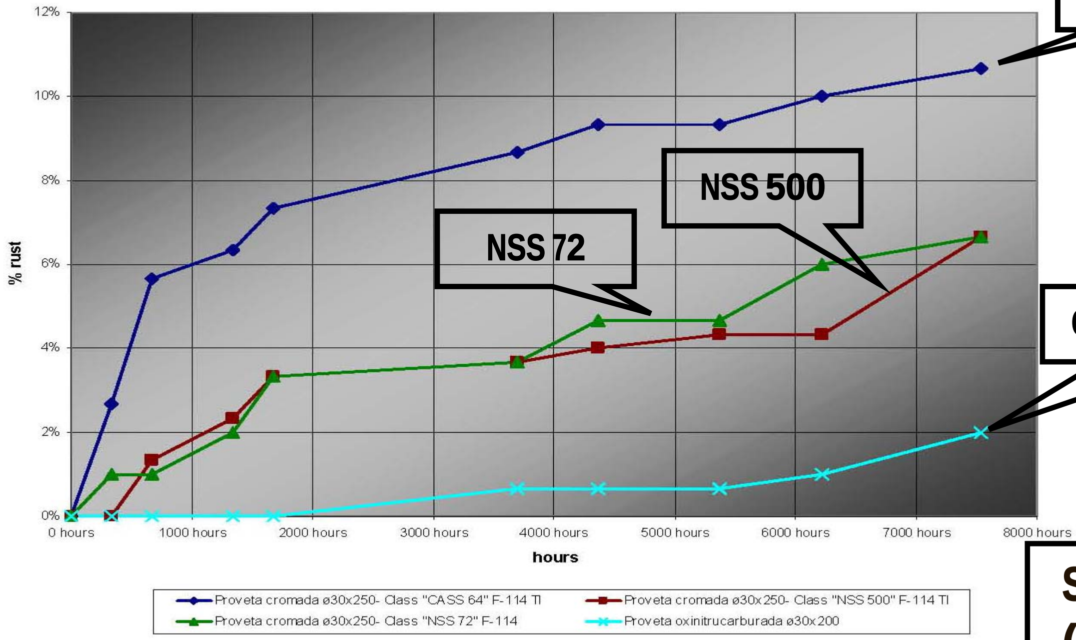
HORAS	% OXIDACIÓN		
	9941/3.04 Zincado y Bicromatado	9941/3.04 Dacromet 500B	9941/3.04 Oxinitrocarburación
72			
192			
264			
360			
824	100%		

ROQUET - COORDINADOR

Are laboratory tests results, representative of the actual behavior of the protection layers??

Saline atmosphere





Samples buried in salt (mineral)


Thanks for your attention