RELATION BETWEEN TOUGHNESS, INFINITE FATIGUE LIFE AND MICROSTRUCTURE IN LARGE BLOOMS FOR AUTOMOTIVE PLASTIC MOLDS.

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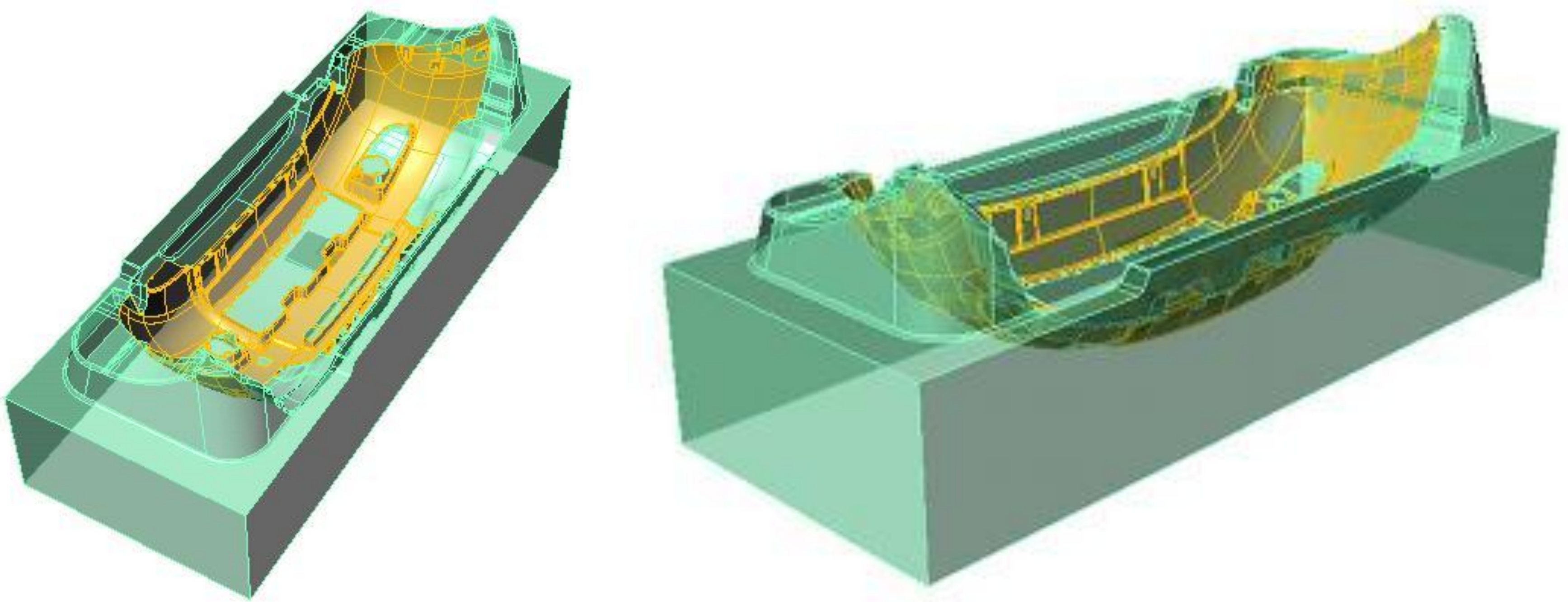
GRUPPOLUCCHINI

EURO MAT 2005

Overall views of a bumper mold.



Plastic molds machined from 1x1x3 m forged and pre-hardened steel blooms

Applications

- ***automotive components (bumpers, dashboards, …)***

Stresses

- ***applied stresses:***
  - injection pressure
  - thermal gradients
  - notch effects
  - wear by reinforced resins flow
  - fatigue: millions of pieces
- ***stresses raised by:***
  - cracks (improper weld bed depositions),
  - abnormal operations (incomplete extraction).

- ***Experience-based design, no usual defect-allowance calculation procedure***
- ***Reported macroscopically brittle in-service failures***

- ***different microstructures expected at increasing depths after quench***
- ***any microstructure could be found at mold face***

Usual Production cycle

➢ Steel composition

	C	Cr	Mn	Ni	Mo	Si	S	P
1.2738 40CrMnNiMo8-6-4	0.35 0.45	1.8 2.1	1.3 1.6	0.9 1.2	0.15 0.25	0.2 0.4	<0.03	<0.03
Examined bloom	0.42	2.0	1.5	1.1	0.21	0,37	0.002	0.006

➢ Steel mill operations

ingot casting (ESR refining is not possible)
forging to 1x1 m sections
dehydrogenization
oil quenching
tempering (one or more stages)

➢ Commercial warehouse operations

removal of rough and decarburized surfaces (up to 10-20 mm)
sawing to requested dimensions

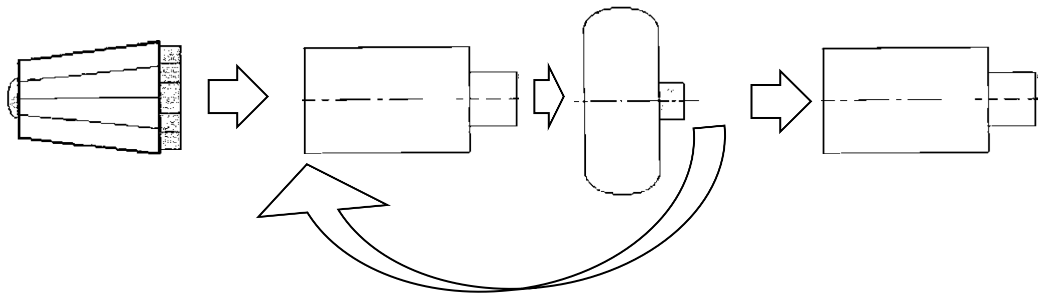
➢ Mold machining shop operations

chip-removal and/or electrical-discharge machining to the mold shape, grinding with or without polishing in selected areas
local surface treatments
eventual corrections using weld bed depositions

Usual Production cycle (cont.)

