OXIDATION RESISTANT

HIGH TEMPERATURE COATINGS

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REFERENCES

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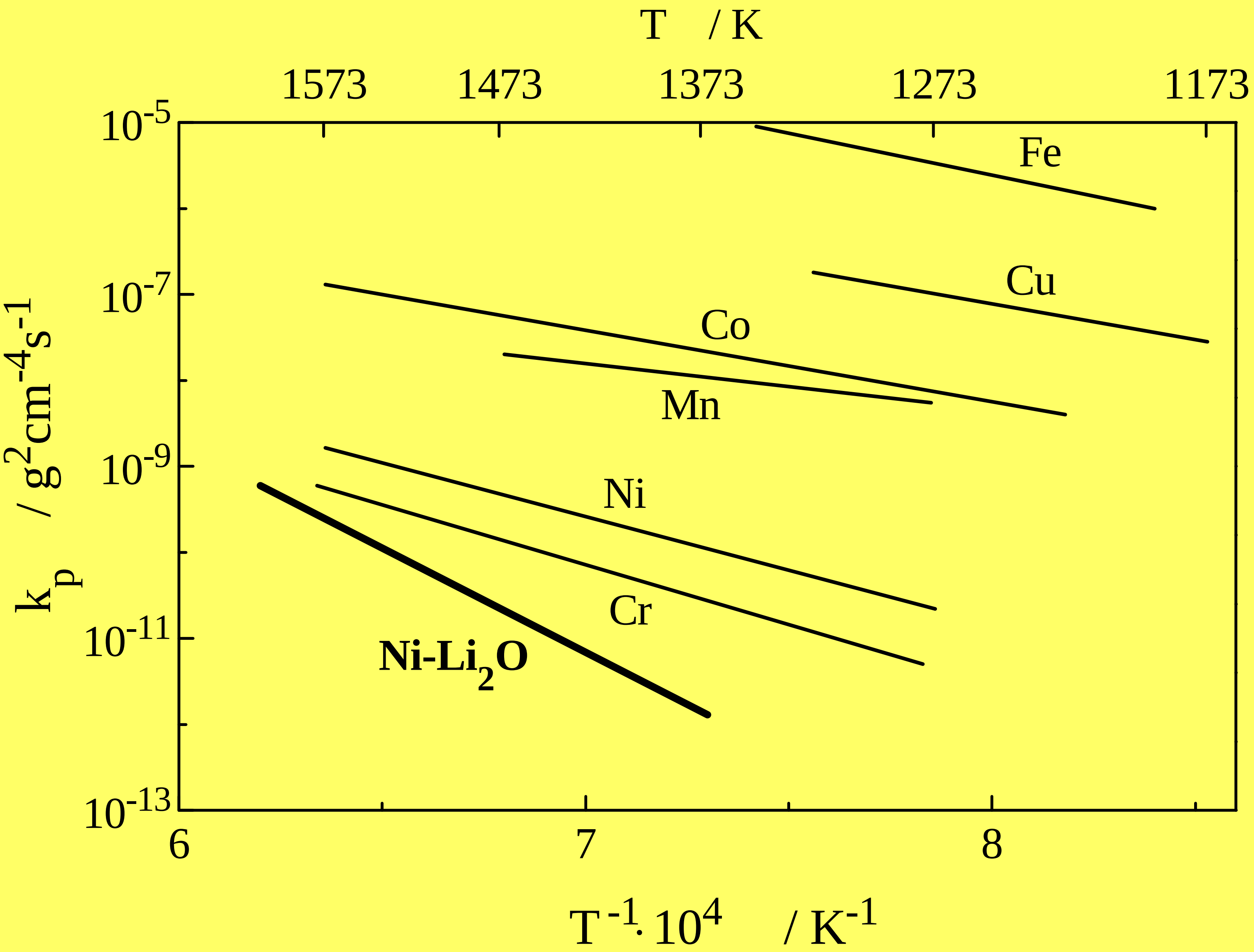
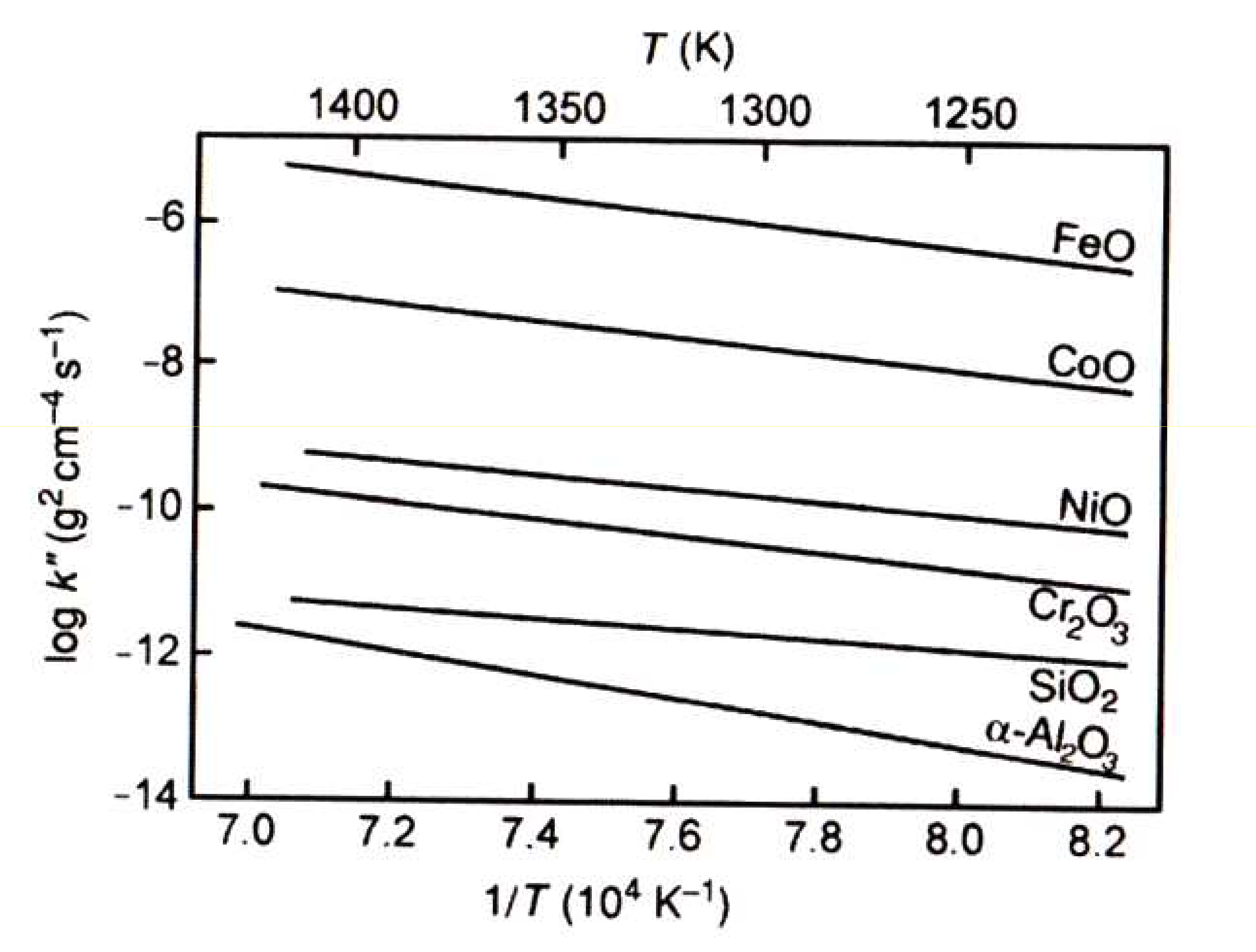
2. P. Kofstad, „High-Temperature Oxidation of Metals”, John Wiley & Sons, Inc, New York-London-Sydney, 1978.
3. A.S. Khanna, „Introduction to High Temperature Oxidation and Corrosion”, ASM International, Materials Park, 2002.
4. S. Mrowec, „An Introduction to the Theory of Metal Oxidation”, National Bureau of Standards and the National Science Foundation, Washington, D.C., 1982.
5. Wei Gao and Zhengwei Li ”Developments in high-temperature corrosion and protection of metals”, Ed, Woodhead Publishing Limited, Cambridge, England, 2008.
6. R. Cottis, M. Graham, R. Lindsay, S. Lyon, J. Richardson, J. Scantlebury, F. Stott, „Basic Concepts, High Temperature Corrosion”, vol. I, in „Shreir’s Corrosion”, Elsevier, Amsterdam, 2010.

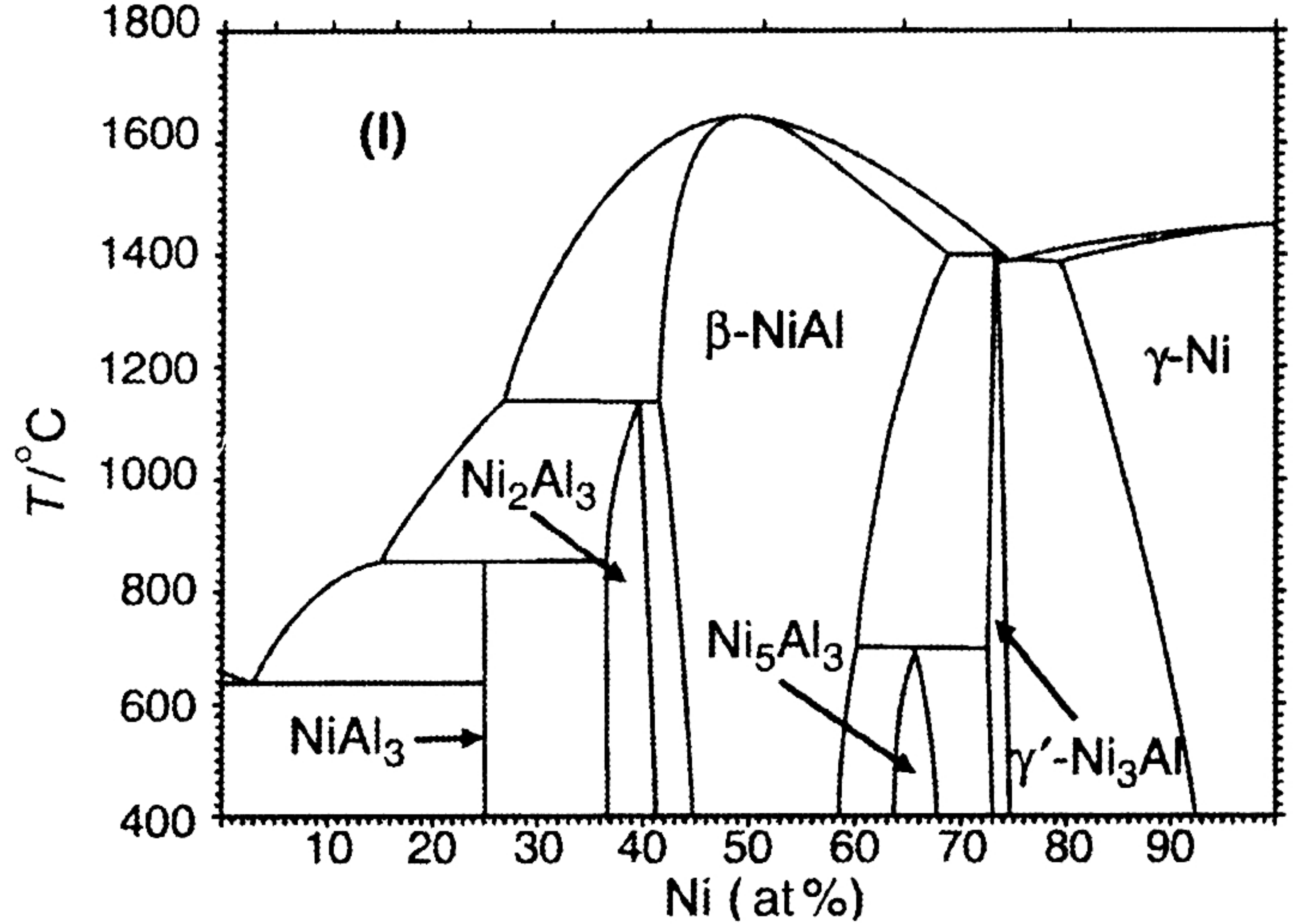
Oxidation resistance of selected metals



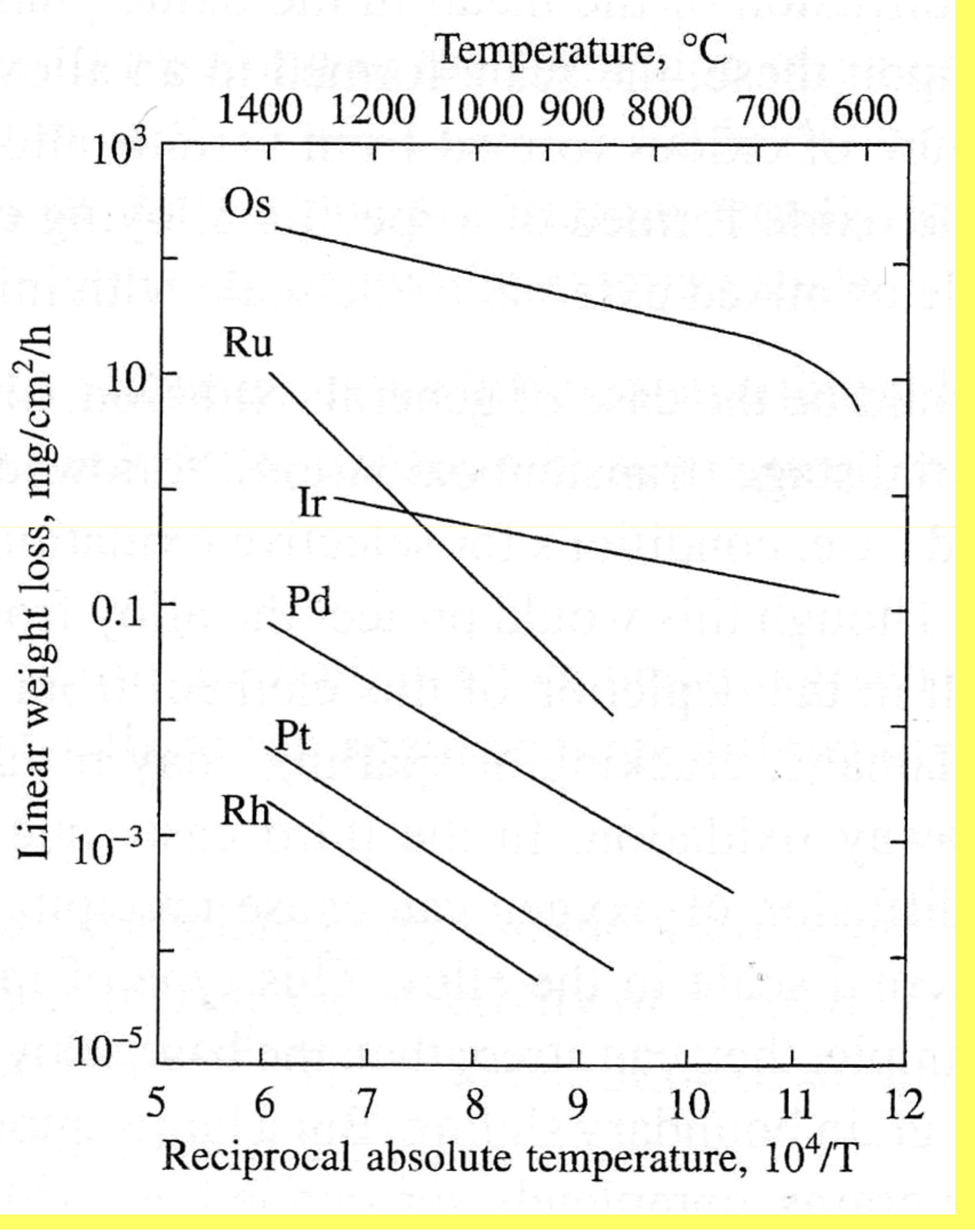
Oxidation resistance of selected metals



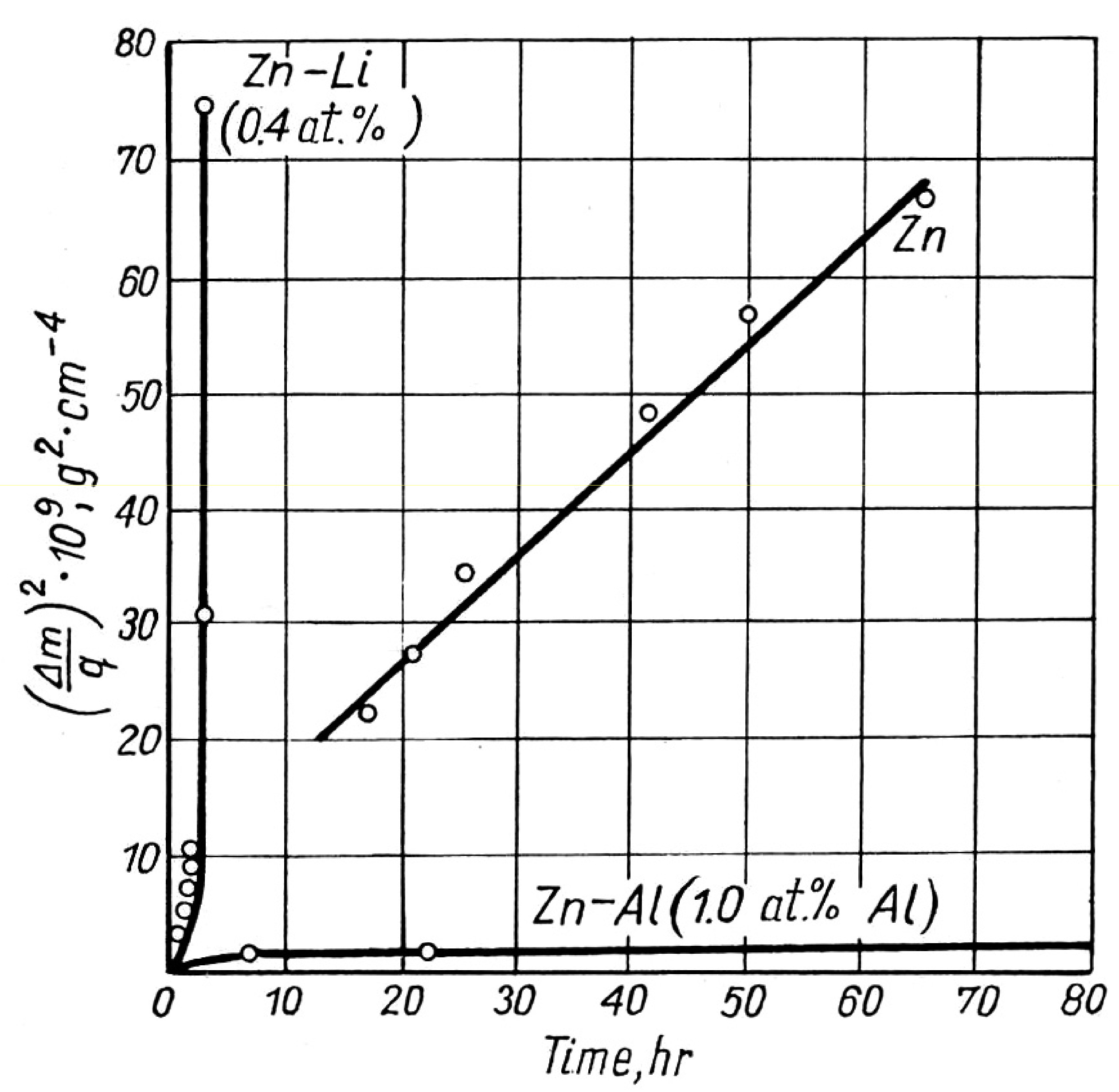
Ni-Al phase diagram



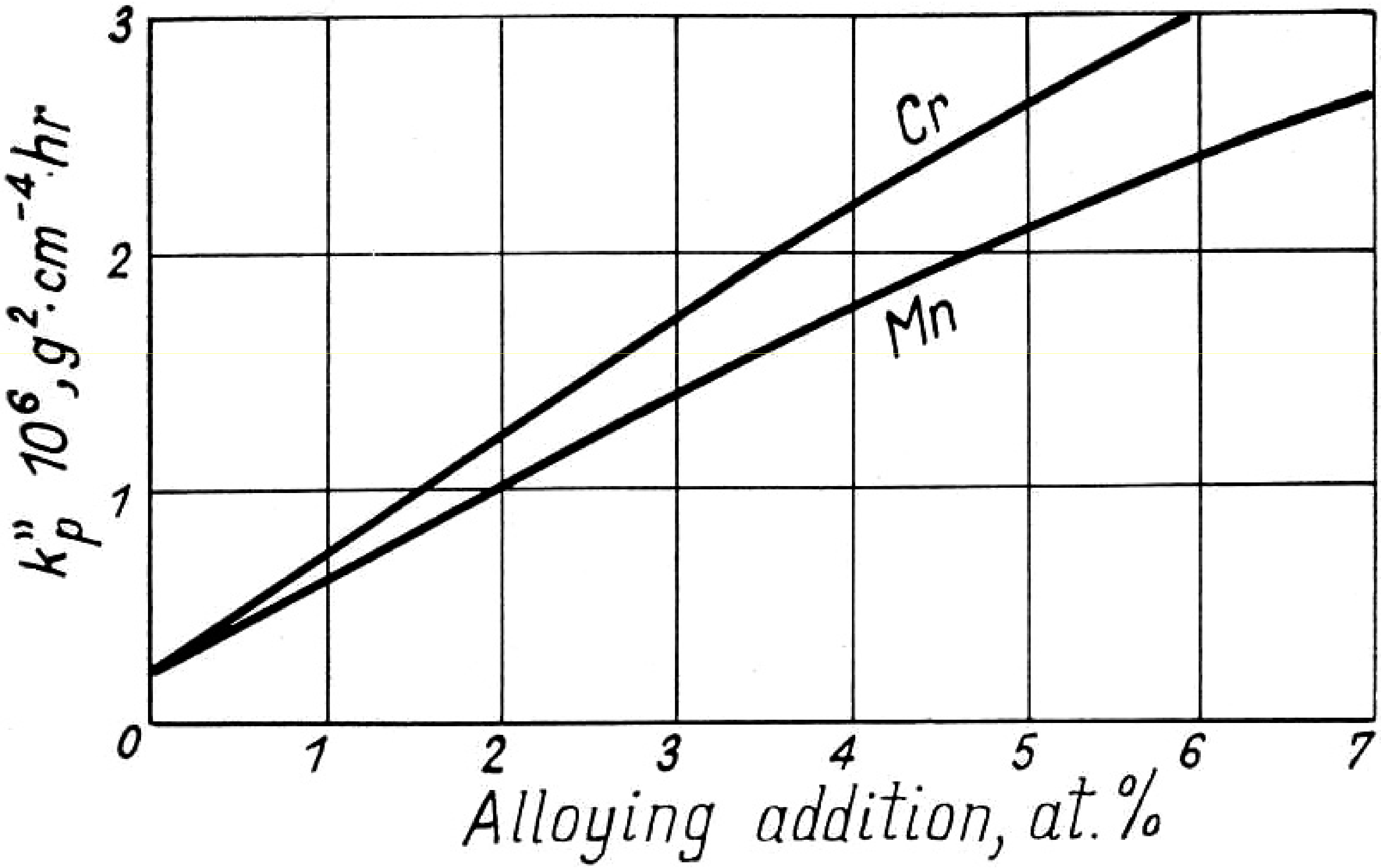
Degradation rate of noble metals at high temperatures



