Use of diffraction in determine the residual stress of HVOF WC-17Co coatings

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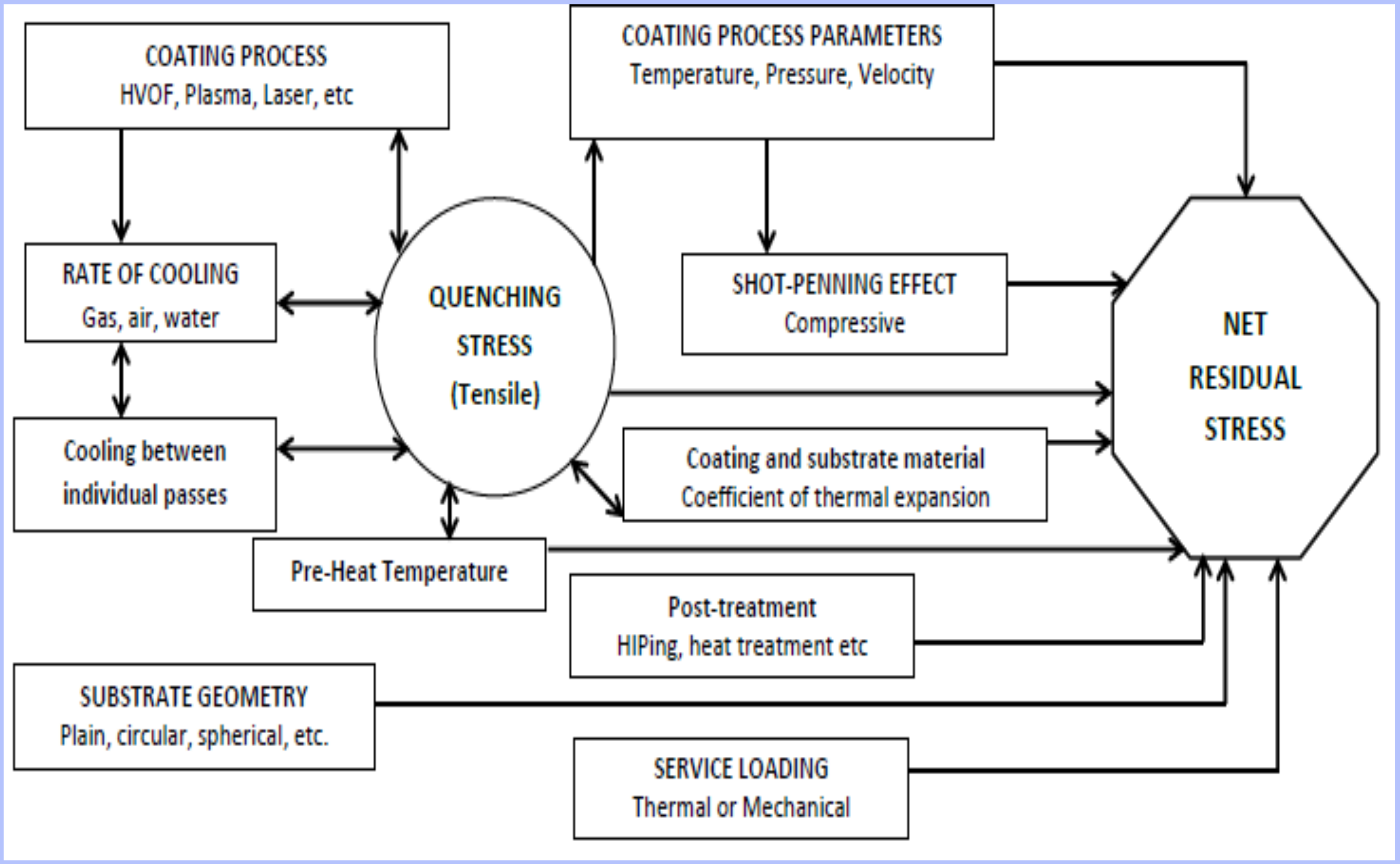
Introduction

- Thermal spray WC-Co coatings protect substrates against different environments and loads e.g. abrasive wear, high temperatures, chemically aggressive fluids and hot gas corrosion.
- WC-Co cermet composites are widely used, owing to their high hardness, reasonable toughness and excellent wear resistance [1].
- Residual stresses are a contributing factor in shortening service life for thermal spray coatings [2].
- Residual stresses in thermal spray coatings are responsible for decreased bending strength, fatigue life and bond strength [3].

Factors influencing the generation of residual stresses in thermal spray coating



Aims and objectives

- Identifying & understanding the nature of stresses between the coating and substrate.

- To study the microstructures of HVOF sprayed WC-Co coatings on different metal substrates.

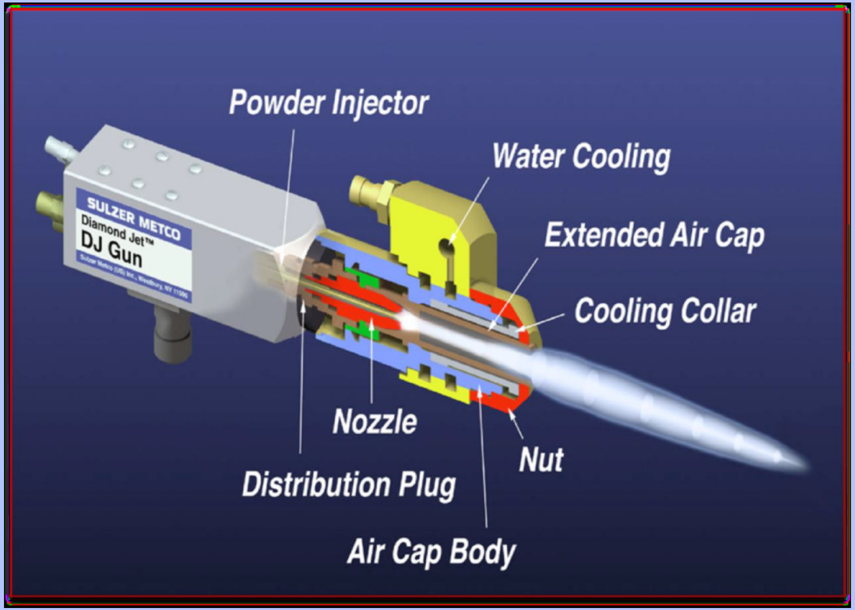
- To explore systematically the residual strains measured by different techniques, i.e. X-ray diffraction, synchrotron XRD and neutron diffraction.

- This project should assist users of coatings in matching substrates and coatings and/or selecting the deposition procedure.