Forging

- comparable ingot and bloom section
- some repeated forging steps

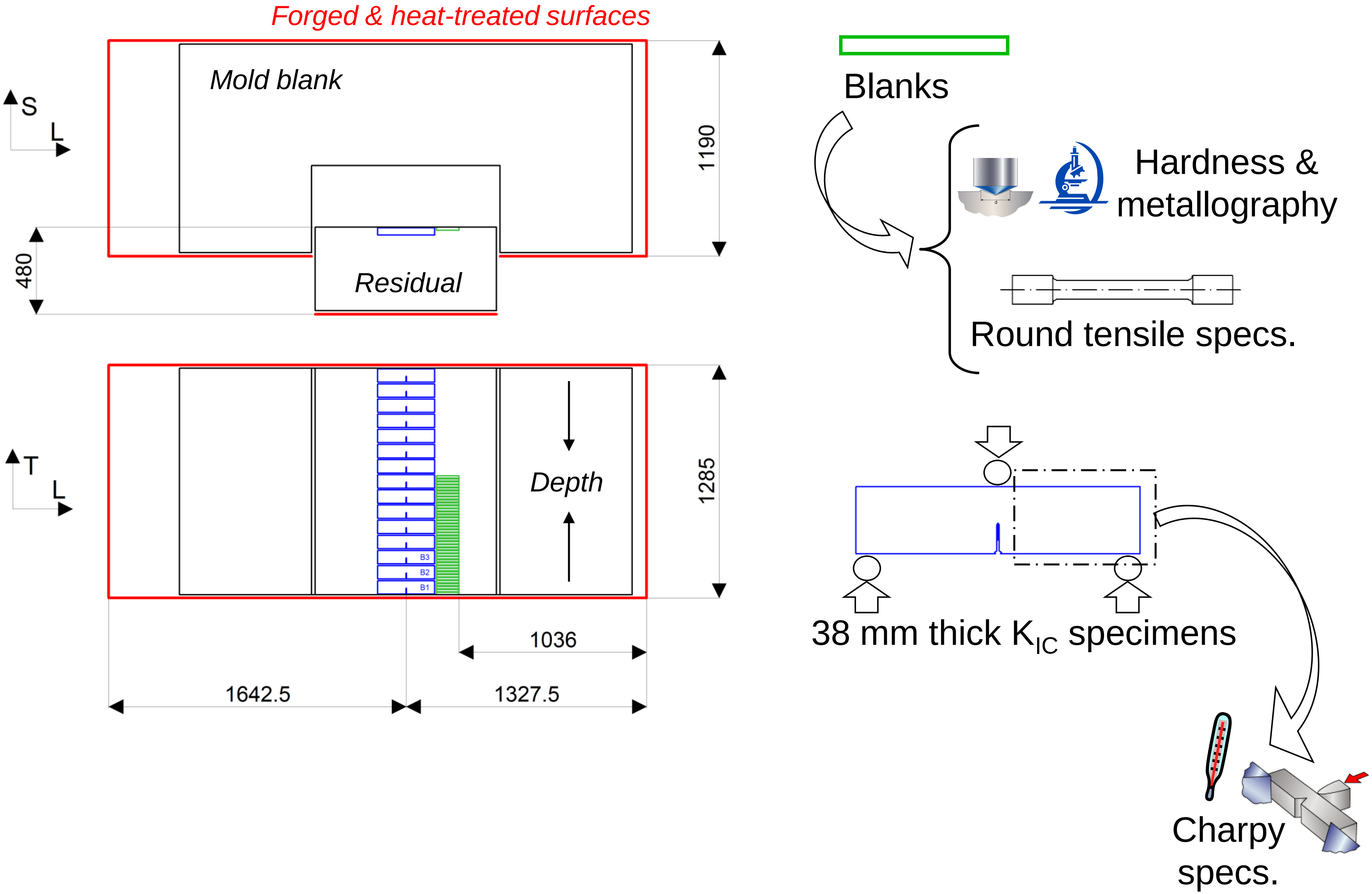


- total reduction ratio much lower than in rolling (and not comparable)

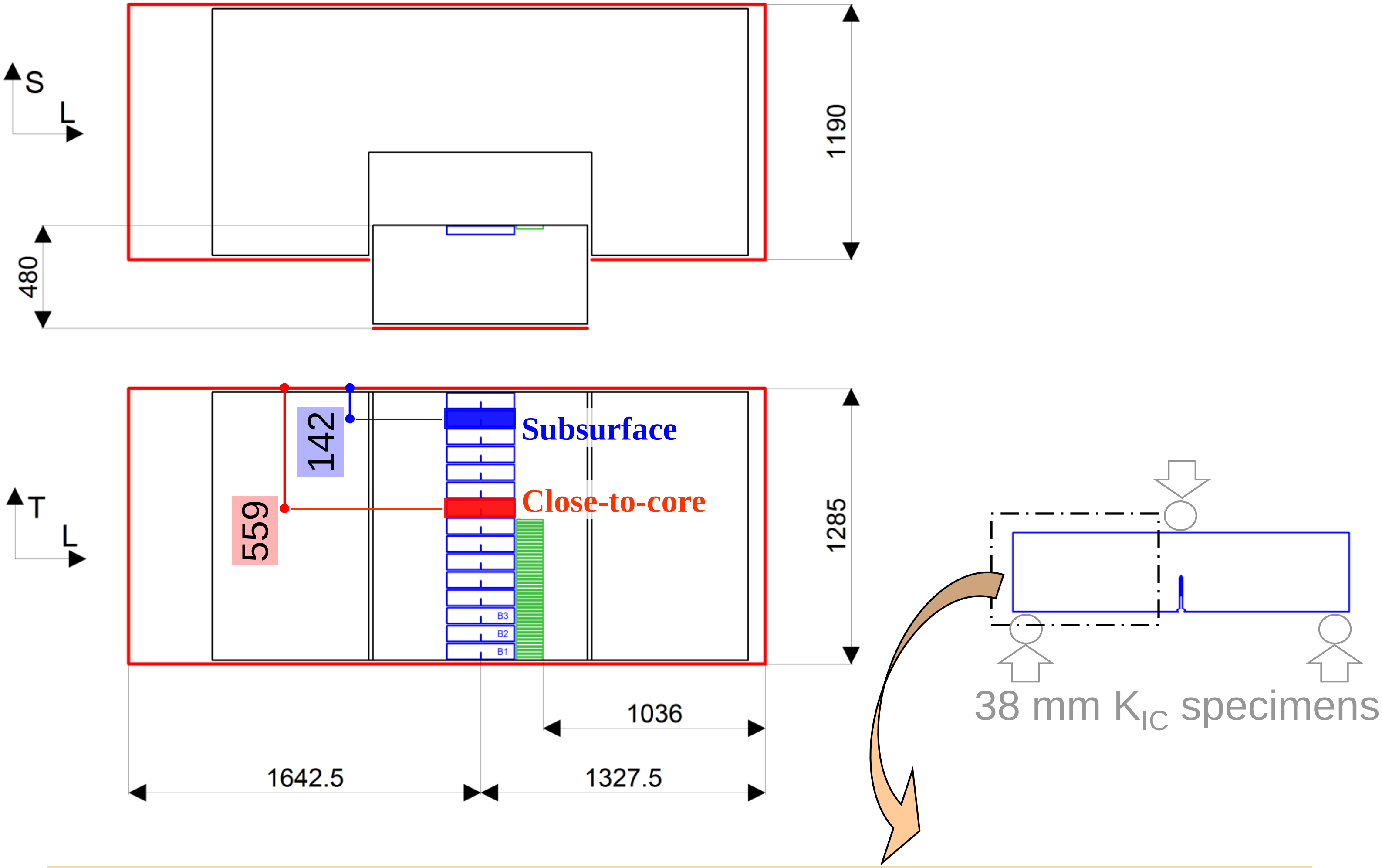
Heat treating in air

Step	Temperature	Duration
hydrogen removal		a few days
austenitizing	840-880°C	1-2 days
oil quench	-	-
tempering to 330-300 HB (two stages)	550-600°C	1-2 days (each stage)

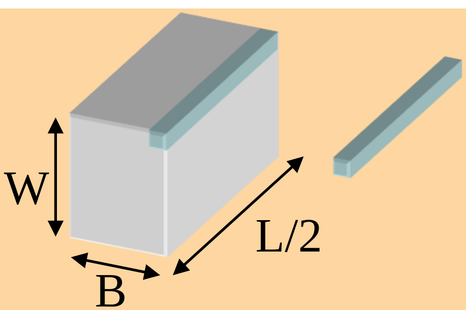
Sampling


Forged & heat-treated surfaces
Mold blank
S
L
1190
480
Residual
T
L
B3
B2
B1
Depth
1285
1036
1642.5
1327.5
Blanks
Hardness &
metallography
Round tensile specs.
38 mm thick K$_{IC}$ specimens
Charpy
specs.