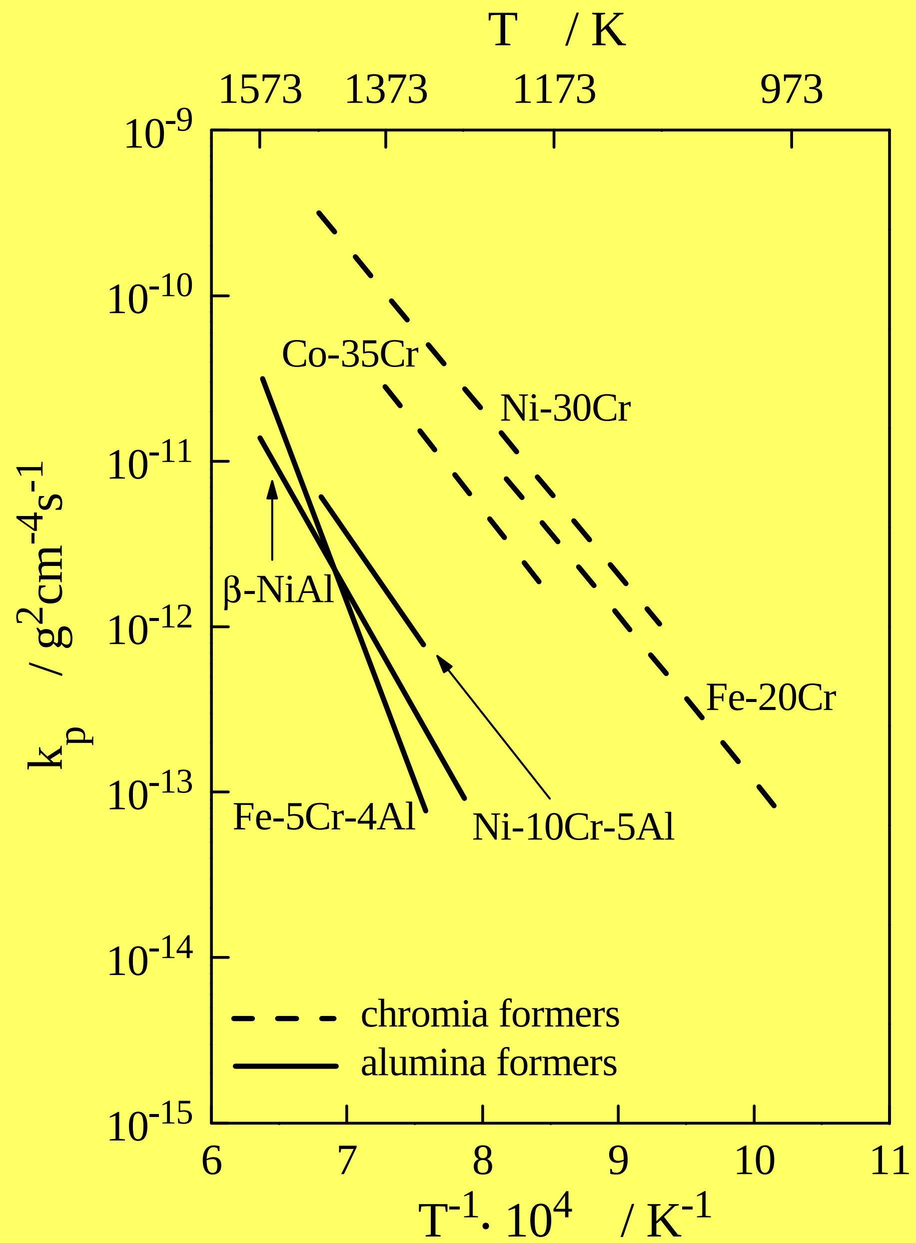
The influence of dopping effect on oxidation resistance



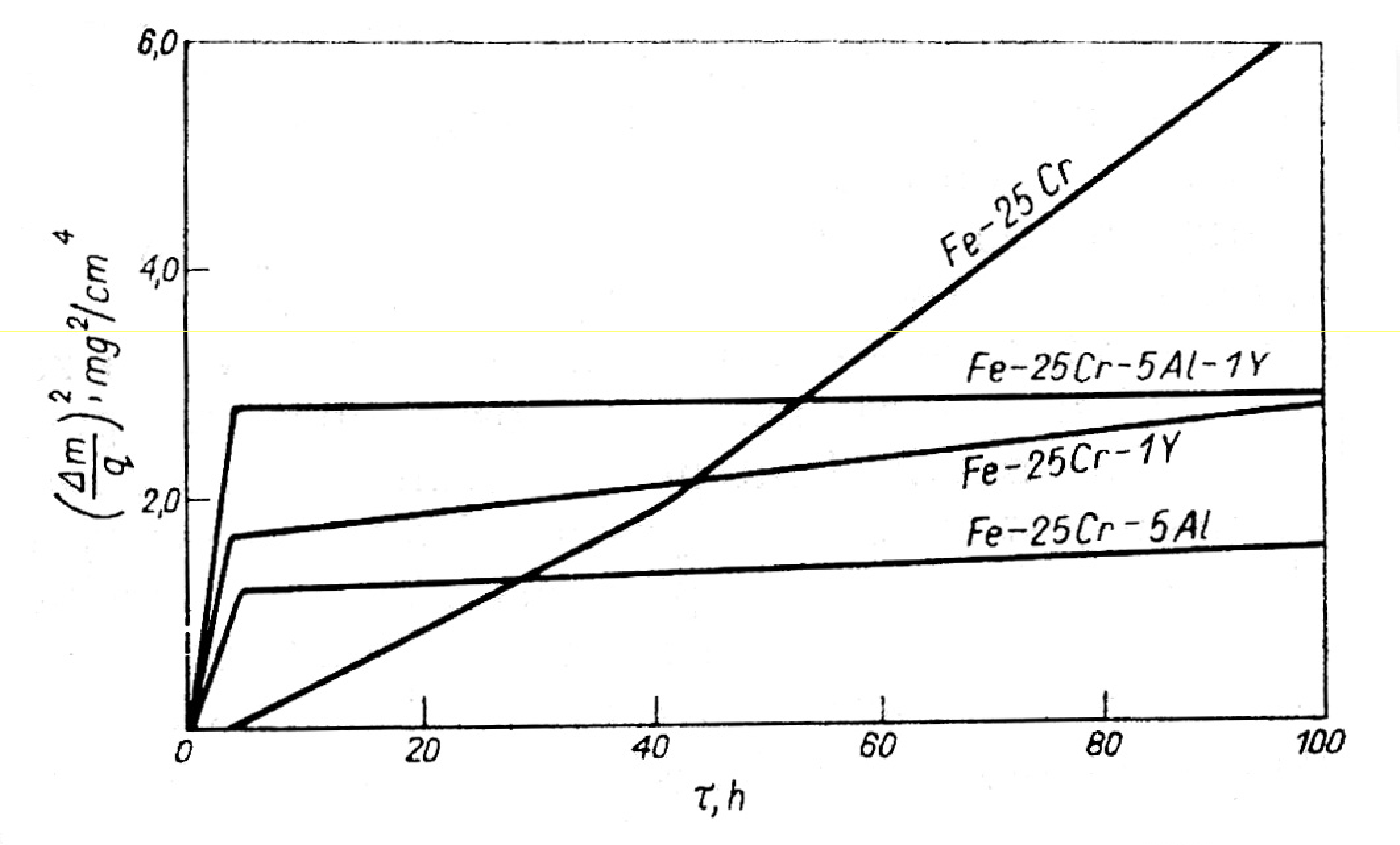
The influence of dopping effect on oxidation resistance



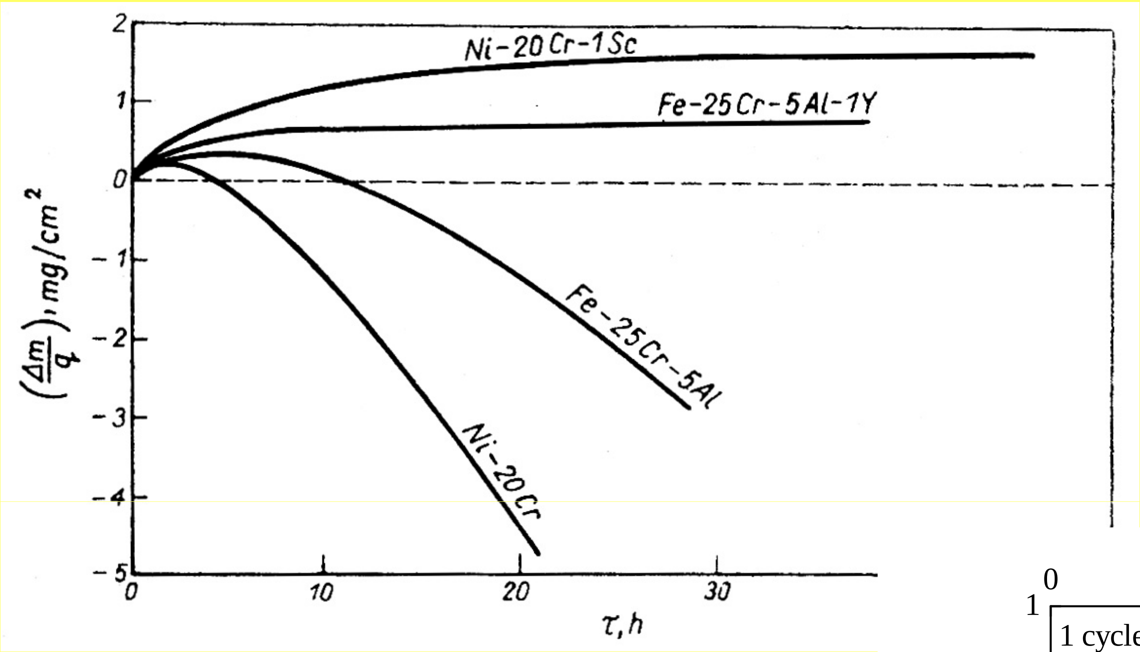
Oxidation resistance of selected alloys

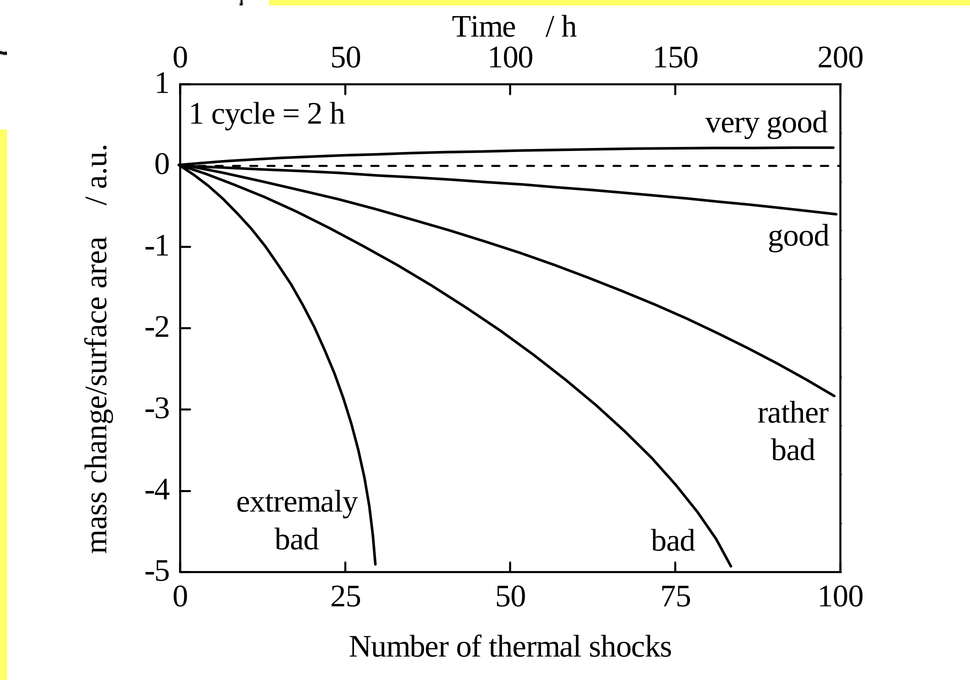


The influence of Y on the oxidation rate of the Fe-25Cr-5Al alloy



The influence of Y and Sc on the degradation rate of the Fe-25Cr-5Al and Ni-20Cr alloys under thermal shock conditions





MATERIALS USED AS PROTECTIVE COATINGS IN OXIDIZING ATMOSPHERES

Cr – Cr_2O_3

Al – Al_2O_3

Si – SiO_2

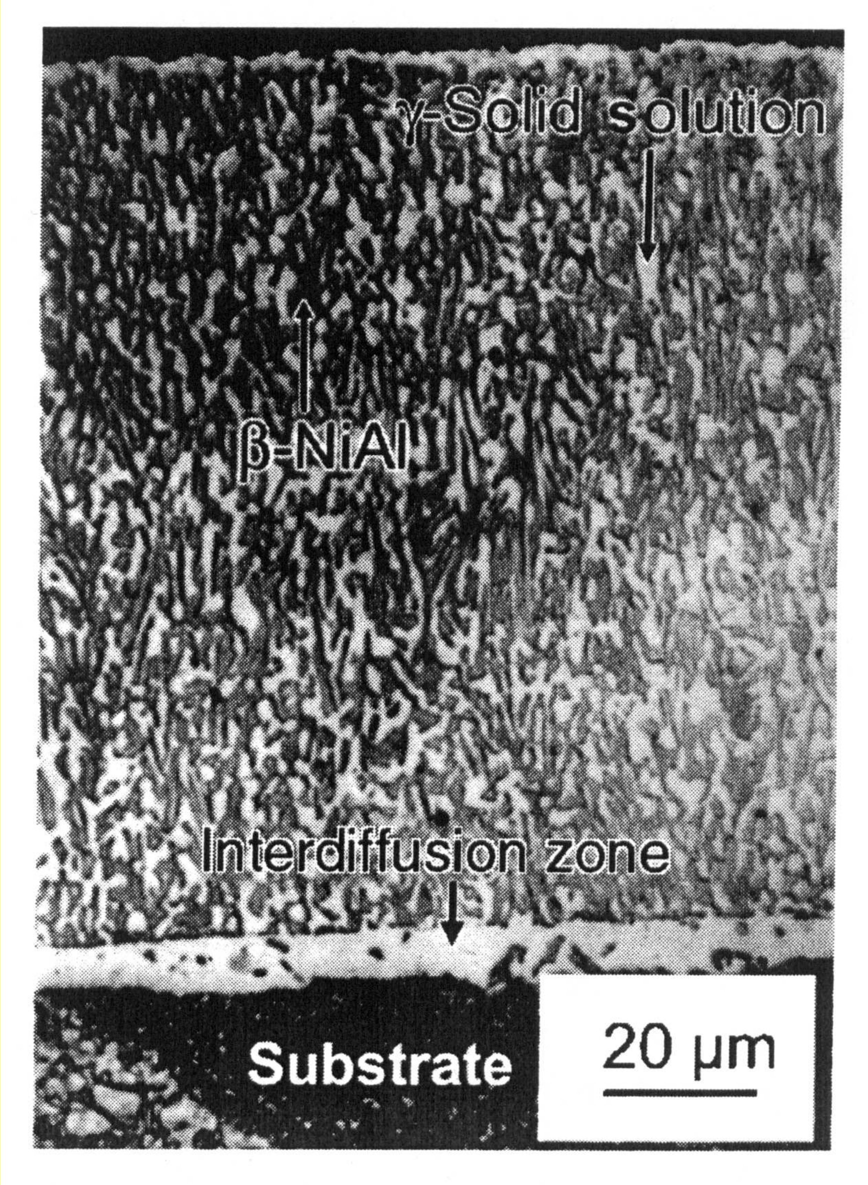
MCrAlY (where M = Co, Ni, Co/Ni) – Al_2O_3, Cr_2O_3

MCrAlY-Si – Al_2O_3, Cr_2O_3

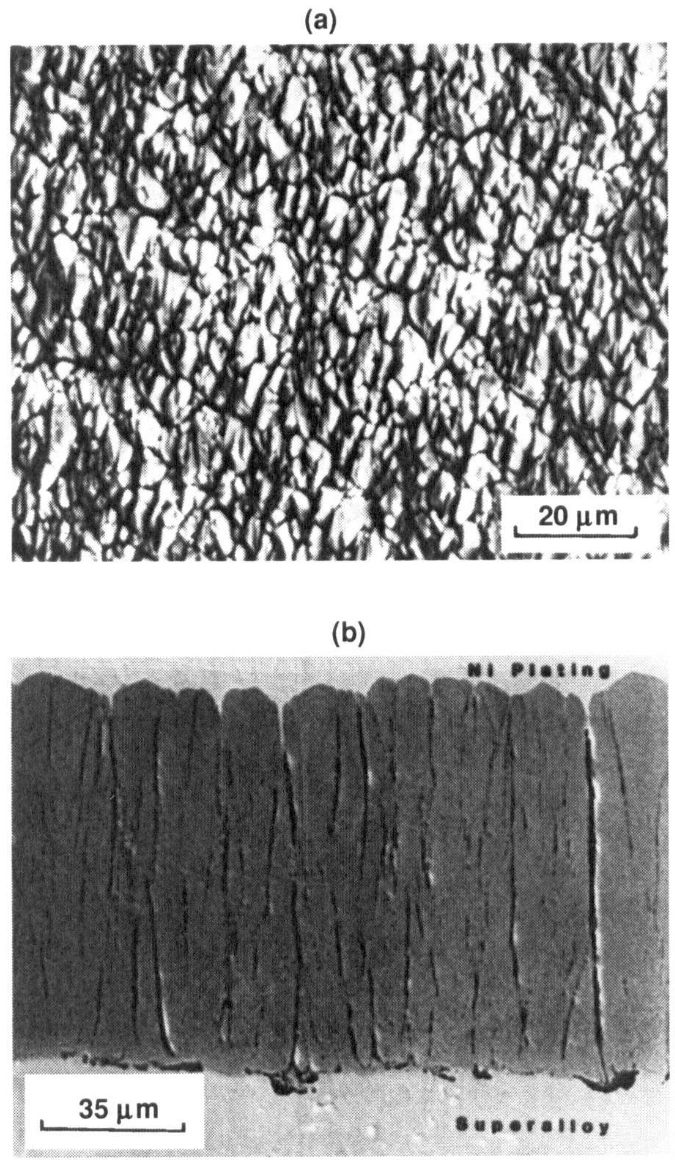
MCrAlY-RE (where RE = Y, Hf, Zr) – Al_2O_3

NiAl – Al_2O_3

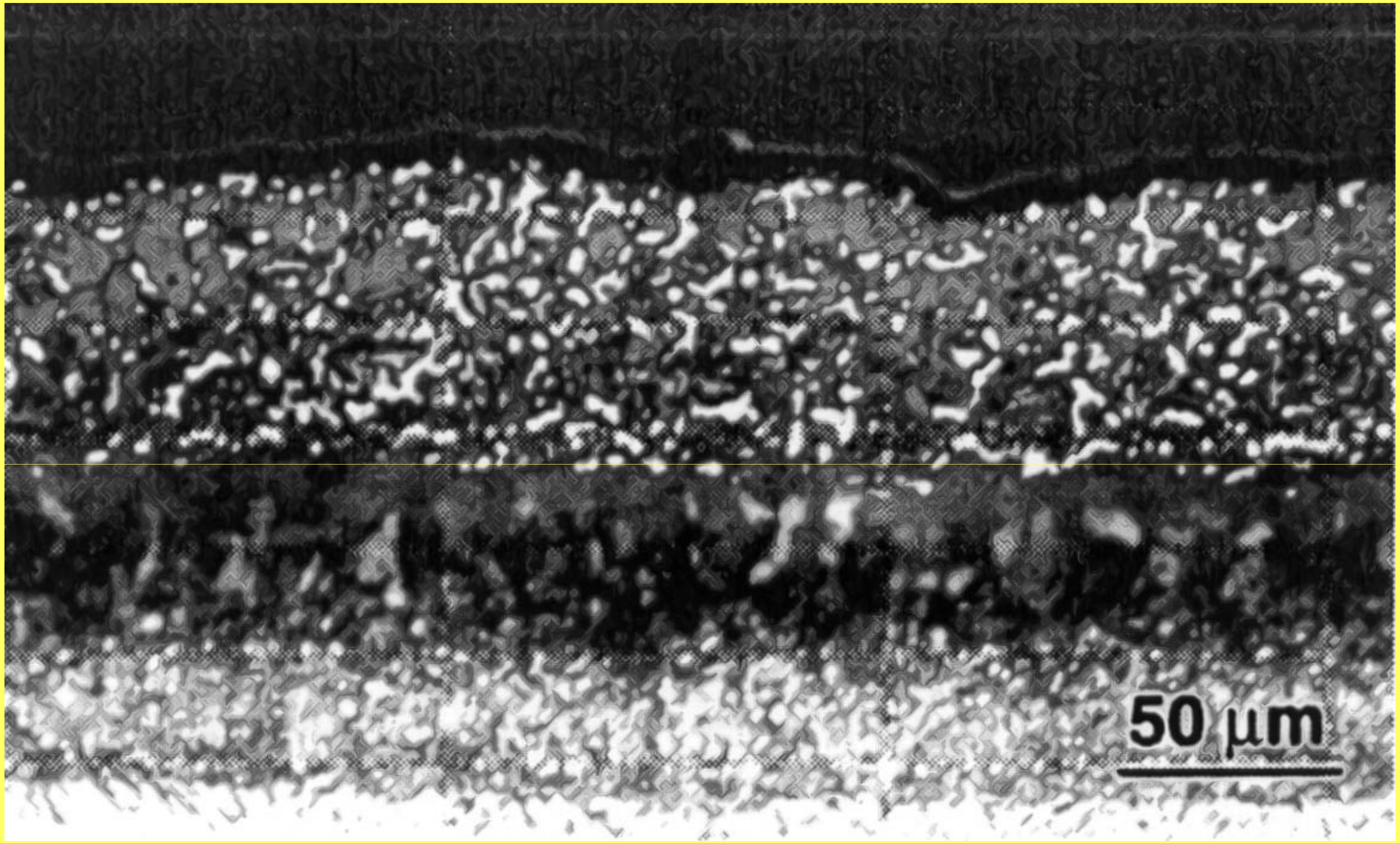
Cross-section of the Ni-Cr-Al-Y coating obtained by the EB-PVD method



Surface and cross-section of the Co-Cr-Al-Y coating obtained by the EB-PVD method on the IN-738 alloy

