Enhancing steel health monitoring in the sub-grain level

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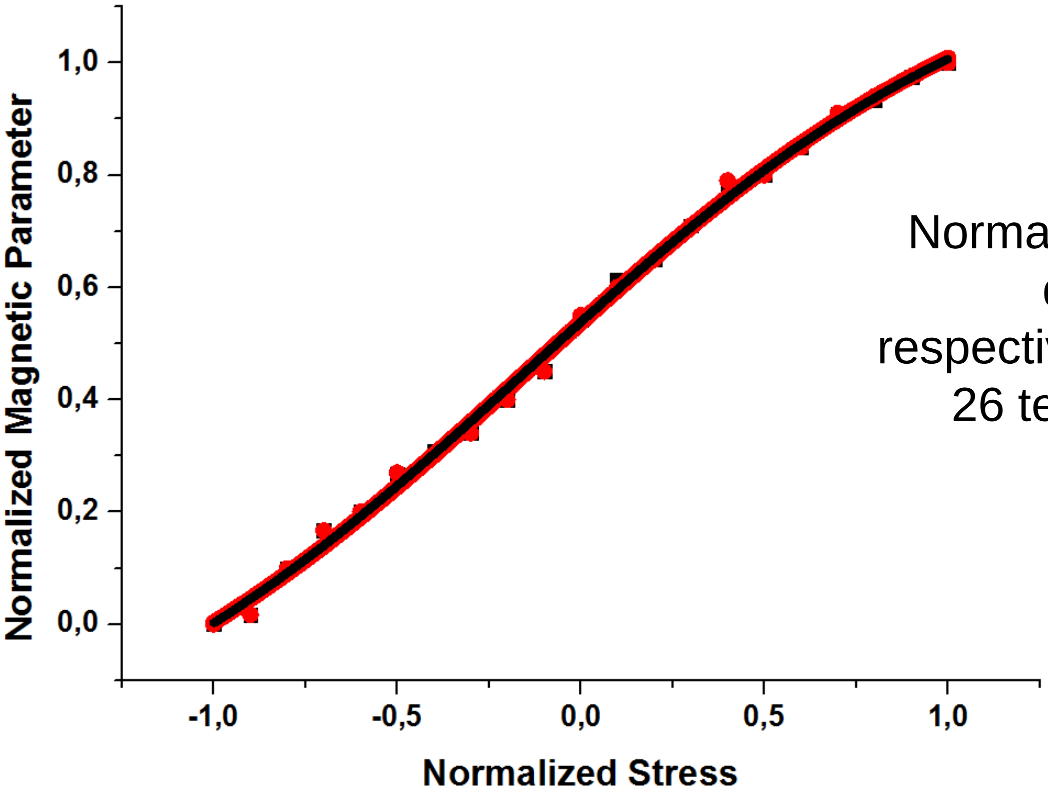
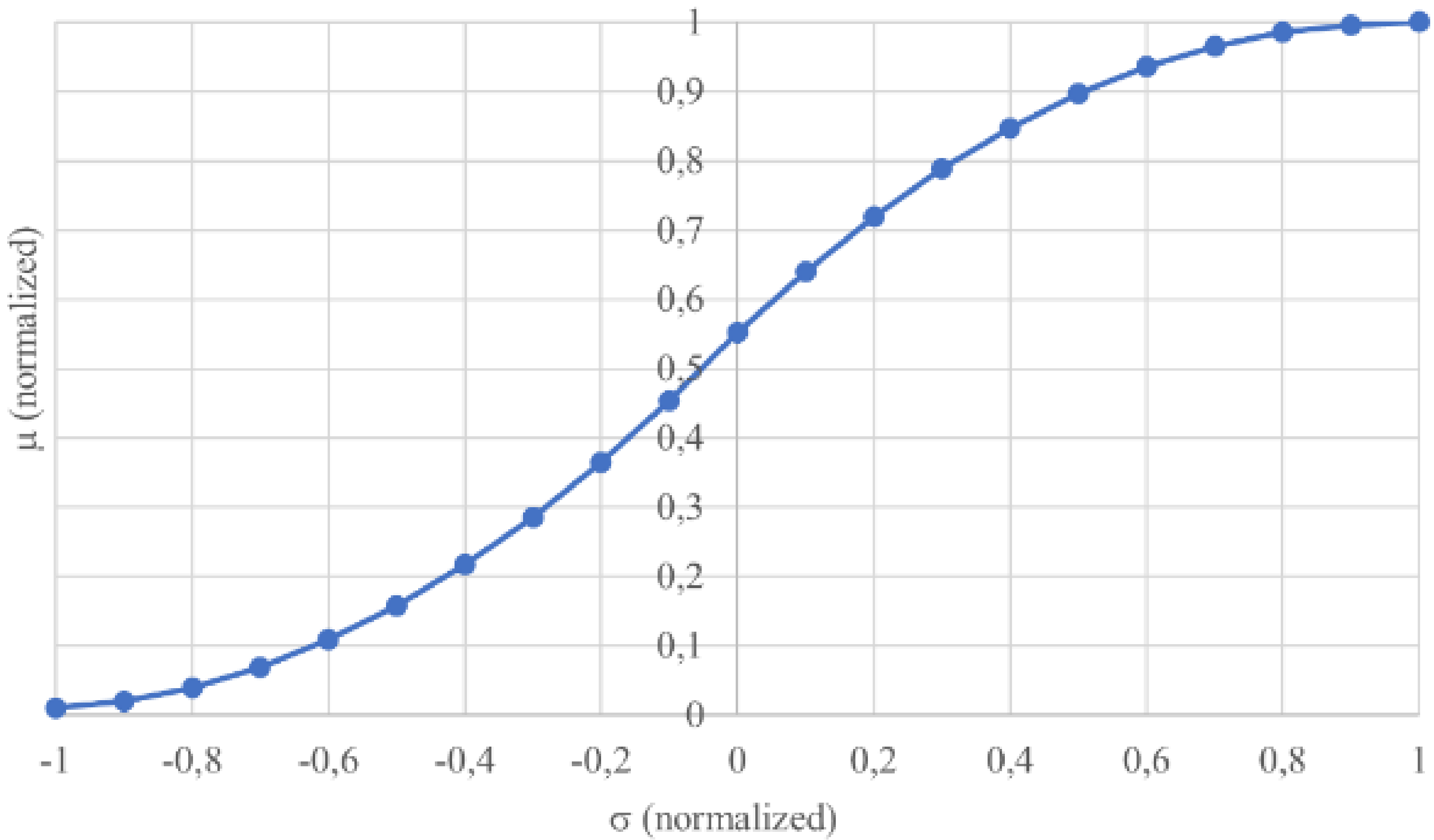
The Universal Magnetic Stress Calibration (MASC) curve