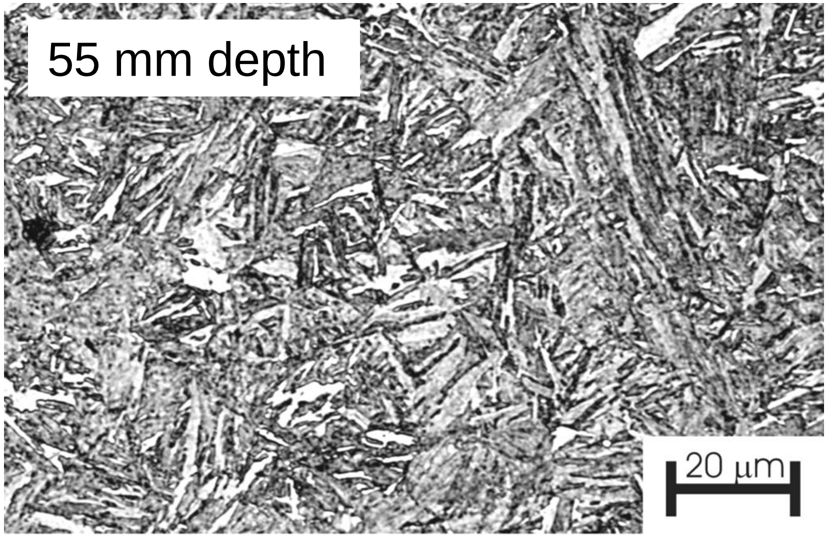
Sampling (cont.): fatigue specimens



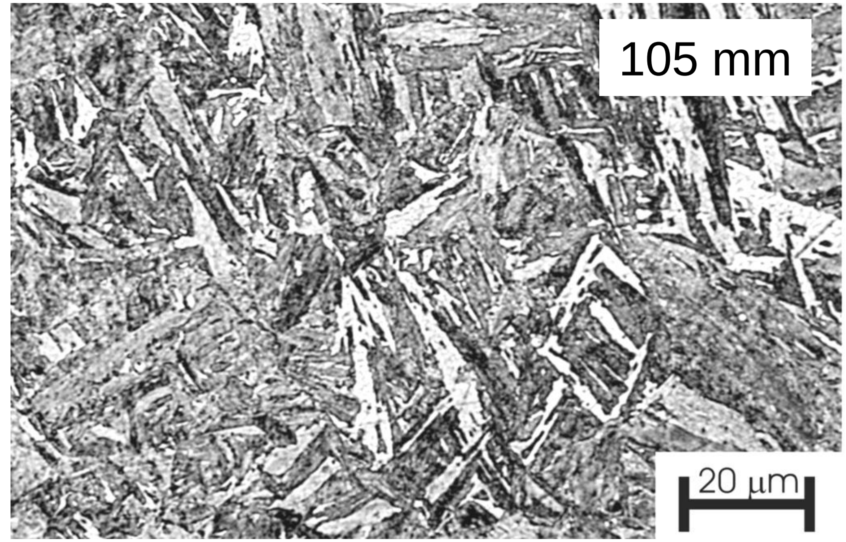
Rotating bending fatigue specimens (L)



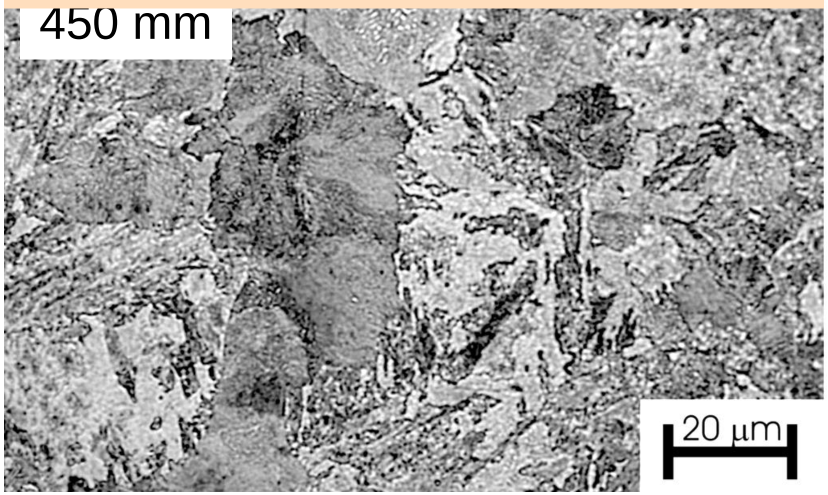
Metallography – microstructures vs. depth *(Nital etch)*



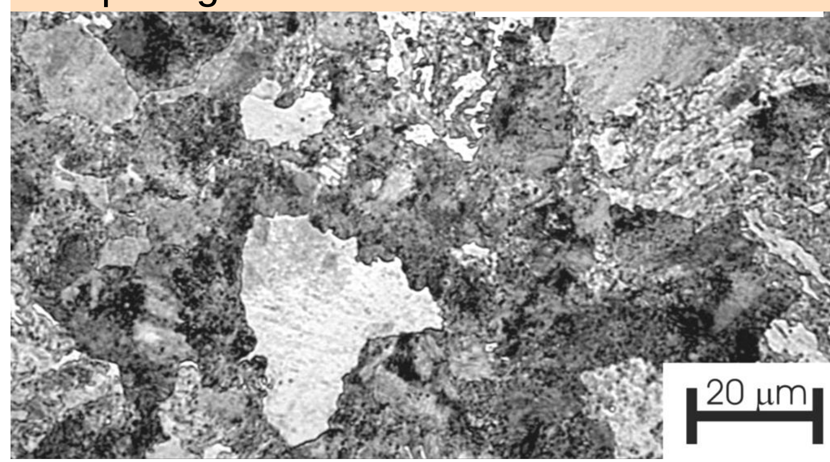
Tempered martensite, retained austenite transformed during tempering.