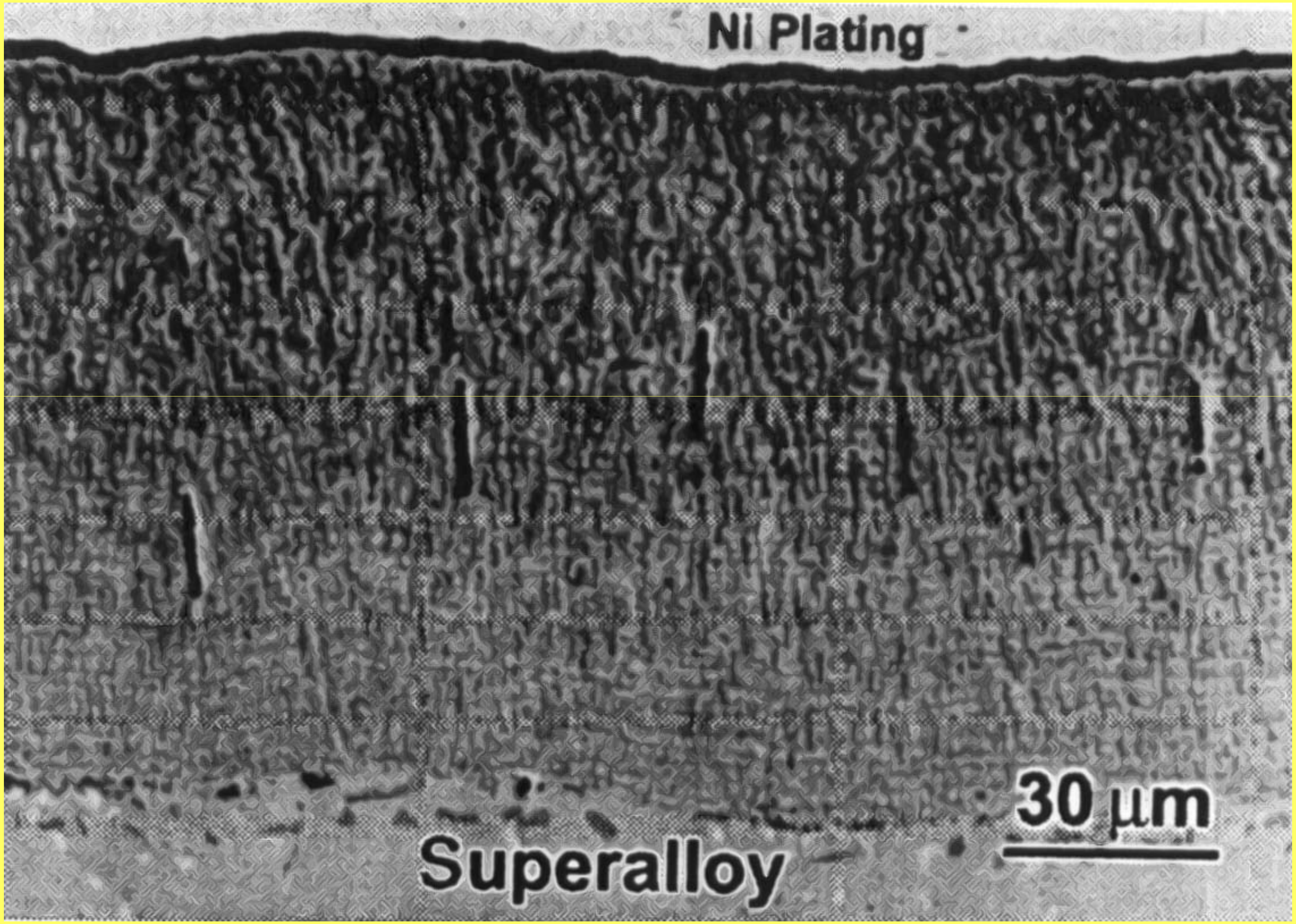


Micrograph of Pt modified aluminide coating on nickel-base superalloy

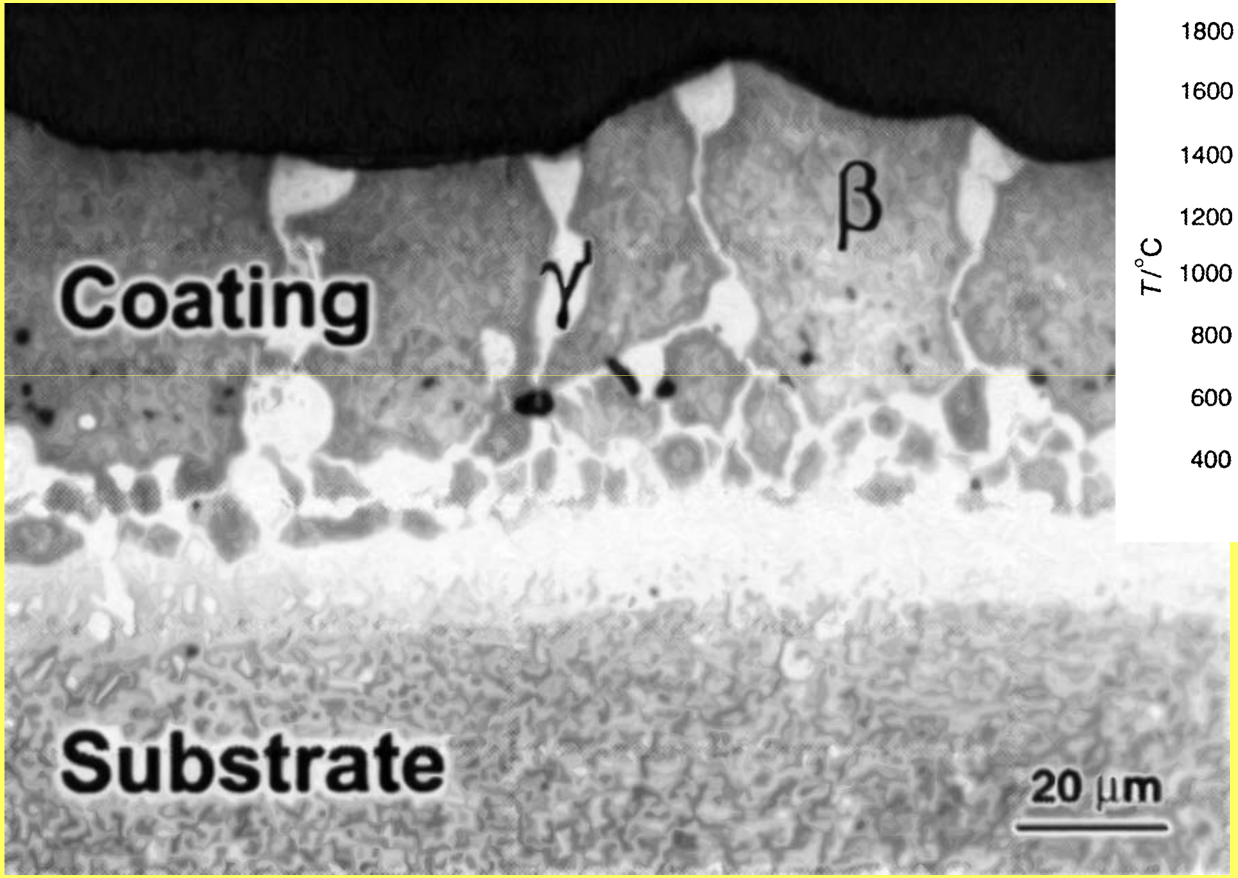


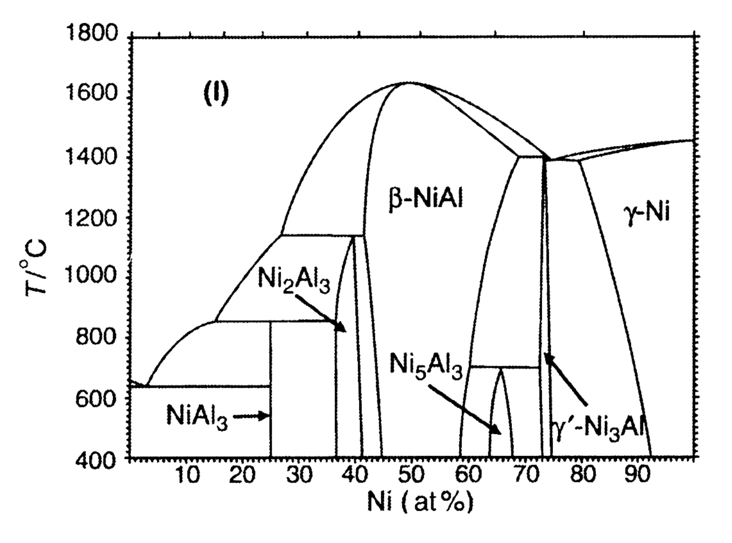
$PtAl_2$ phase (white color) in a matrix of β-NiAl

Micrograph of cross-section of an EB-PVD Co-Cr-Al-Y coating, deposited on IN-738



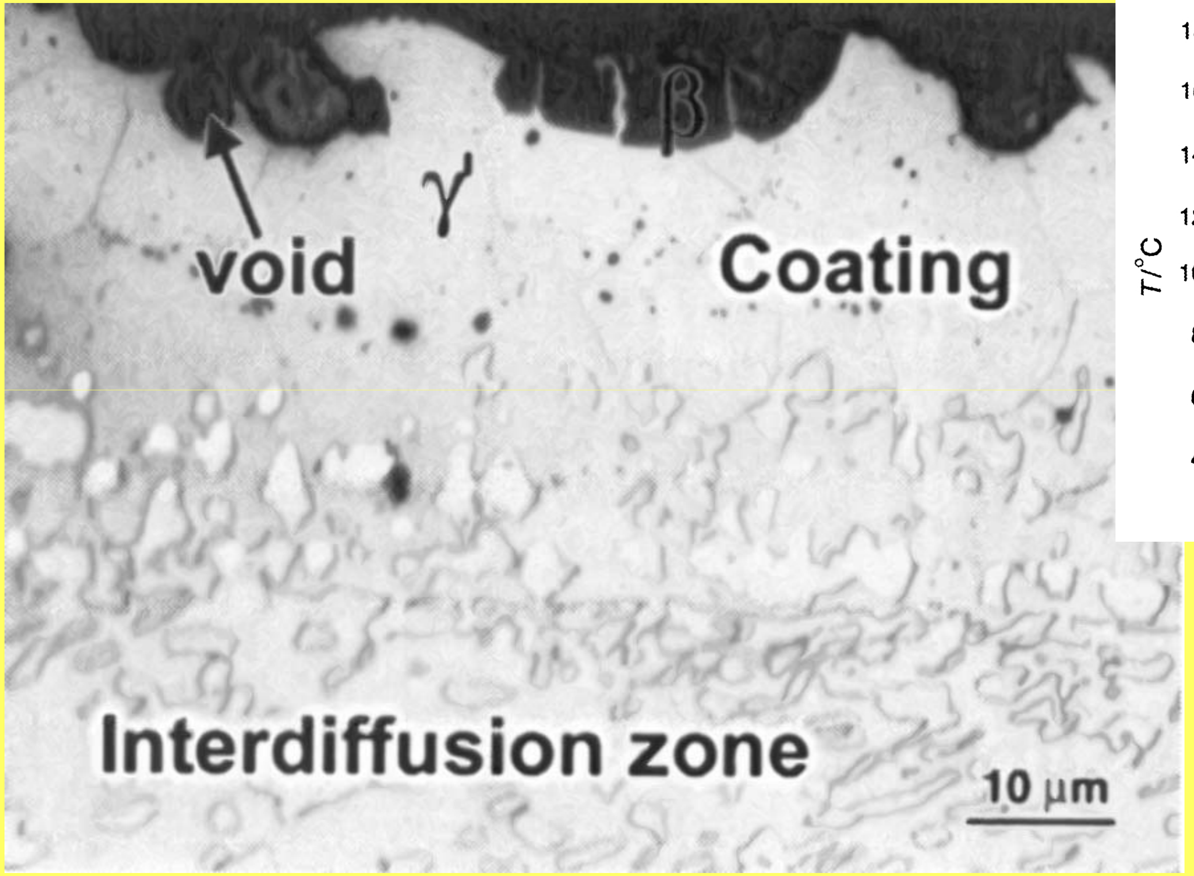
Micrograph of cross-section of Pt-modified aluminide coating on nickel-base single-crystal superalloy after oxidation at 1200°C for 20 h

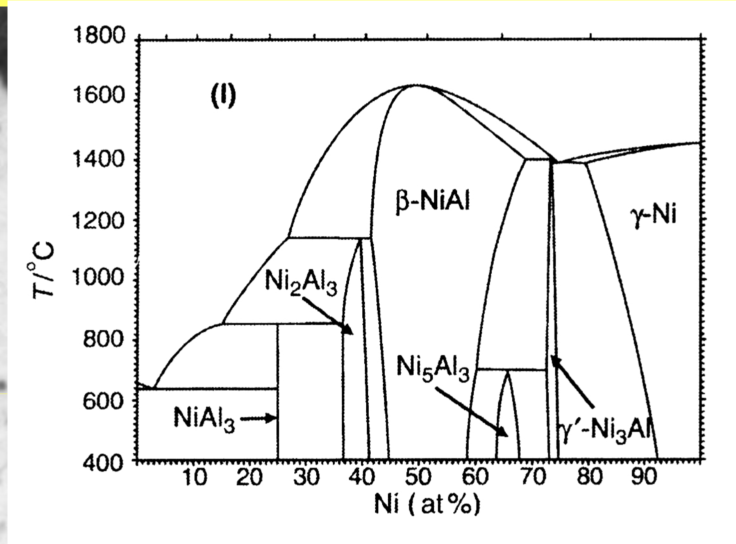




The original grain structure of the β-phase is evident and γ' has begun to nucleate at β grain boundaries as a consequence of Al depletion

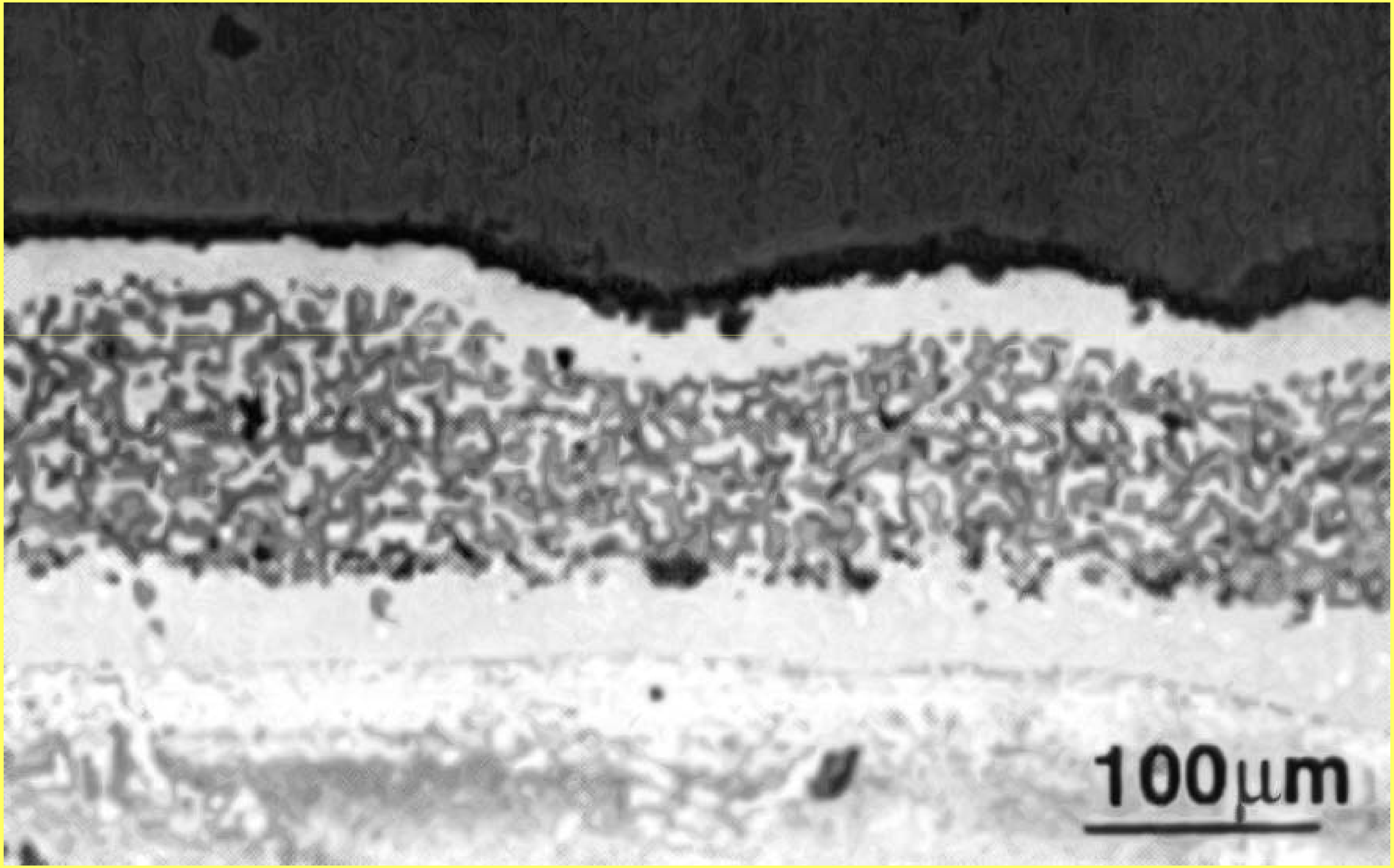
Micrograph of cross-section of Pt-modified aluminide coating on nickel-base single-crystal superalloy after oxidation at 1200°C for 200 h



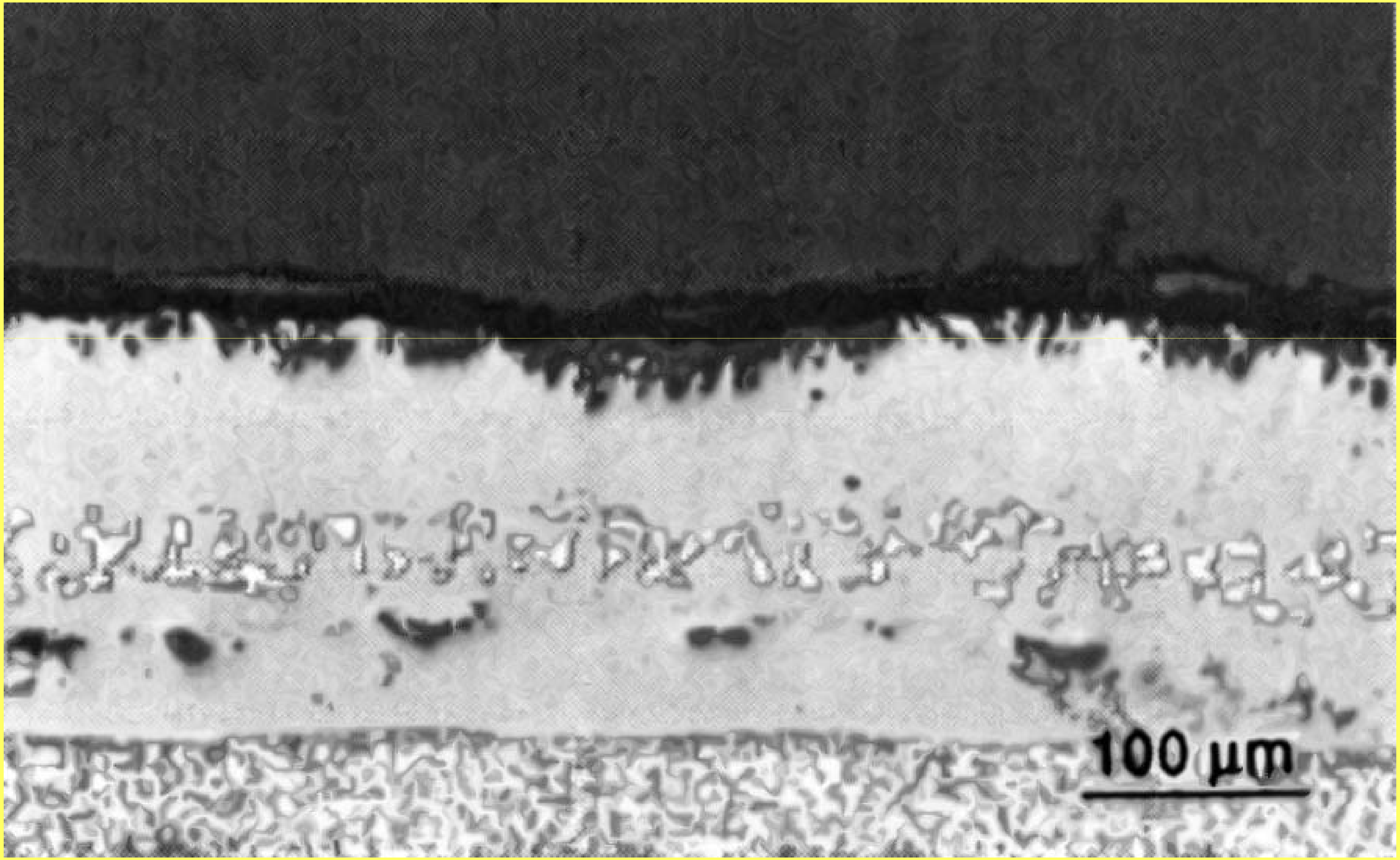


The coating had been converted almost completely to γ', as a result of Al depletion. Further exposure would result in the γ' transforming to γ.

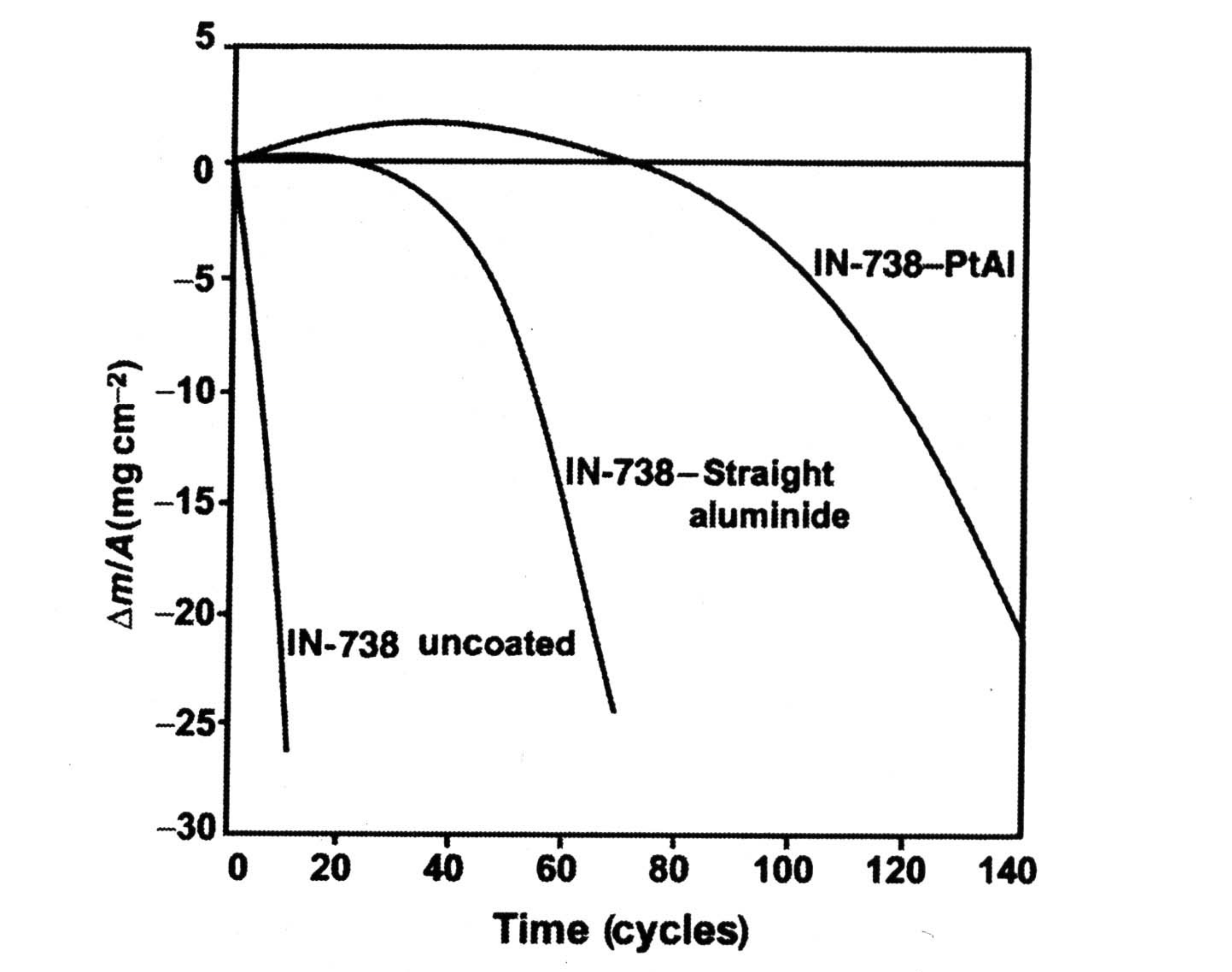
Micrograph of cross-section of a Ni-Co-Cr-Al-Y coating on a single-crystal Ni-base superalloy after 200 one-hour cycles at 1100^{o}C in air



