Chapter 9: Hardness and toughness

9.1 Techniques

Although surfaces can be relatively rough for hardness measurement by indentation, finishes needs be smoother for toughness measurement by the same technique, as cracks need to be differentiated. Accordingly, surfaces were polished as for microscopy (table 8-1, page 68). The micrography arrangement that was used is shown in fig. 9-1. All actual measurements were made on the PC screen, as this was deemed to give the best resolution. (The video monitor was only used as a focussing aid, which was neccesary as the 'Snappy' only updates the PC image every half a second; the video monitor image is live.) Identical conditions of resolution and magnification were used for measurements. Where in doubt the location of the end of cracks was confirmed by observation at the microscope itself.

It should be noted that the use of a video camera and a 'Snappy' is a low cost alternative to proper digital photography equipment. It does not give images of high quality (as can be seen in fig.9-4 to 9-9). The accuracy of hardness and toughness values reported here is adversely affected by the low quality of micrography.

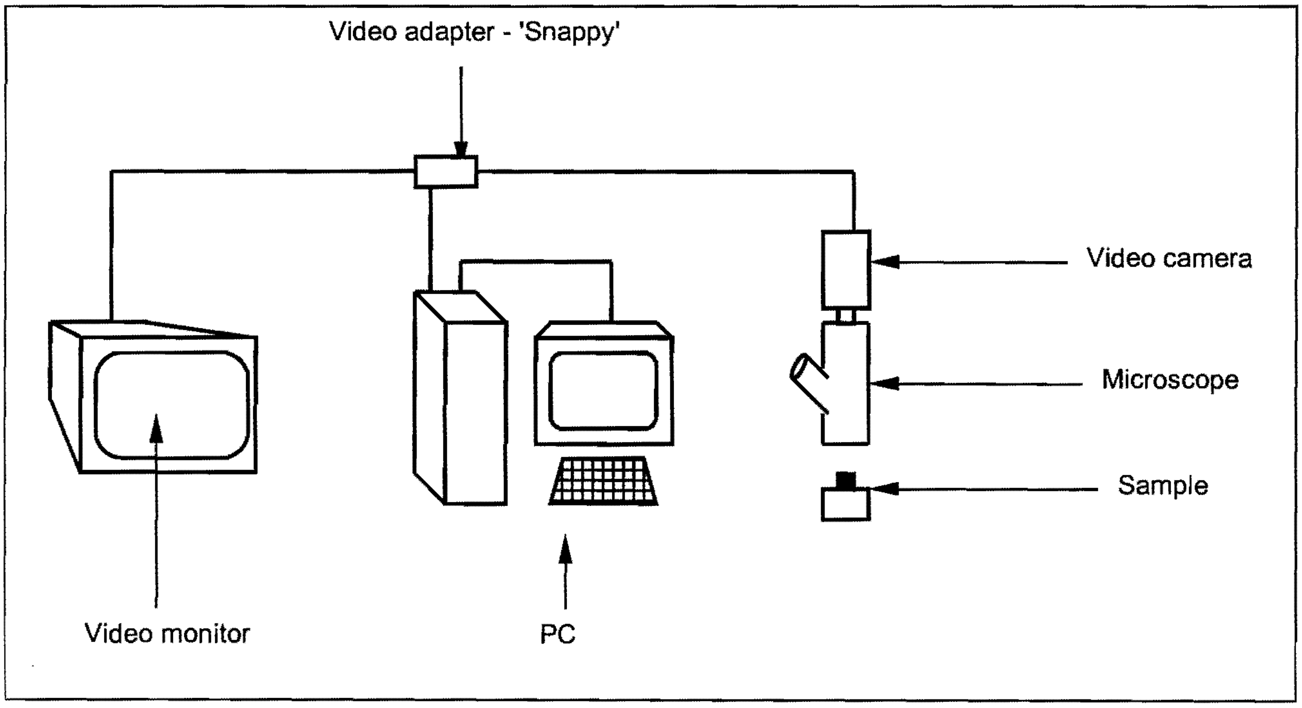

***Fig. 9-1**: Micrography set-up for crack length measurements.*

The lengths of the diagonals, d, were measured under the same conditions as the crack length. The edges of the indent were not always well defined and the error in the measurement of the diagonal length, d, is judged from repeated measurements to be approximately $^{+4.4\ \mu m}/_{-4.4\ \mu m}$. This translates to quite a large possible error in the reported hardness values (fig. 9-2).