Experimental procedure

- Commercially available WC-17Co powder was used as the feedstock.
- Five different substrates: 304L SS, brass, aluminium, super-invar and mild steel of 25x25x6mm sample size were thermally sprayed by HVOF.
- Samples were studied in: as-sprayed, grit-blasted and annealed grit-blasted conditions.
- XRD, SEM-EDX and Vickers hardness tests were undertaken.
- Stress analyses were carried out by X-ray diffraction, synchrotron XRD and neutron diffraction.

High Velocity Oxyl-fuel (HVOF)

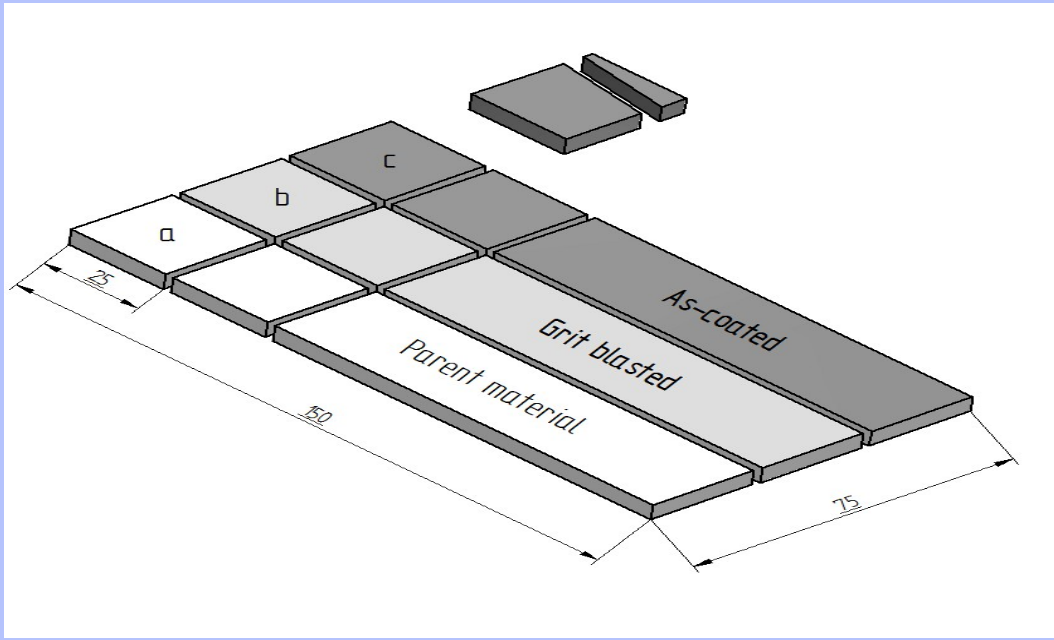


Advantages of HVOF [4]:

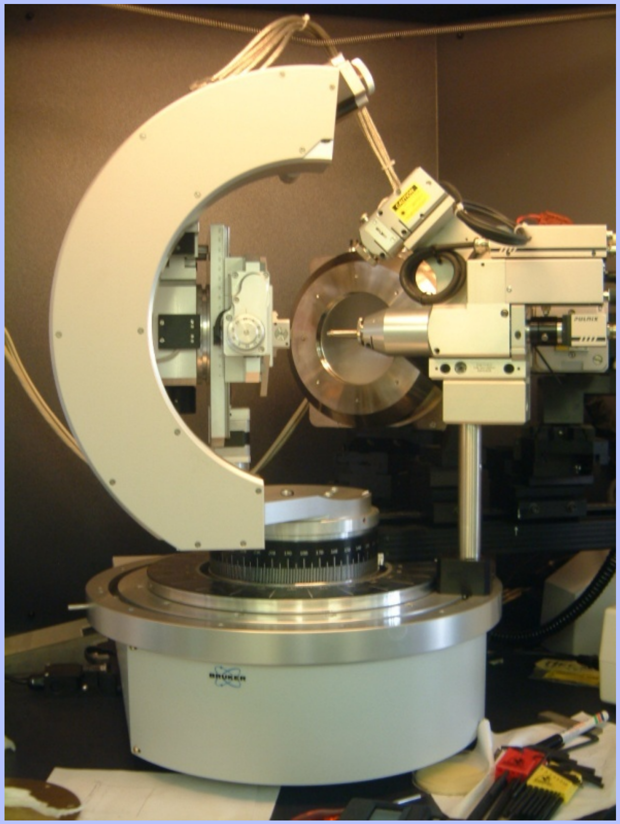
- High velocity and low oxygen.
- Lower decarburization.
- Coatings have low porosity and high bond strength.

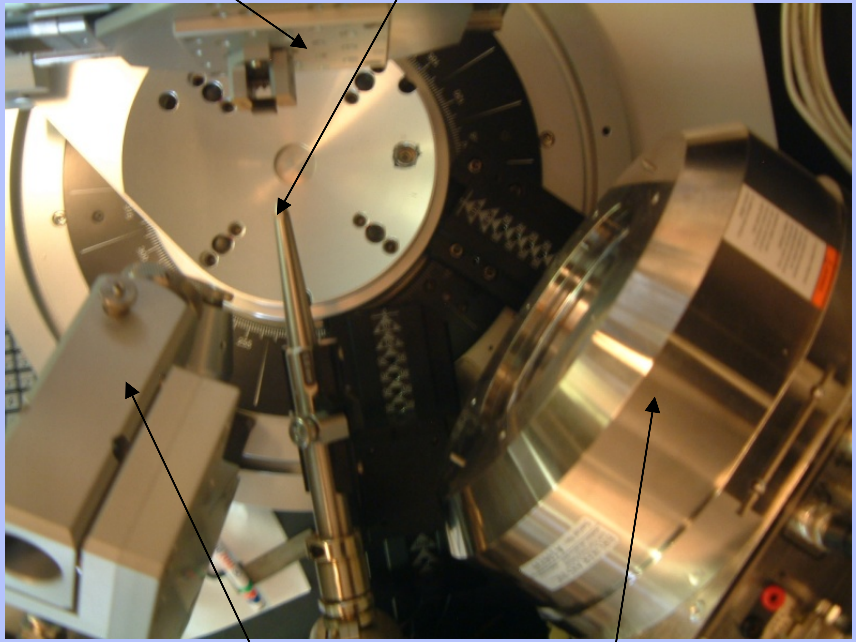
Typically used to deposit wear and corrosion resistant coatings on materials, while protecting from oxidation.