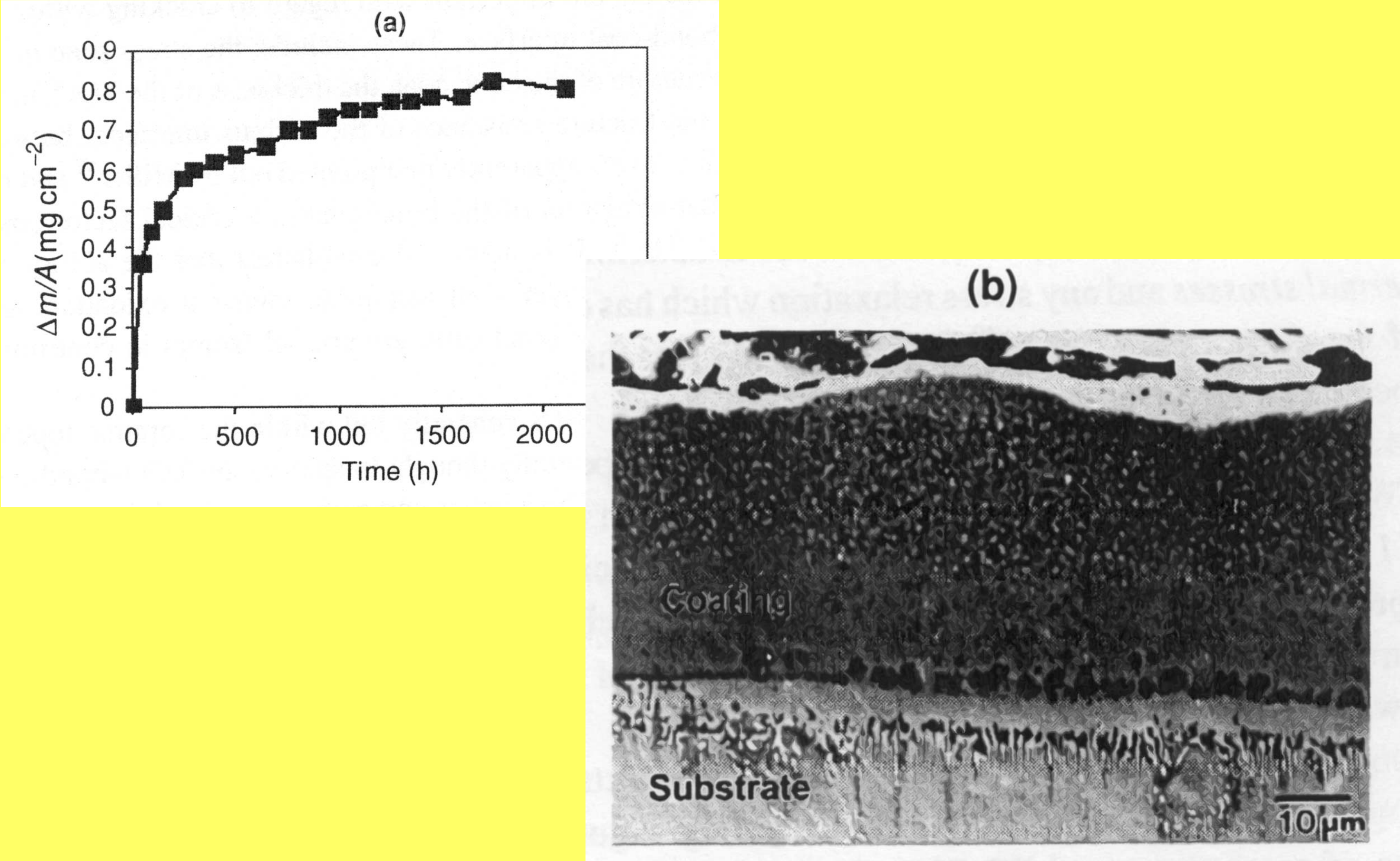
Micrograph of cross-section of a Ni-Co-Cr-Al-Y coating on a single-crystal Ni-base superalloy after 1000 one-hour cycles at 1100^{o}C in air



Cyclic oxidation data for a straight aluminide and a platinum aluminide on IN-738 at 1200^oC in air



Cyclic oxidation data for a sputtered Ti-Cr-Al coating on γ–TiAl at 900ºC and the cross-section of coating after exposure

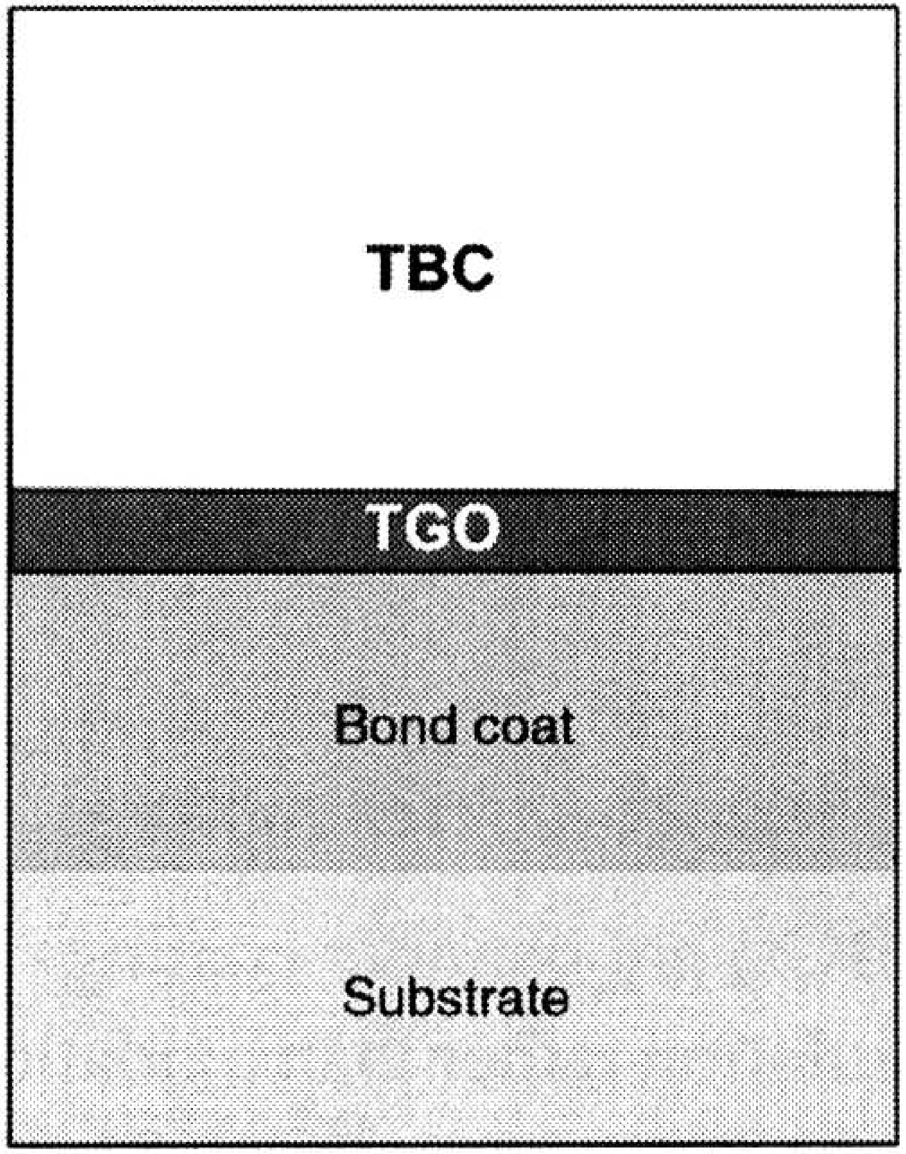


Thermal barrier coatings (TBC)

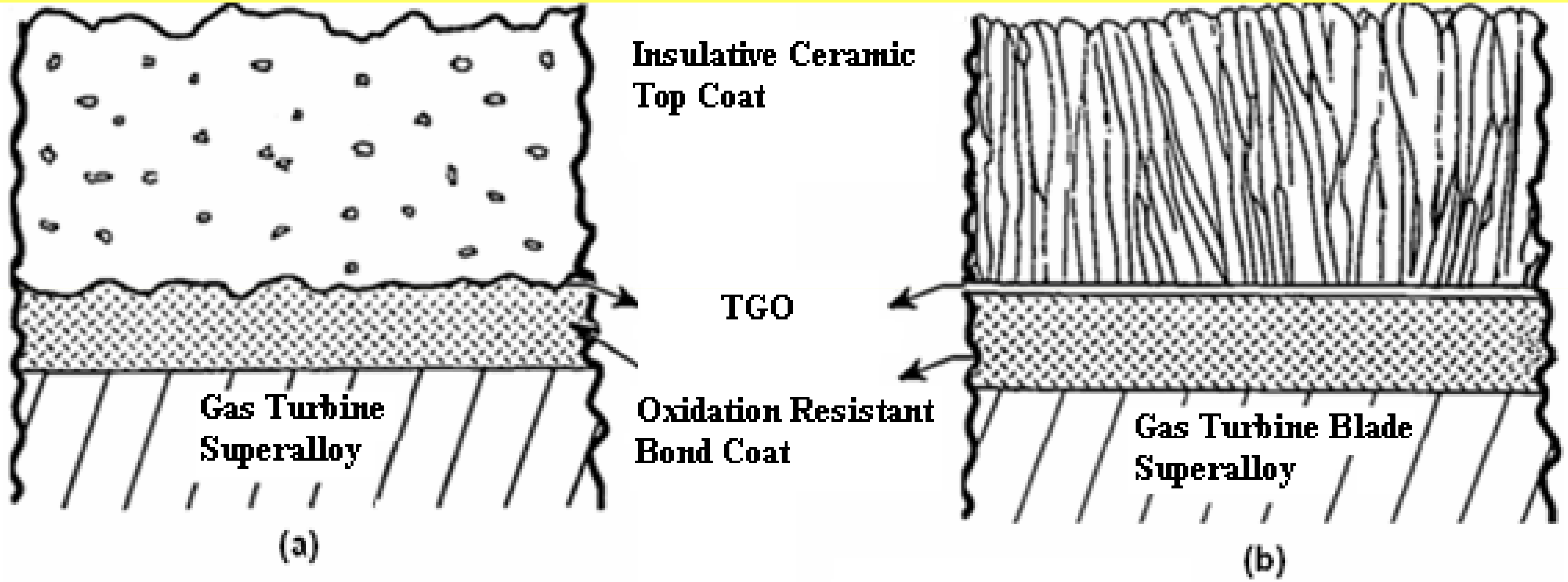
Thermal barrier coatings (TBC) are highly advanced materials systems usually applied to metallic surfaces, such as on gas turbine or aero-engine parts, operating at elevated temperatures, as a form of *exhaust heat management*.

These coatings serve to insulate components from large and prolonged heat loads by utilizing thermally insulating materials which can sustain an appreciable temperature difference between the load-bearing alloys and the coating surface. TBC coatings can allow for higher operating temperatures while limiting the thermal exposure of structural components, extending part life by reducing oxidation and thermal fatigue. In conjunction with active film cooling, TBCs permit working fluid temperatures higher than the melting point of the metal airfoil in some turbine applications.

Scheme of a typical TBC system

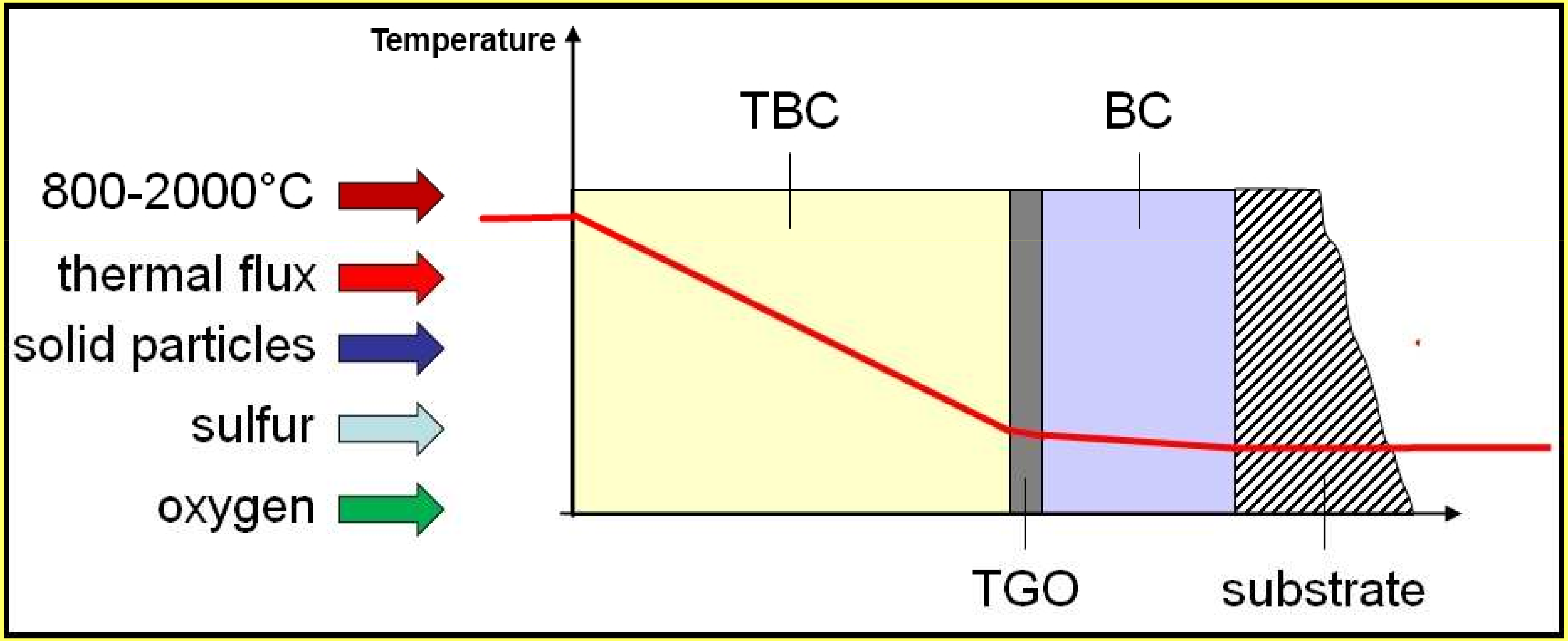


Scheme of a typical TBC system

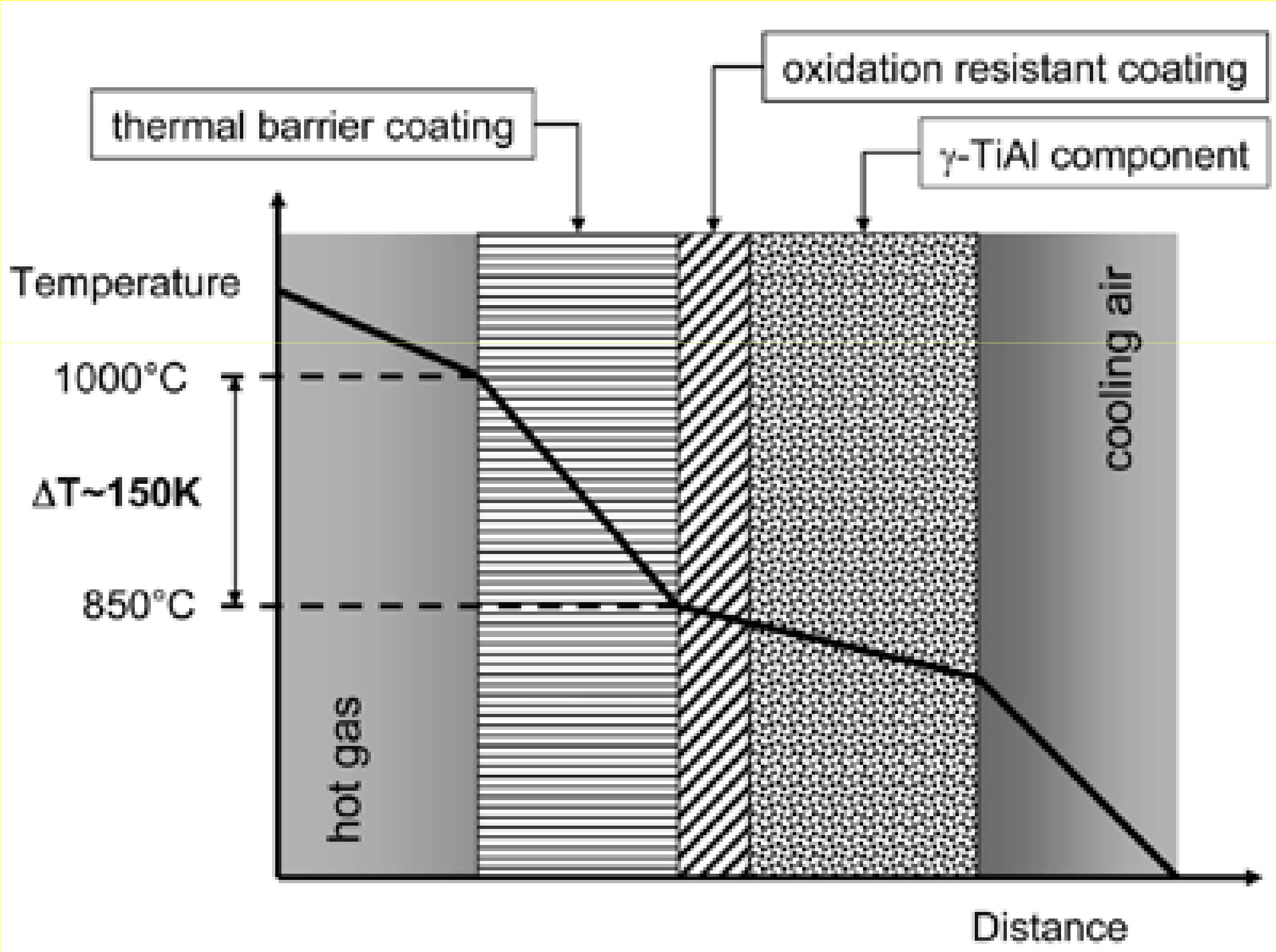


a) before and b) after oxidation

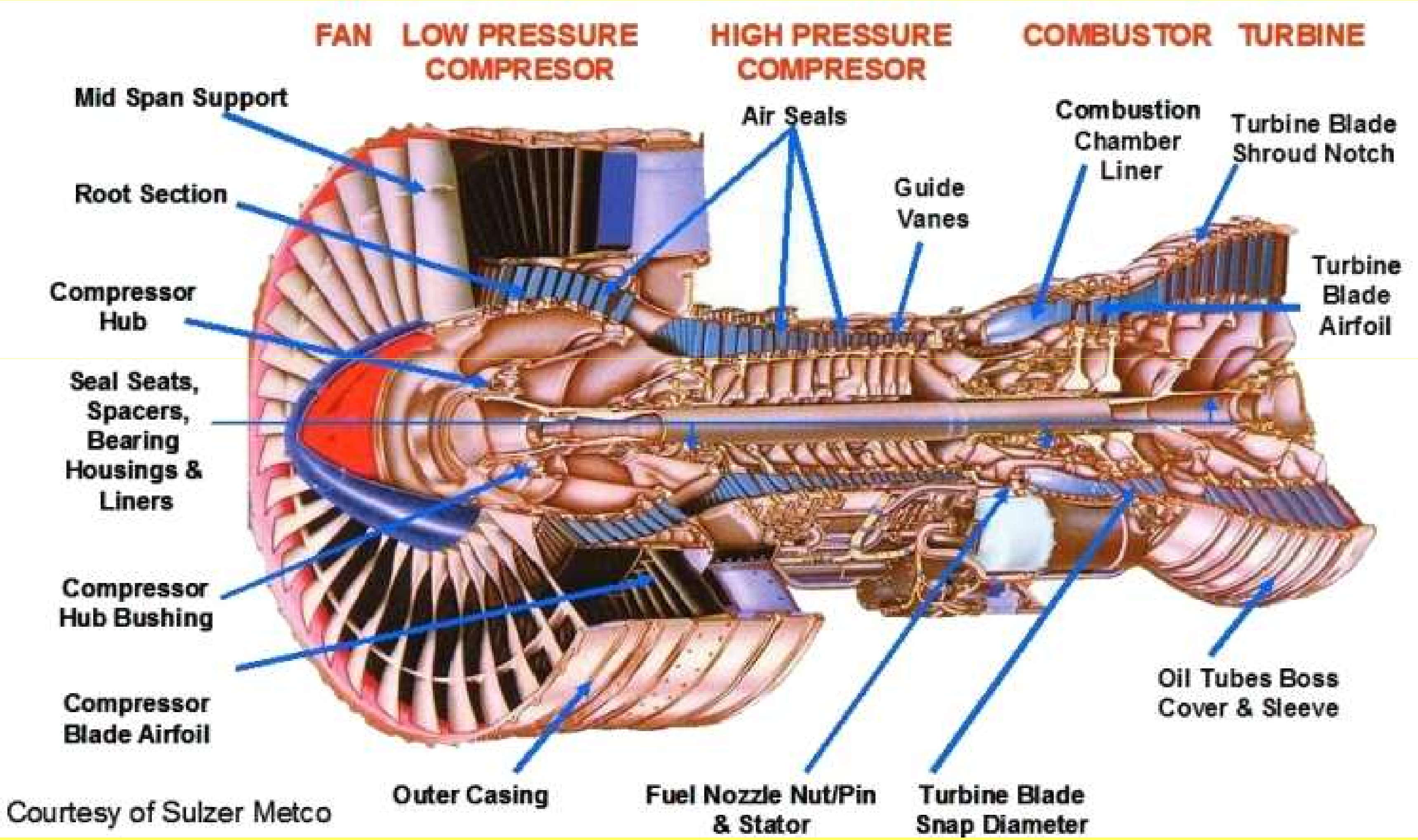
Scheme of the structure of a thermal barrier coating with a temperature profile



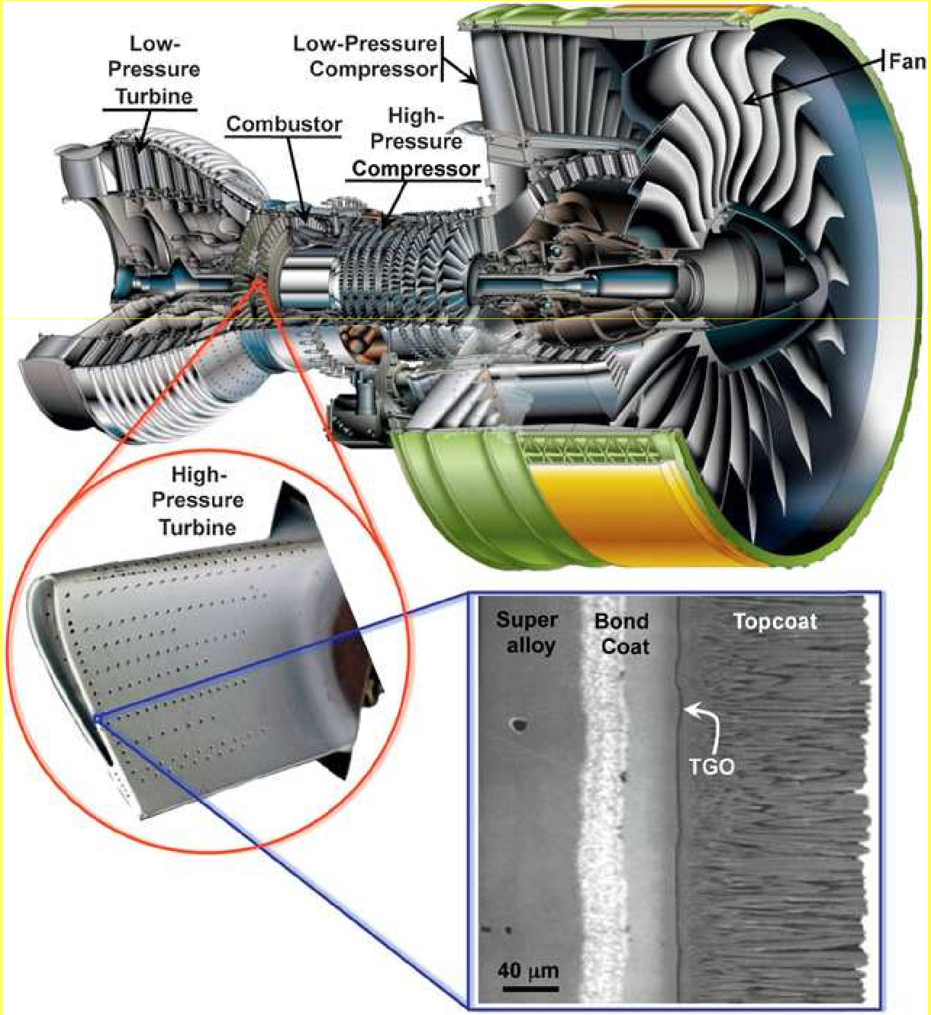
Scheme of the structure of a thermal barrier coating with a temperature profile