The value of c needed in equation 5-12 (page 39) was taken from the average of the four values of c that each indentation has. The hardness and toughness of each sample was determined from the average of three indentations' hardness and toughness measurements.

Indentor load was 10 kg throughout. This was also the load used by Noma and Sawaoka (1984 and 1985).

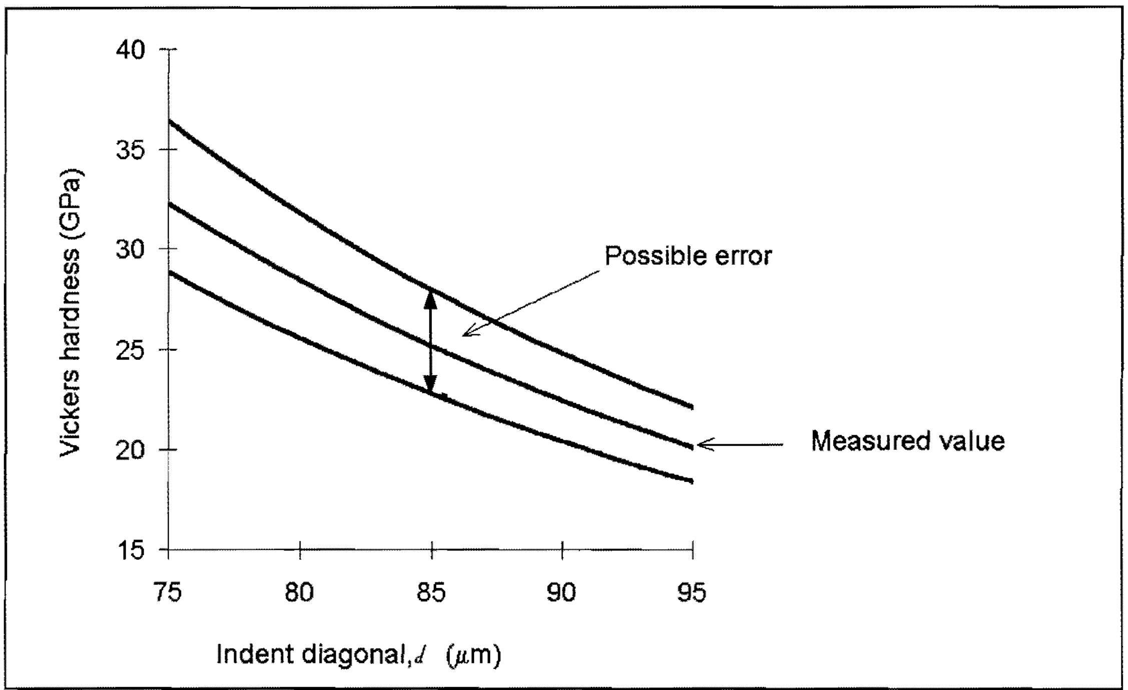

***Fig. 9-2**: The possible error in reported hardness due to the error of $^{+4.4\ \mu m}/_{-4.4\ \mu m}$ in measuring indent diagonal size. E.g. if the indent diagonal is measured as 85 µm the reported hardness would be 25 GPa but due to the error in measurement actual hardness may be any value between 22.5 and 27.5 GPa.*

9.2 Results

The recorded values of d and c and the calculated hardness and toughness are reported in table 9-1. Hardness was calculated as the pressure exerted on the indent surface area, i.e.

$$H_V = \frac{9.81\,M}{\frac{(10^{-6} d)^2}{2\cos 22^\circ}} \qquad (9\text{-}1)$$

with H_V in Pa if the indentor load M is given in kg and d is given in µm, 22° being the angle between the surfaces of the indentor's tip and the surface of the sample. Toughness was calculated from equation 5-12. The Young modulus (E) for the diamond containing samples, which is required for toughness calculation (equation 5-9, page 40), is estimated in appendix A4.

Examples of indentations for each of the three types of material (Toshiba LX11, non-diamond containing alumina, and diamond-alumina composite) are shown in fig. 9-3 to 9-8. Note that the crack lengths were not measured at the magnification or resolution of fig. 9-3 to 9-8 but were measured on the PC screen. If crack lengths were to be measured from the micrographs as they are printed here they will not correspond to those reported in table 9-1.