Sample cutting and measuring position



D8 Discover X-ray diffractometer





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Measurement details

Parameters used:

- Bragg peak: 112_{WC} reflections ($2\ \varphi = 92.093°$)
- Radiation: Co
- Azimuth orientation ϕ: 0, 180, 90, 270 ,45 and 225°
- Tilt angle ψ : 0.0 – 70.0°
- Steps $\Delta\psi$: 10°
- Software: Leptos V6

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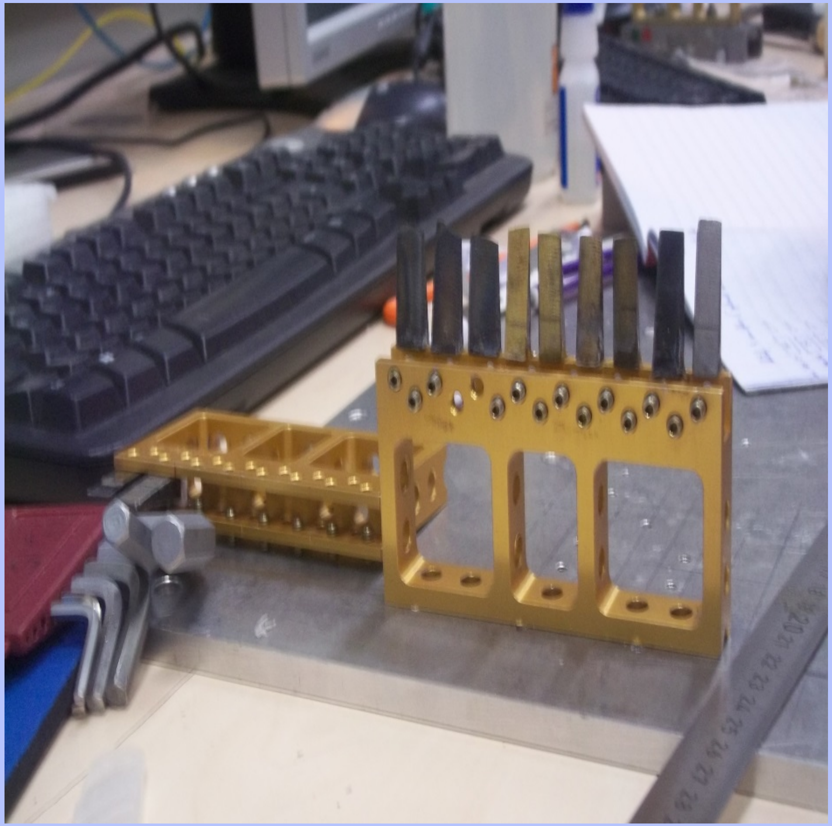
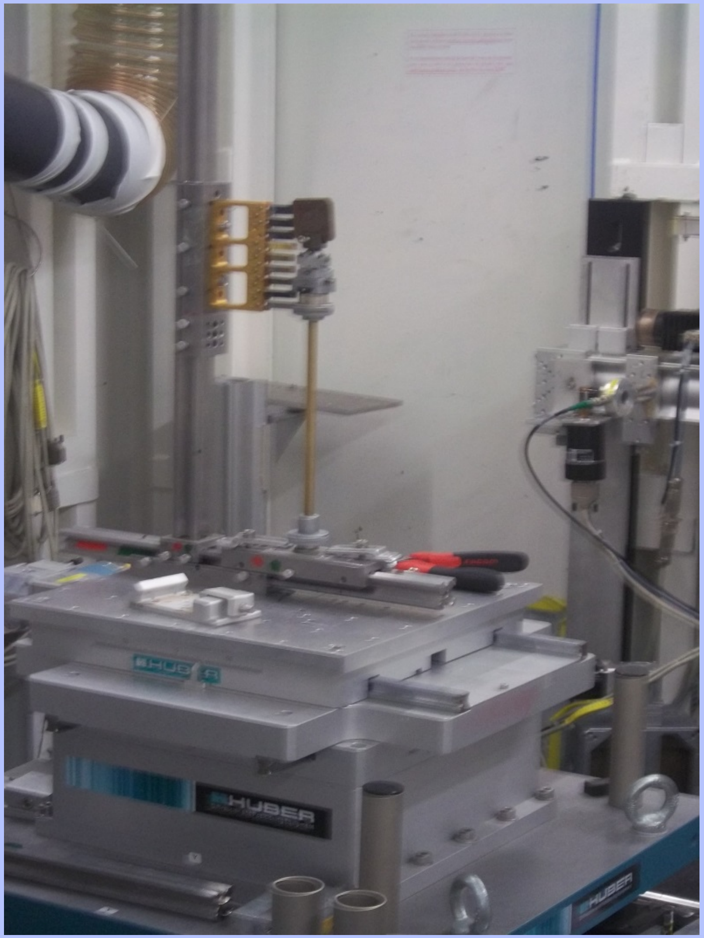
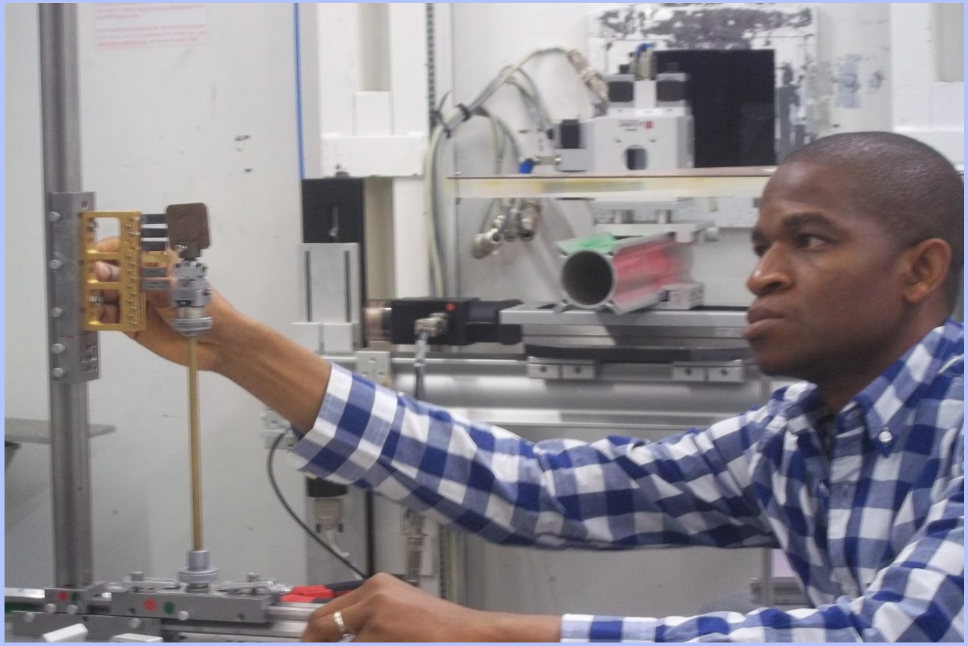
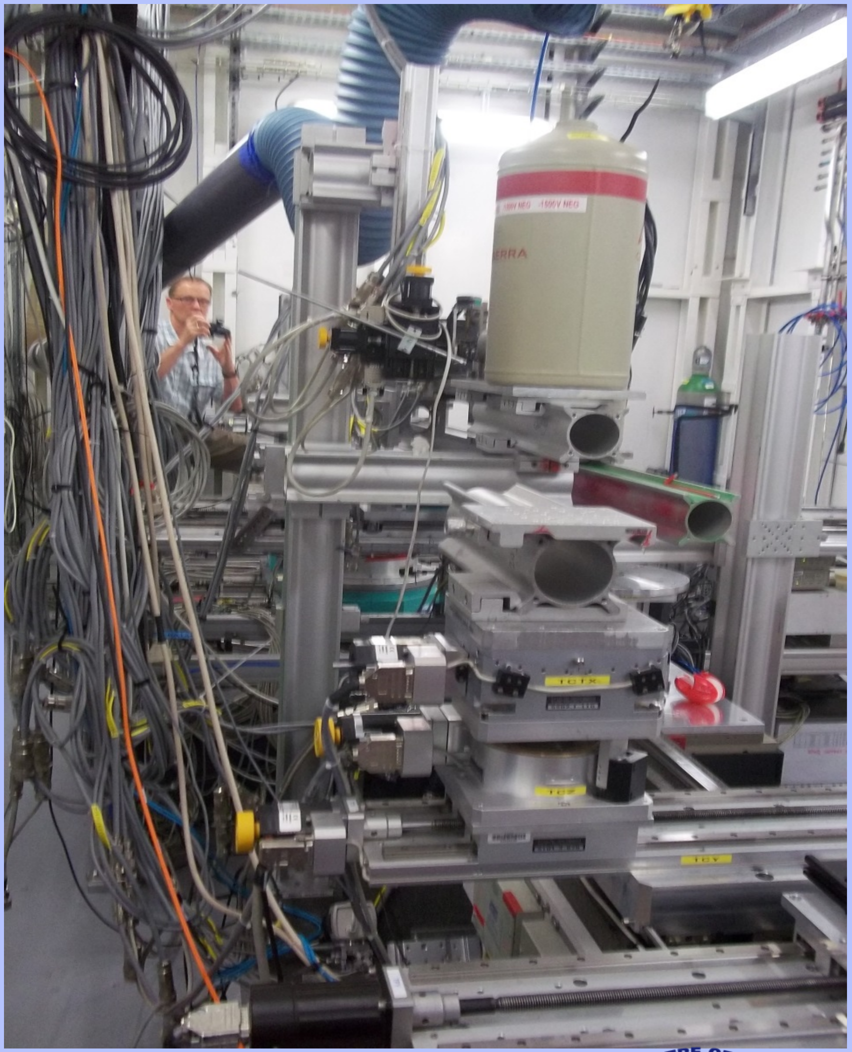
XRD Synchrotron measurement