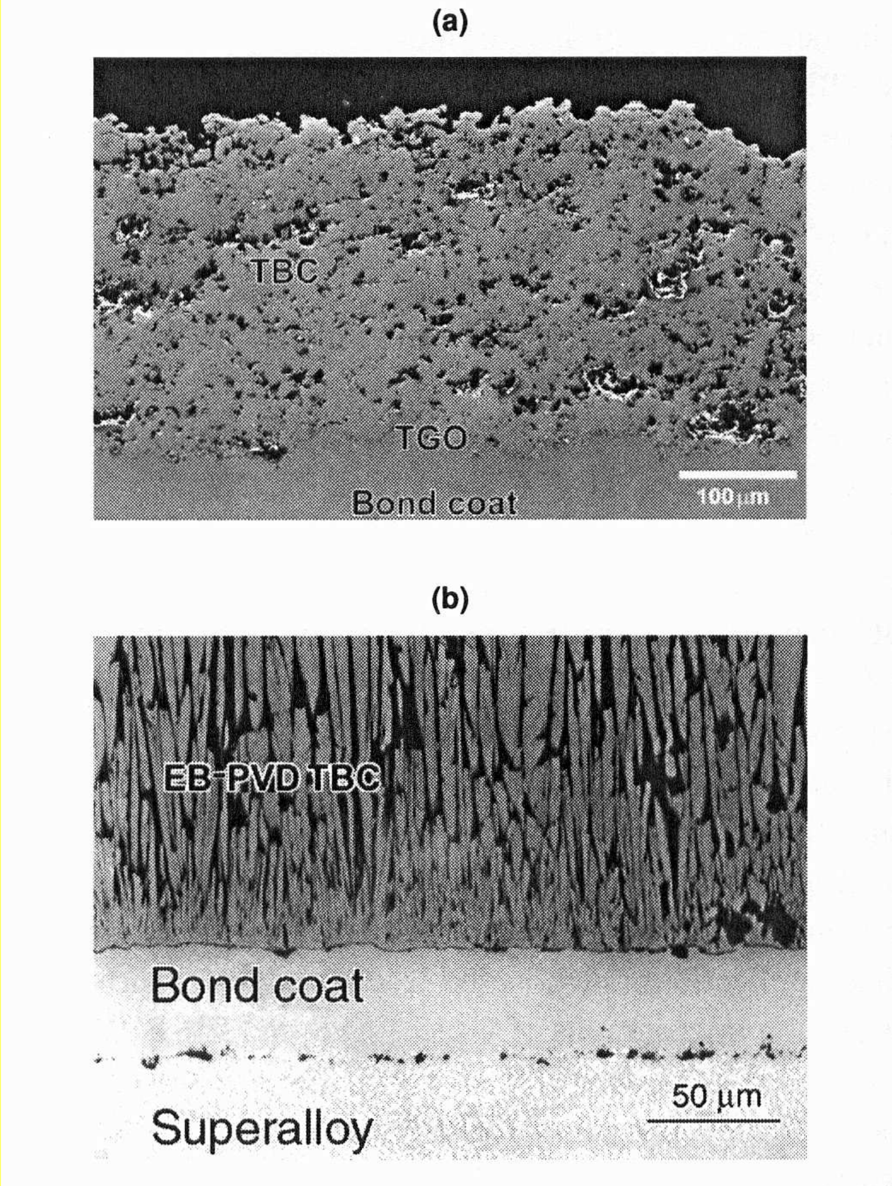
The parts of an aircraft engine using a plasma spray coating



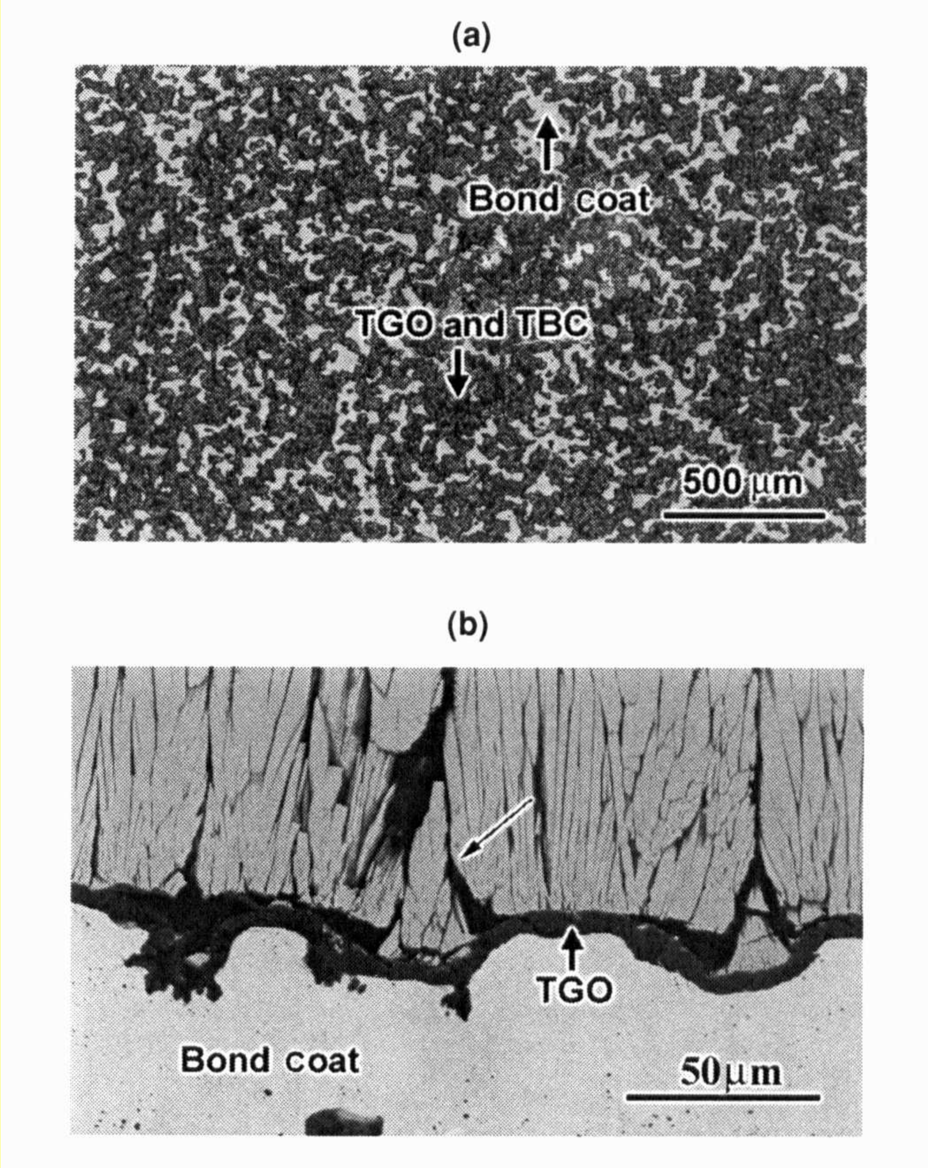
View of Engine Alliance GP7200 aircraft engine with photograph of a turbine blade (~ 10 cm long) with thermal-barrier coating (TBC) from the high-pressure hot section of an engine, and a scanning electron microscope (SEM) image of a cross-section of an electron beam physical vapor deposited 7 wt% yttria-stabilized zirconia TBC.



Cross-sections of TBC coatings



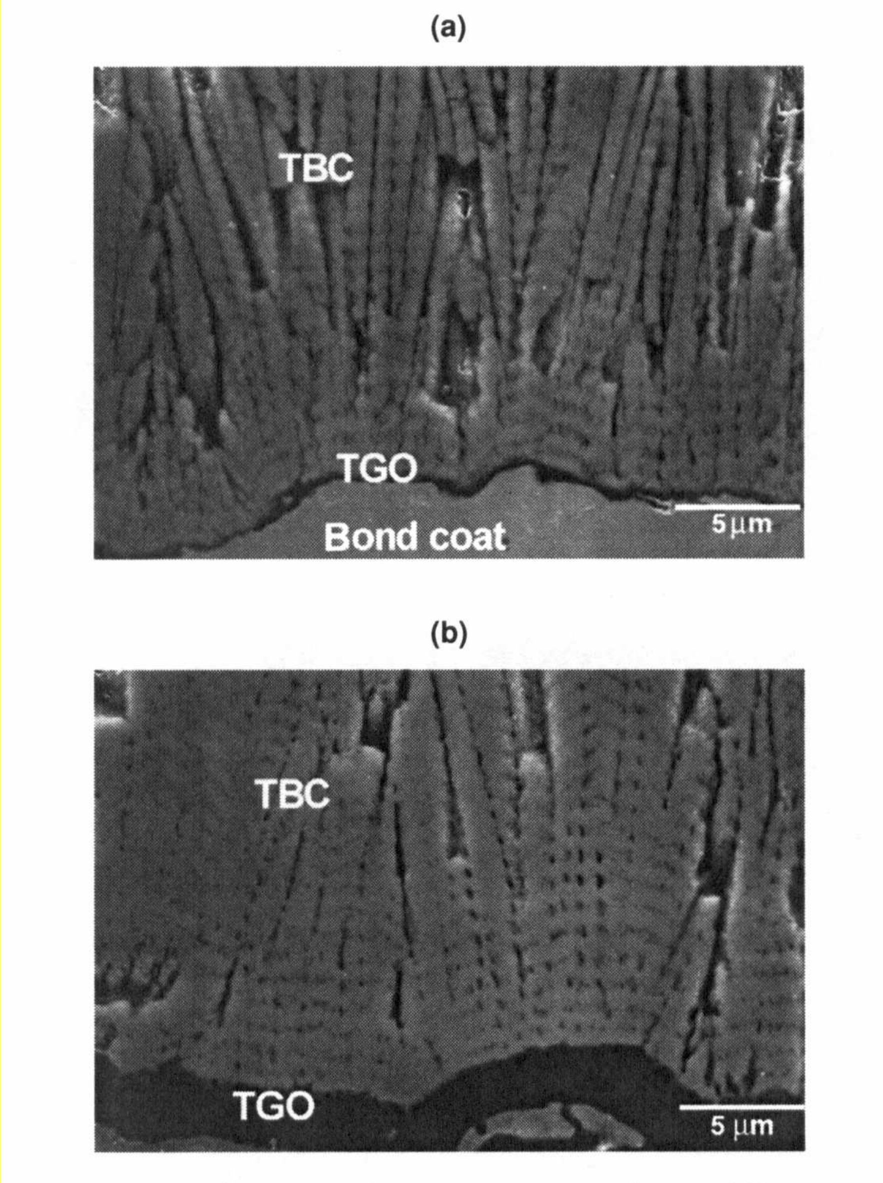
Surface and cross-sections of a layer of TBC protective coating after oxidation



EB-PVD YSZ TBC

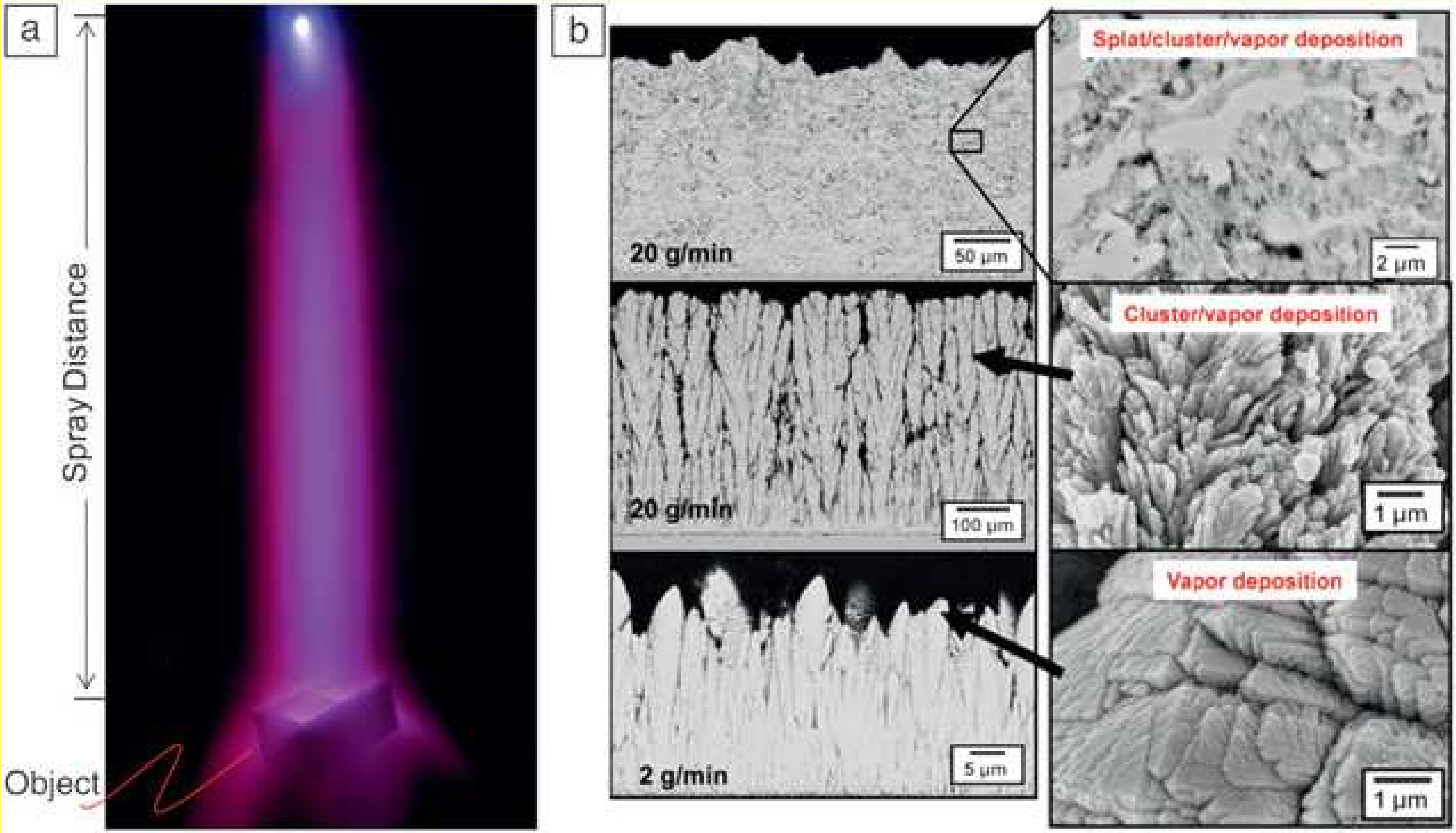
Pt-modified bond coat

Cross sections of a layer of TBC protective coating after oxidation

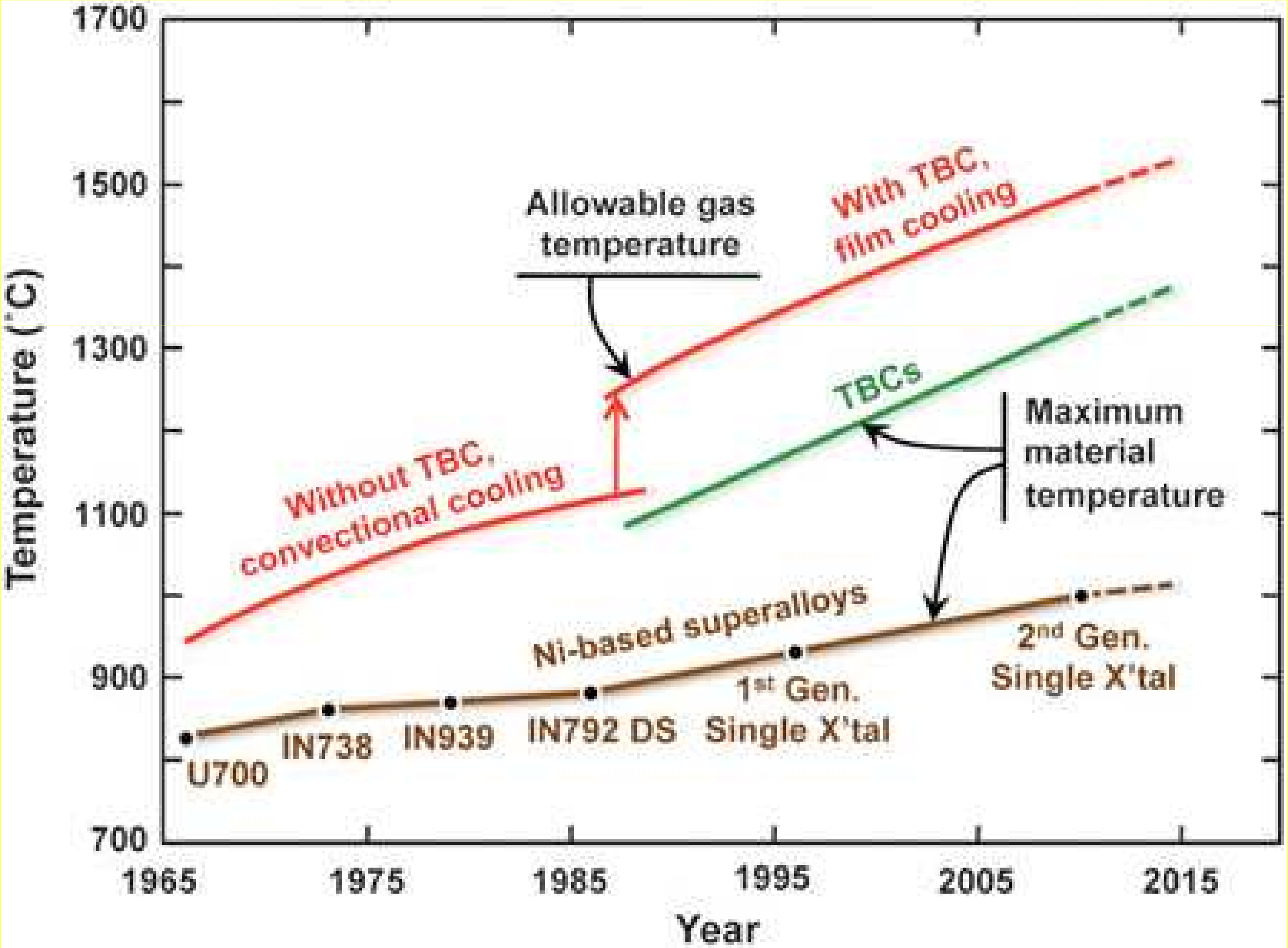


EB-PVD YSZ TBC

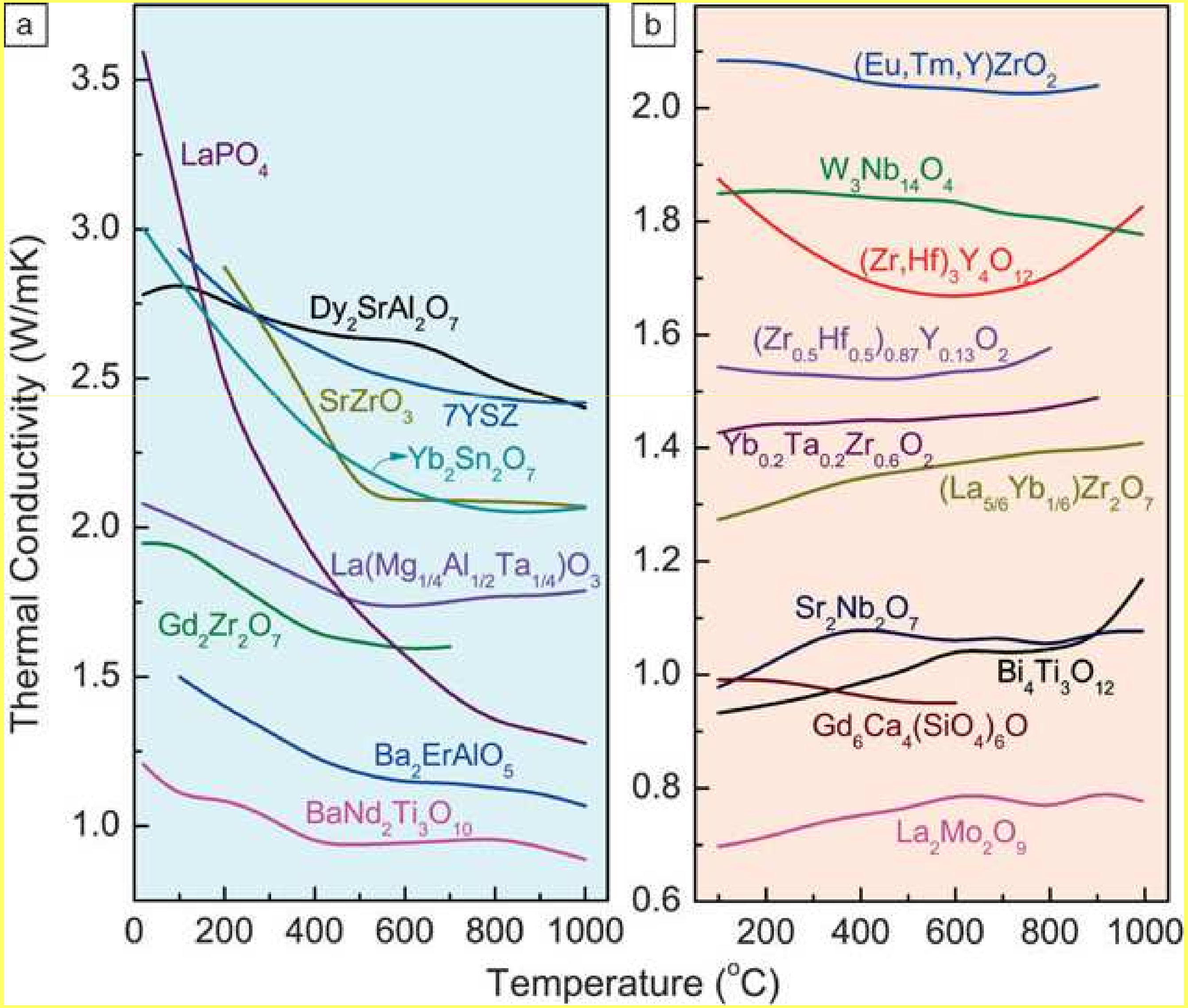
Photograph of a plasma spray physical vapor deposition (PSPVD) plume coating (a) and (b) scanning electron microscopy images of PSPVD microstructures from splat/cluster deposition all the way to vapor deposition obtained at different deposition rates



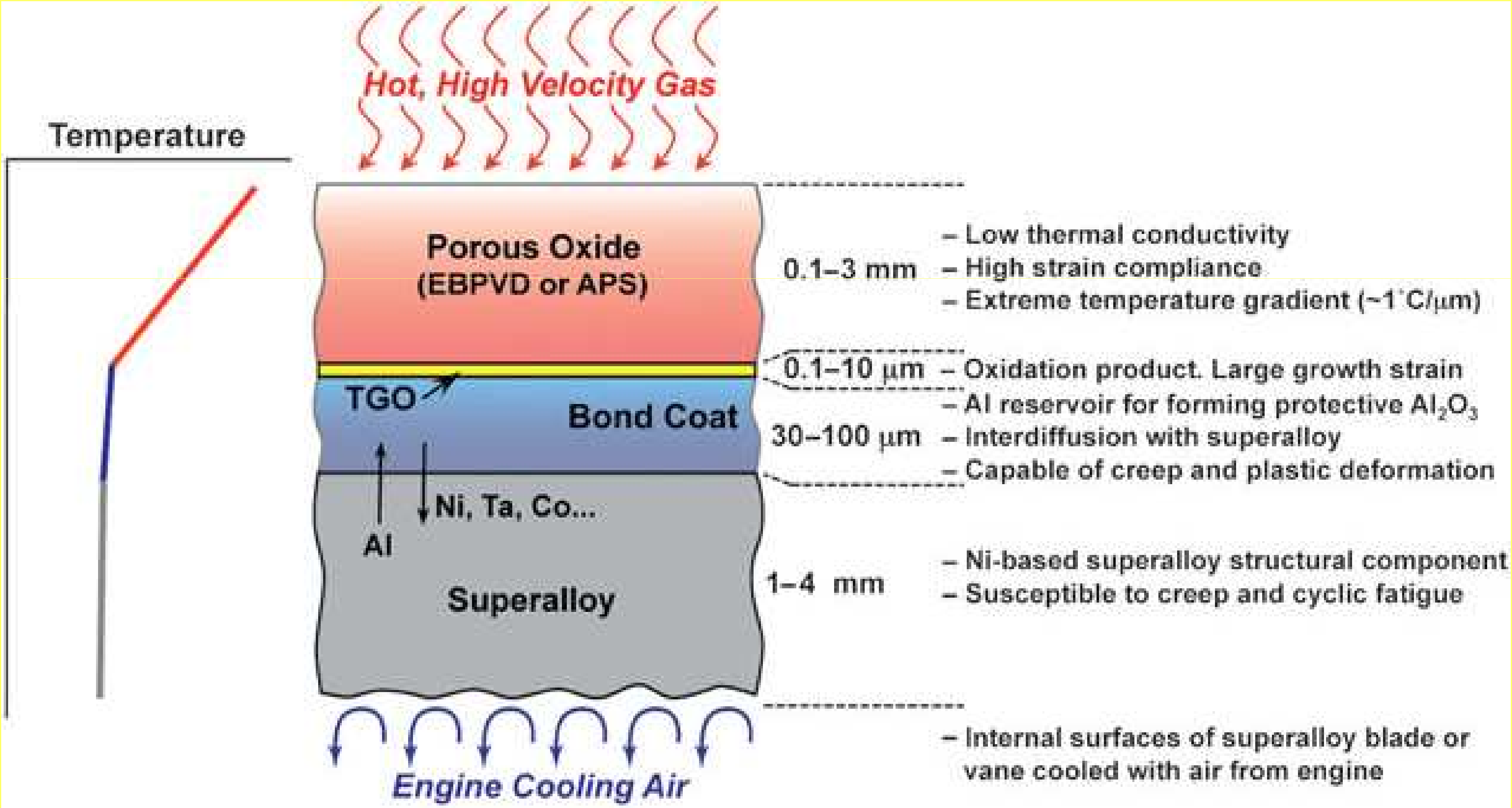
Progression of temperature capabilities of Ni-based superalloys and thermal-barrier coating (TBC) materials over the past 50 years. The red lines indicate progression of maximum allowable gas temperatures in engines, with the large increase gained from employing TBCs.



