INFLUENCE OF PRE-EXPOSITION IN LIQUID LEAD ON THE MECHANICAL PROPERTIES OF FERRITIC/MARTENSITIC STEEL T91

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Content

INTRODUCTION

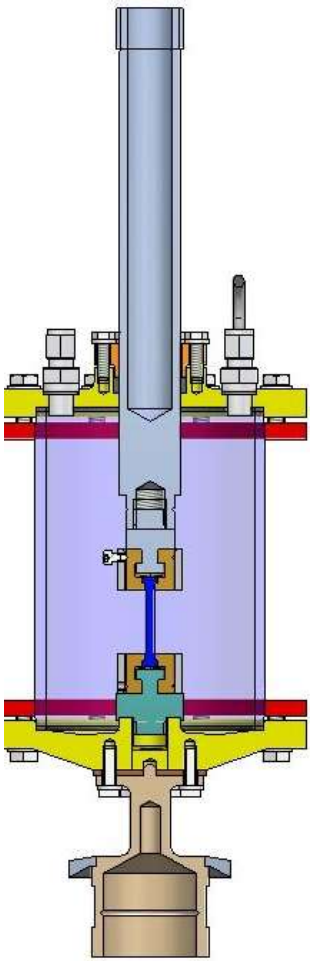
- The study of mechanical properties and boundary conditions necessary to ascertain the sensitivity of T91 to LME when specimens loaded in contact with heavy liquid metal is realized in NRI Řež plc.
- LME – Liquid Metal Embrittlement ⇒ several different definitions exist; e.g., mechanism of LME means reduction in ductility and fracture toughness of metals when are simultaneously subjected to stresses and wetting by liquid metals [*].
- Boundary conditions

  - metallurgical state,
  - surface state,
  - composition,
  - solubility,
  - temperature,
  - strain rate,
  - stress concentrators etc.

[*] E. Glickman, "Mechanism of Liquid Metal Embrittlement by Simple Experiments: From Atomistics to Life-time", In "Multiscale Phenomena in elasticity", J. Lepinous, et al. (Eds.), Kluwer Academic Pulbishers, the Netherlands (2000) pp 383-401.

EXPERIMENTAL

- Experimental facility for mechanical tests of specimens immersed in liquid metals, Pb-Bi and Pb ⇒ experimental cell CALLISTO (see Figure).
- The tensile tests were carried out at 300 °C in air and at 350 °C in liquid lead.
- Specimens from T91 were machined from the plates in the L direction ⇒ round specimens with a diameter d = 4mm and a gauge length l_0 = 20 mm, surface ground up to 600 grit finish.
- Some of the specimens were pre-exposed in lead at 600 °C for 400 h and $0_2 = 1x10^{-6}$.
- Two different strain rates 10^{-4} a 10^{-6} were used.



Parameters of CALLISTO:

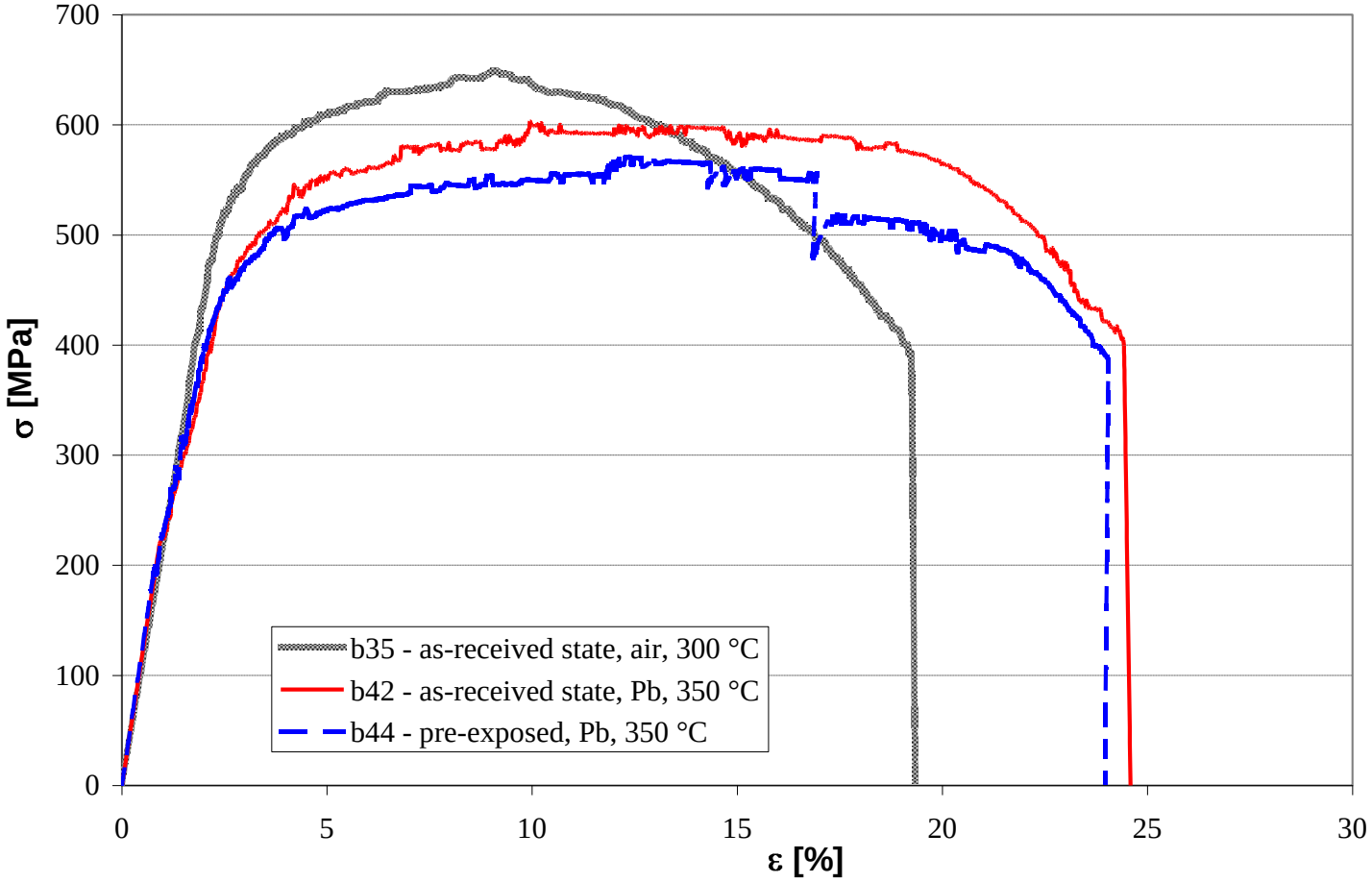
- Temperature operating range cca 200÷700 °C
- Maximum loading capacity = 50 kN
- Specimens and grips are totally immersed into the HLM

EXPERIMENTAL

Summary of the testing conditions for each specimen:

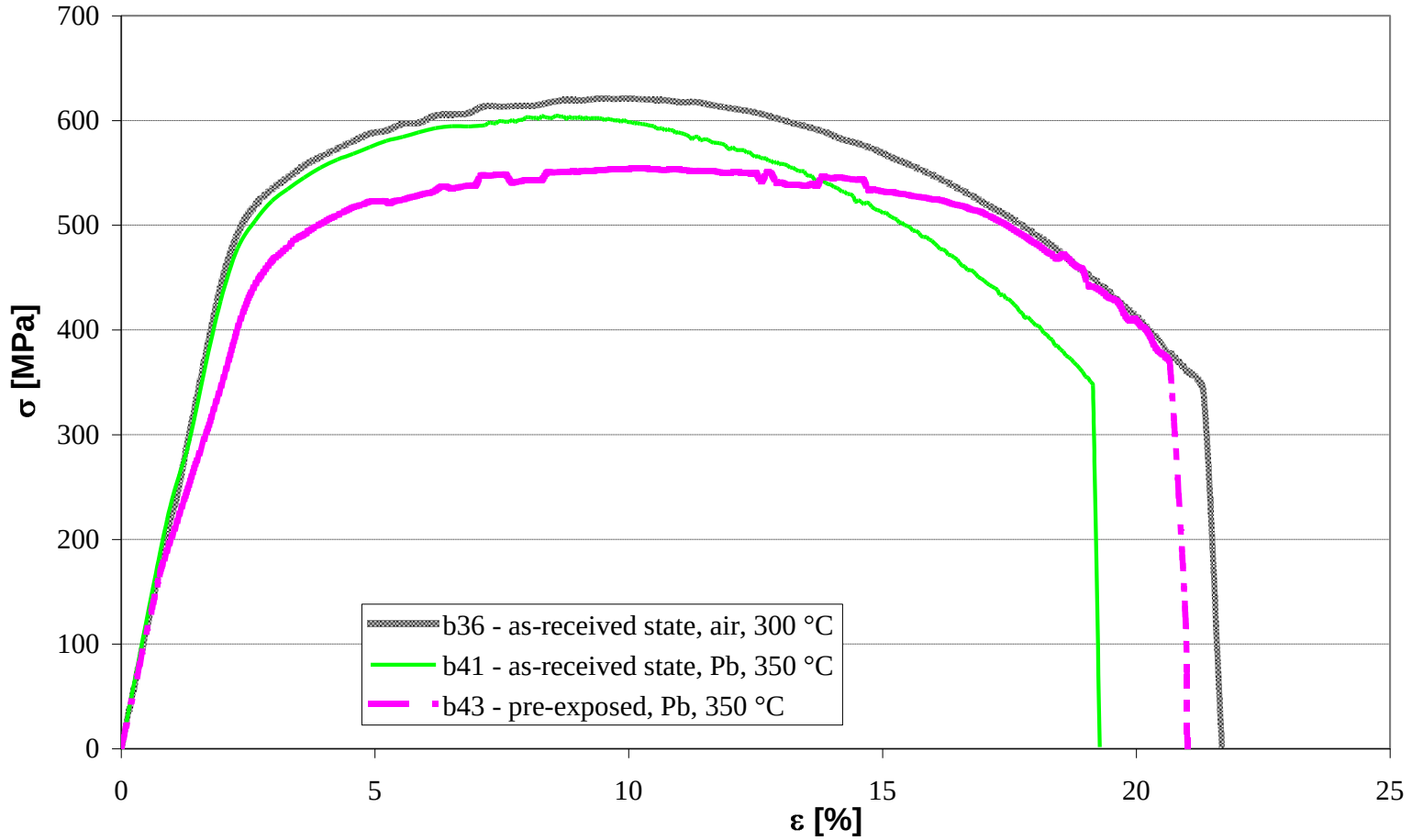
Spec.	Pre-treat.	Medium	T [°C]	Strain rate [s^{-1}]
B35	as/rec	air	300	$1x10^{-6}$
B36	as/rec	air	300	$1x10^{-4}$
B41	as/rec	Pb	350	$1x10^{-4}$
B42	as/rec	Pb	350	$1x10^{-6}$
B43	exp. Pb	Pb	350	$1x10^{-4}$
B44	exp. Pb	Pb	350	$1x10^{-6}$

EXPERIMENTAL - results



Stress-strain curves for specimens tested at strain rate 10^{-6} s^{-1}

EXPERIMENTAL - results



Stress-strain curves for specimens tested at strain rate 10^{-4} s^{-1}

EVALUATION OF EXPERIMENTAL

Summary of tensile tests results:

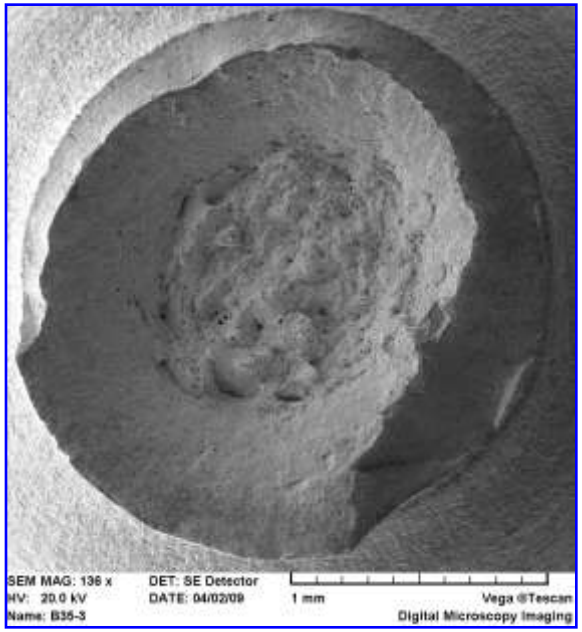
Spec.	Conditions				RESULTS				
	pre-treat	environ	T [°C]	strain rate [s^{-1}]	Z%	σ_y [MPa]	σ_{uts} [MPa]	ε_{uts} [%]	ε_{tot} [%]
B35	as/rec	air	300	$1x10^{-6}$	71	575	646	9,3	19,3
B42	as/rec	Pb	350	$1x10^{-6}$	70	478	603	10,0	24,6
B44	exp. Pb	Pb	350	$1x10^{-6}$	74	450	571	12,4	24,0
B36	as/rec	air	300	$1x10^{-4}$	73	499	620	10,2	21,7
B41	as/rec	Pb	350	$1x10^{-4}$	75	490	604	8,7	19,3
B43	exp. Pb	Pb	350	$1x10^{-4}$	75	451	555	10,2	21,0

- *The reduction of area did not changed markedly in both environments and for specimens pre-exposed in Pb, as well as.*
- *The slight decrease of engineering values, such as yield stress and UTS compared to the values measured in air and Pb without pre-exposition.*
- *Elongation to rupture is increased for lower strain rates 10^{-6} s^{-1} compared with the rates 10^{-4} s^{-1}.*

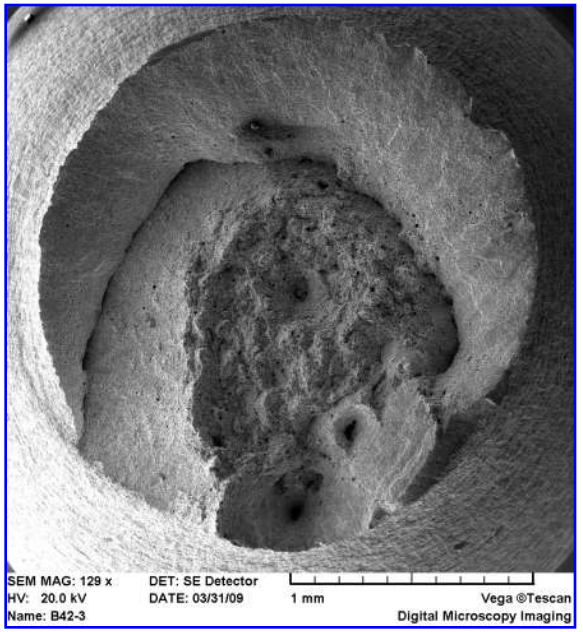
EVALUATION OF EXPERIMENTAL

Fractographic analysis

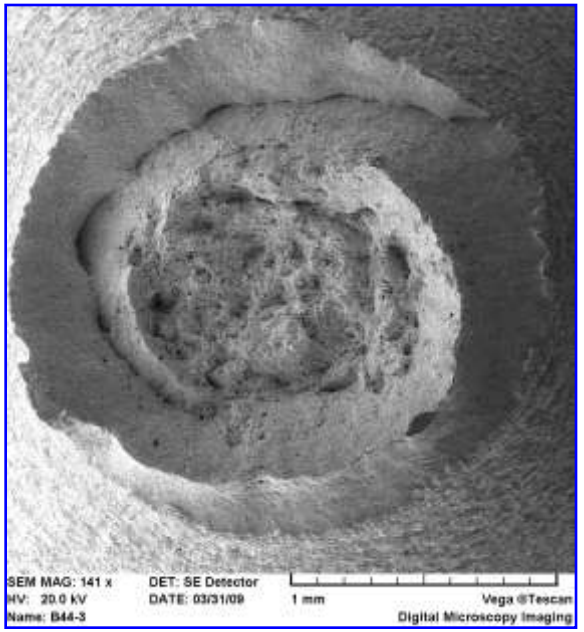
Specimens tested at strain rate 10^{-6} s^{-1}