The Toshiba LX11 can be used as a crude control for the toughness measurement, as some indication of its toughness is available. Toshiba replaced their grade LX10 with grade LX11. Grade LX10 is unobtainable, although specifications (from a pamphlet of Toshiba) are only available for LX10. According to the local suppliers (Toolquip), LX11 is an improved version of LX10. It can therefore not be expected to be very different from that of LX11. Also, the measured density of 4.3 g/cm^3 for the LX11 insert used corresponded to the 4.30 g/cm^3 given for LX10. The specified toughness for LX10 is 3.3 MPa.m^{½}, with no indication of the method used. This value is reasonably close to the value of 2.7 MPa.m^{½} measured for LX11.

***Table 9-1**: Results from indentation.*

Sample	d (μm)	Average c (μm)	Estimated E (GPa)	Hardness (GPa)	Fracture toughness (MPa.m^{½})	Average hardness (GPa)	Average toughness (MPa.m^{½})
LX11	85	145	390	25	2.9	26	2.7
	83	153		27	2.6		
	83	155		27	2.5		
15◊-α-CP-H1400	83	109	460	27	4.6	26	4.2
	85	128		25	3.7		
	83	117		27	4.2		
0◊-α-Pα-H1400	89	174	390	23	2.3	24	2.1
	87	180		24	2.1		
	87	185		24	2.0		
15◊-α-CP-H1250	83	140	460	27	3.2	27	2.7
	83	166		27	2.5		
	83	169		27	2.4		
15◊-α-pHα◊-H1250	87	145	460	24	3.2	22	3.3
	94	153		21	3.2		
	91	137		22	3.6		
15◊-α-HP-H1250	85	135	460	25	3.5	25	3.8
	85	112		25	4.6		
	85	136		25	3.4		

Table 9-1 *continued.*

Sample	d (μm)	Average c (μm)	Estimated E (GPa)	Hardness (GPa)	Toughness (MPa.m^{½})	Average hardness (GPa)	Average toughness (MPa.m^{½})
15◊-α-HP-H1300	89	147	460	23	3.2	24	2.8
	85	160		25	2.7		
	87	169		24	2.5		
0◊-α-Pα-H1350	89	235	390	23	1.5	24	1.5
	87	222		24	1.5		
	87	217		24	1.6		
0◊-α-Pα-H1200	85	216	390	25	1.6	26	1.7
	83	205		27	1.7		
	83	192		27	1.8		