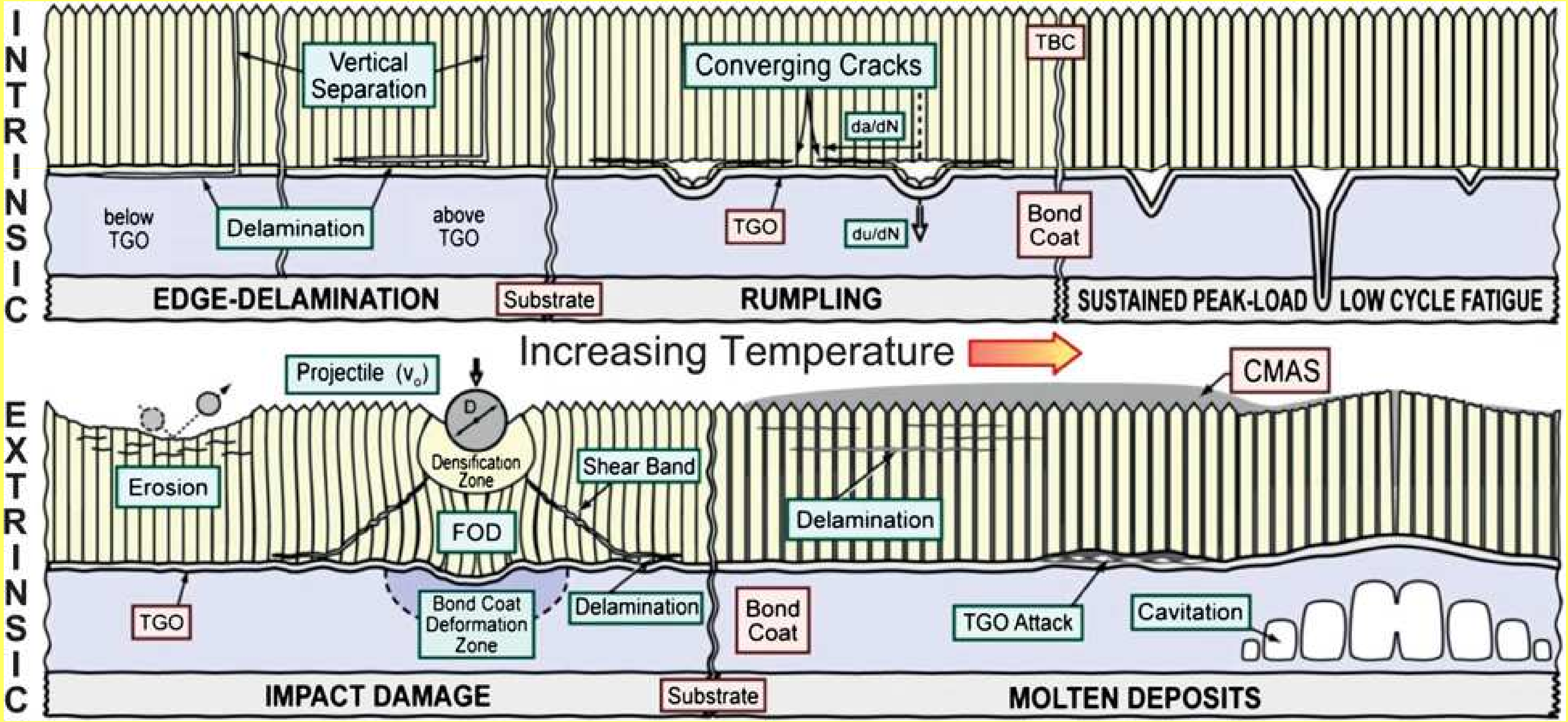
Thermal conductivity summary of the emerging ceramics for thermal-barrier coatings, whose conductivities vary with temperature (a) and temperature-independent thermal conductivities of ceramics (b)



Schematic illustration of the multilayer, multifunctional nature of the thermal barrier coating system. The ceramic topcoat is deposited by electron beam physical vapor deposition (EBPVD) or air plasma-spraying (APS).

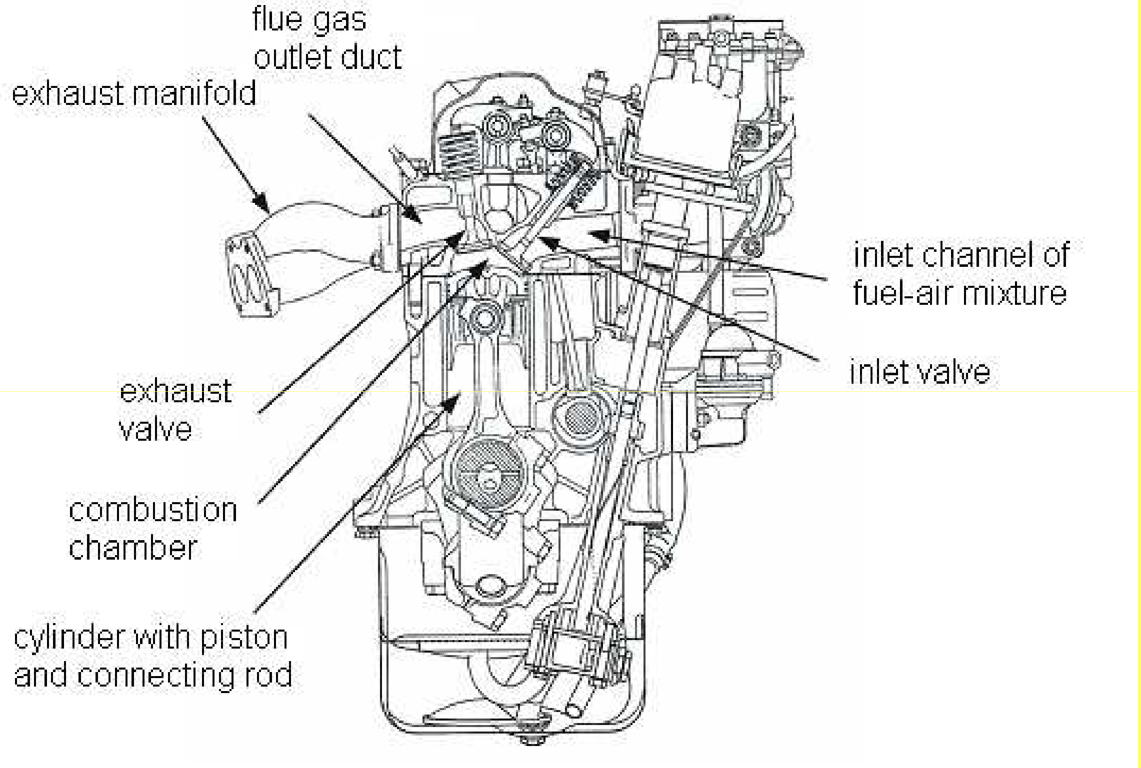


Failure mechanisms typical of current thermal-barrier coatings (TBCs): delamination cracks propagating through the TBC, chemical attack of the thermally grown oxide (TGO) with concomitant loss of adherence, creep cavitation of the bond coat below a heavily penetrated TBC



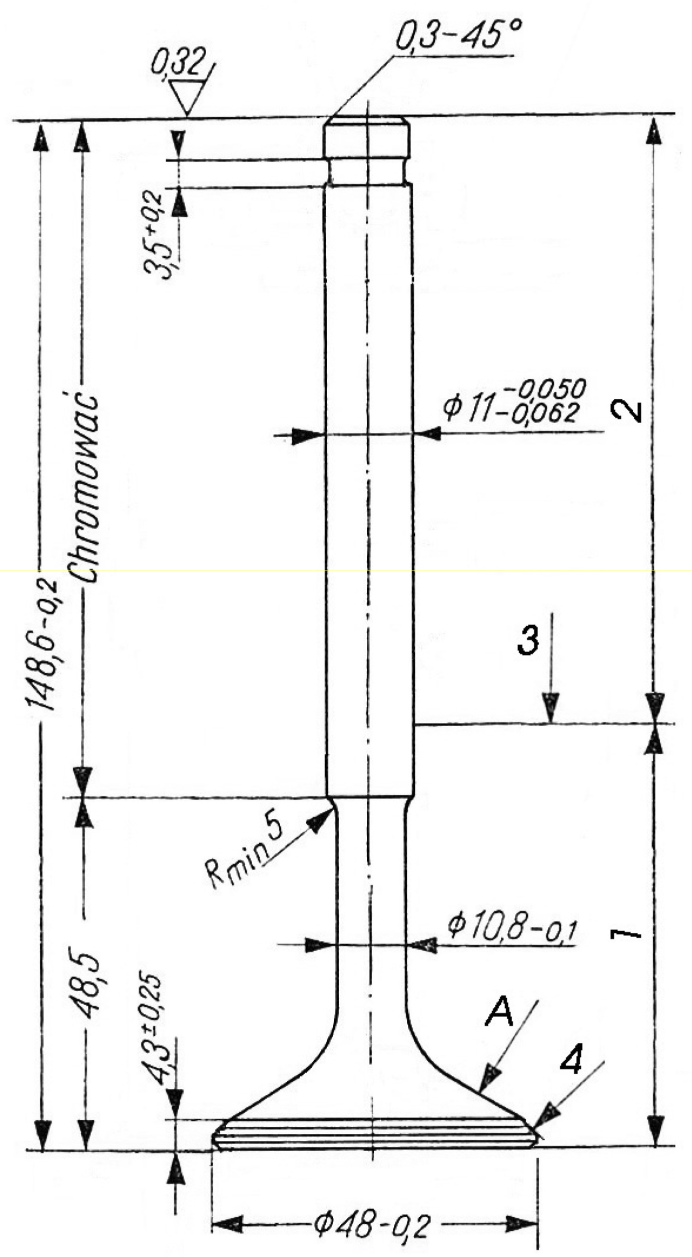
Thermal barrier coatings in automobiles

Cross section of four-cylinder in-line engine with spark ignition, Fiat



M. Bernhardt, S. Dobrzyński, E. Loth, *Silniki samochodowe*, Wydawnictwo Komunikacji i Łączności, Warszawa, 1988, s.327

Construction of an exhaust valve

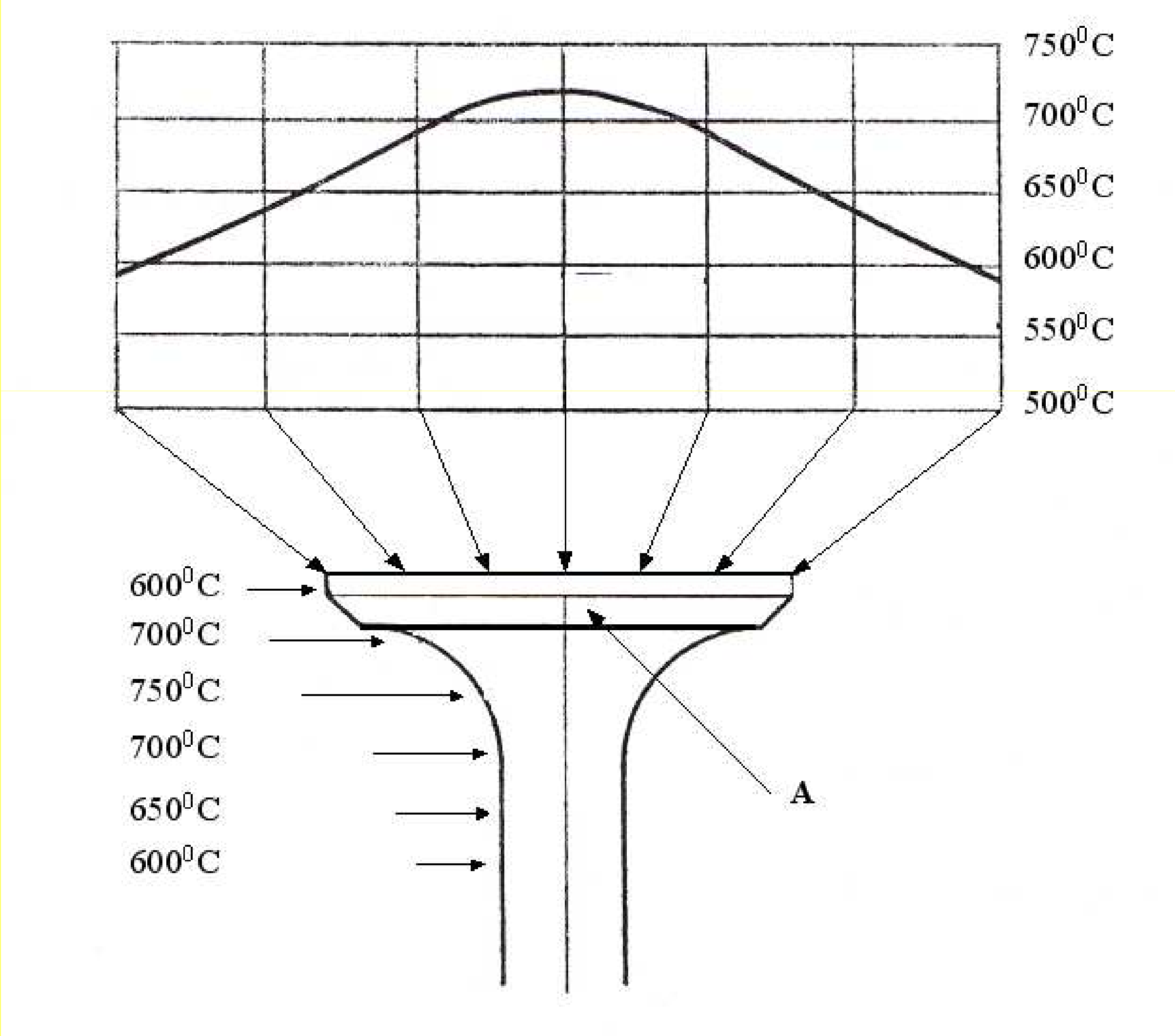


1 – mushroom - austenitic steel Cr-Ni-W-Mo in supersaturated and aged state,
2 – handle - Cr-Si-Mo steel thermally improved,
3 – place of friction welding,
4 – valve face hard coated of stellite Co-Cr-W

Working conditions of valves in car engines

- aggressive atmosphere of combustion gases
- high temperature ($T \approx 1173$ K)
- rapid changes of temperature (thermal shocks)

Temperature distribution in the exhaust valve - petrol engine with spark ignition



Chemical compositions of an engine gases with spark and spontaneous ignition (wt. %)

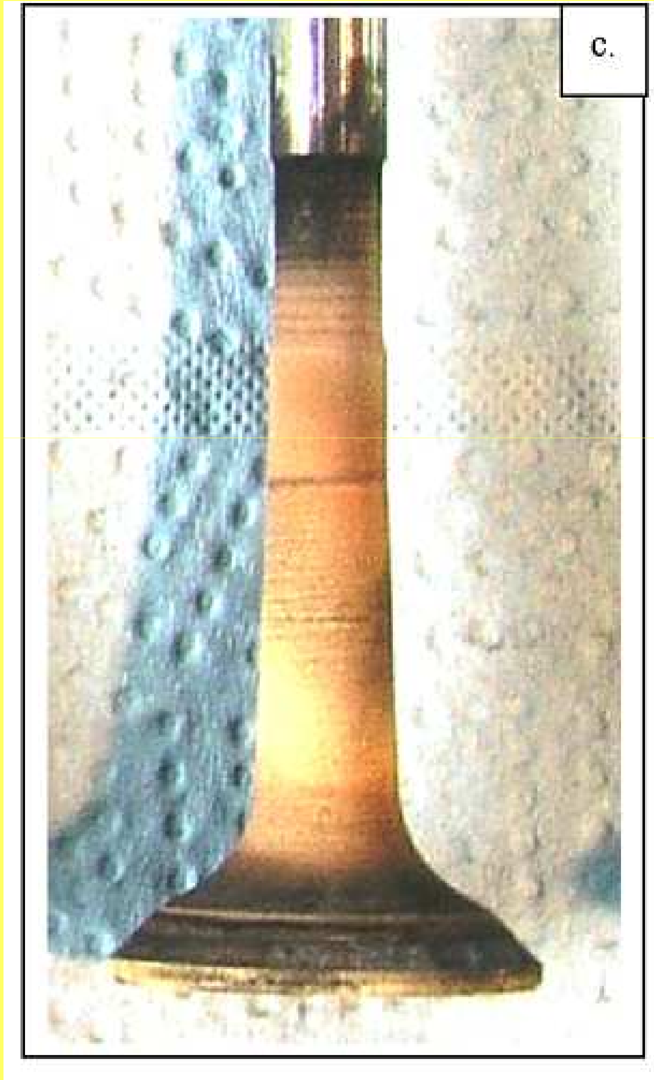
Components of exhaust gases	**Units**	**Method of ignition**		**Toxicity evaluation**
		spark ignition	**spontaneous**	
Nitrogen	% vol.	74-77	76-78	neutral
Oxygen	**% vol.**	0,3-8,0	2,0-18,0	as above
Water vapor	**% vol.**	3,0-5,5	0,4-5,0	as above
Carbon dioxide	**% vol.**	5,0-12,0	1,0-10,0	as above
Carbon monoxide	% vol.	5,0-10,0	0,01-0,5	toxic
Nitrogen oxides	% vol.	0,0-0,8	0,002-0,5	as above
Hydrocarbons	% vol.	0,2-3,0	0,009-3,0	as above
Aldehydes	% vol.	0,0-0,2	0,001-0,009	as above
Soot	g/m^3	0,0-0,04	0,01-1,1	as above
3,4 benzopyrene	g/m^3	to 15,0	to 10,0	carcinogenic

Merkisz J., *Ekologiczne problemy silników spalinowych Tom I i II.*
Wydawnictwo Politechniki Poznańskiej, Poznań 1999

Exhaust valves after the 1000 hour test - engine with spontaneous ignition


a.

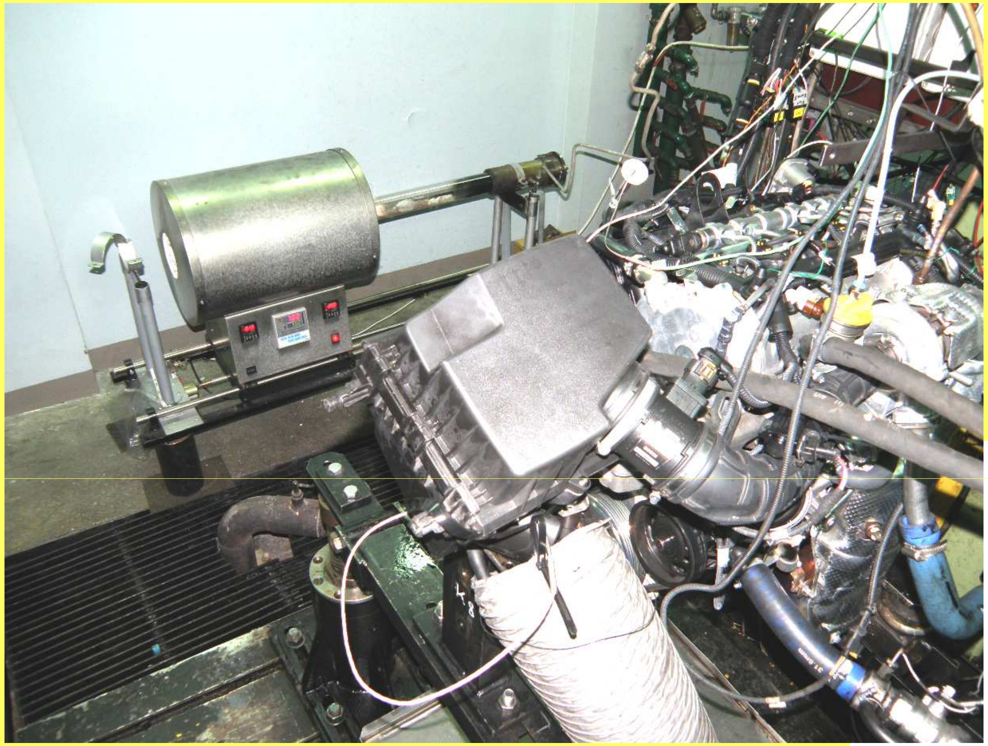

b.

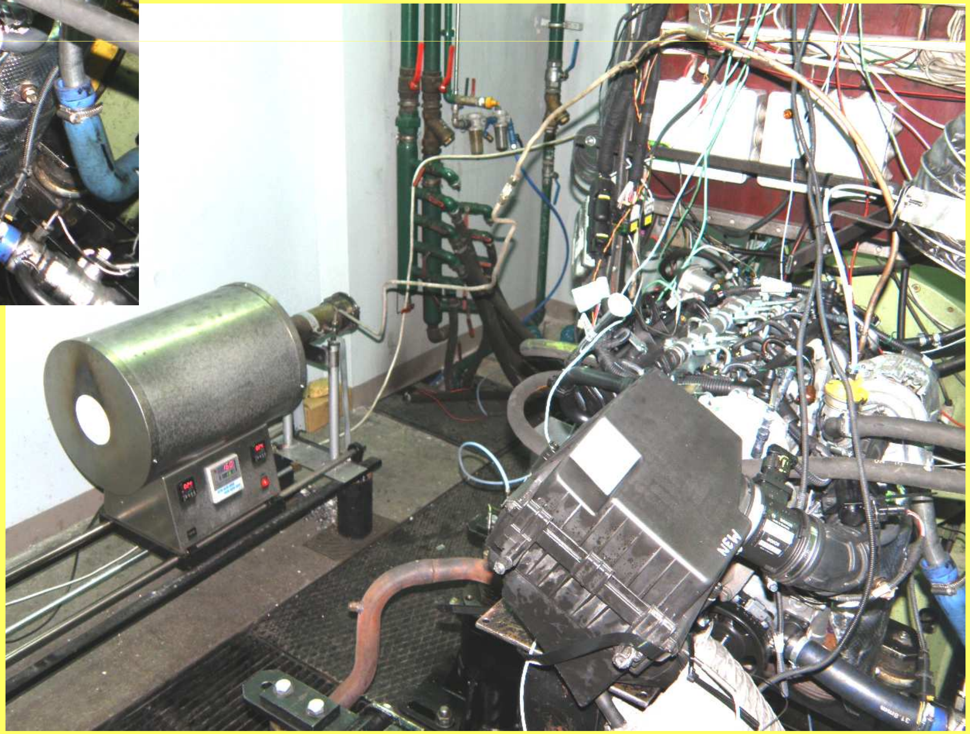

c.

The chemical composition of valve steels (% wt.)