As-received state,
air, 300 °C



As-received state,
Pb, 350 °C

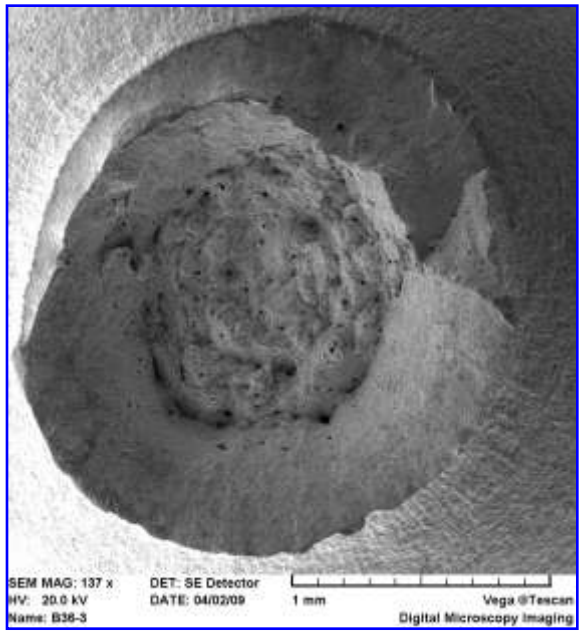


Pre-exposed in Pb
at 600 °C for 400 h,
Pb, 350 °C

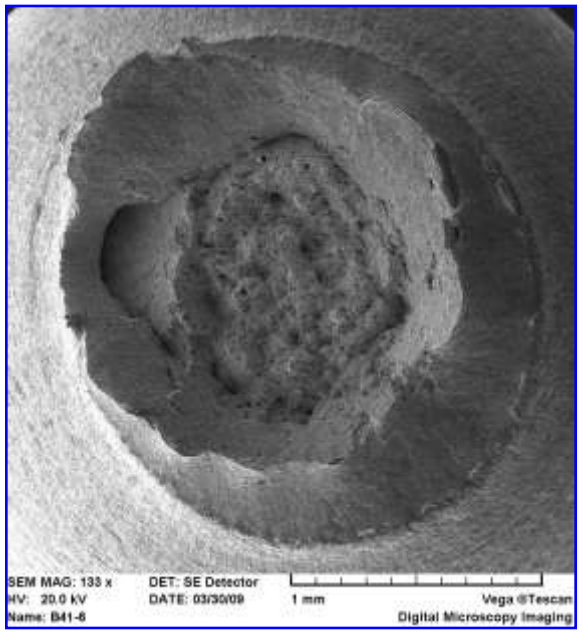
EVALUATION OF EXPERIMENTAL

Fractographic analysis

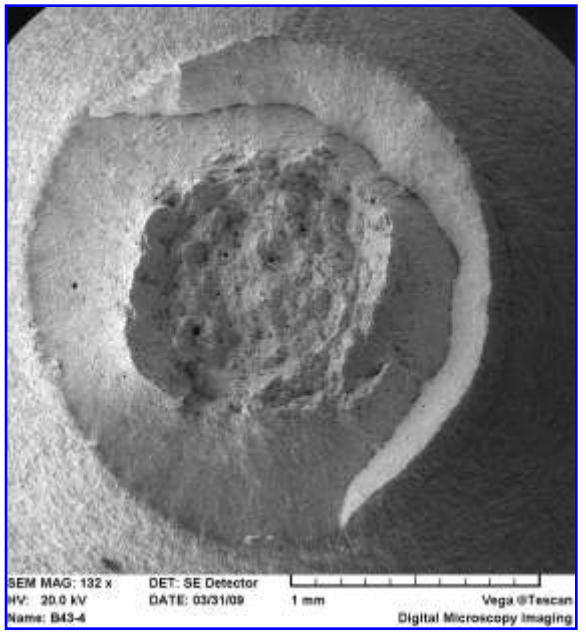
Specimens tested at strain rate 10^{-4} s^{-1}