Lower bainite modified by tempering, retained austenite transformed during tempering

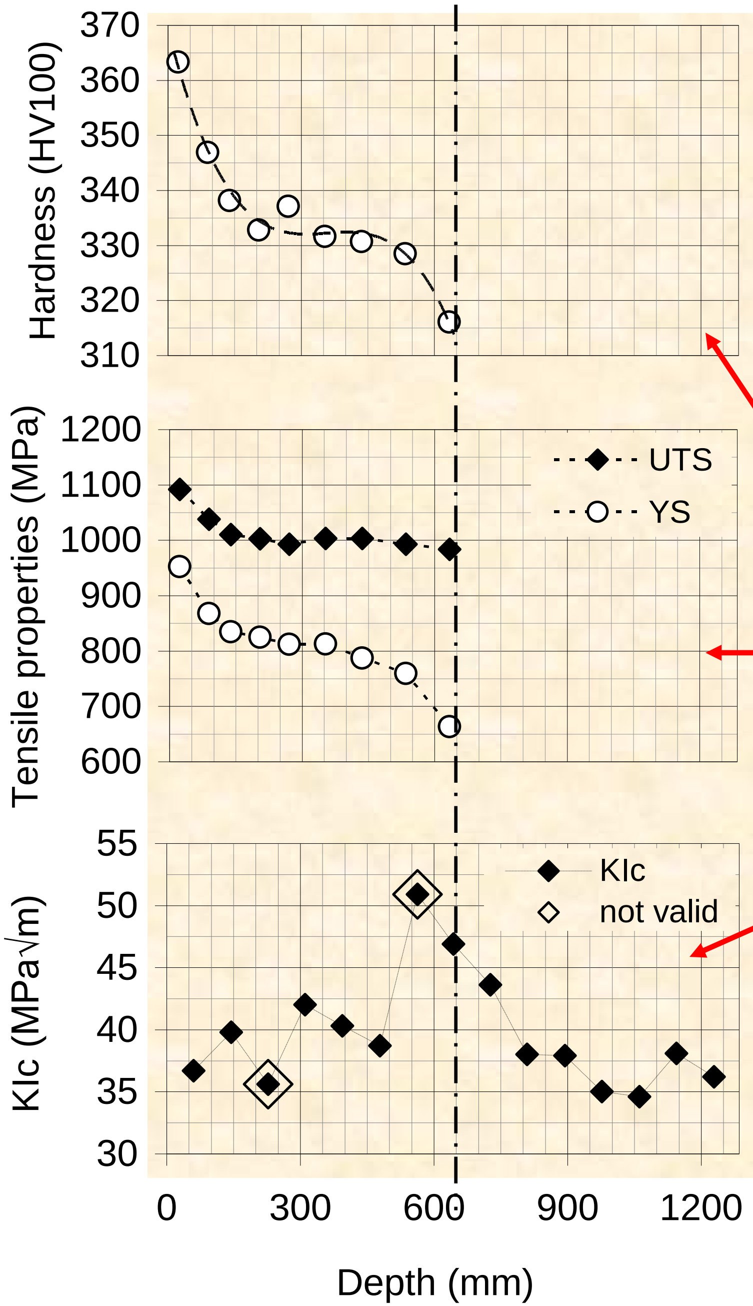


Fine and ultra-fine pearlite, upper bainite modified by tempering



Fine pearlite, upper bainite modified by tempering

Mechanical properties: hardness, tension, fracture toughness



Charpy KV impact absorbed energy

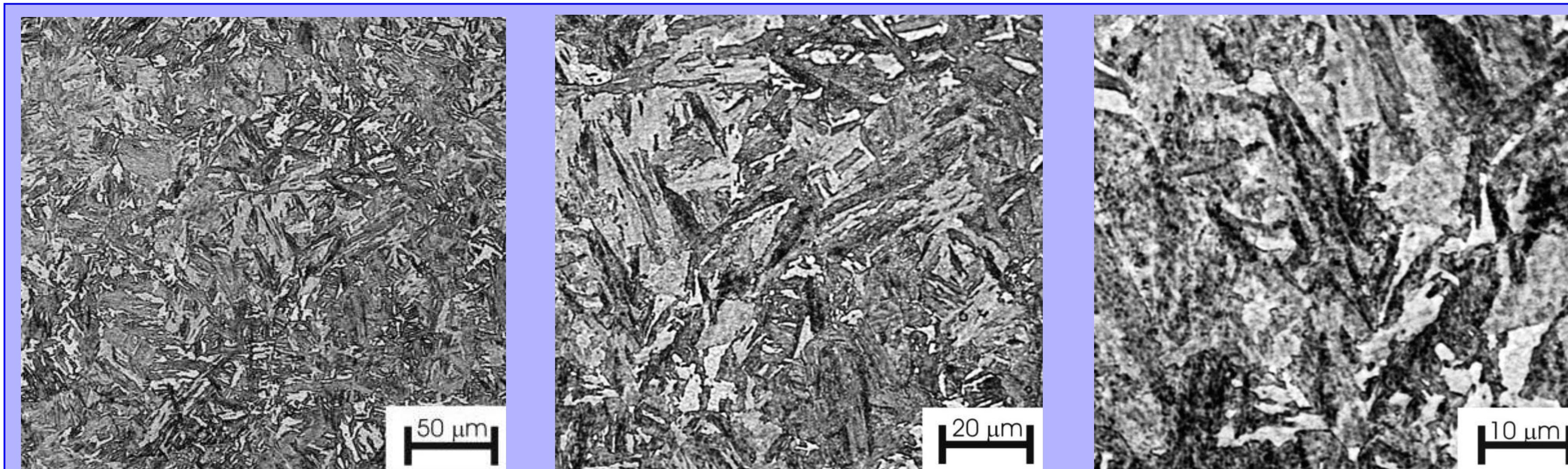
50% FATT: Core 150°C - Surface 270°C

Hardness decreases from surface to core.

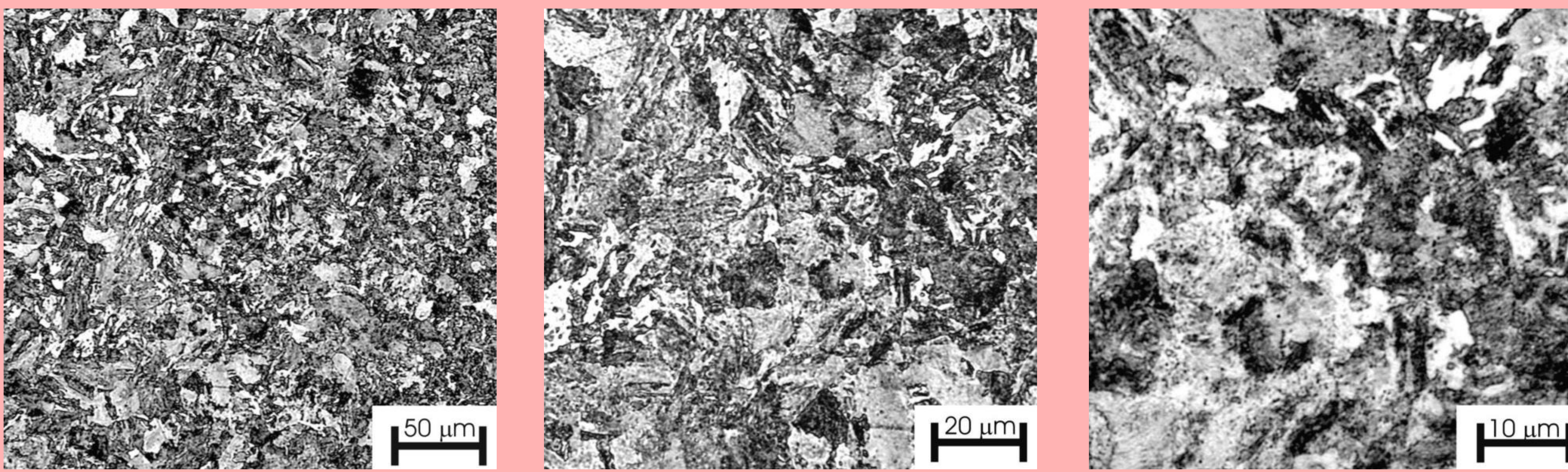
Tensile properties are adequate at the surface and decrease markedly at core (esp. YS).