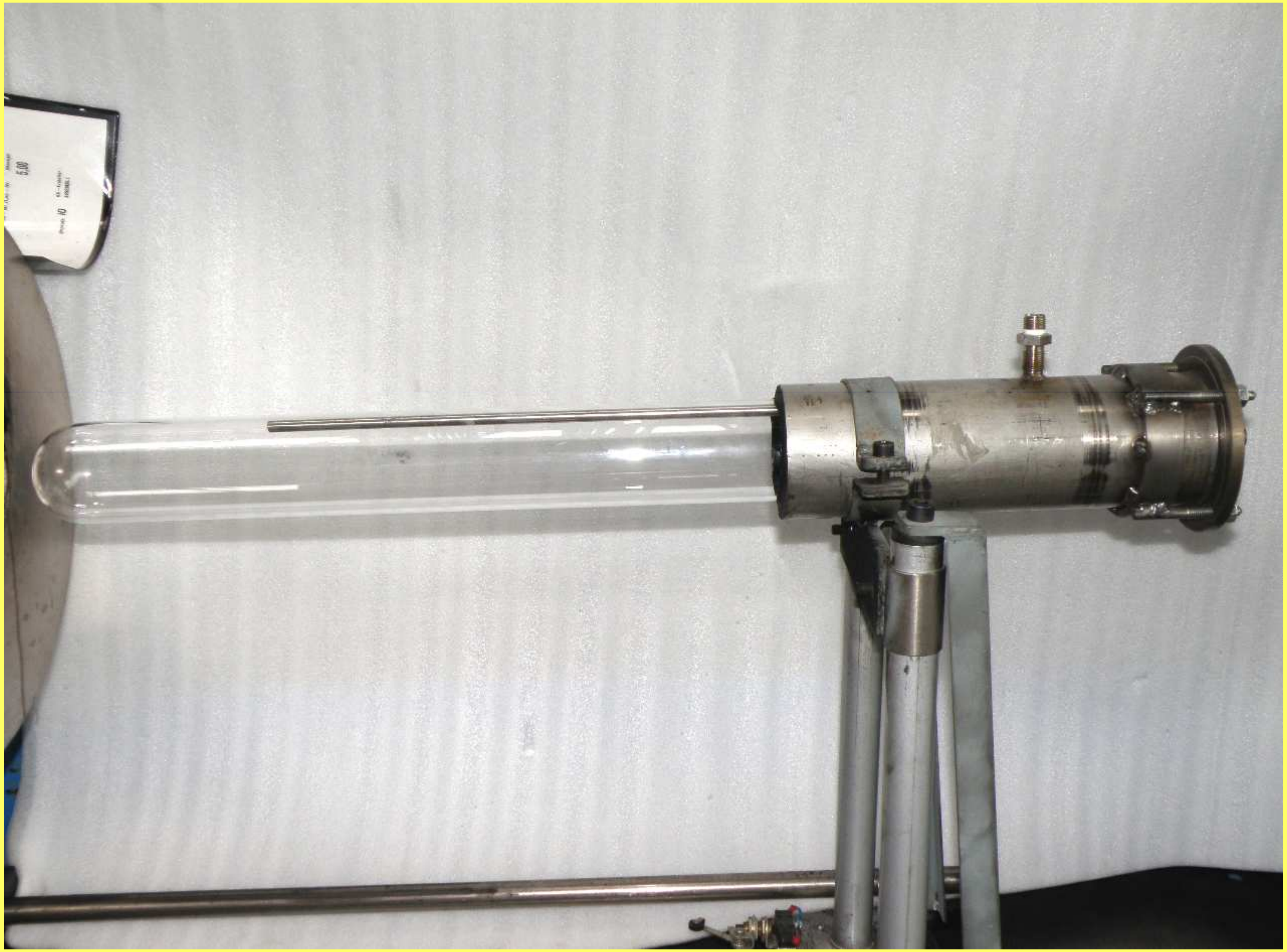
Type of steel	C	Mn	Si	Cr	Ni	N	W	Nb	S	P	Mo	Fe
X33CrNiMn23-8	0.35	**3.3**	0.63	**23.4**	**7.8**	0.28	0.02	-	<0.005	0.014	0.11	bal.
X50CrMnNiNbN21-9	0.54	**7.61**	0.30	**19.88**	**3.64**	0.44	0.86	2.05	0.001	0.031	-	bal.
X53CrMnNiN20-8	0.53	**10.3**	0.30	**20.5**	**4.1**	0.41	-	-	<0.005	0.04	0.12	bal.
X55CrMnNiN20-8	0.55	**8.18**	0.17	**20.0**	**2.3**	0.38	-	-	<0.005	0.03	0.11	bal.

The corrosion test of valve steels under thermal shock conditions in engine house

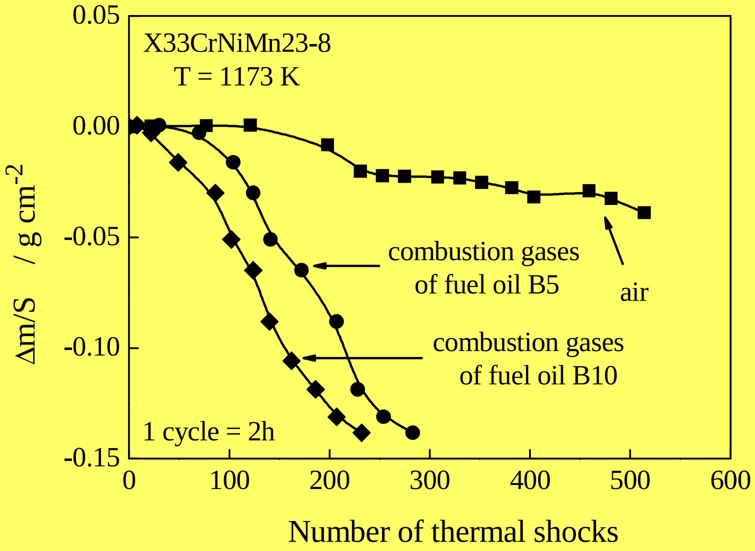


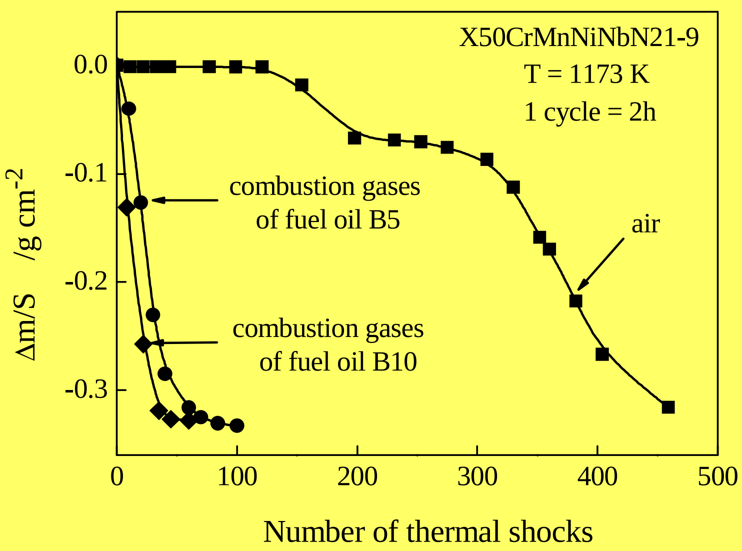


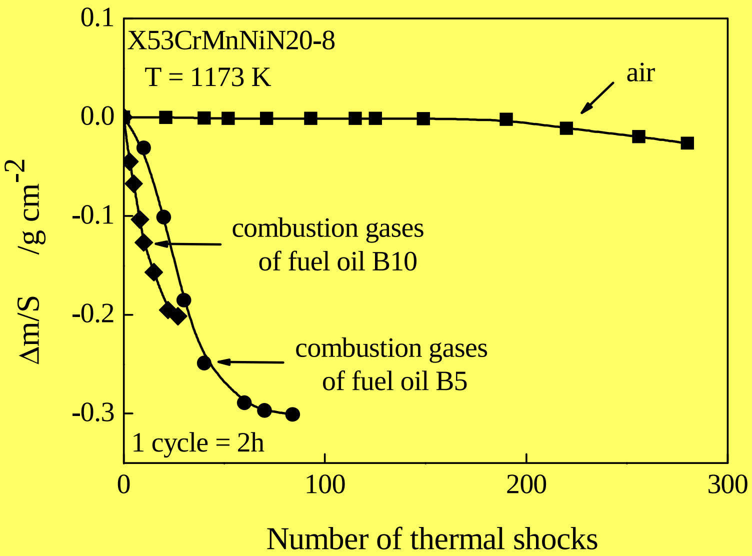
Hybrid reactive head

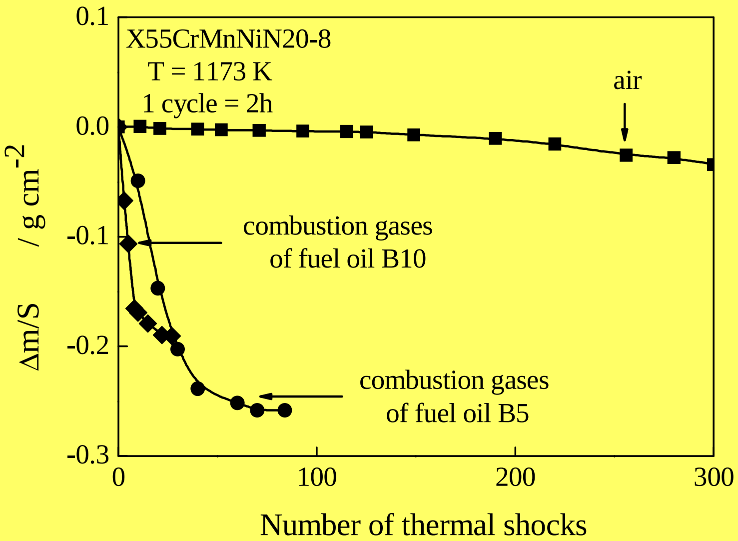


Corrosion kinetics of tested valve steels under thermal shock conditions

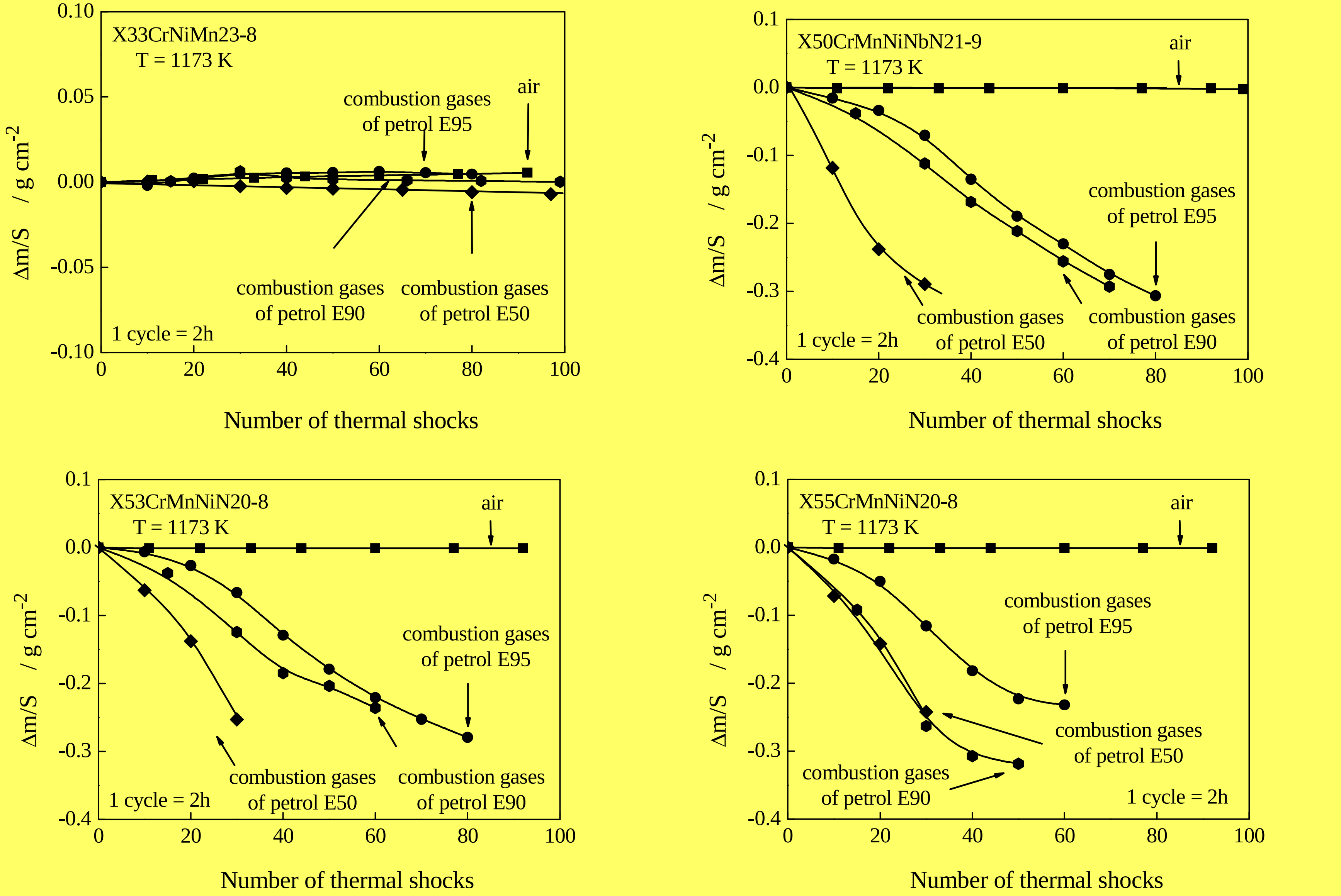




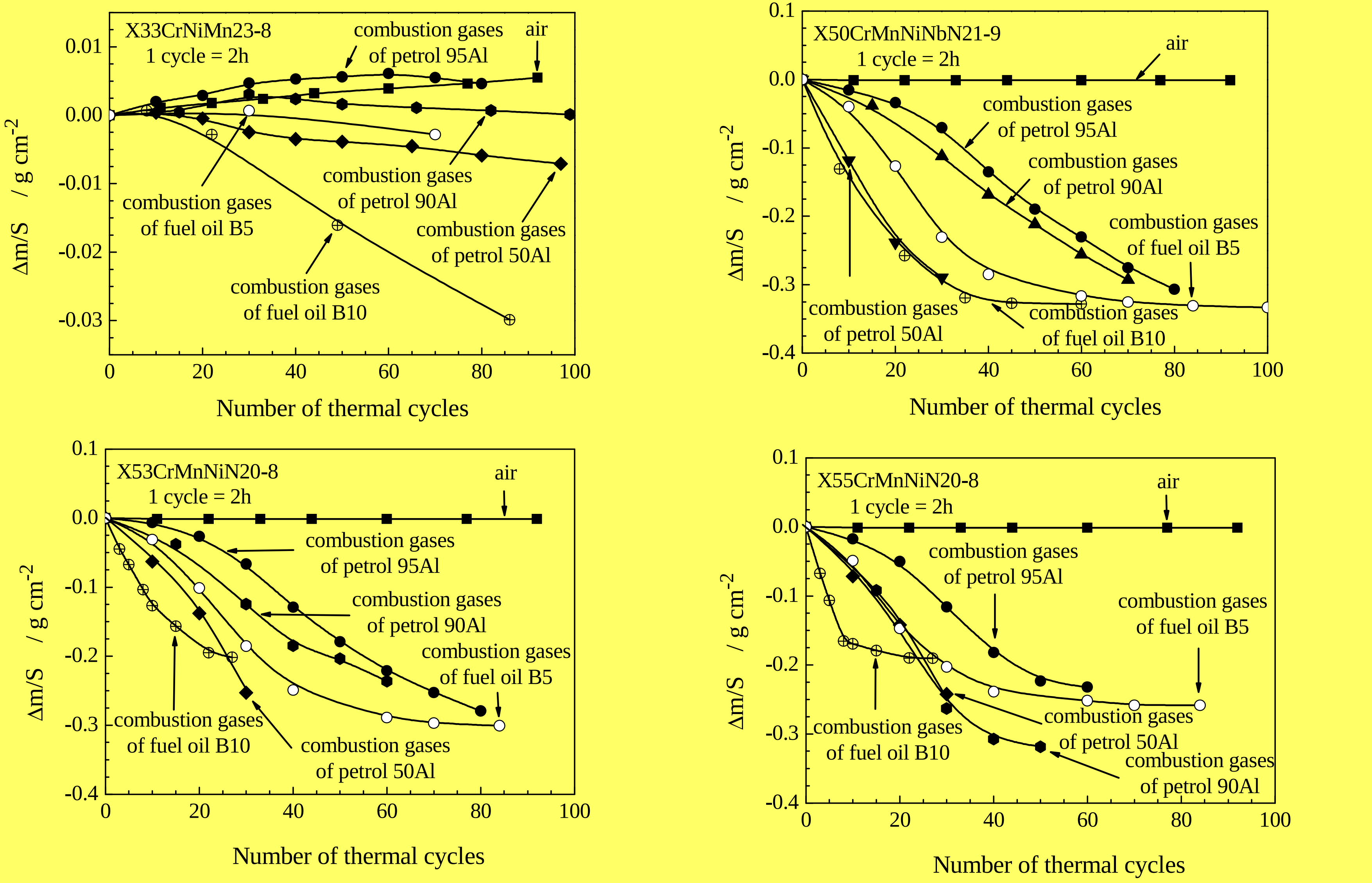




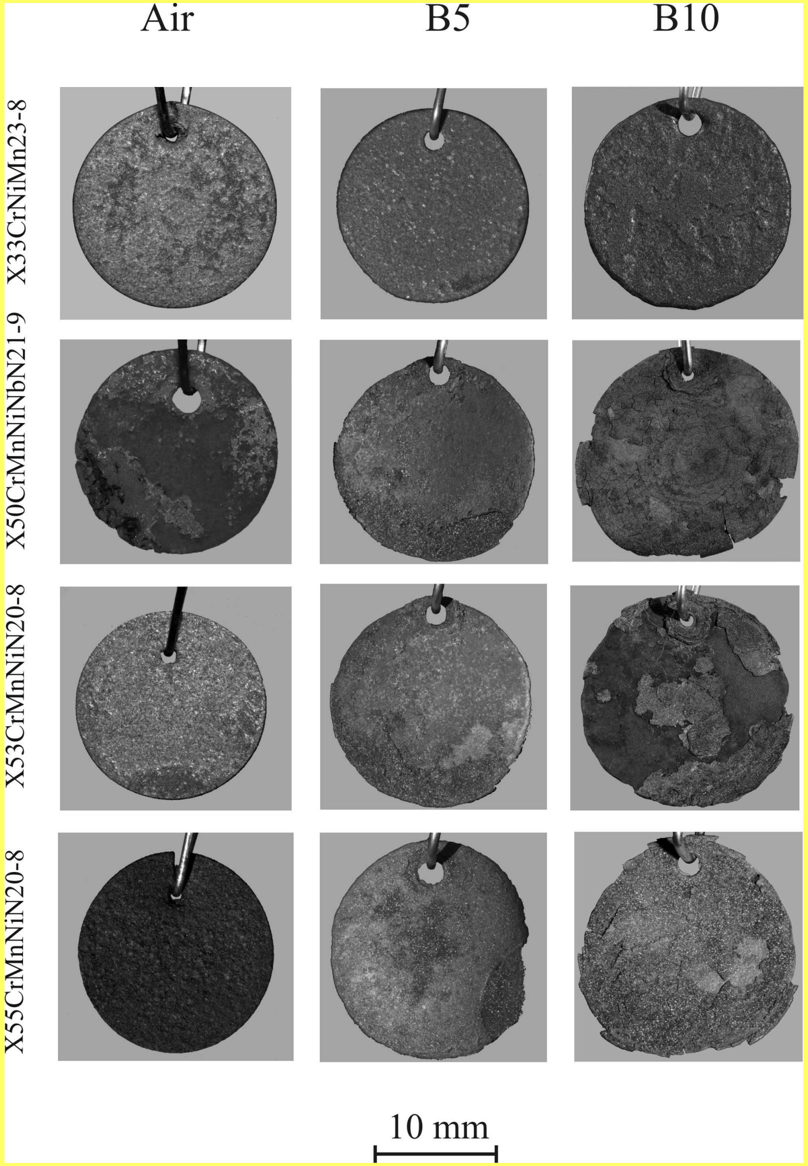
Corrosion kinetics of tested valve steels under thermal shock conditions



Comparison of corrosion kinetics of valve steels under thermal shock conditions at different atmospheres

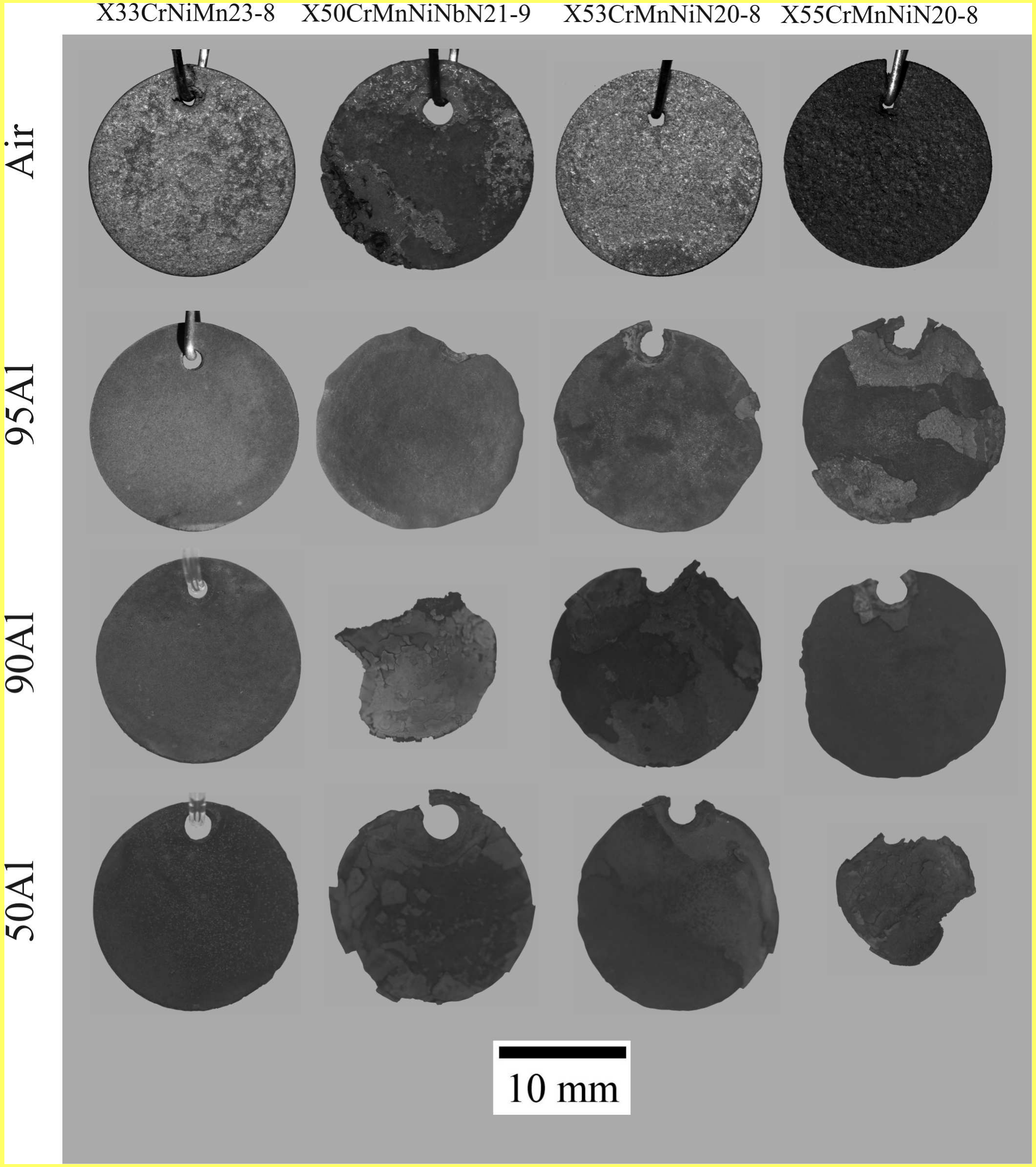


Images of valve steel samples corroded under thermal shock conditions in a number of aggressive atmospheres