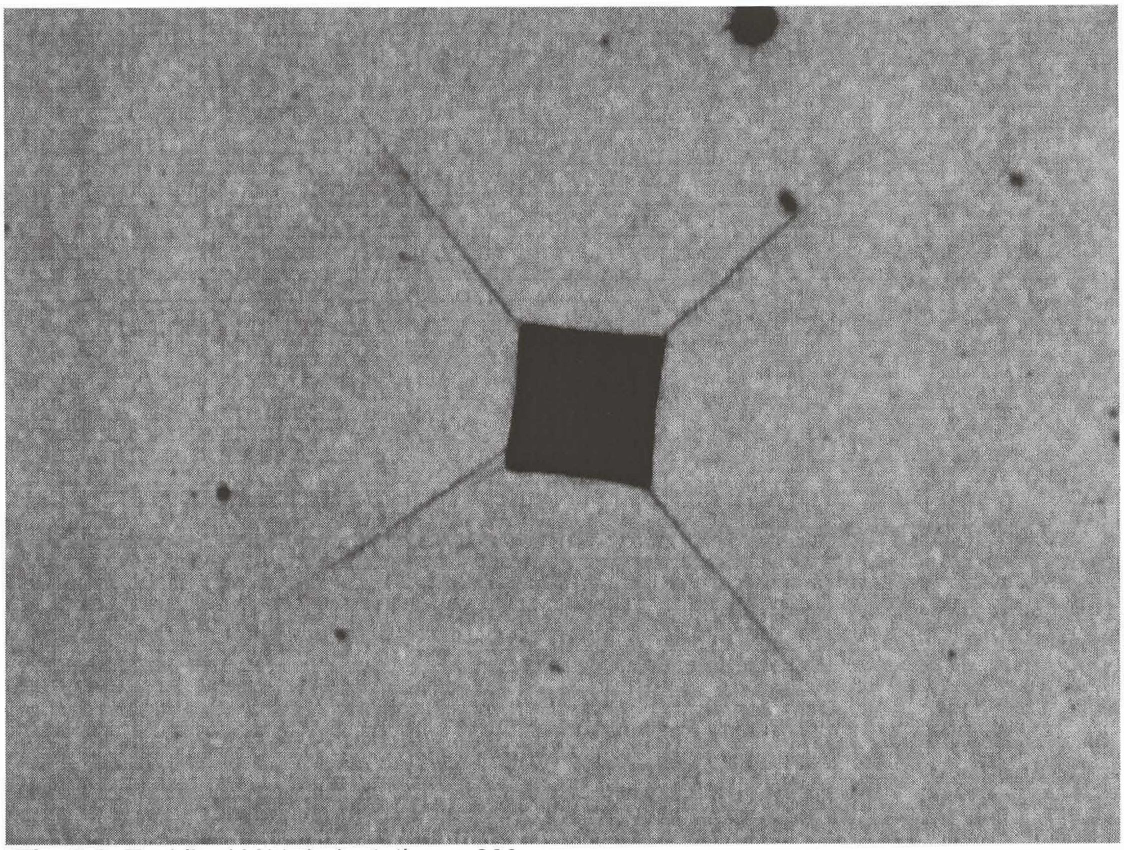

Fig. 9-3: *Toshiba LX11. Indentation. × 300.*

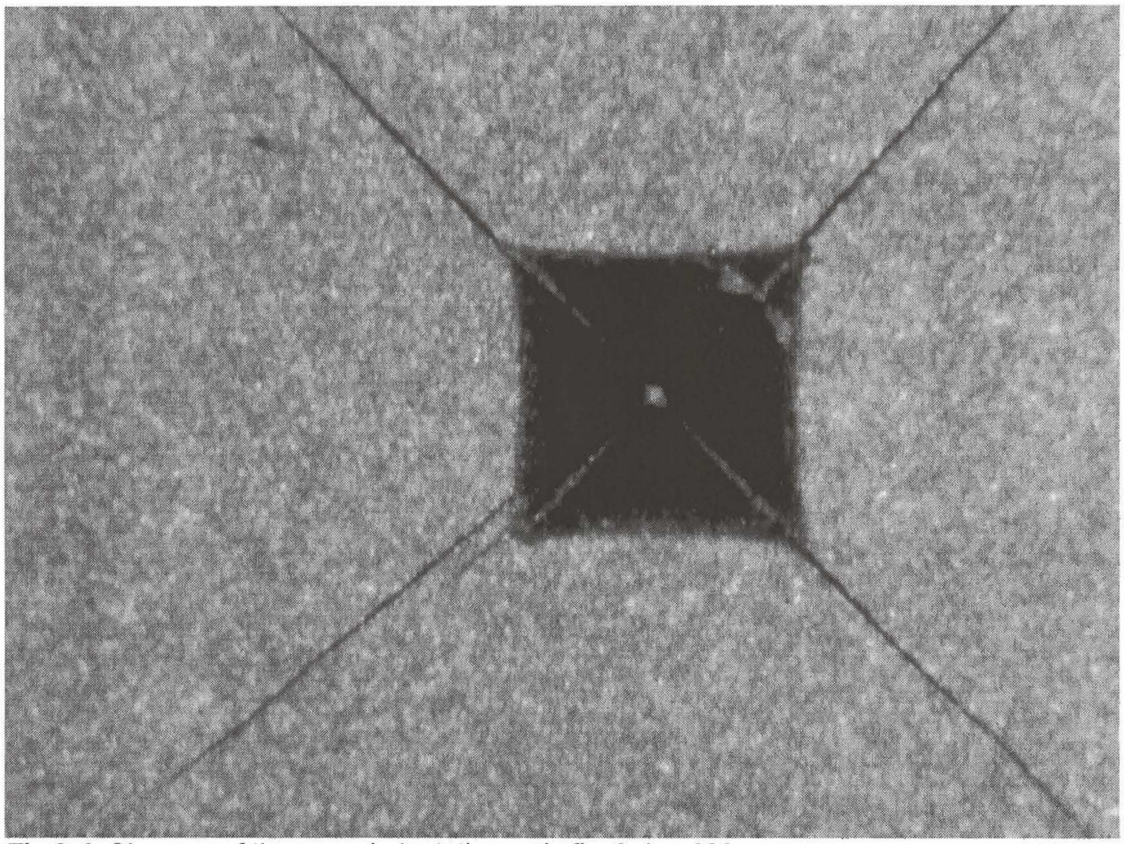

Fig 9-4: *Close up of the same