As-received state,
air, 300 °C



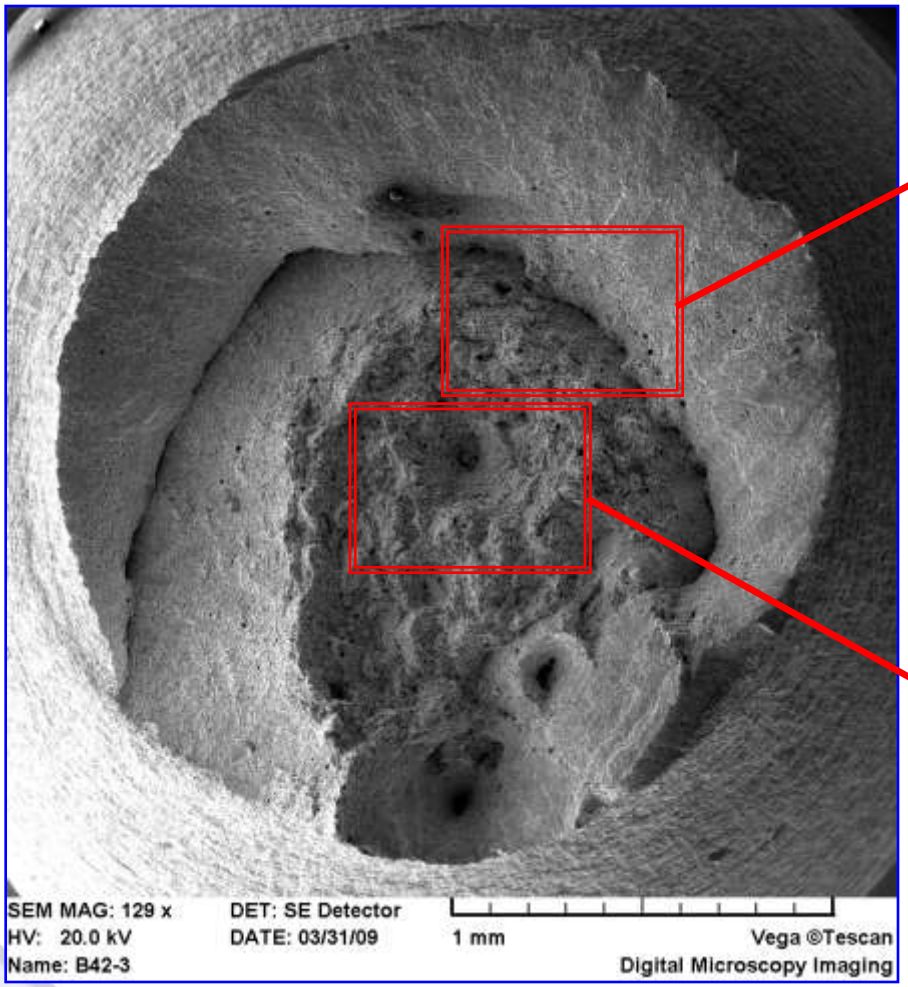
As-received state,
Pb, 350 °C

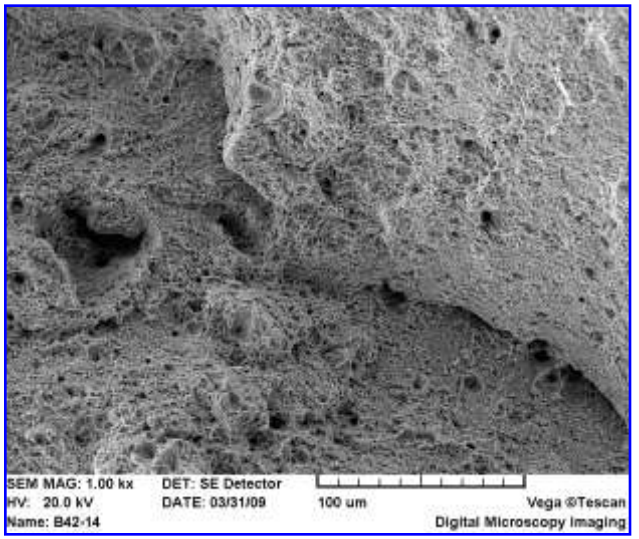


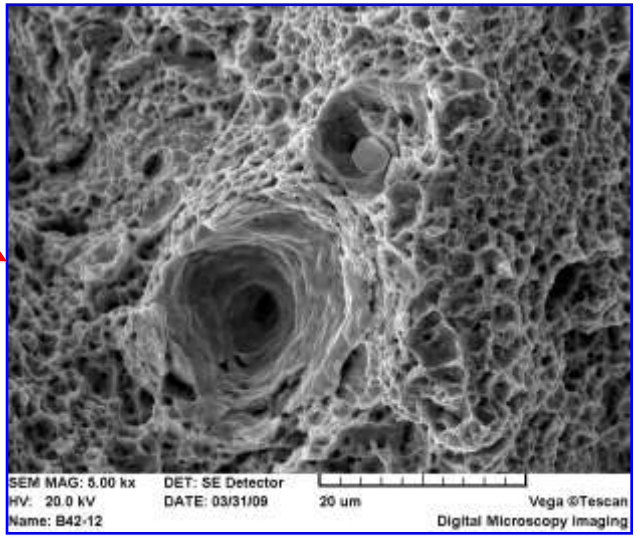
Pre-exposed in Pb at
600 °C for 400 h,
Pb, 350 °C