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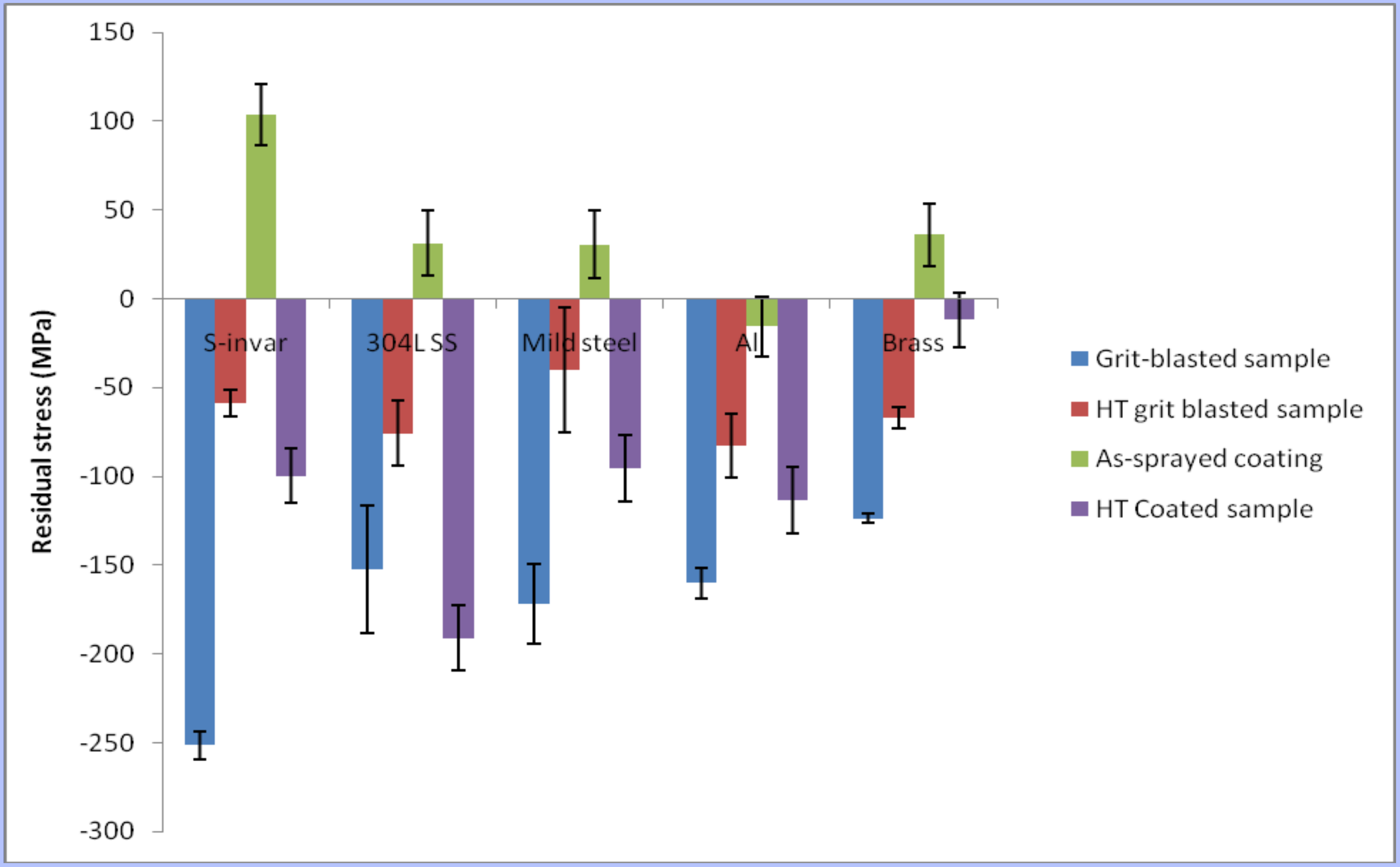
