Determination and uncertainty propagation of sensitivity coefficients in rockwell hardness measurements

$$u_Y^2 = \sum_{i=1}^{N} \left(\frac{\partial \mathcal{F}}{\partial X_i}\Big|_{X_0} \right)^2 u^2(X_i) +$$

$$2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{\partial \mathcal{F}}{\partial X_i}\Big|_{X_0} \frac{\partial \mathcal{F}}{\partial X_j}\Big|_{X_0} u(X_i, X_j),$$

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sensitivity coefficients ?Ü

$$u_Y^2 = \sum_{i=1}^{N} c_i^2 u^2(X_i) + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} c_i \, c_j u(X_i, X_j)$$

2.2 Sensitivity coefficients with non-negligible uncertainties

$$Y = \widetilde{\mathcal{F}}(c_1, X_1; \ldots; c_N, X_N)$$

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$$\sum_{i=1}^{N} \left(\frac{\partial \mathcal{F}}{\partial c_i}\Big|_{c_0, X_0} \right)^2 u^2(c_i) +$$

$$+2 \sum_{i=1}^{N-1} \sum_{j>i}^{N} \frac{\partial \mathcal{F}}{\partial c_i}\Big|_{c_0, X_0} \frac{\partial \mathcal{F}}{\partial c_j}\Big|_{c_0, X_0} u(c_i, c_j) +$$

$$+ \sum_{i,j=1}^{N} \frac{\partial \mathcal{F}}{\partial c_i}\Big|_{c_0, X_0} \frac{\partial \mathcal{F}}{\partial X_j}\Big|_{c_0, X_0} u(c_i, X_j),$$

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$$\boldsymbol{c} = \boldsymbol{c}(X_1^{\mathrm{ref}}, \ldots, X_N^{\mathrm{ref}}),$$

$$\boldsymbol{X}_0 = (\delta X_1 + X_1^{\mathrm{ref}}, \ldots, \delta X_N + X_N^{\mathrm{ref}})$$

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3. CASE STUDY: HARDNESS MEASUREMENTS AND THE PROBLEM OF TRACEABILITY

$$\mathrm{HR} = N - \frac{h}{S}$$

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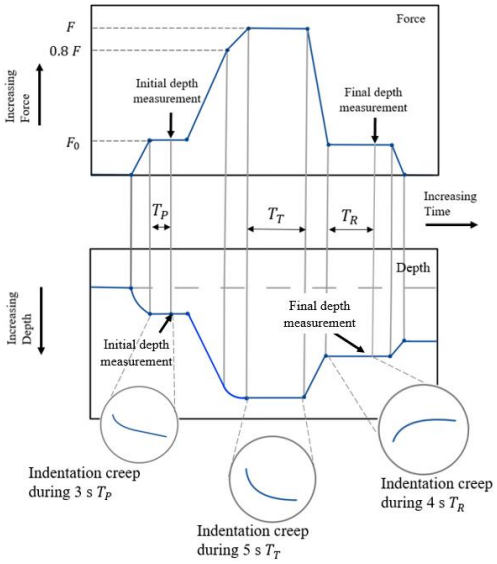

$$\mathrm{HR} = N - \frac{h}{S} + \sum_{i=1}^{N} c_i \, X_i,$$

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Nominal	c_P/(HRA/s) (3s)	c_T/(HRA/s) (5s)	c_R/(HRA/s) (4s)
83 HRA	0.0004 ± 0.0098	−0.0149 ± 0.0072	0.0038 ± 0.0065
73 HRA	0.0120 ± 0.0173	−0.0210 ± 0.0102	0.0067 ± 0.0945
63 HRA	0.0347 ± 0.0301	−0.0490 ± 0.0512	0.0256 ± 0.0298

3.1 Case A: Evaluation of the sensitivity coefficients

P T

R

$$\mathrm{HR} = N - \frac{h}{S} + c_\mathrm{P}\,\delta T_\mathrm{P} + c_\mathrm{T}\,\delta T_\mathrm{T} + c_\mathrm{R}\,\delta T_\mathrm{R},$$

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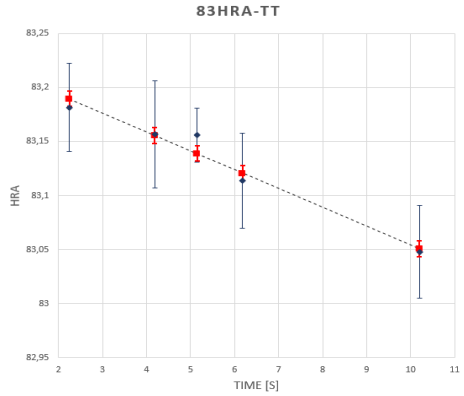

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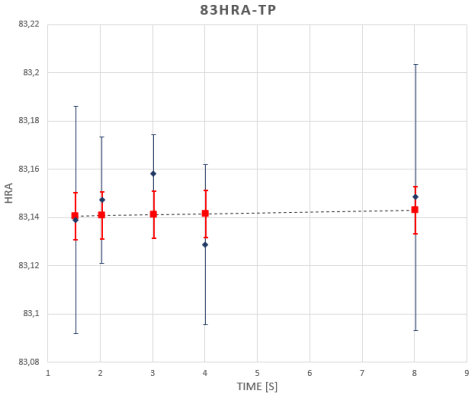

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3.2 Case B: Evaluation of the combined standard uncertainty

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v *F*

r, indenter angle α, preliminary test force dwell
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r

and α, since those quantities were obtained via an

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	Estimate	*U*
c_{F_0} [HRC/N]	0.05	0.02
c_F [HRC/N]	0.02	0.003
c_α [HRC/°]	0.04	0
c_r [HRC/μm]	0.05	0
c_h [HRC/μm]	0.5	0
c_v [HRC/(μm/s)]	0.03	0.01
c_{t_0} [HRC/s]	0.004	0.003
c_t [HRC/s]	0.03	0.02

Such a model (for r and α) could not be fully

		U
a	HRC EURAMET [4] $\delta X_i = 0$	1.26
b	HRC MODIFIED $\delta X_i = 0$	1.27
c	HRC EURAMET [4]	0.07
d	HRC MODIFIED	0.11

$$\mathrm{HR} = N + c_h\, h + \sum_i c_i\, \delta X_i,$$

?Ü= −1/S ?Ü

4. CONCLUSIONS

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$$u^2_{\mathrm{HR}} = \frac{u^2(h)}{S^2} + \sum_i c_i^2 u^2(\delta X_i) + \sum_i \delta X_i^2\; u^2(c_i)$$

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5. REFERENCES

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test, Proc. of the HARDMEKO ‘98, Sept (1998) 21–

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“guide to the expression of uncertainty in measurement”, Propagation of distributions using a

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