EVALUATION OF EXPERIMENTAL

Fractographic analysis

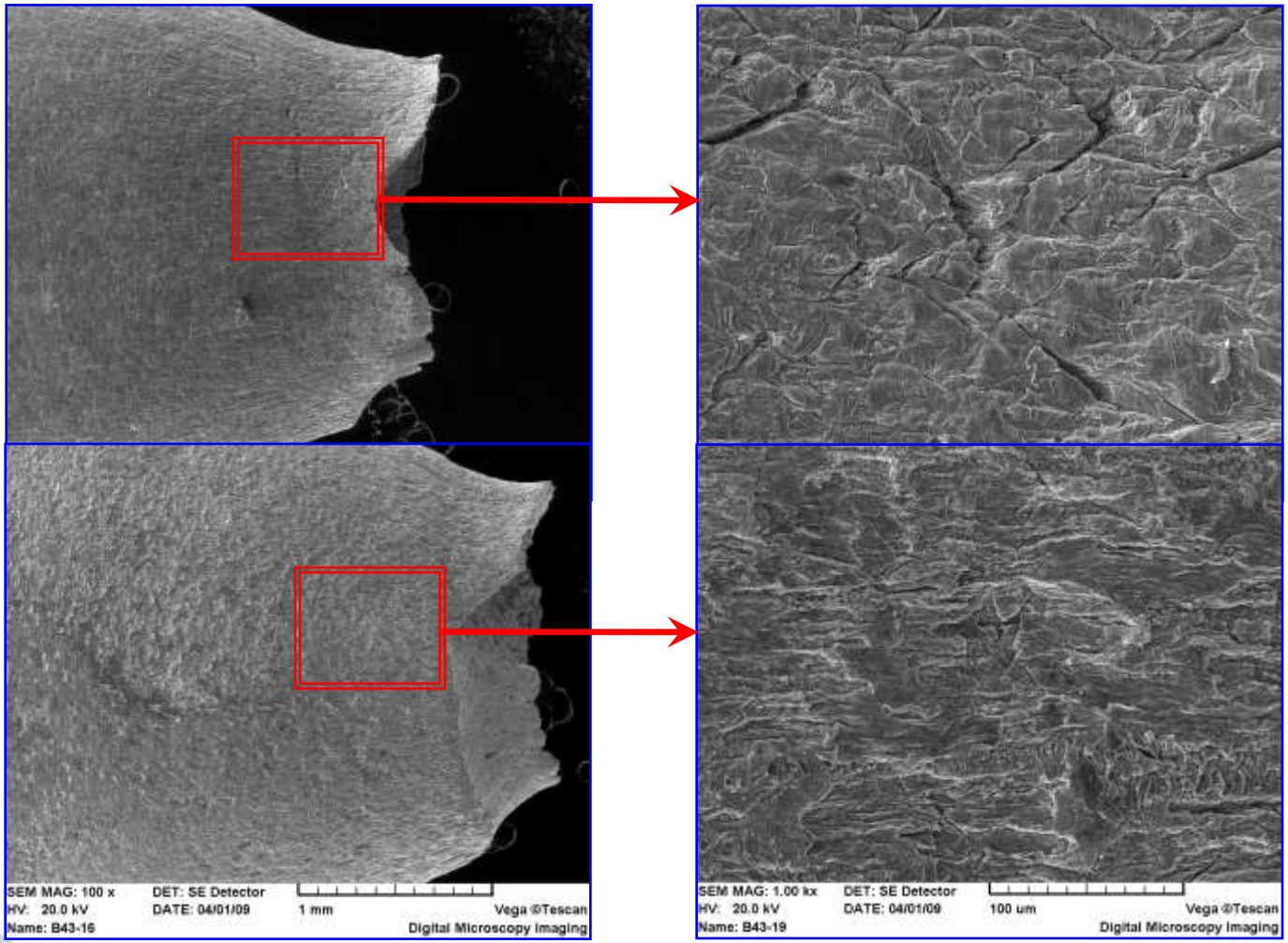






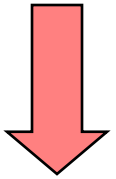
EVALUATION OF EXPERIMENTAL

Fractographic analysis of specimens´surfaces – Pb, 350 °C, strain rate 10^{-4} s^{-1}



DISCUSSION OF RESULTS

Aim: The study of sensitivity of ferritic-martensitic 9 Cr steel to LME when is in contact with liquid lead at 300÷350 °C, different strain rates and with or without pre-exposition in Pb.



By comparison of results for specimens in as-received state tested in Pb and specimens that were pre-exposed in convection loop, it was possible to evaluate the influence of pre-exposition on the mechanical properties changes.

All results from the tensile tests were complemented with the results of fractographic analysis in order to have a direct correlation between the mechanical properties measured and the characteristic fracture features.

DISCUSSION OF RESULTS

- The oxide layers on the surface of all tested specimens were found out → the oxygen dissolved in liquid Pb was sufficient to develop a protective oxide layer on the steel that prevented direct contact between the steel and heavy liquid metal.

- At lower strain rates 10^{-6} s^{-1}, the increase in ductility of specimens tested in Pb (in as-received state and with pre-exposition) and the decrease of ultimate tensile strength, σ_{UTS}, was observed. By comparison of results obtained in air and in Pb with previous pre-exposition in Pb, the decrease in σ_{UTS} was 11.5%.