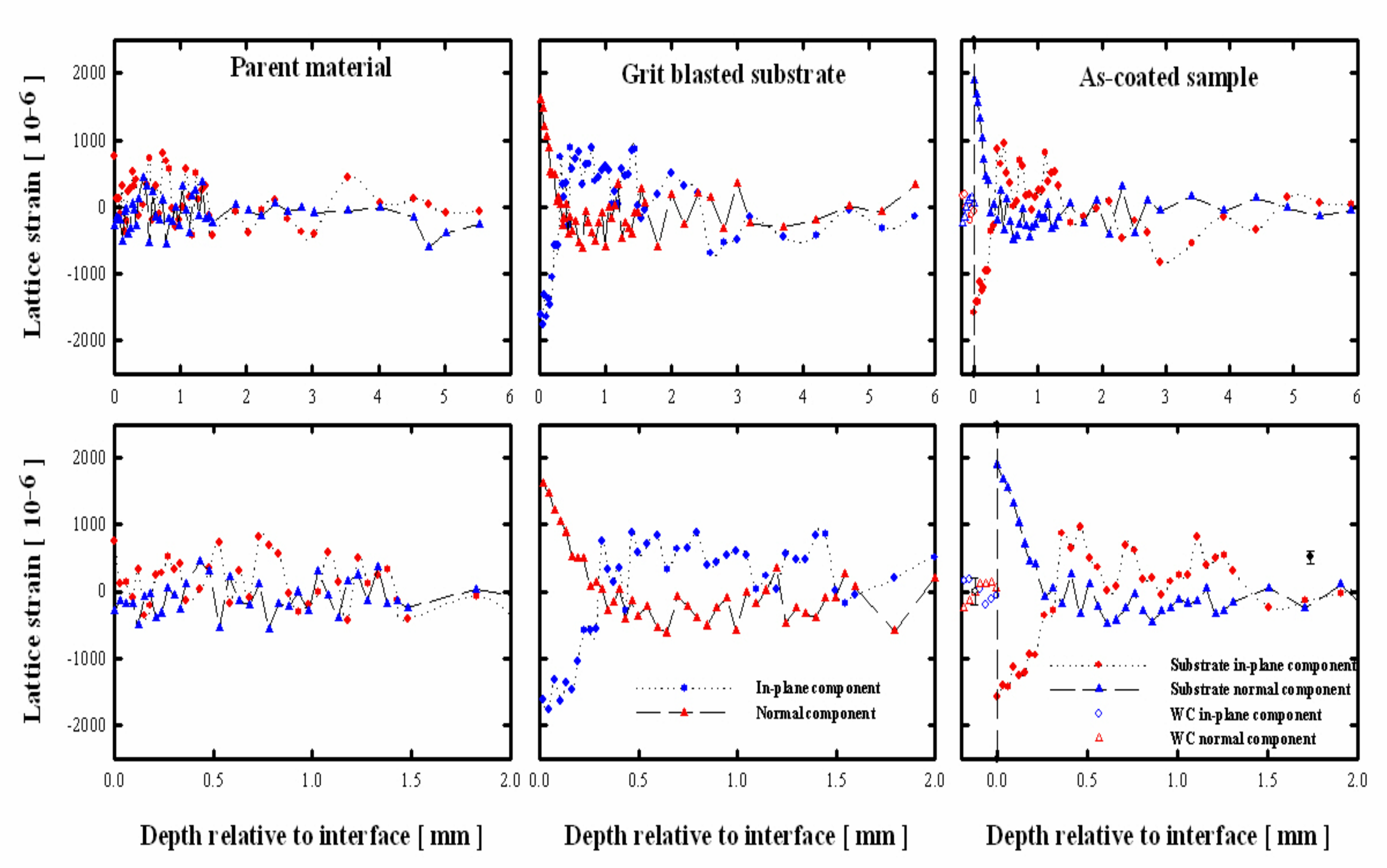
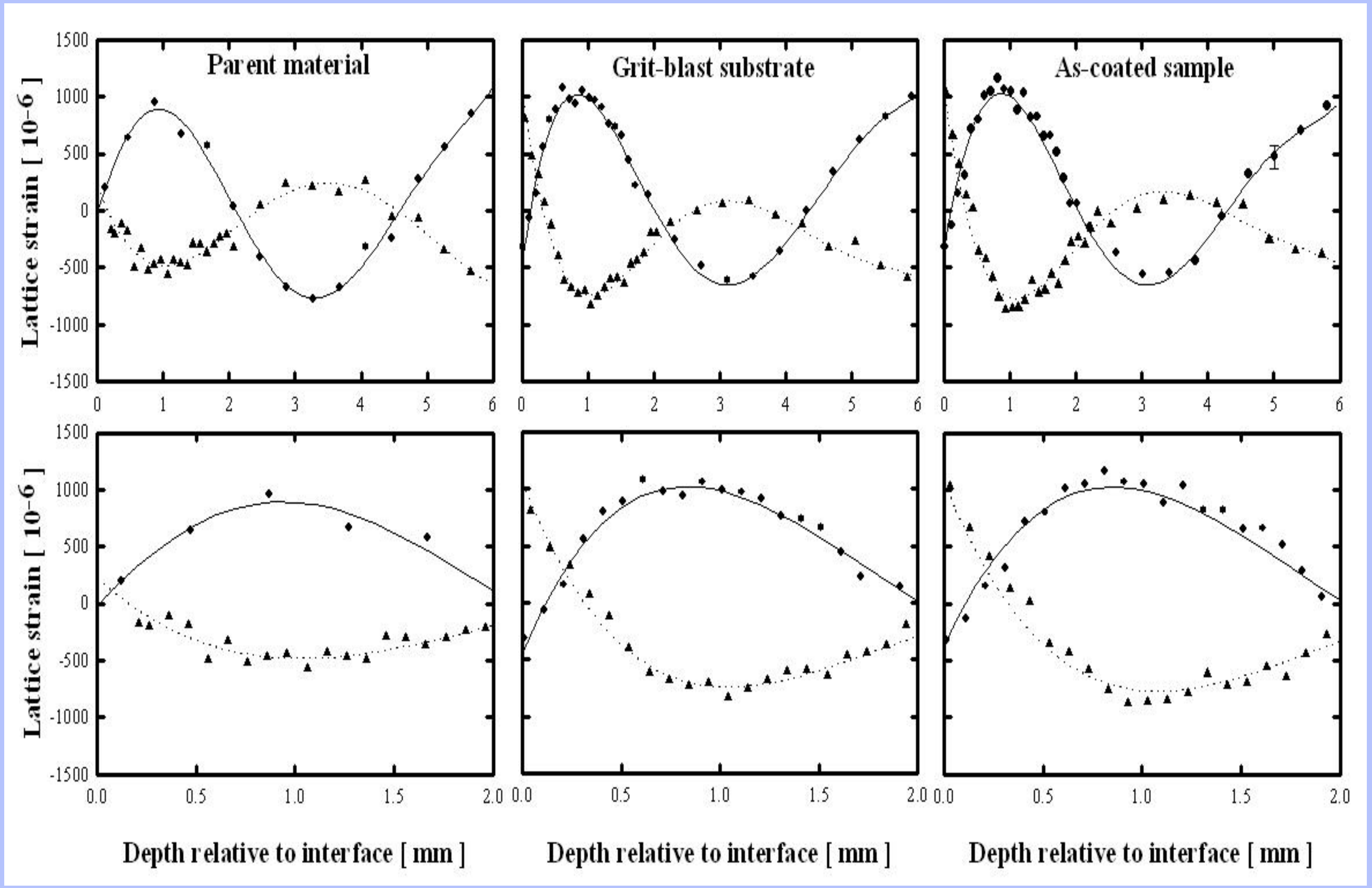
Results and Discussion