Fracture toughness values are rather low.

Metallography: microstructures at chosen positions *(Nital etch)*



Subsurface position (156 mm depth)



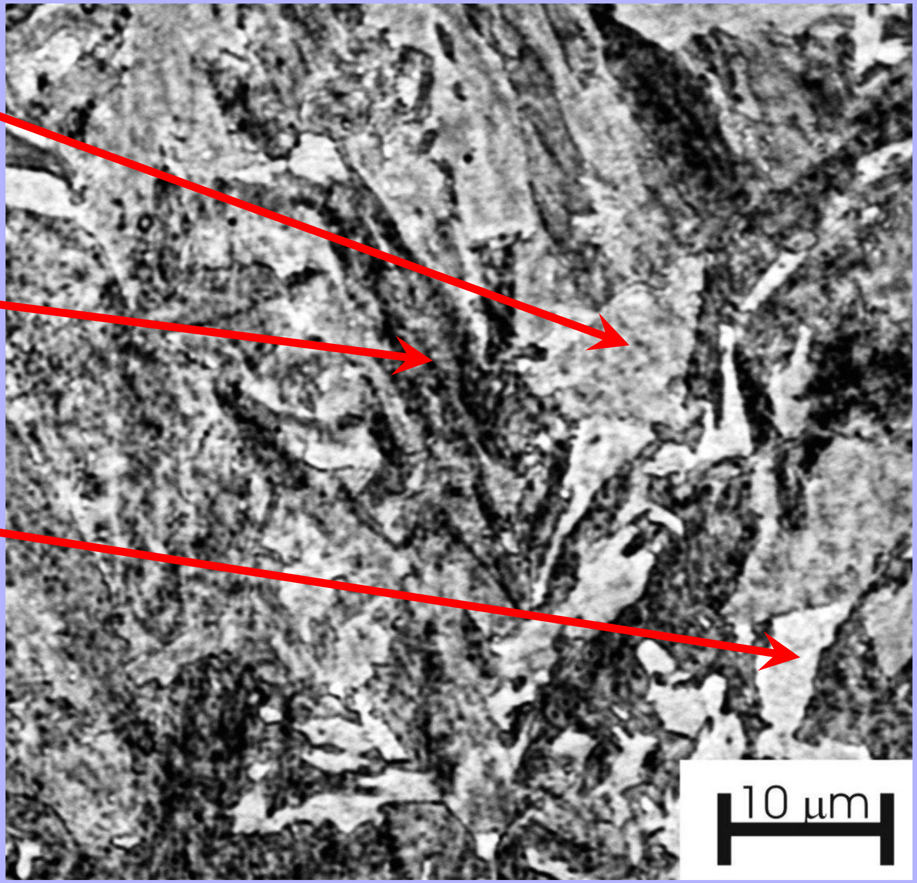
Close-to-core position (552 mm depth)

Metallography: subsurface microstructure – detail *(Nital etch)*

Tempered martensite

Lower bainite modified by tempering

Retained austenite with finely scattered dark carbides due to its transformation during tempering



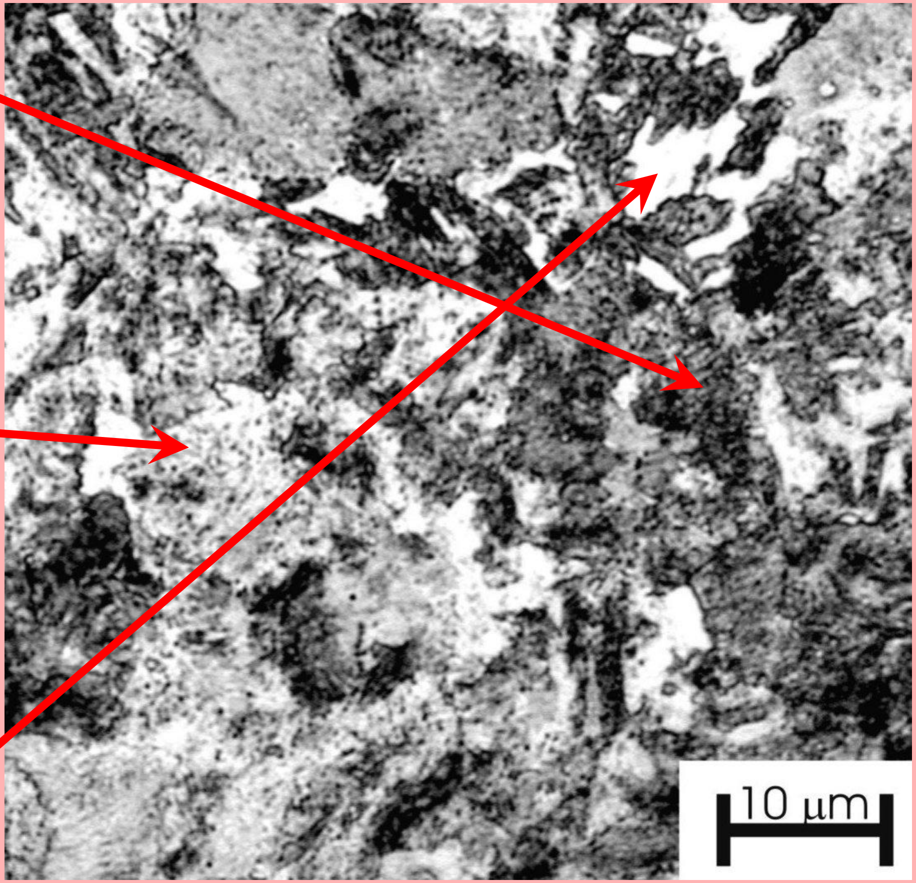
Pearlite is completely absent.