indentation as in fig. 9-4. × 600.*

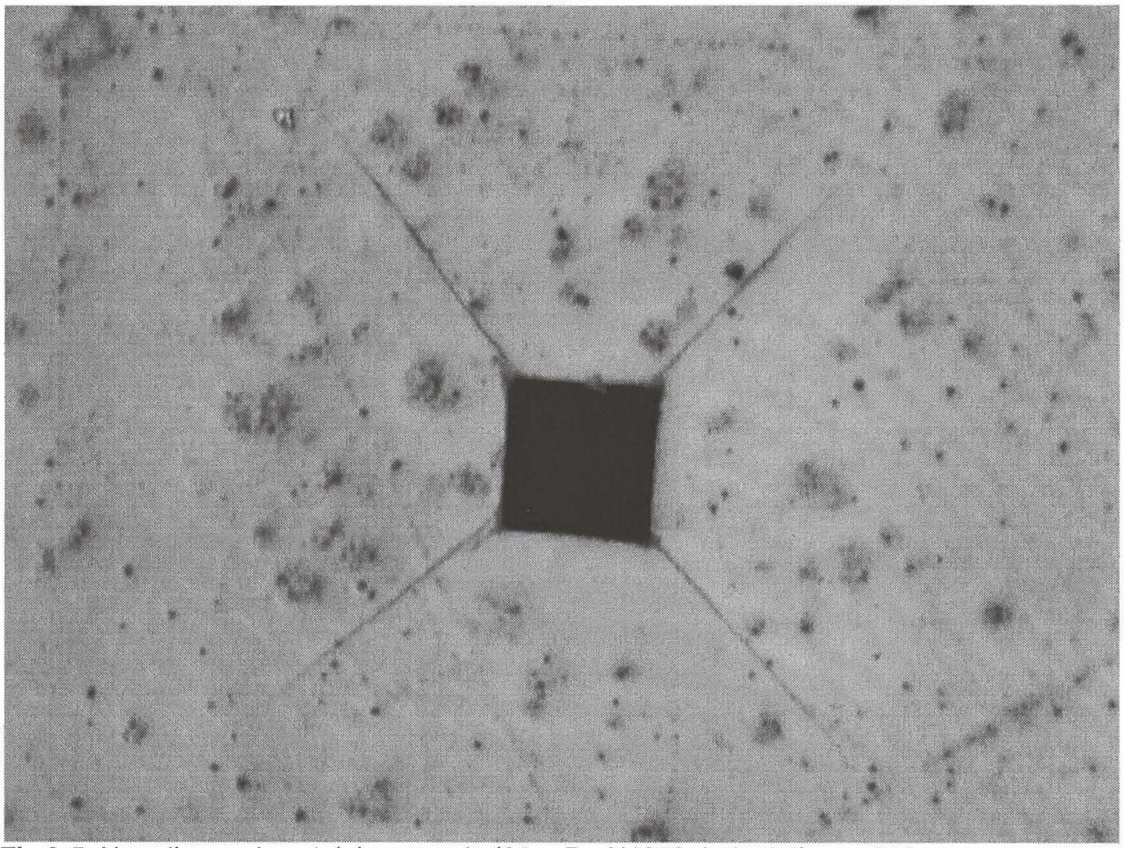

Fig 9-5: *Non-diamond containing sample (0◊-α-Pα-H1350. Indentation. × 300.*