Normalizing X and Y axes with the maximum detected stress and magnetic property respectively, resulted in all MASC curves of all 26 tested steels collapsing in the Universal MASC curve

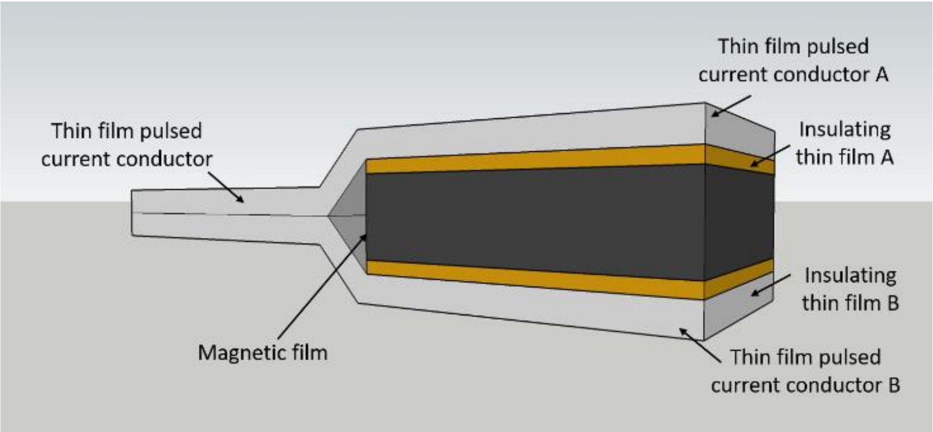
Autogenously welded steels include residual stresses that are characterized by X-ray or neutron diffraction (surface and bulk stress determination respectively) allowed for the generation of residual stresses in the steel, that are compared with magnetic properties at the vicinity of measurement. Plotting the pairs of values of magnetic properties (differential permeability in our case) and residual stresses results in the MASC curves.