Metallography: close-to-core microstructure – detail *(Nital etch)*

Fine and ultra-fine pearlite

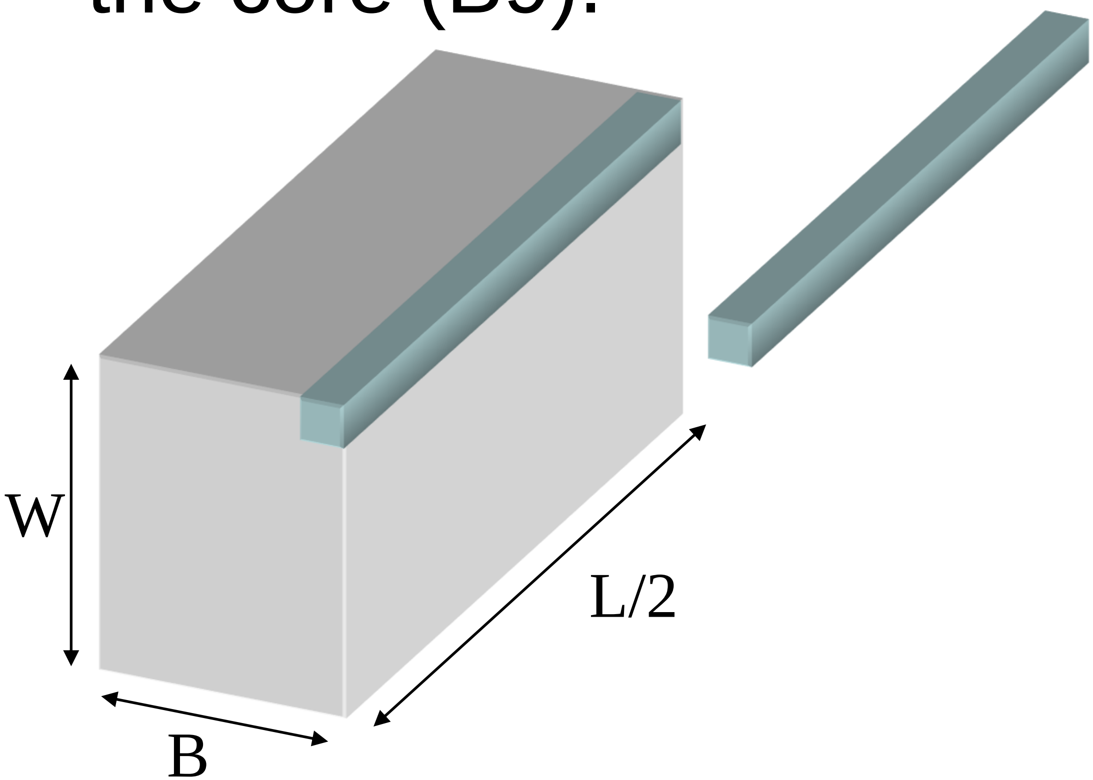
Upper bainite, modified and subjected to carbide coarsening during the tempering stages

(lightly attached upper bainite)



Rotating Bending Fatigue

- All samples have been machined from the two halves of two broken K_{Ic} samples, one near the surface (B14) and the other next to the core (B9).



$D_{min\ (nom)} = 6$ mm

Rotating Bending Fatigue

For each of the two broken K_{Ic} samples, two different conditions have been investigated:

- Samples from two halves were tested in the original condition (B9 and B14);
- Samples from the other two halves were tested after air quenching and double tempering (B9T and B14T). Austenitization was carried out at about *860°C* for *45 minutes*, the first tempering at *590°C* for *3 hours* and the second at *550°C* for *3 hours*.

Rotating Bending Fatigue

σ_D values were calculated according to the staircase method (UNI-3964); the maximum number of cycles was assumed at $4.2 \cdot 10^6$ (frequency = 50 Hz). Here follows an example.

Test n.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
σ[MPa]															
540															
530															
520															
510															
500								X				X			
490							O		X		O		X		
480						O				O				X	
470			X		O										O
460		O		O											
450	O														
440															

o = test passed

x = test failed

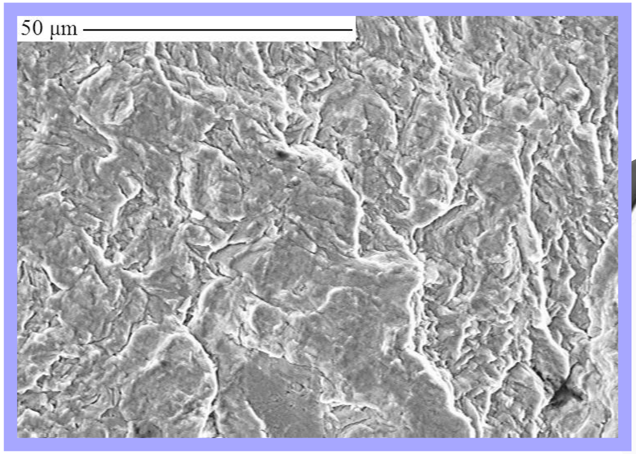
Rotating Bending Fatigue Limits
-Results-

	Depth [mm]	σ_D (50%) [MPa]
B9	625	493
B9T	625	618
B14	181	559
B14T	181	700

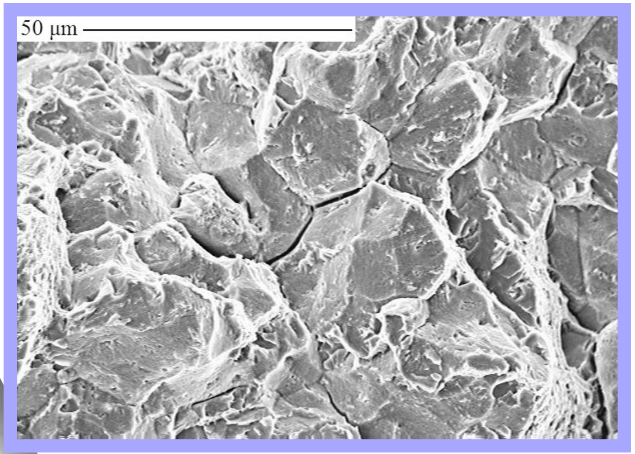
- The material near the surface has a better fatigue behaviour than the one next to core
- Re-heat treatment highly improves the fatigue limit (25%)

Fractography (As-received specs.)