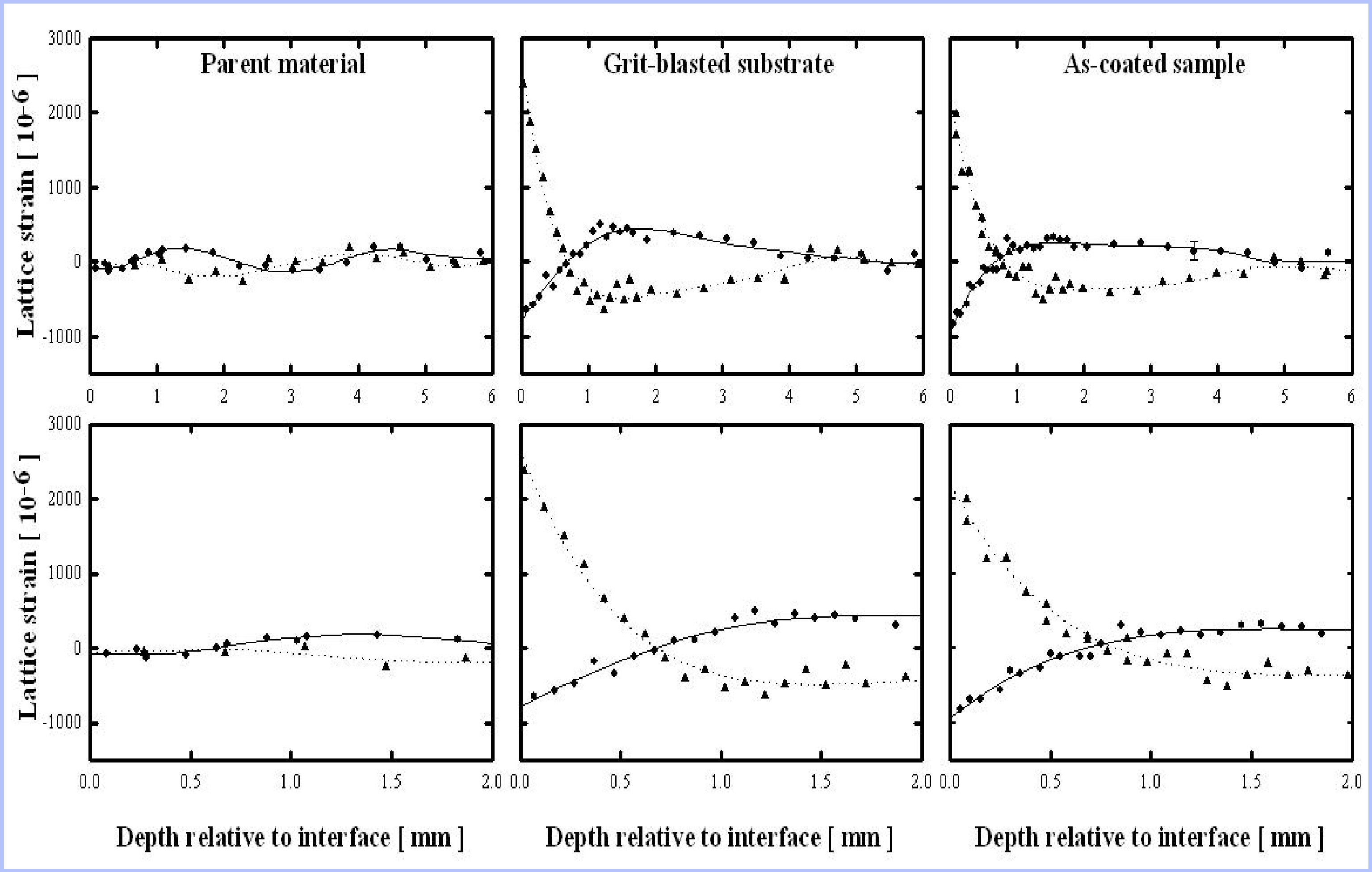
Residual stress of WC-Co coatings measured by X-ray diffraction