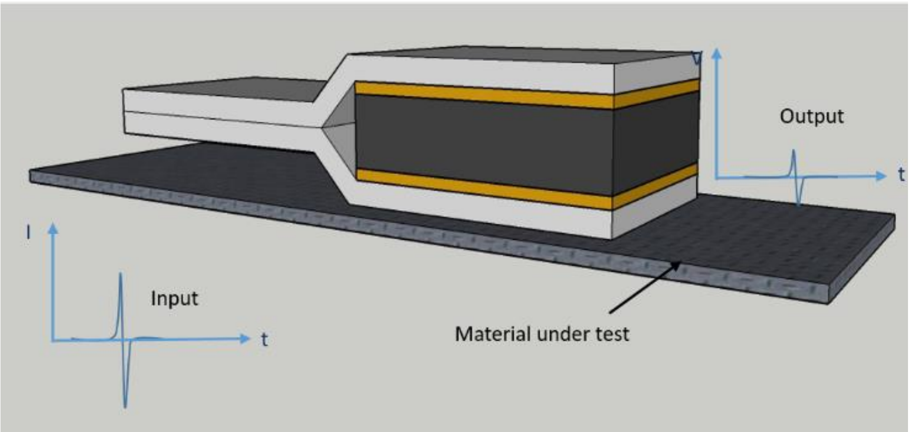
The enhanced Universal MASC Curve

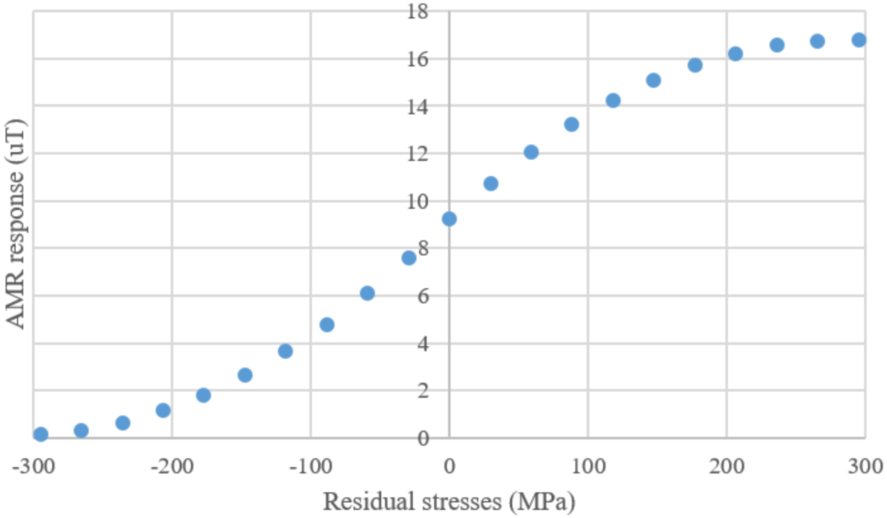


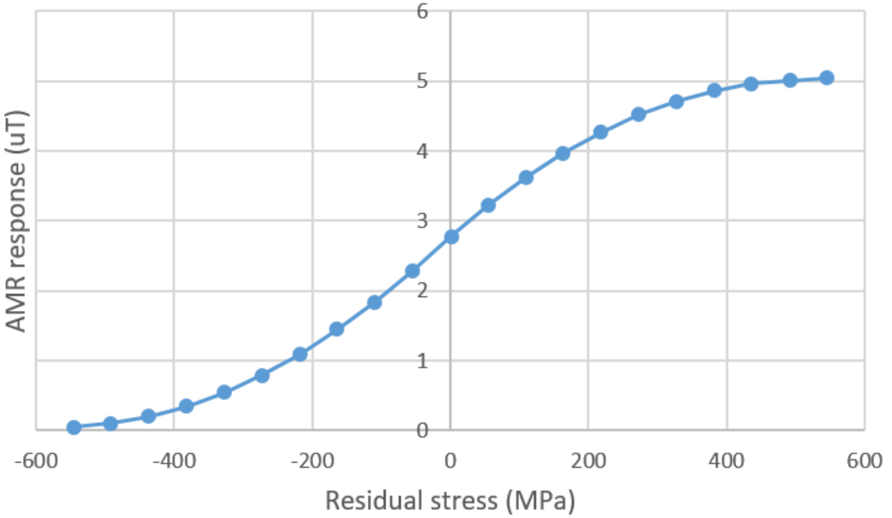
An RF induction heater induces a temperature profile in the steel and a consequent quenching generates a stress profile. The resulting MASC curves are far more reproducible reaching much closer to the yield point of steel.