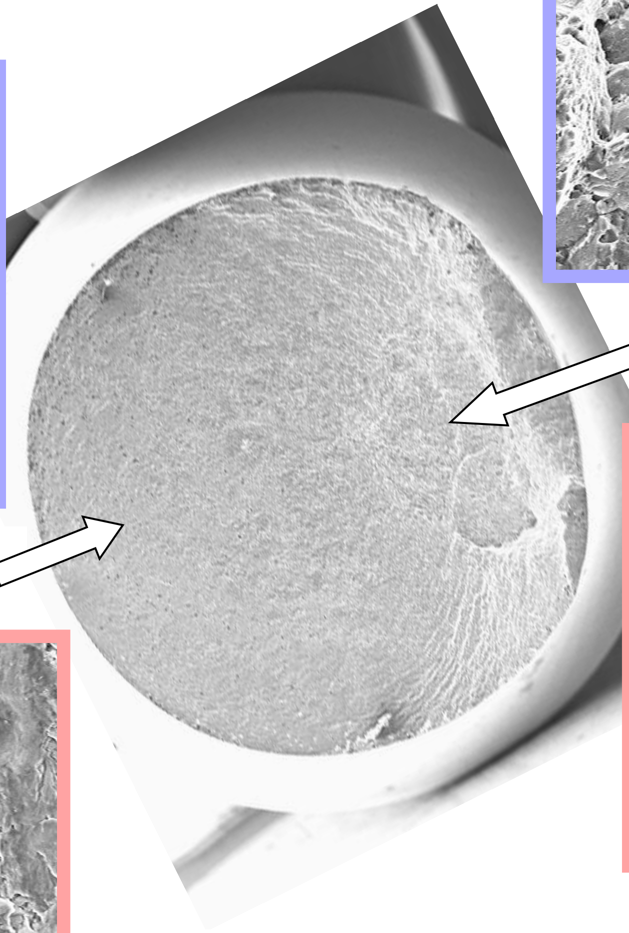
Subsurface



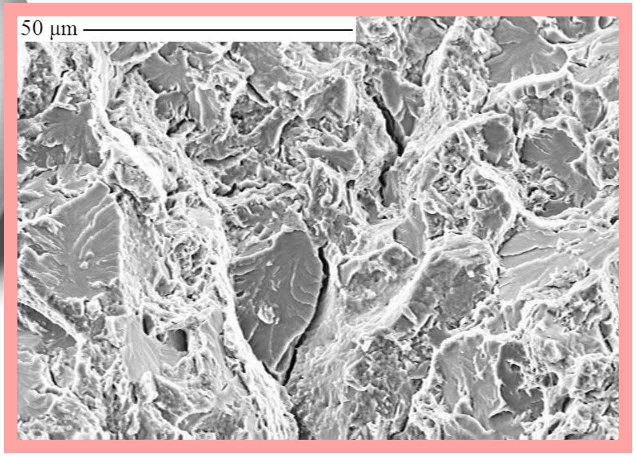
Subsurface



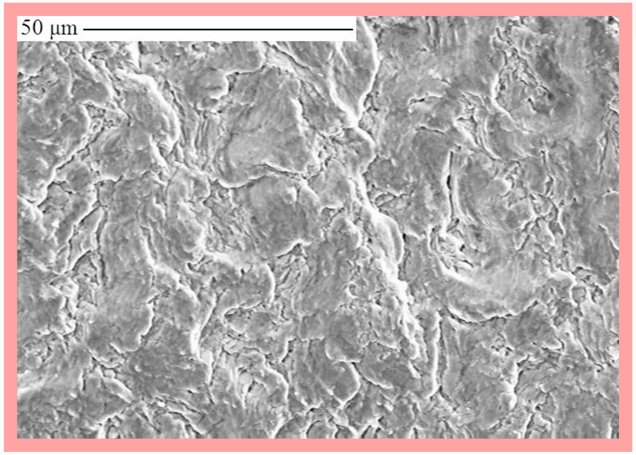
Overload fracture surface



Fatigue fracture surface



Close-to-core



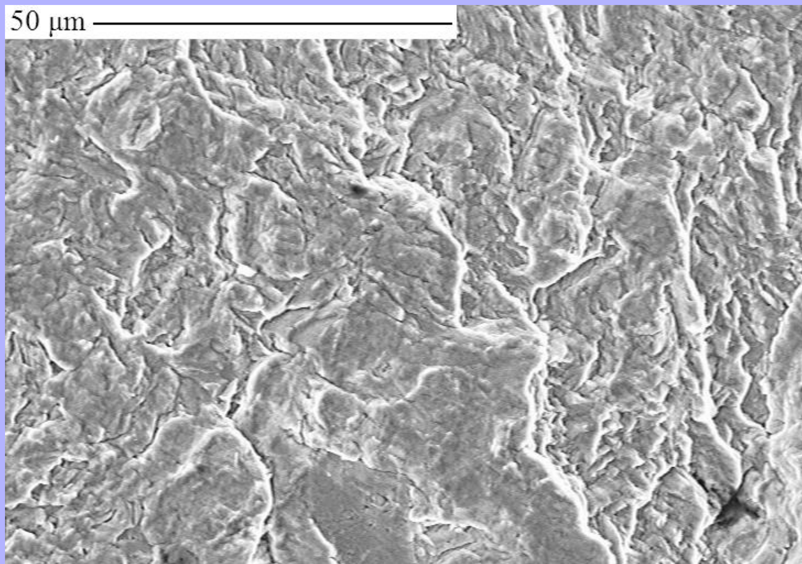
Close-to-core

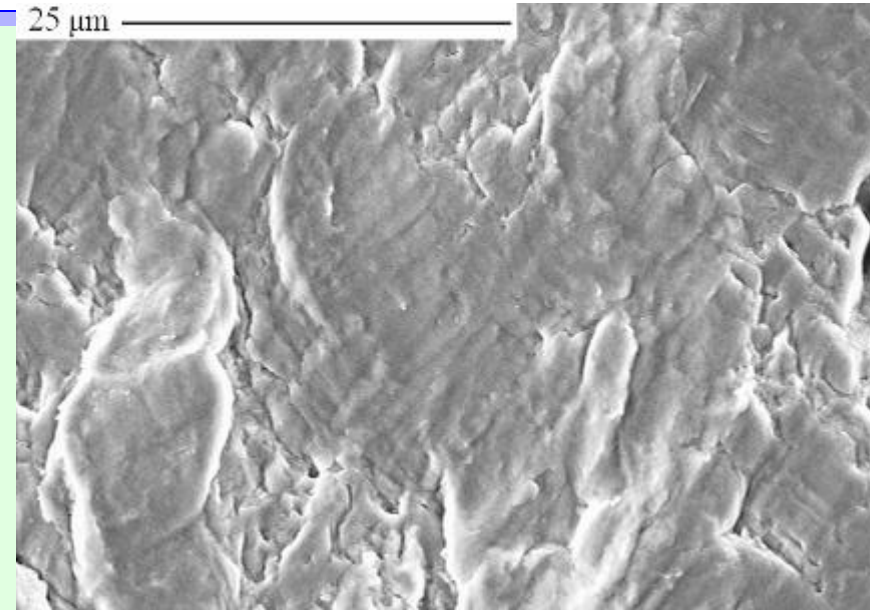
Initiation at inclusions
was rare

Fractography: fatigue areas

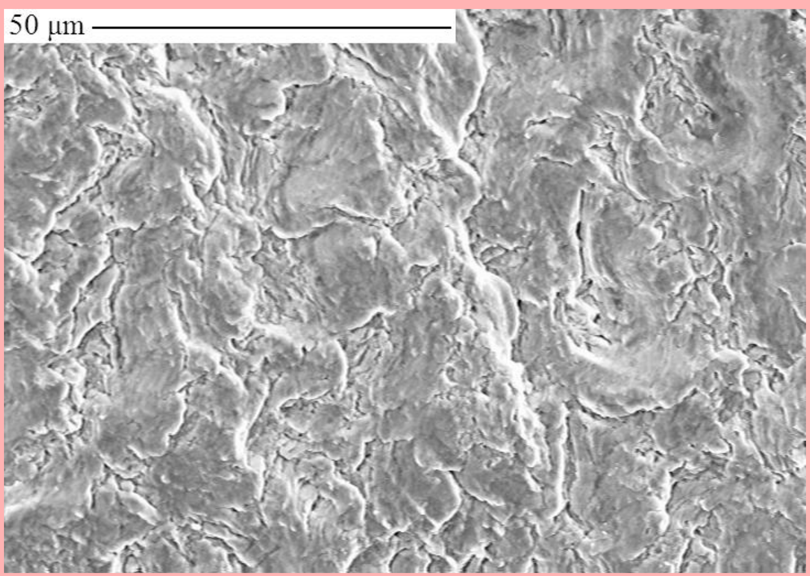
As-received | **Re-heat-treated**

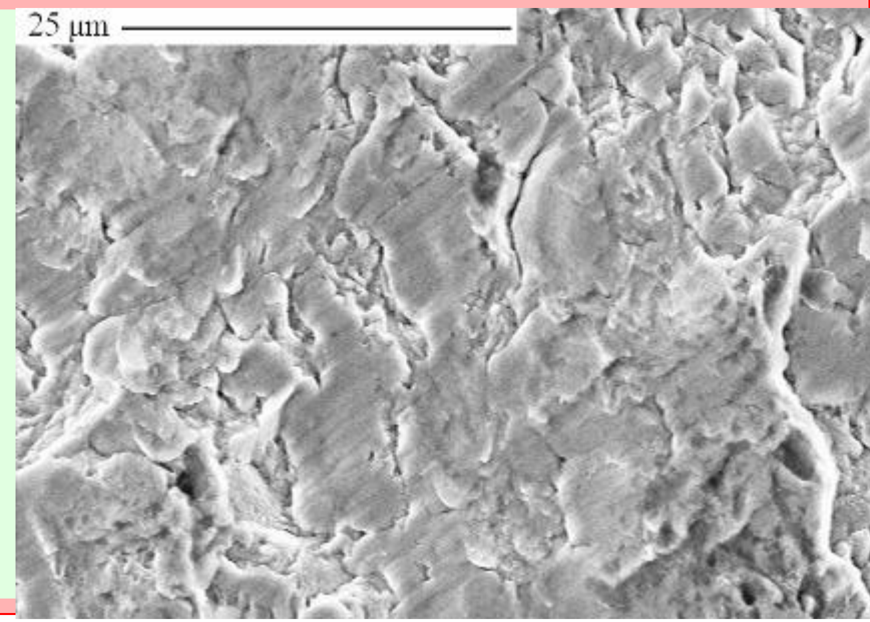
Subsurface



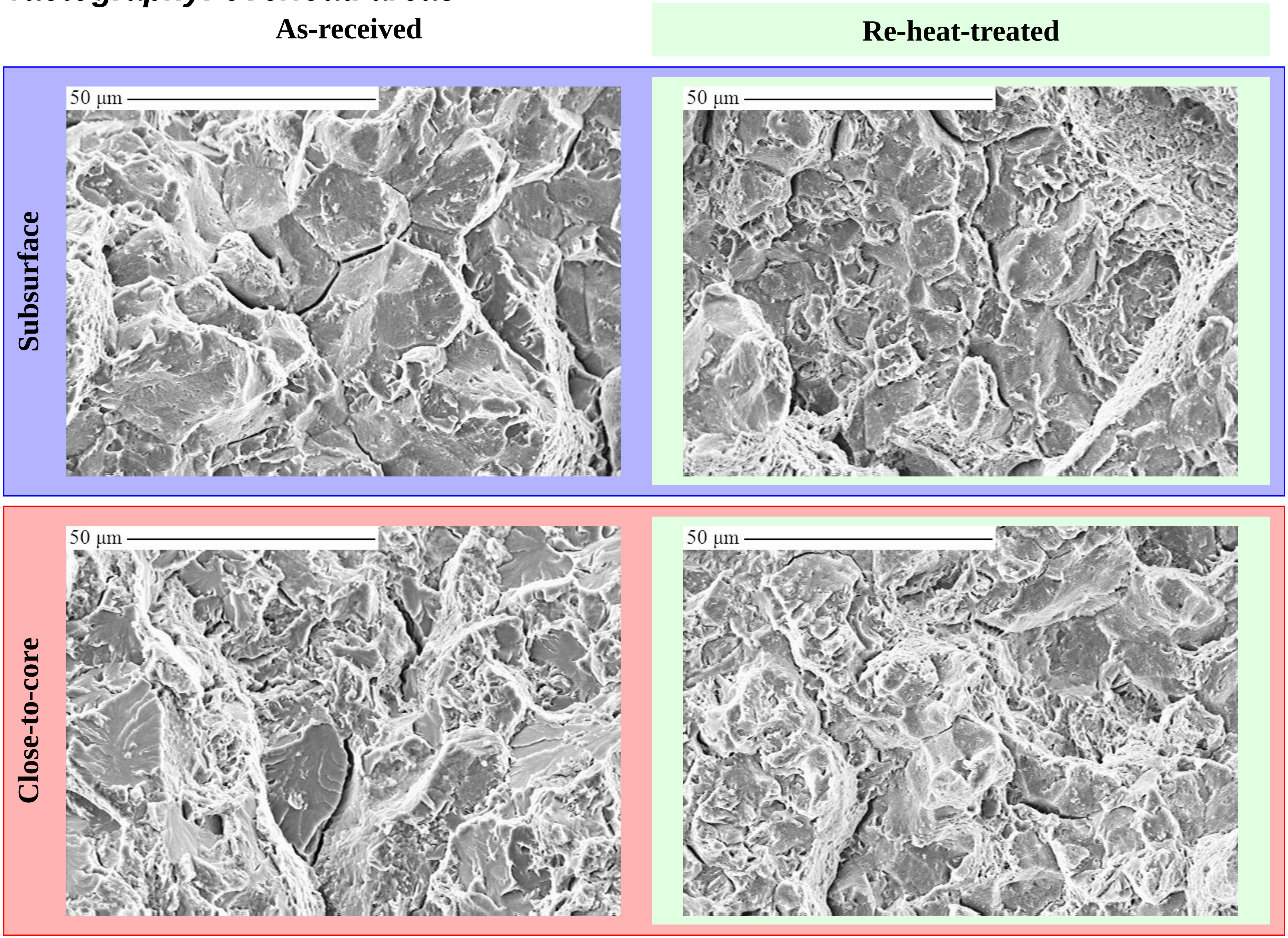


Close-to-core





Fractography: overload areas



Conclusions

Mixed microstructures occur throughout a pre-hardened steel bloom for dies apt to large plastic components fabrication.

The fracture toughness is exceptionally low for a Q&T steel. At the tested depths, K_{Ic} values were 38 MPa√m ca. close to the bloom surface and 43 MPa√m ca. near the core.

The low toughness is attributed to the slack quench, due to the large molds dimensions (1x1x3 m).

Endurance limits were about 560 MPa for the steel close to the surface and 495 MPa for the steel near the core. They scale with the steel tensile strength, not with its fracture toughness.

Endurance limits for samples individually re-heat-treated increased 25%, keeping the differences due to the location.

This presentation was titled

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The authors were Italian

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..JUST IN CASE YOU WERE LATE

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Sorry, do not ask for me; sometimes I have difficulty in finding myself

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