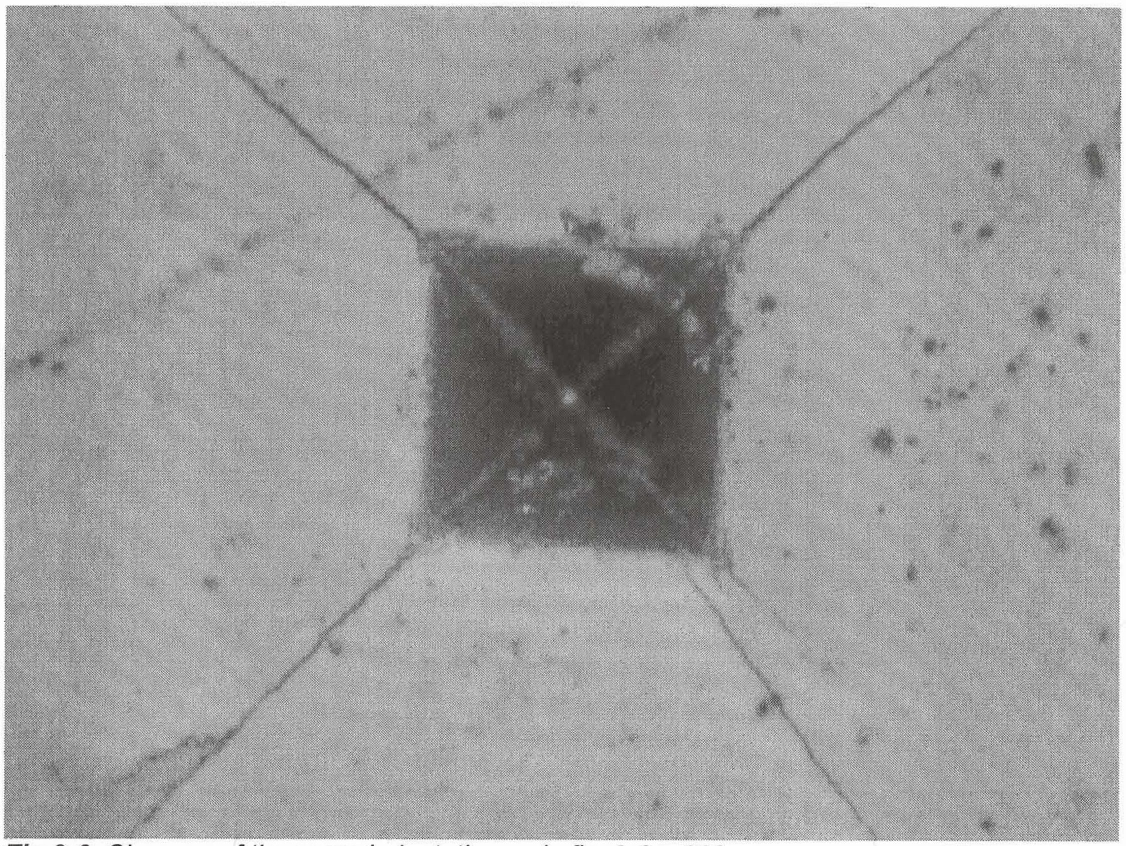

Fig 9-6: *Close up of the same indentation as in fig. 9-6 × 600.*

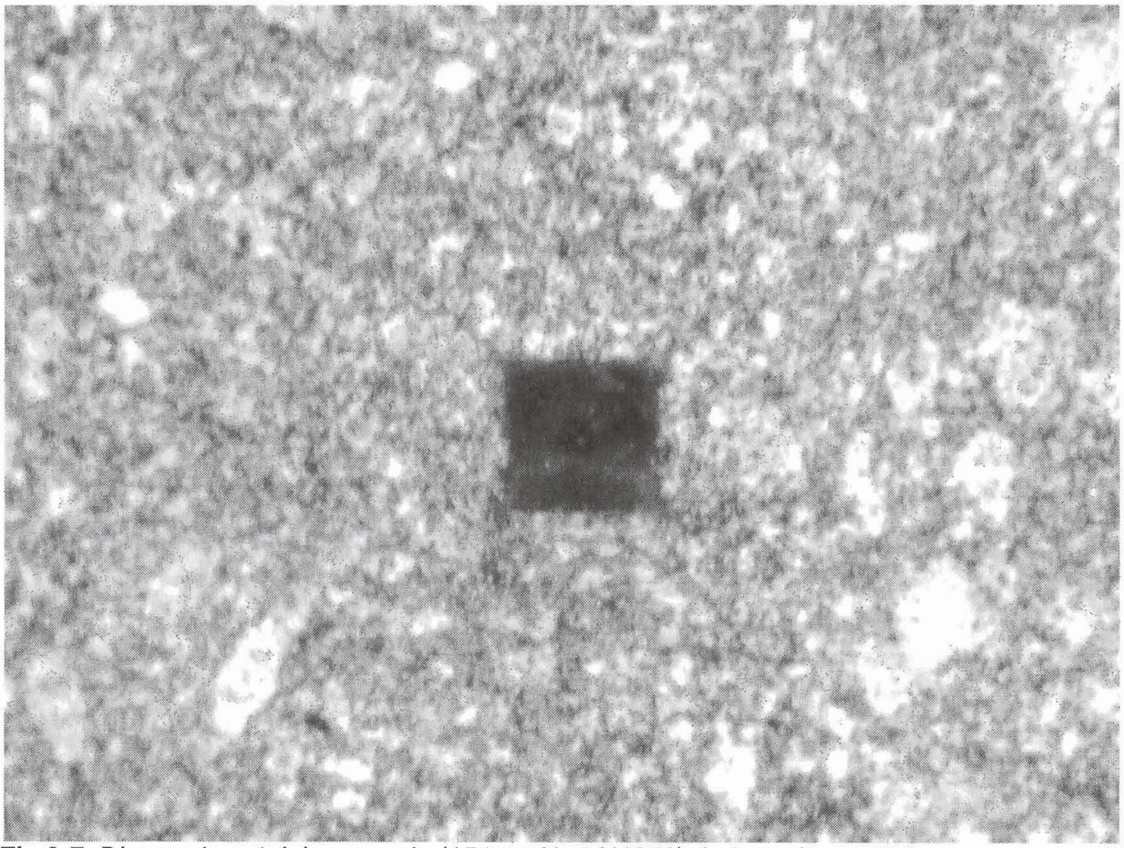