A new magnetic microsensor, with spatial resolution of 1um X 1um

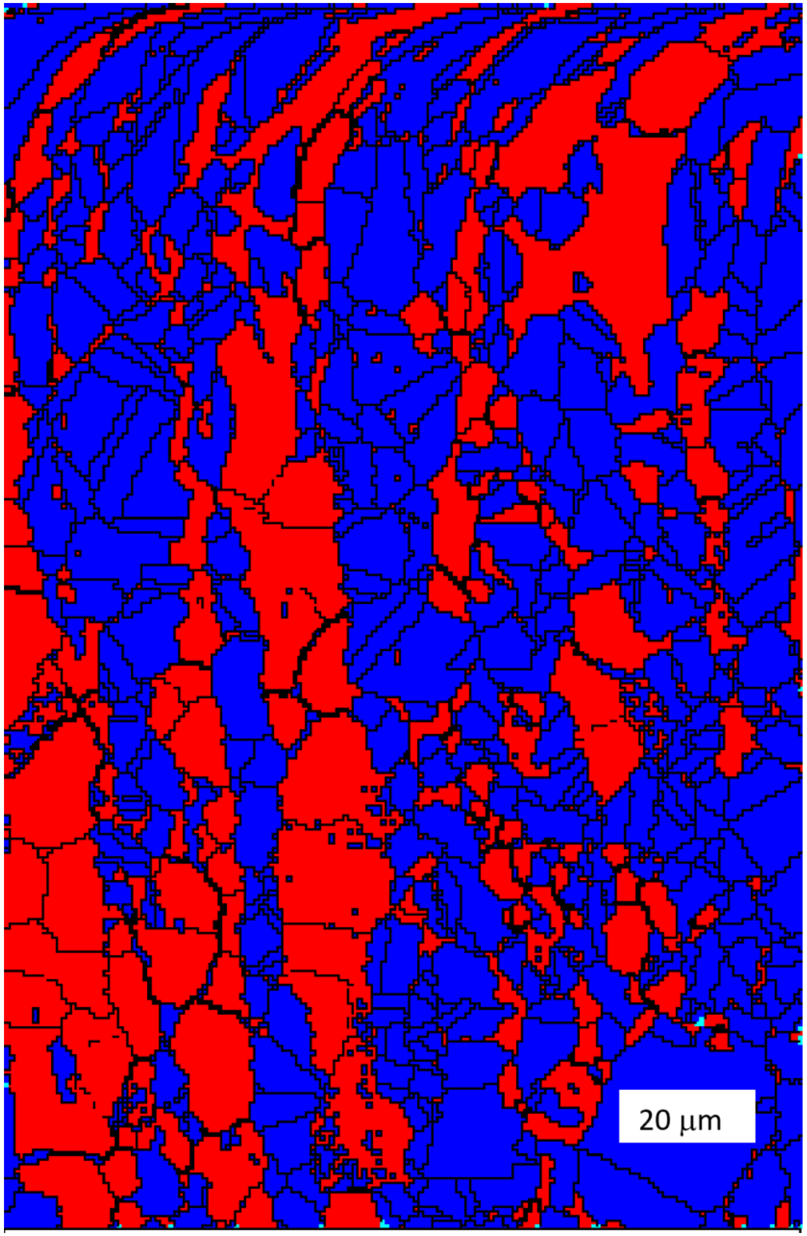






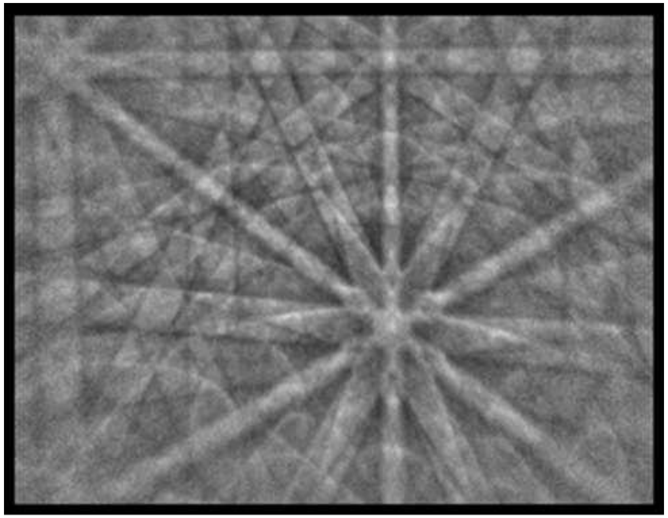


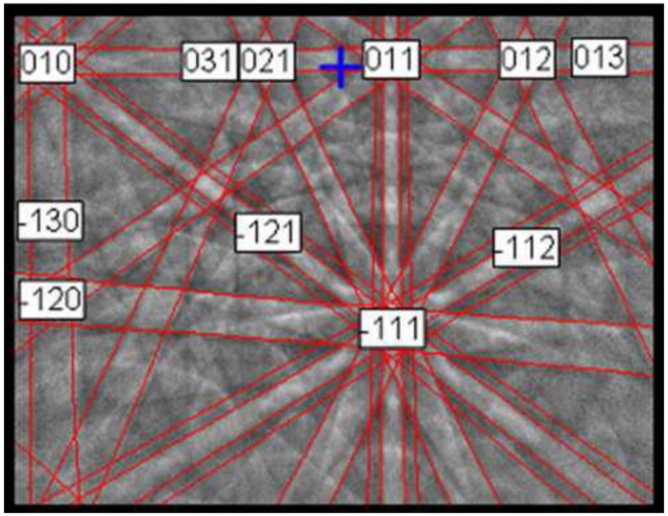
The recent development of our new micro-sized AMR magnetic permeability sensor (US Patent) allowed for the MASC curve realization based on the residual magnetic flux micro-leakage due to compressive or tensile stresses.

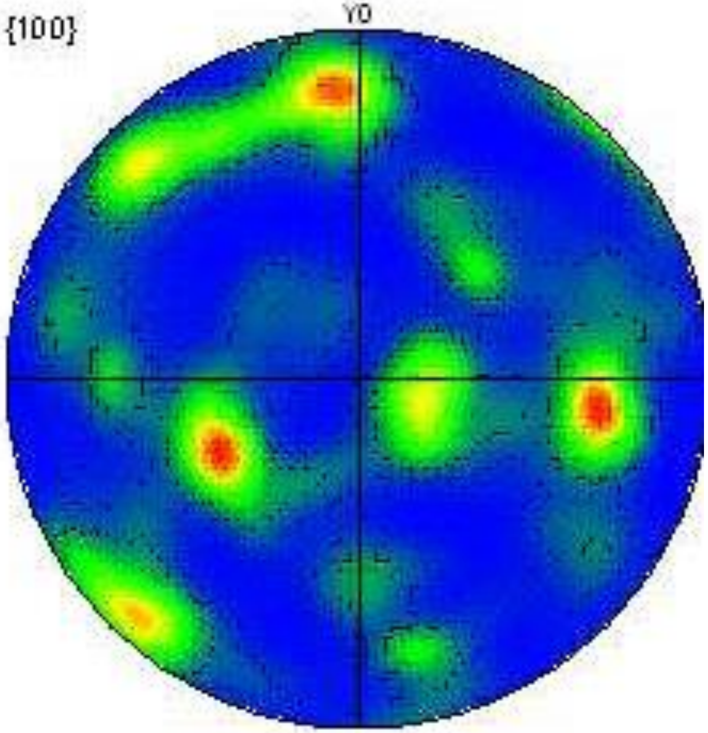


This resulted in the need to move from the macroscale (detection of average residual stresses in the order of mm) down to microscale (detection of average residual stresses in the order of um) Thus, we employed the Electron Back Scattering (EBSD) technique.