Residual strain depth profile for a coated stainless steel

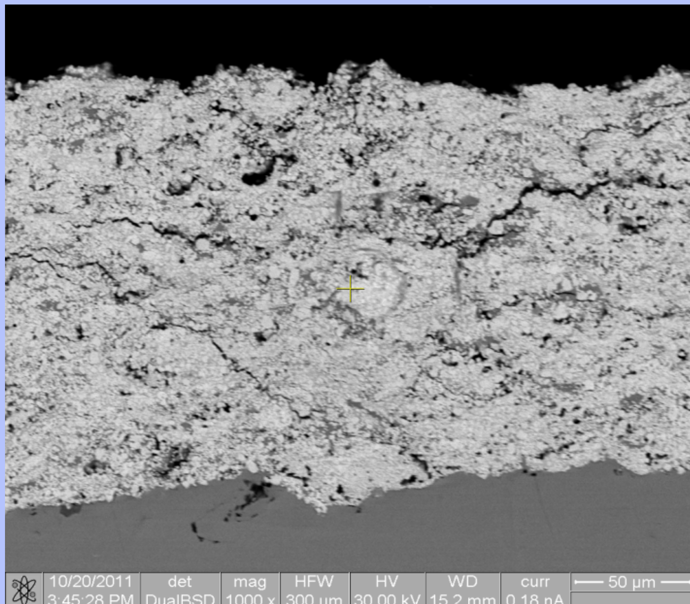


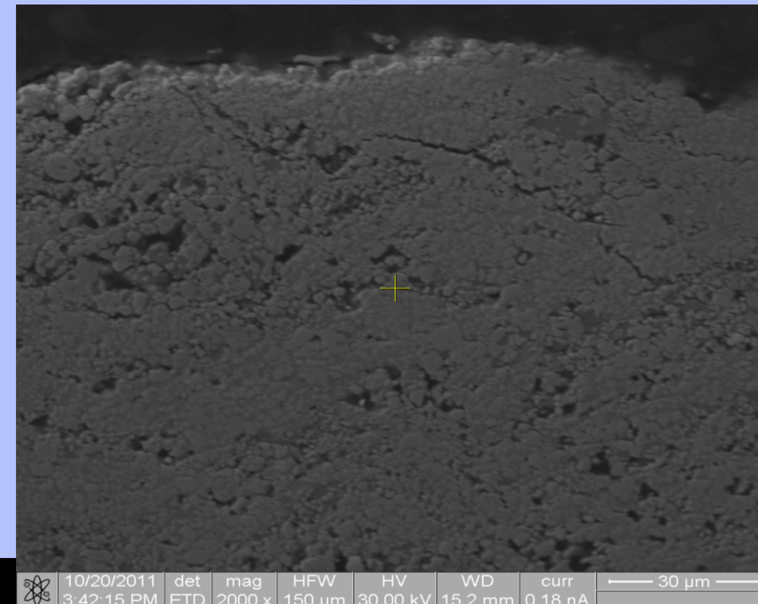
Residual stain depth profile for the coated brass

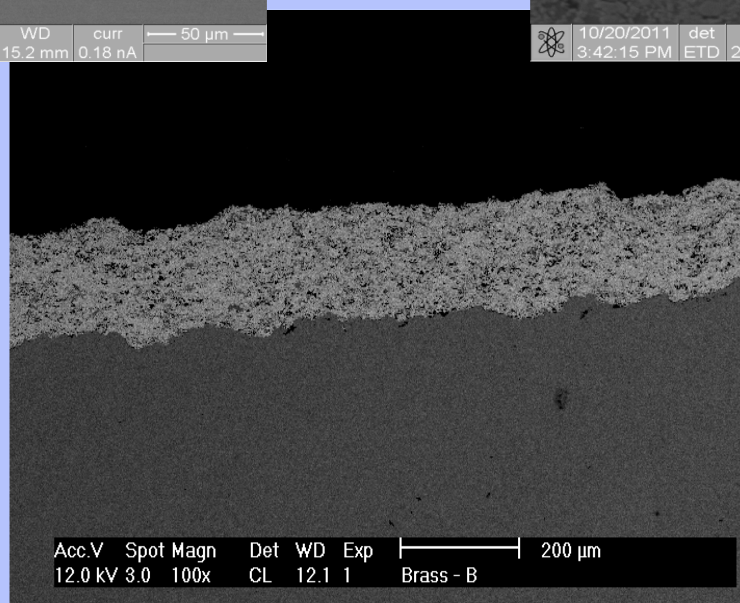


Residual strain depth profile of a coated Super-Invar

Results: Coated brass sample

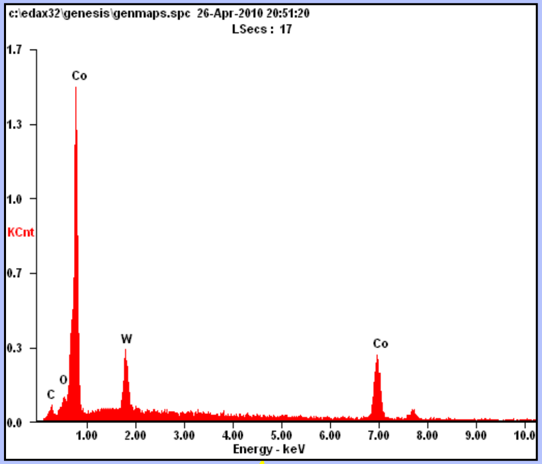


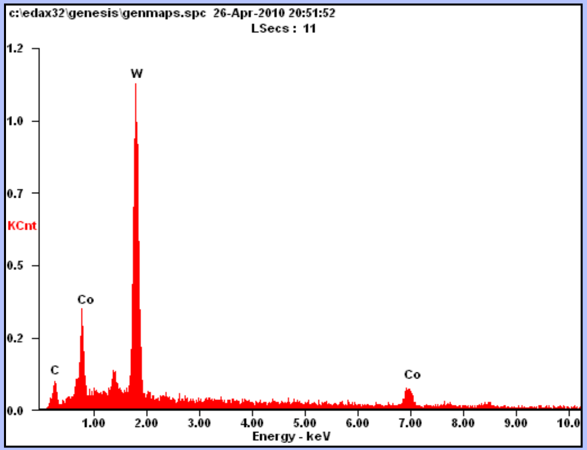




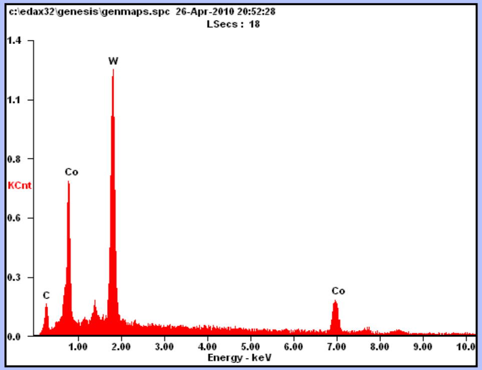
SEM-BSE images of WC-Co coating on brass substrate.