- Different results were obtained for higher strain rates 10^{-4} s^{-1} → lower elongation to rupture was found out for specimen tested in Pb in as-received state. The decrease in σ_{UTS} of pre-exposed specimen tested in Pb in comparison of specimen tested in air was also almost 11%.

- The reduction of area, Z, was for all specimens in a range of 70÷75%.

DISCUSSION OF RESULTS

- The results of fractograpic analysis correlate with the obtained stress-strain curves.
- All specimens failed in ductile mode, evidencing that the material was beyond the UTS point when it normally started necking and cracking.
- However, the difference between the surfaces of specimens with and without pre-exposition was observed by SEM → in longer distance from fracture, the surface affected by pits with character of selective corrosion was observed → this kind of surface damage was possibly caused due to the previous specimens pre-exposition in Pb → further investigation will be connected.

CONCLUSIONS

- It was proved that the pre-exposition in Pb influences the engineering values, i.e., the decrease of yield stress and ultimate tensile strength in comparison with the values obtained in air and Pb (specimens without pre-exposition).

- The increase in ductility, i.e., the increase in elongation to rupture, was found out for specimens immersed in Pb at 350 °C and strain rate 10^{-6} s^{-1} compared with the same test in air.

- Generally, the elongation to rupture of specimens immersed in Pb is also influenced by the changes in strain rate. For lower strain rates 10^{-6} s^{-1}, elongation to rupture is increased than for higher rates 10^{-4} s^{-1}.

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Thank you for your attention

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