The EBSD analysis

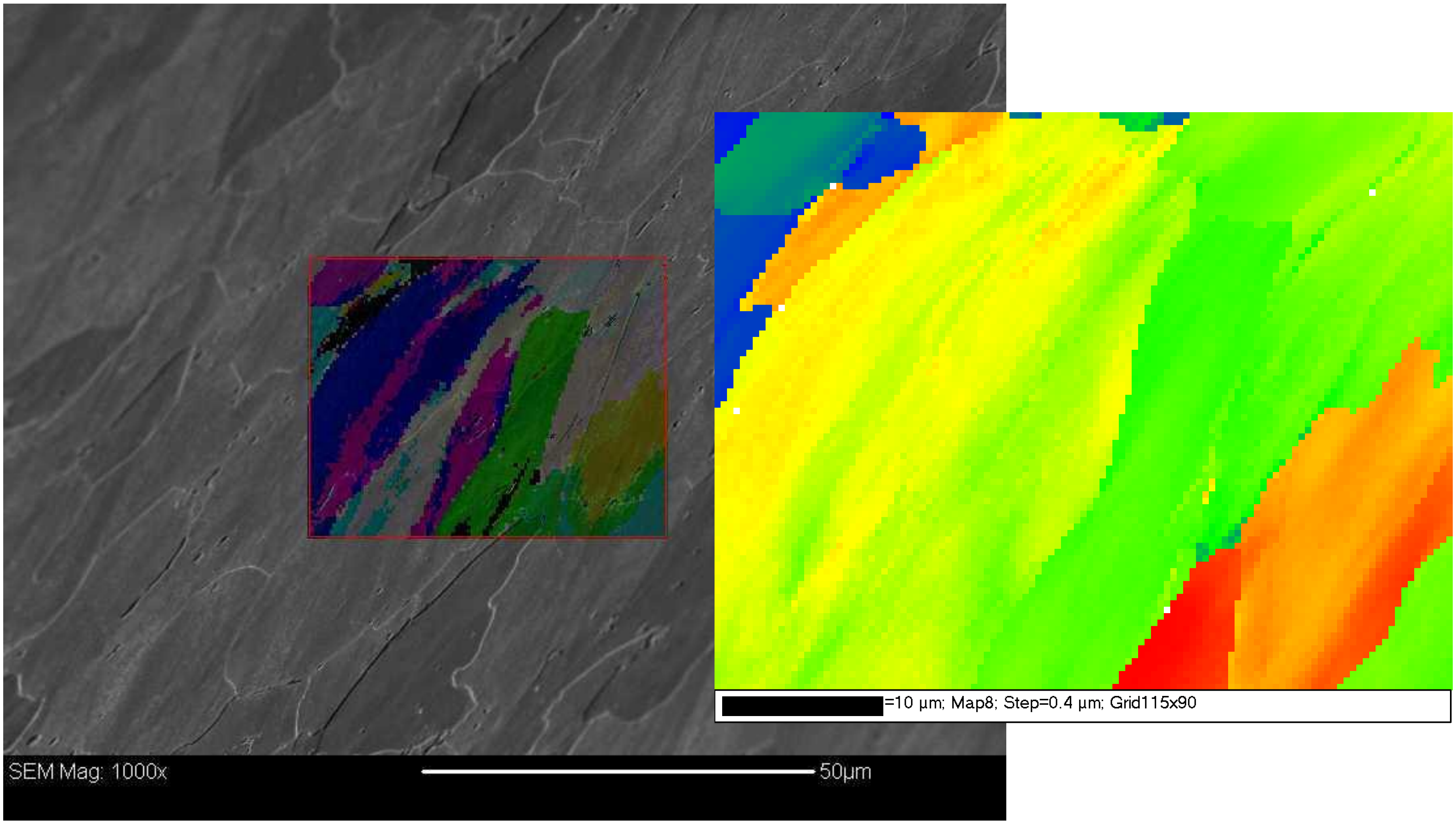




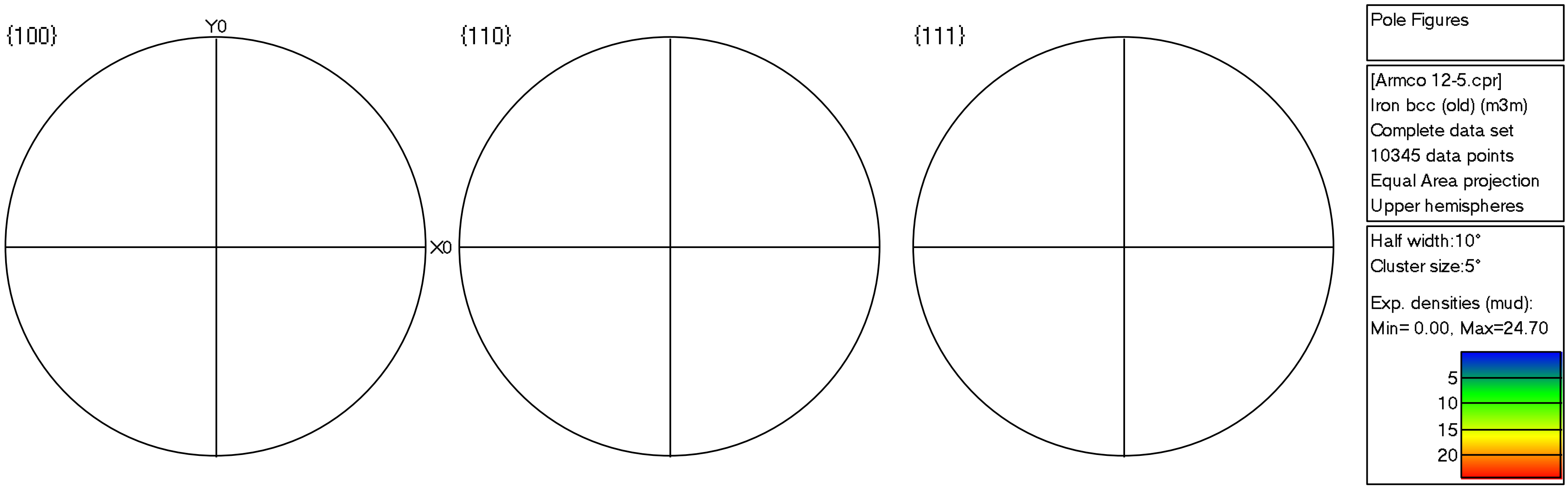


Kikuchi lines (left) and pole figures (top)

Cold rolled stress type III (using EBSD)

