

## Vickers Hardness Sensitivity Coefficients

ISO 6507-1 defines the Vickers hardness value,  $HV$ , as:

$$HV = 0.102 \times \frac{2F \sin\left(\frac{\alpha}{2}\right)}{d^2}$$

where:  $F$  = force (in N)  
 $\alpha$  = plane angle of the indenter (136°)  
 $d$  = mean indentation diagonal length (in mm)

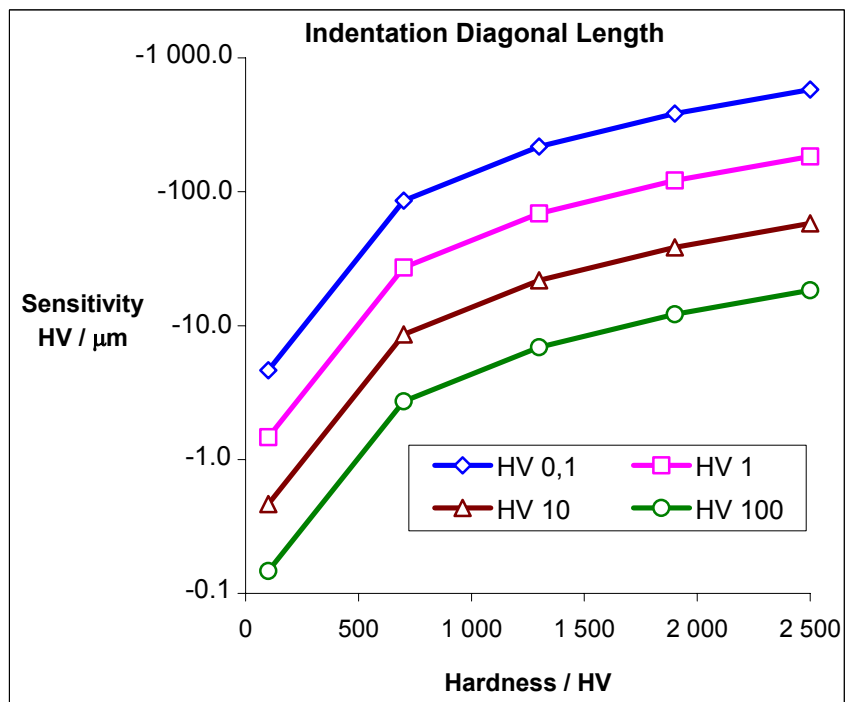
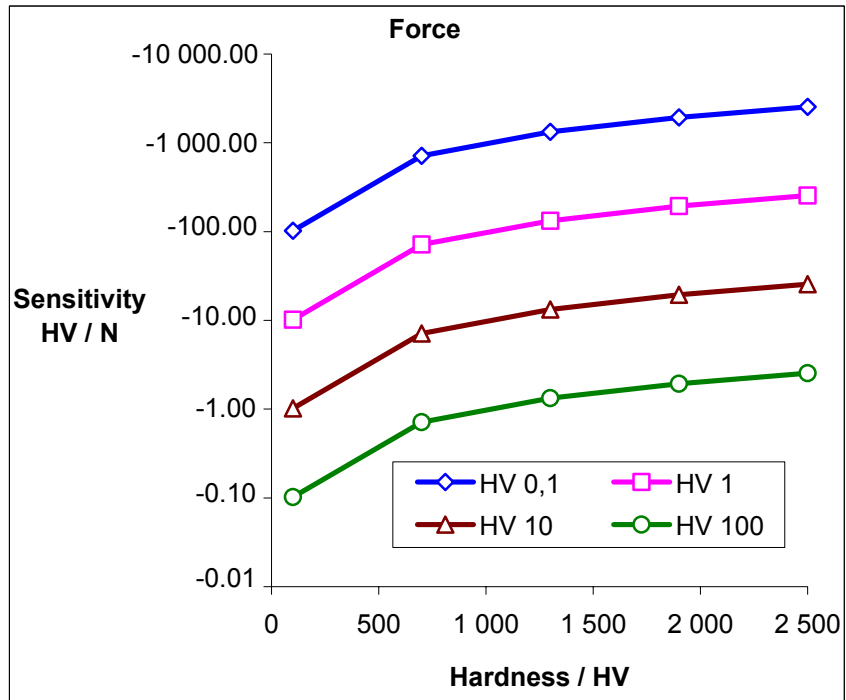
Partial derivatives allow the sensitivity coefficients for force, indenter angle, and indentation diagonal length to be determined:

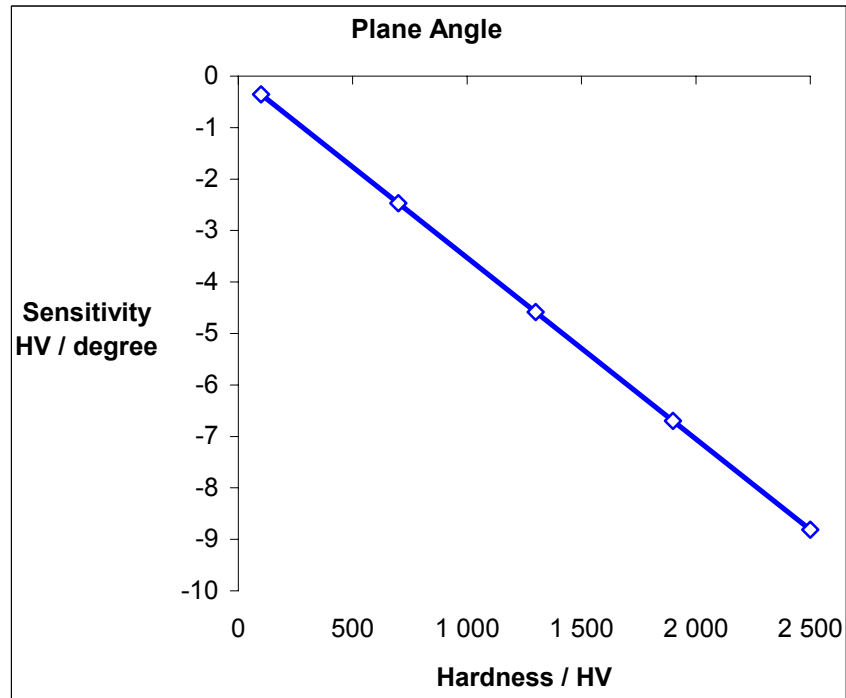
$$\frac{\partial HV}{\partial F} = \frac{HV}{F}$$

$$\frac{\partial HV}{\partial \alpha} = \frac{HV}{2 \tan\left(\frac{\alpha}{2}\right)}$$

$$\frac{\partial HV}{\partial d} = -2 \times \frac{HV}{d}$$

**Important note:** the first two equations suggest that the sensitivity coefficients for force and indenter angle are positive - i.e. an increase in force or indenter angle will increase the hardness value. This is only the case if the resulting indentation diagonal length does not also increase – in practice, it always will, to give a similar hardness value. As the hardness value is actually calculated from the nominal force and indenter angle values, together with the measured indentation diagonal length, the sensitivity coefficient values for force and indenter angle should be treated as negative - an increase in the parameter value will lead to a decrease in the calculated hardness - and they are plotted as such in the following graphs:





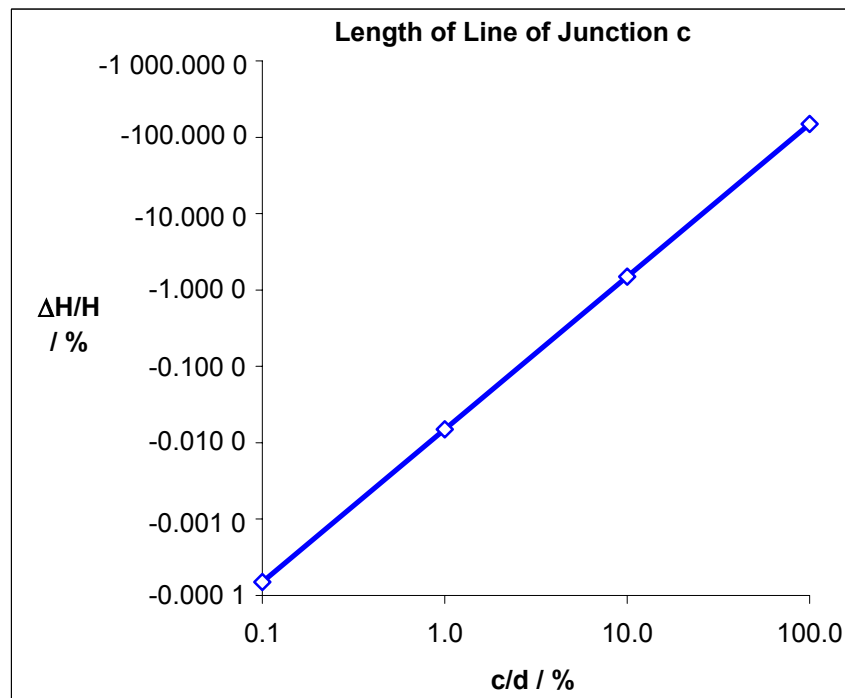
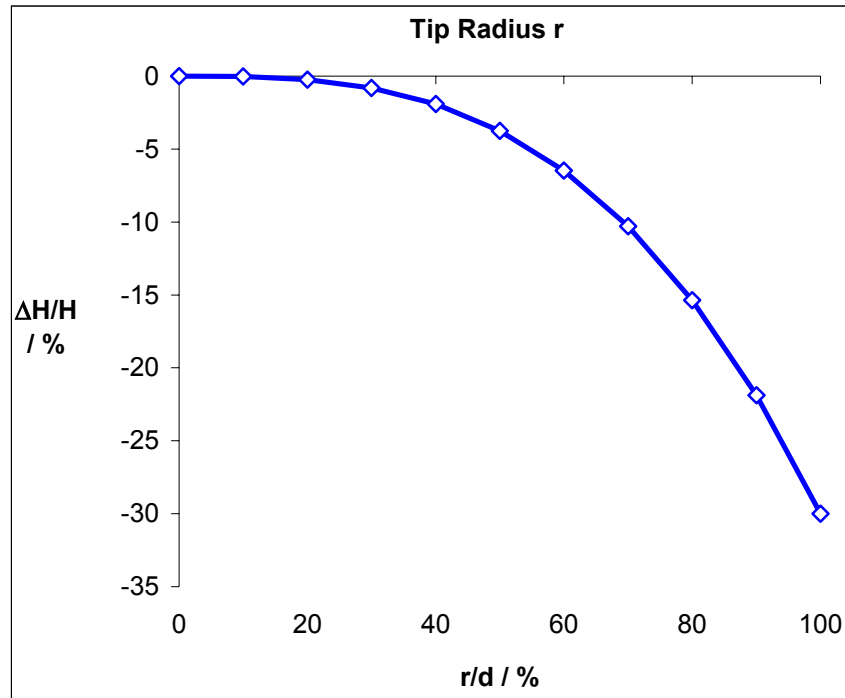
Geometrical considerations allow the sensitivity coefficients for tip radius and length of line of junction to be determined:

$$\frac{\partial HV}{\partial r} = -0.3 \left( \frac{r}{d} \right)^3$$

$$\frac{\partial HV}{\partial c} = -1.5 \left( \frac{c}{d} \right)^2$$

where:  $r$  = tip radius (in mm)  
 $c$  = length of line of junction (in mm)

The assumption made in both cases is that the volume of the indentation remains the same, for varying values of  $r$  and  $c$ , as would be the case with an indenter of perfect geometry. Graphs showing values of these two parameters are given below:



Practical experiments were carried out, for the HV 10 and HV 30 ranges, to determine the sensitivity coefficients for loading time and test force duration. In addition, the sensitivities to force value were also determined, to see how well they agreed with the theoretical values.