Fig 9-7: *Diamond containing sample (15◊-α-pHα◊-H1250). Indentation. × 600.*

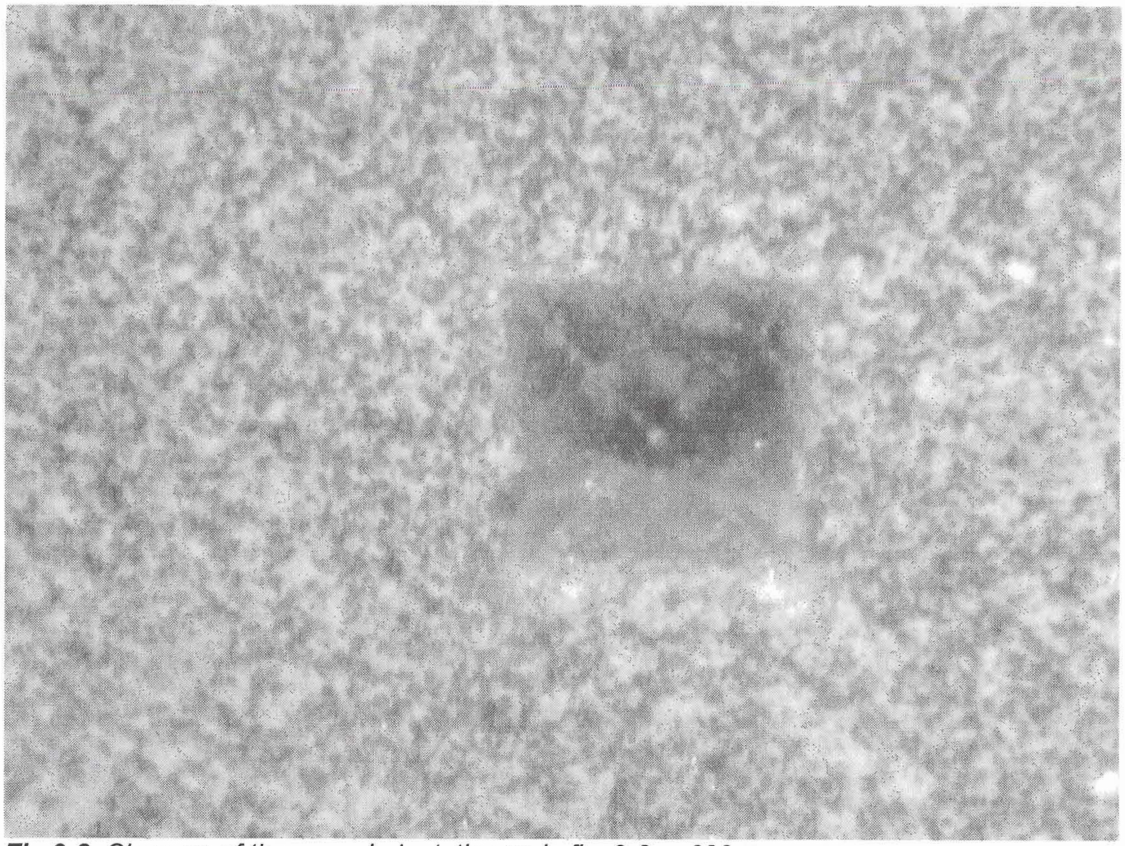

Fig 9-8: *Close up of the same indentation as in fig. 9-8. × 600.*