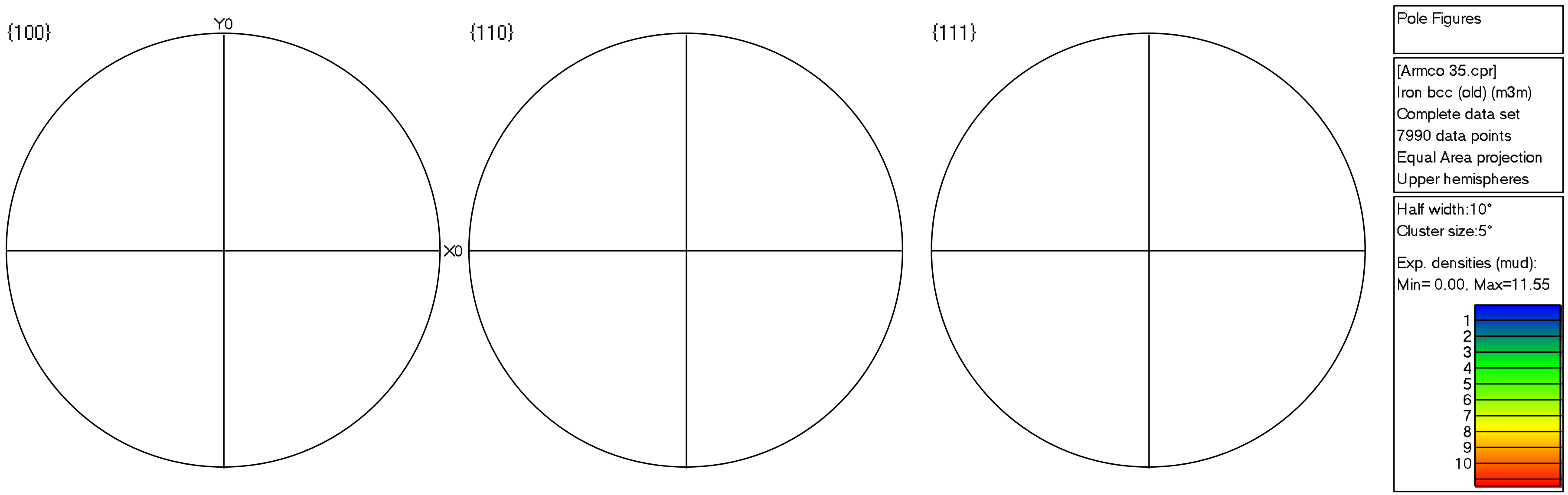


EBSD Pole Figure in 25% CR Armco steel



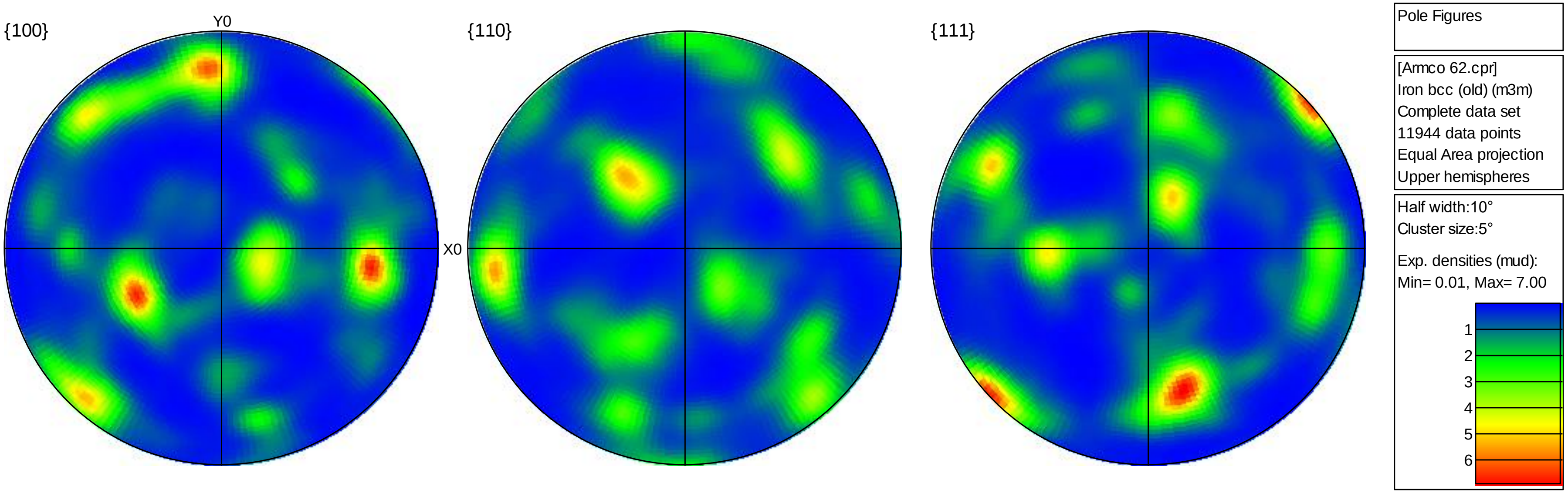
Why studying Cold Rolled (CR) steel: large effect in microstructural changes
Why studying Armco steel: low amount of carbon (7 ppm) – easier correlation