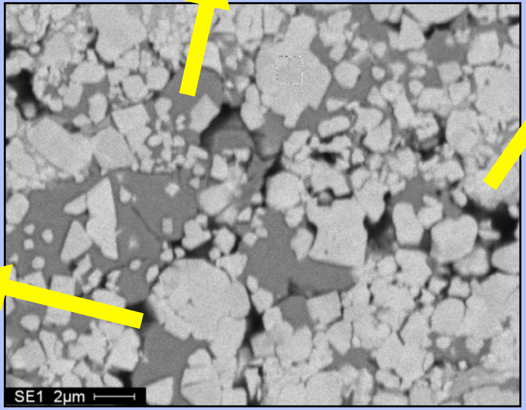
Element	wt%	at.%
CK	09.1	34.7
OK	03.8	10.9
WM	25.8	06.5
CoK	61.4	47.9





Element	wt%	at.%
CK	10.3	57.6
WM	77.2	28.2
CoK	12.5	14.2

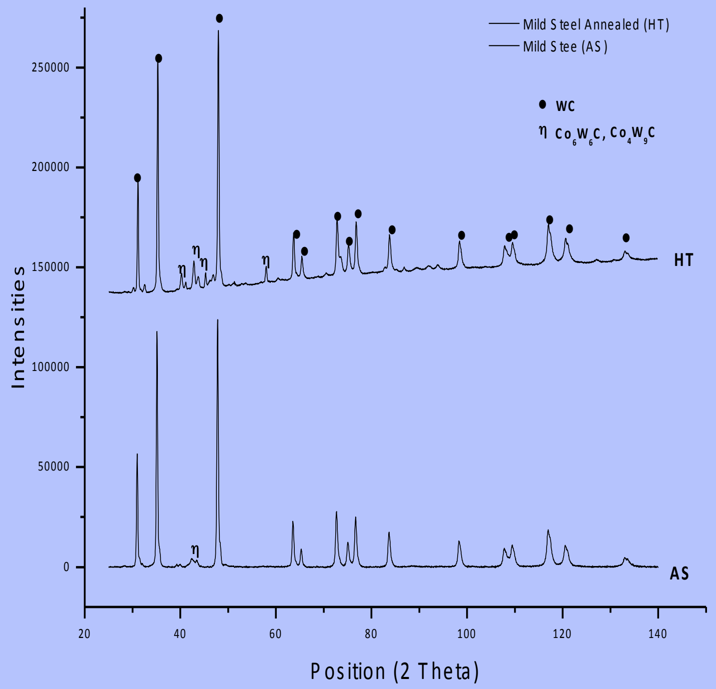


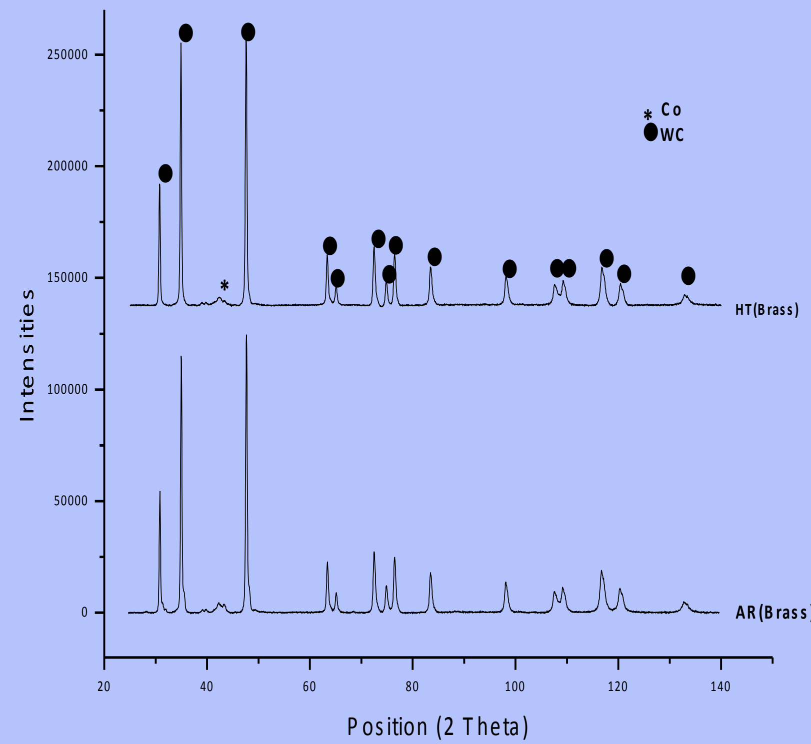


Element	wt%	at.%
CK	12.4	59.1
WM	66.9	20.8
CoK	20.7	20.1

SEM-BSE image and EDX results of WC-Co coating on brass cross-section showing (Co) (grey), WC (light) and pore (black).

XRD results





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Materials characteristics

Substrate	Wear mass loss (g)	HV Coating (GPa)		Phases (from XRD)		Porosity (%)	WC grain size (μm)
		Substrate	Coating	Substrate	Coating		
Alpha brass (Cu_{63}:Zn_{37})	0.073±0.010	1.29±0.01	6.60±0.01	Cu_5Zn_3, Zn	WC, Co	0.630±0.1	1.00±0.2
Super-invar (Fe_{64}:Ni_{36})	0.161±0.010	1.35±0.01	7.53±0.01	FeNi, C	WC, Co Co_6W_6C	0.863±0.2	0.83±0.1
Mild steel	0.084±0.010	1.25±0.01	7.01±0.01	Fe, Ni	WC, Co, Co_6W_6C	0.570±0.1	1.07±0.2
2xxx aluminium alloy	0.057±0.010	1.45±0.01	8.55±0.01	Al	WC, Co	0.618±0.1	0.94±0.2
304L stainless steel	0.066±0.010	1.74±0.02	9.11±0.01	Fe, Ni, Cr	WC, Co	0.436±0.2	1.14±0.2

Summary of residual stresses in substrates and coatings

Material	CTE (10^{-6}/K)	Reflection	DEC (TPa^{-1})		Residual stress in grit-blast substrates (MPa)		Residual stress in as-coated coatings (MPa)	
			S_1	$½S_2$	XRD	SR [6]	XRD	SR [6]
WC-17Co	2	WC (101)	-0.321	1.707	---	---	---	---
Aluminium	23	Al (3110	-5.05	19.462	-160 ± 10	-200± 25	-15.7 ± 17	-160 ± 50
Brass	19	Cu (311)	-2.902	11.106	-123 ± 10	-303 ± 25	-53.5 ± 28	-40 ± 25
304L SS	17	Fe (311)	-1.598	7.034	-159 ± 36	-458 ± 25	24.6 ± 19	22 ± 50
Mild steel	12	Fe (211)	-1.26	5.72	-172 ± 23	-441 ± 25	30.5 ± 19	60 ± 50
Super invar	≤ 1	Ni (200)	-1.91	7.539	-251 ± 10	-695 ± 25	74 ± 31	288 ± 25

Conclusions

- The residual stresses were tensile for the as-sprayed coatings on all substrates, except for coated aluminium and brass which were compressive. Compressive stresses were found in the other conditions due to effect of heat treatment.

- An order of magnitude correlation was found between the residual stress in the coatings determined by X-ray diffraction and Synchrotron XRD measurements, although they were fairly different due to their respective collimator or gauge volume.

- The residual stresses found on the as-sprayed coatings were quite different from each other due to their coefficients of thermal expansion.

- Moderate compressive residual stresses gave better abrasive wear resistance, whereas coatings with high tensile stresses yielded low wear resistance.

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