*Sensitivity to application time and force duration*

ISO 6507-1 specifies that, for forces of 49.03 N (HV 5) and above, “the time from the initial application of the force until the full test force is reached shall not be less than 2 s nor greater than 8 s” and that “the duration of the test force shall be 10 s to 15 s”.

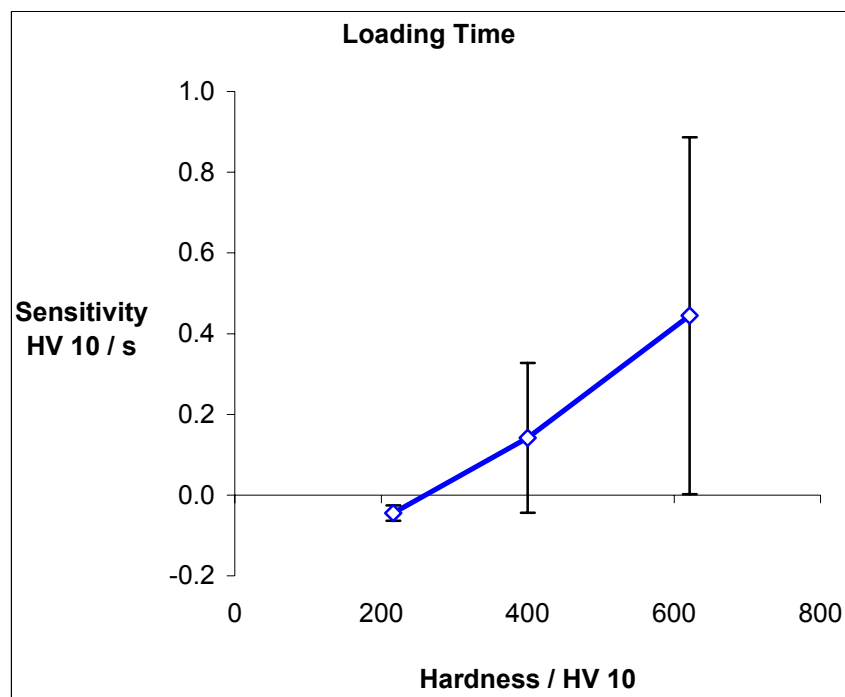
For both ranges, five hardness tests were carried out on each of three blocks of different nominal hardnesses, at different values of the input parameter:

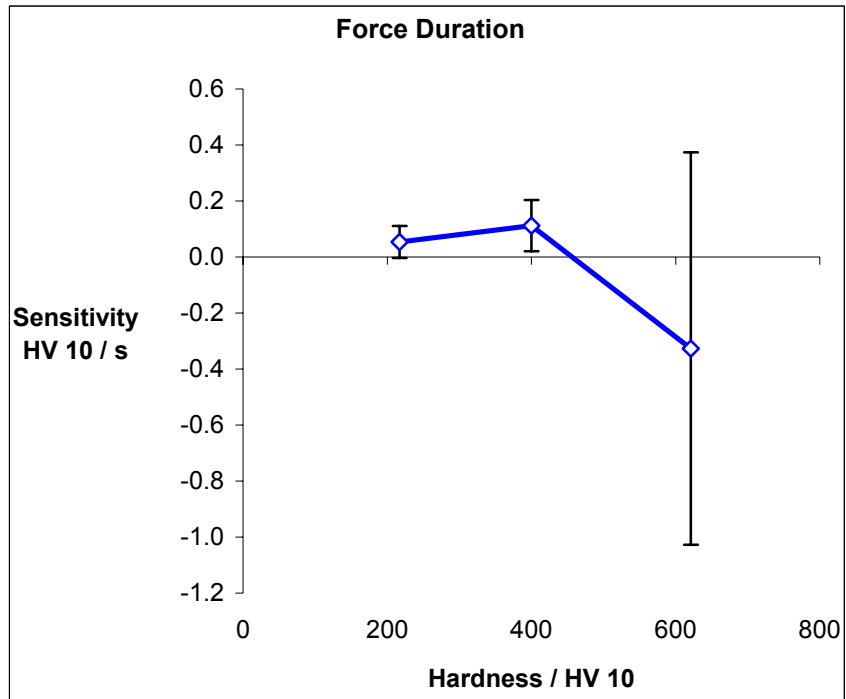
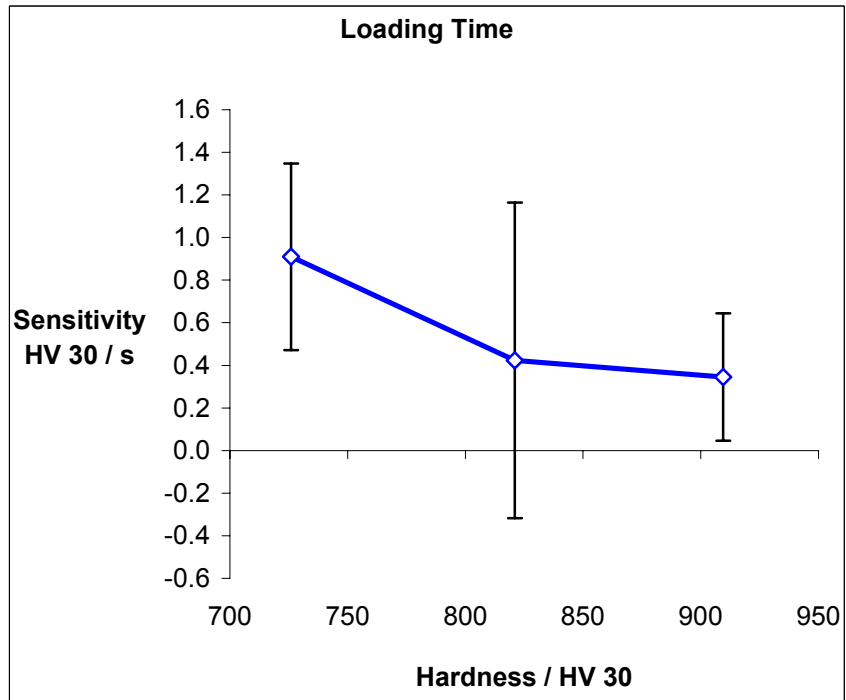
Range	Force	Parameter	Value 1	Value 2	Value 3	Value 4
HV 10	98.07 N	Application time	2 s	4 s	6 s	8 s
		Force duration	10 s	13 s	15 s	N/A
HV 30	294.2 N	Application time	2 s	4 s	6 s	8 s
		Force duration	10 s	13 s	15 s	N/A

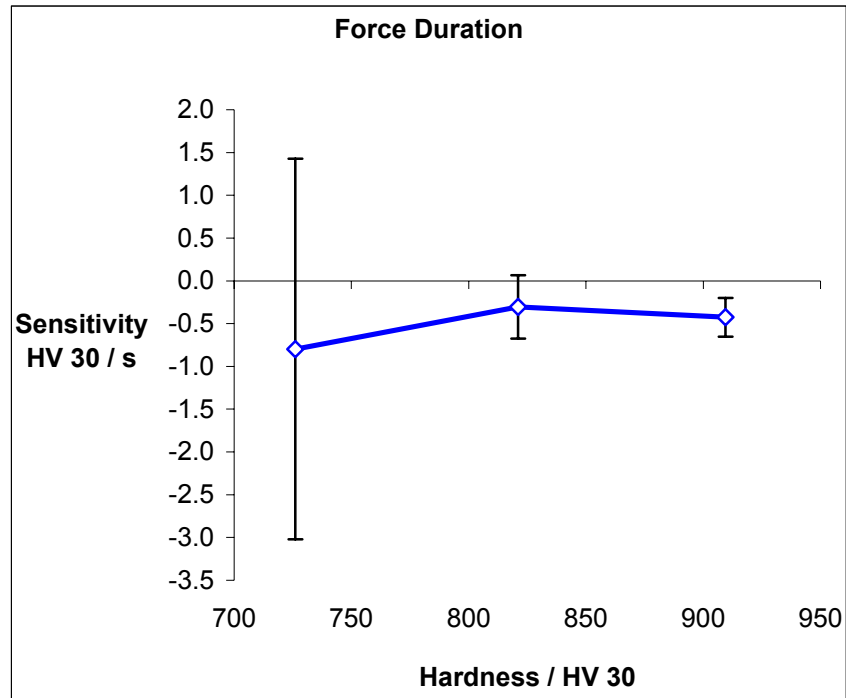
The forces were not applied in a single linear profile, but in two linear sections - 80 % of the force in 25 % of the time followed by the final 20 % of the force in the remaining 75 % of the time:

Range	Application time	Part 1			Part 2		
		Force	Time	Rate	Force	Time	Rate
HV 10	2 s	78.46 N	0.5 s	156.9 N·s <sup>-1</sup>	19.61 N	1.5 s	13.08 N·s <sup>-1</sup>
	4 s		1.0 s	78.46 N·s <sup>-1</sup>		3.0 s	6.538 N·s <sup>-1</sup>
	6 s		1.5 s	52.30 N·s <sup>-1</sup>		4.5 s	4.359 N·s <sup>-1</sup>
	8 s		2.0 s	39.23 N·s <sup>-1</sup>		6.0 s	3.269 N·s <sup>-1</sup>
HV 30	2 s	235.4 N	0.5 s	470.7 N·s <sup>-1</sup>	58.8 N	1.5 s	39.23 N·s <sup>-1</sup>
	4 s		1.0 s	235.4 N·s <sup>-1</sup>		3.0 s	19.61 N·s <sup>-1</sup>
	6 s		1.5 s	156.9 N·s <sup>-1</sup>		4.5 s	13.08 N·s <sup>-1</sup>
	8 s		2.0 s	117.7 N·s <sup>-1</sup>		6.0 s	9.807 N·s <sup>-1</sup>

For each of the three hardness blocks, the mean measured hardness was plotted against the input parameter (application time or force duration) and a linear least squares fit was applied to the data. The gradient of this line (the sensitivity of hardness to the input parameter) was plotted against hardness for the three blocks, and these values are shown in the following graphs. The error bars relate to the linearity of the fit of hardness against input parameter at each of the hardness values – each error bar is  $\pm 2 \times$  the standard error associated with the estimate of the gradient (sensitivity coefficient).







### *Sensitivity to force value*

ISO 6507-2 specifies that, for forces of 1.961 N (HV 0.2) and above, each of three force verification measurements in the machine (made by an ISO 376 Class 1 proving device) shall agree with the nominal force to within a tolerance of  $\pm 1.0\%$ .

For both ranges, five hardness tests were carried out on each of three blocks of different nominal hardnesses, at different values of force:

Range	Force		
	Run 1	Run 2	Run 3
HV 10	96.60 N	98.07 N	99.54 N
HV 30	287.79 N	294.20 N	298.61 N

For each of the three hardness blocks, the mean measured hardness (calculated using the nominal force) was plotted against applied force and a linear least squares fit was applied to the data. The gradient of this line (the sensitivity of hardness to force) was plotted against hardness for the three blocks, and these values are shown in the following graphs. The error bars relate to the linearity of the fit of hardness against force at each of the hardness values – each error bar is  $\pm 2 \times$  the standard error associated with the estimate of the gradient (sensitivity coefficient). The red lines are plots of the sensitivity coefficients obtained from taking a partial derivative of the hardness equation – they are plotted as negative values, rather than positive ones (as the equation suggests), because the hardness values are calculated from the nominal force and the actual indentations, rather than from the actual force and the indentation size at nominal force.