EBSD Pole Figure in 50% CR Armco steel

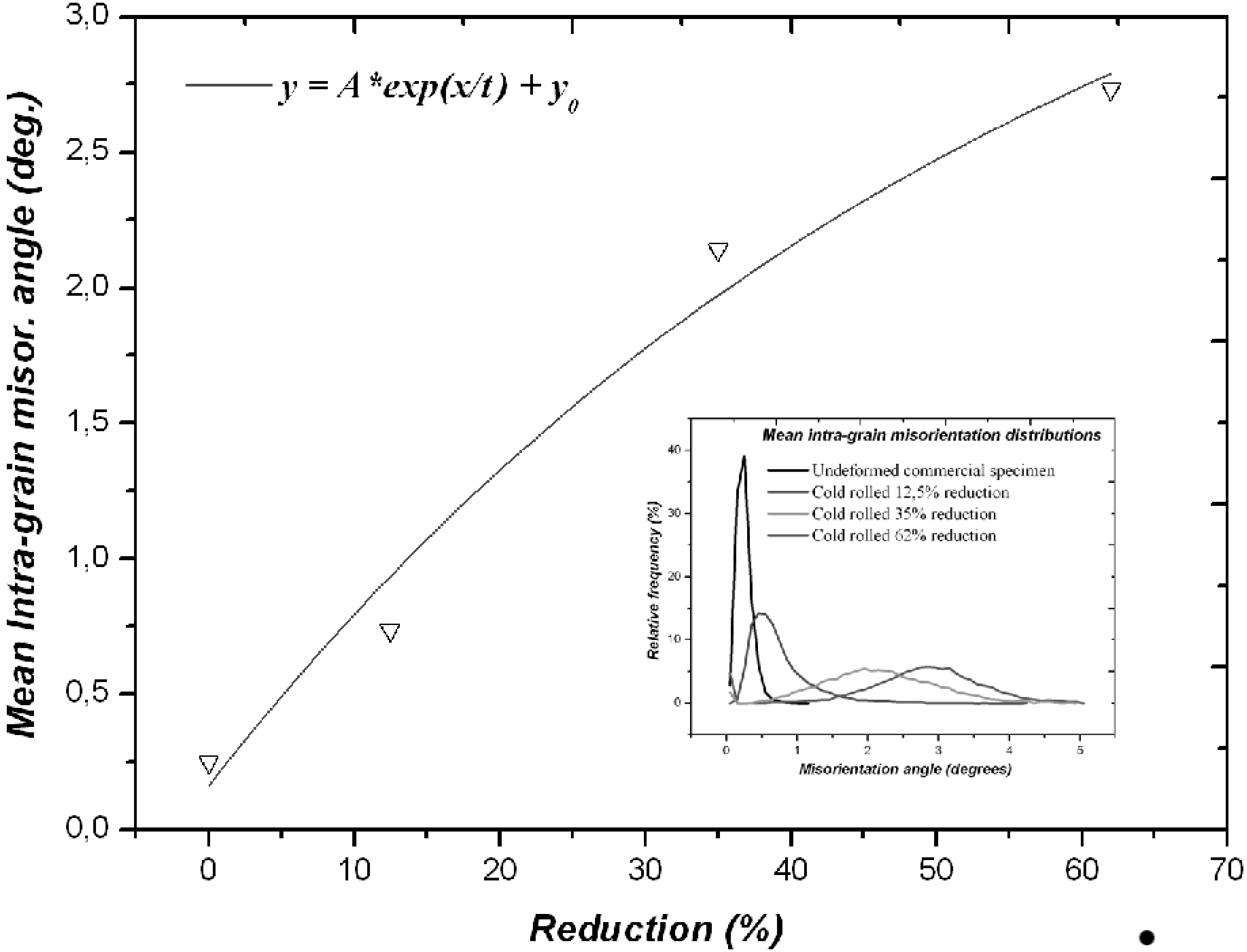


Increase of misorientations in higher cold rolling

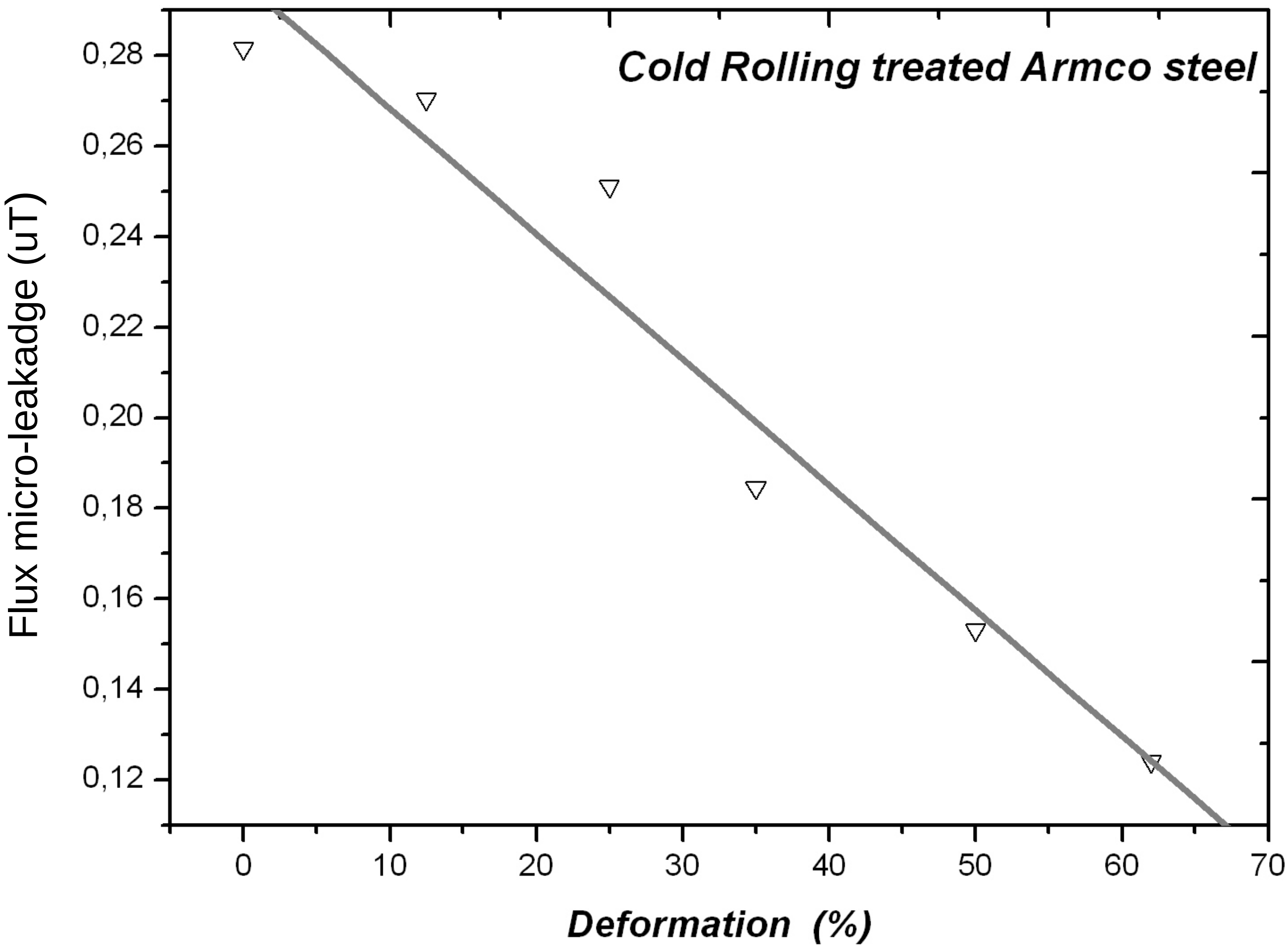
EBSD Pole Figure in 62,5% CR Armco steel