T = 1173K

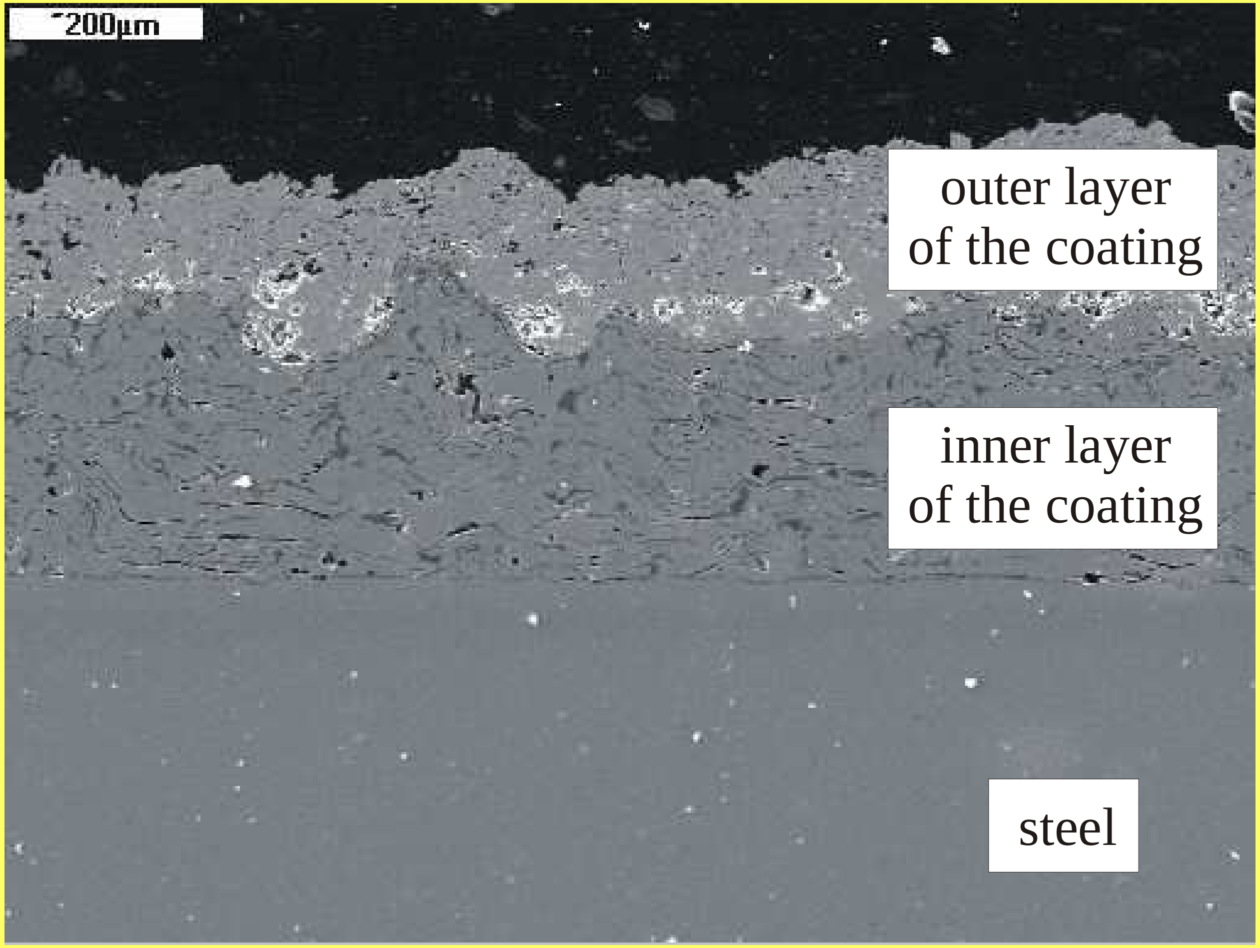
Images of valve steel samples corroded under thermal shock conditions in a number of aggressive atmospheres



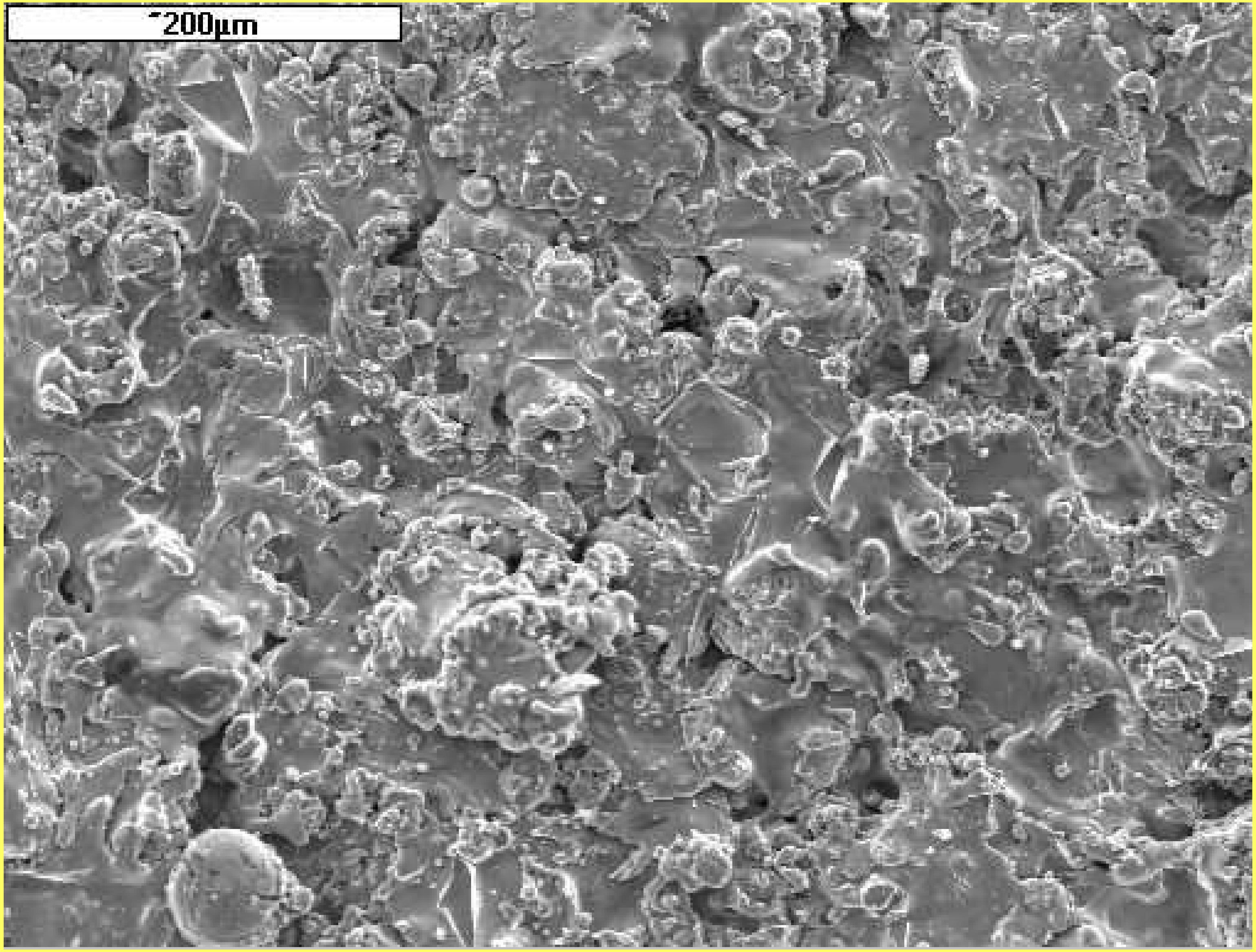
Cross-section of valve steel covered by protective coating with TBC layer

$ZrO_2 \cdot Y_2O_3$

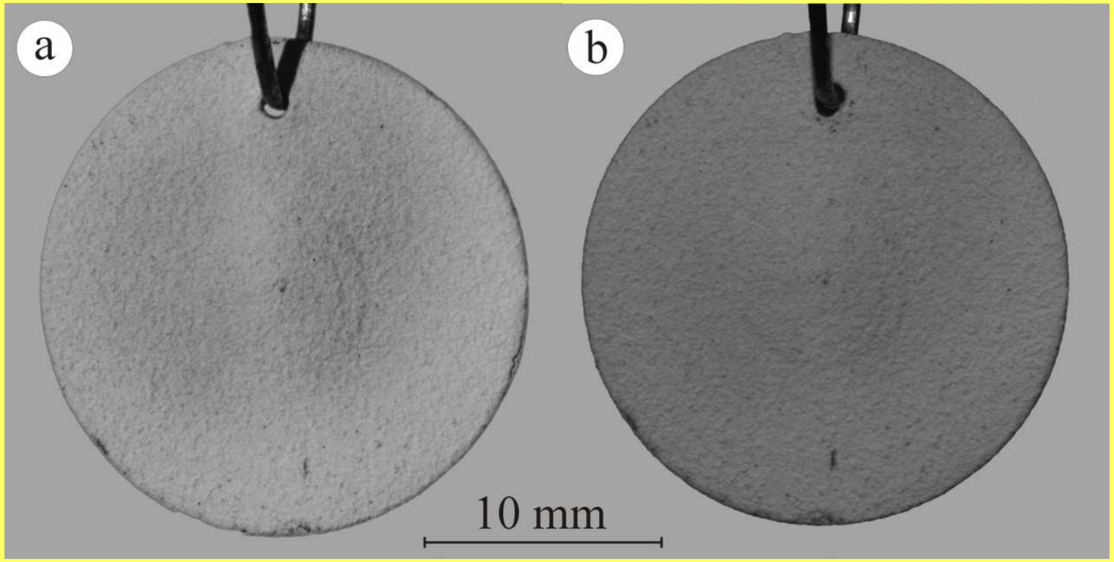
Ni22Cr10AlY



Surface of TBC layer

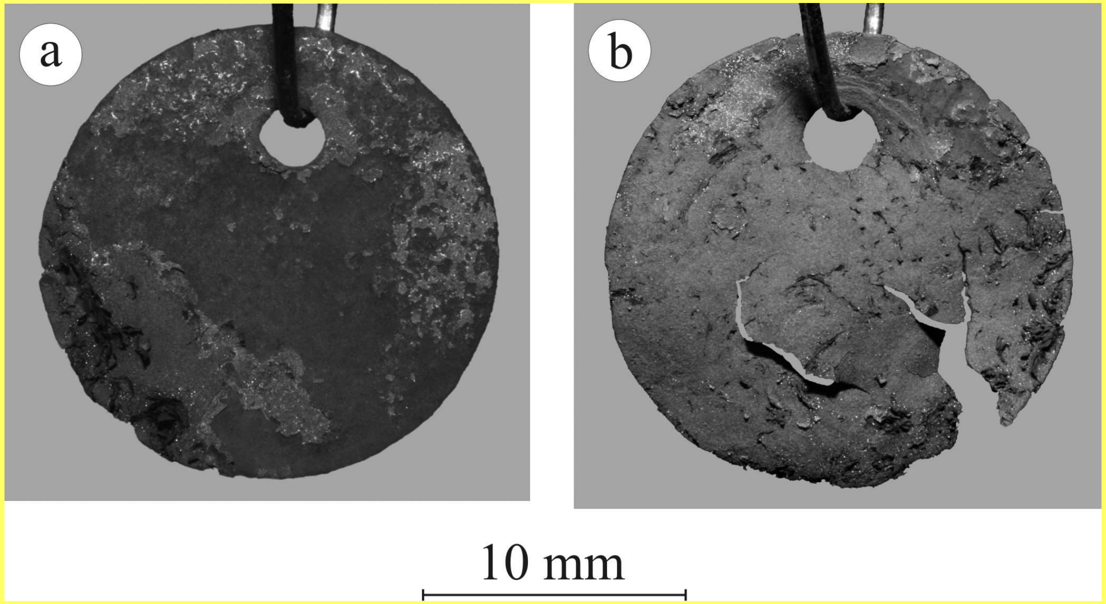


Photographs of surfaces of coated and uncoated valve steels after corrosion tests at 1173 K



a) before tests

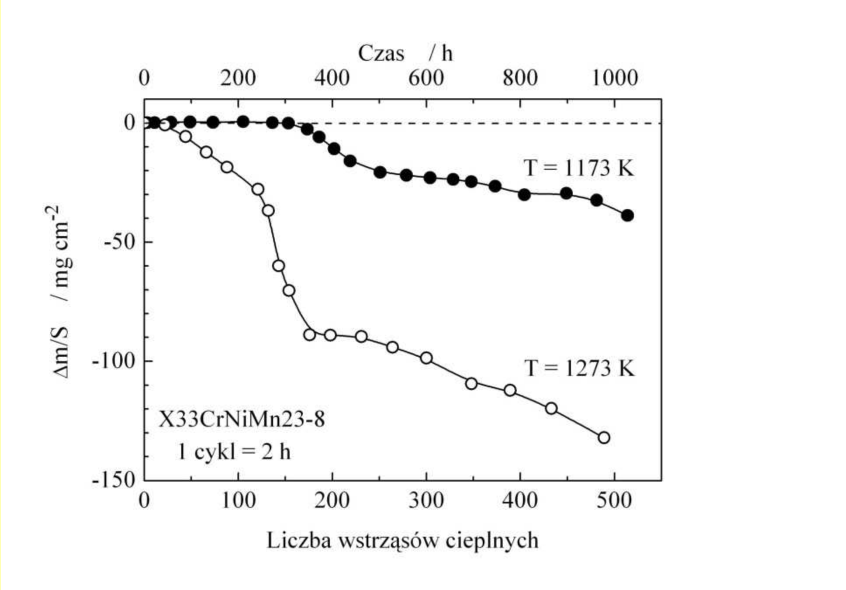
b) after 500 shocks

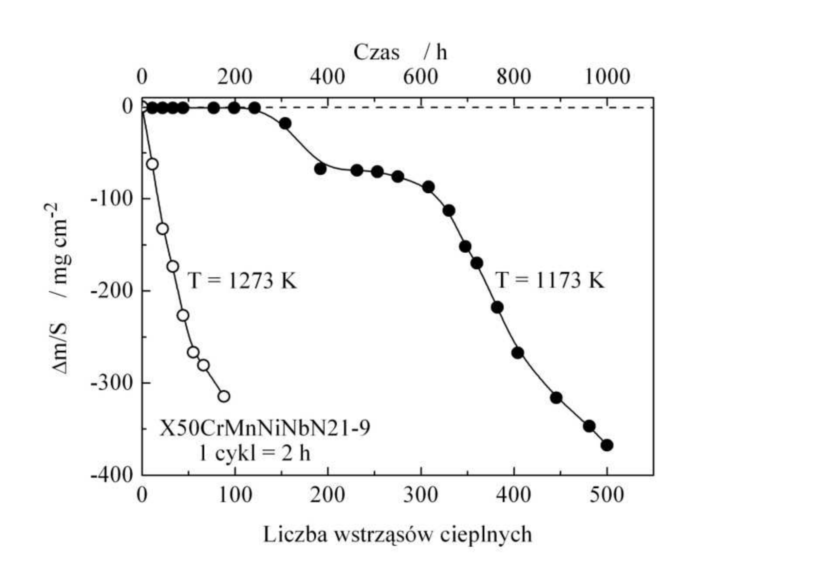


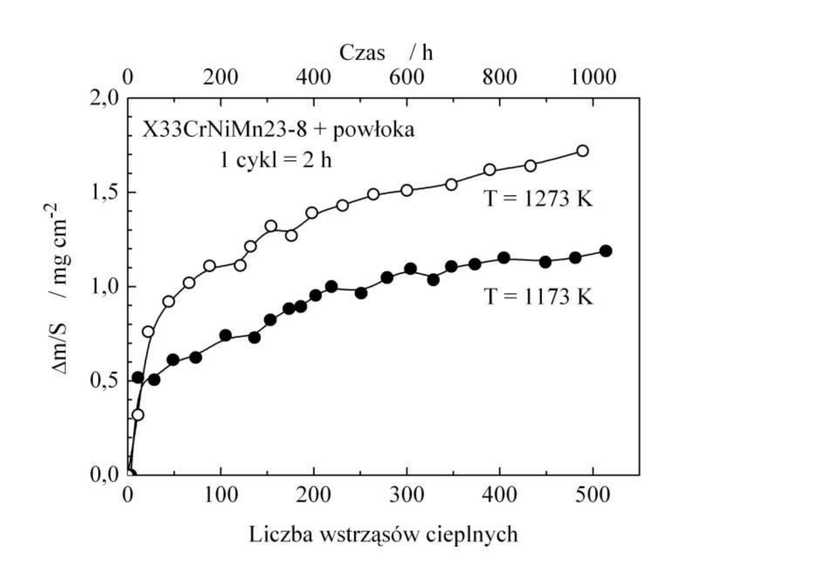
a) after 300 shocks

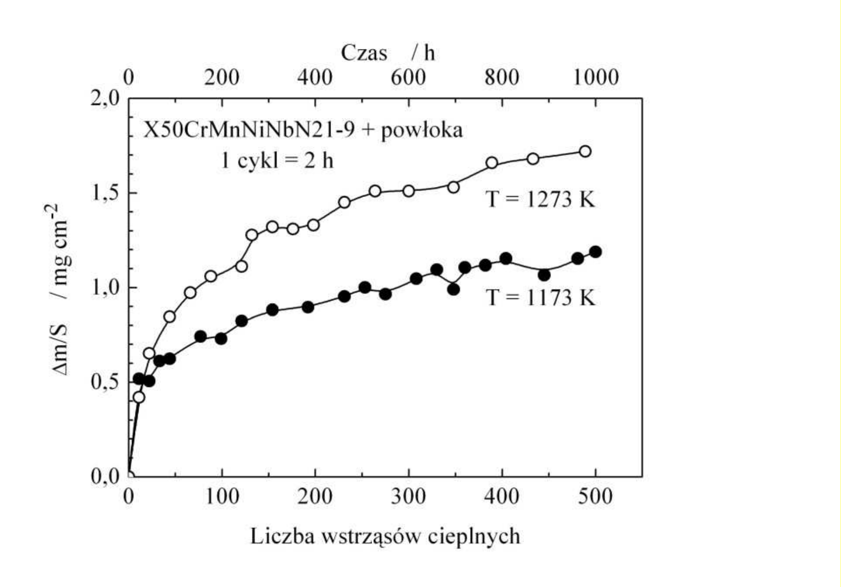
b) after 500 shocks

The results of corrosion tests of uncoated and coated valve steels

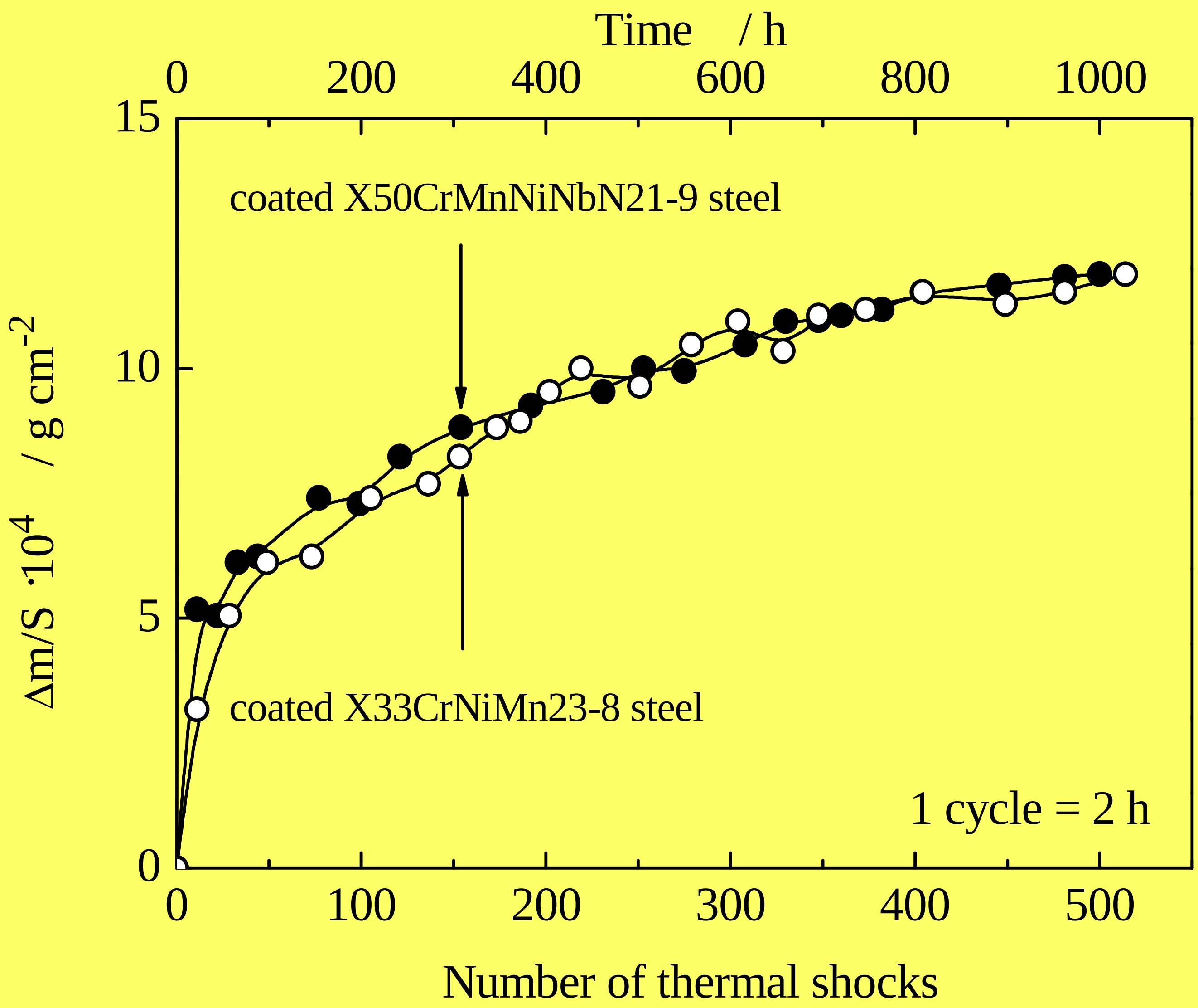




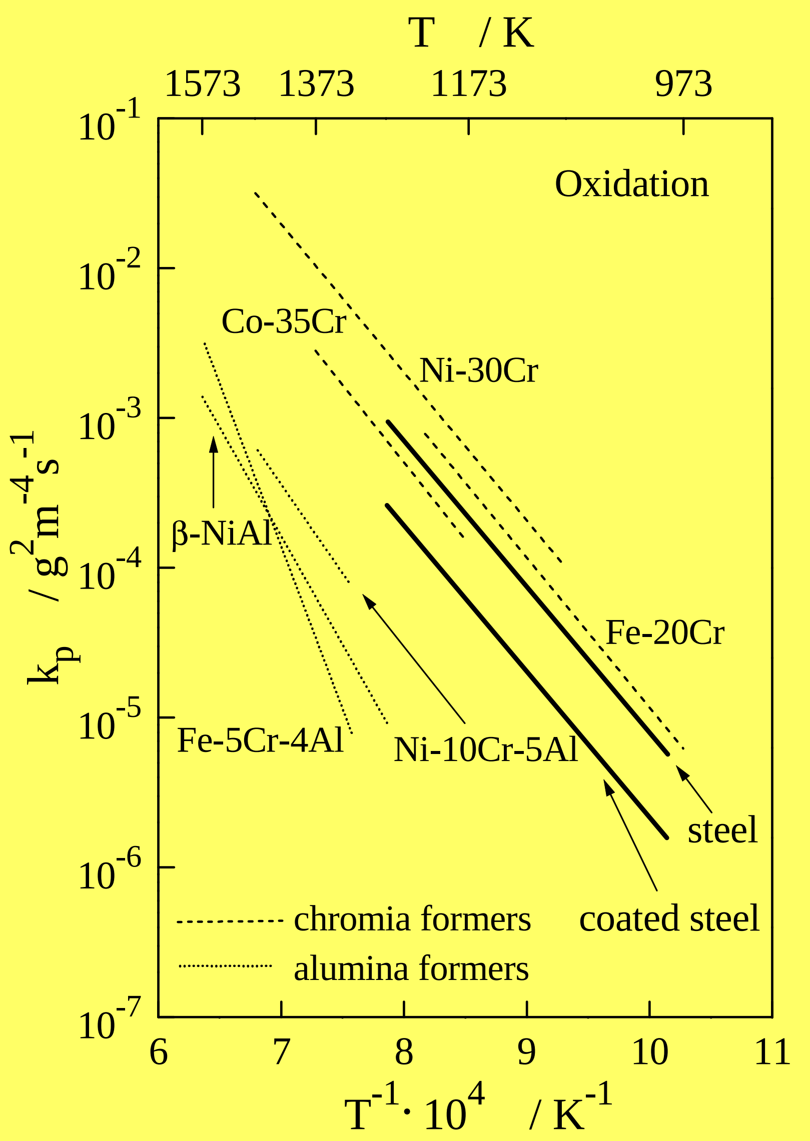




The results of corrosion tests of coated two different valve steels



Temperature dependence of the oxidation rate of steel coated with a protective coating



THE END