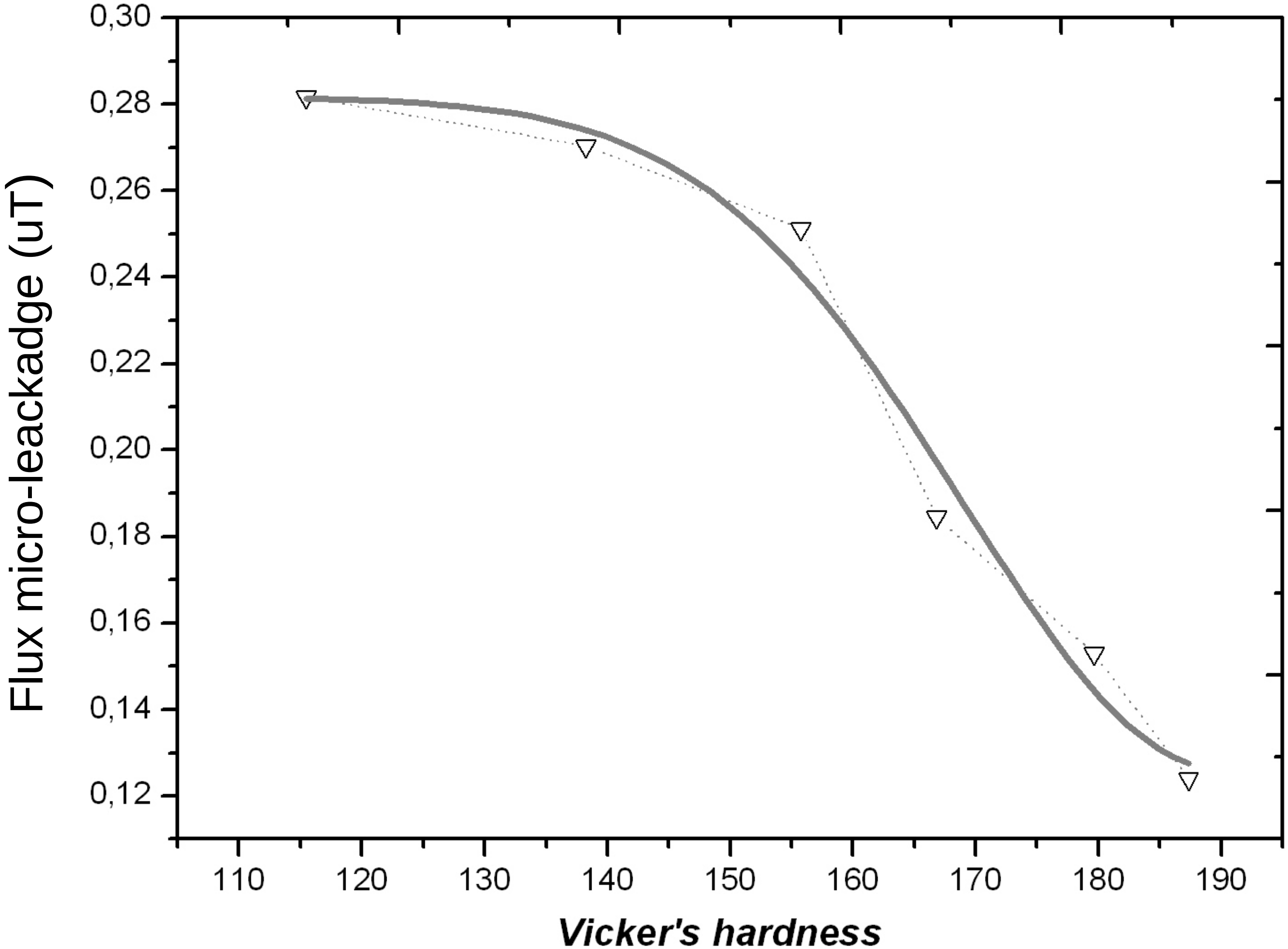


Higher amount of crystal missorientation



3,0
2,5
2,0
1,5
1,0
0,5
0,0
0
10
20
30
40
50
60
70
Mean Intra-grain misor. angle (deg.)
Reduction (%)
y = A*exp(x/t) + y0
Mean intra-grain misorientation distributions
Undeformed commercial specimen
Cold rolled 12,5% reduction
Cold rolled 35% reduction
Cold rolled 62% reduction
Relative frequency (%)
Misorientation angle (degrees)


Cold Rolling treated Armco steel
Flux micro-leakadge (uT)
0,28
0,26
0,24
0,22
0,20
0,18
0,16
0,14
0,12
0
10
20
30
40
50
60
70
Deformation (%)


0,30
0,28
0,26
0,24
0,22
0,20
0,18
0,16
0,14
0,12
Flux micro-leackadge (uT)
110
120
130
140
150
160
170
180
190
Vicker's hardness

Conclusions

- Universal MASC curve reached its best by thermal profiling and consequent quenching
- A new type of AMR microsensor offers surface magnetic monitoring in um^2 resolution
- The correlation of the microsensor response on the EBSD pole figures are well correlated
- The new microsensor can be used for surface studies of magnetic steels (e.g. micro-hardness measurements)

➔ A new era in NDT may be initiated

Thank you very much for your kind attention!