The cracks were homogeneous in length and regular in distance. When the sample was tilted by 45 ° to the electron beam, a small lip around the edge of the indentation could be seen. However, the lip was not prominent. A few cracks could also be found inside the indentation and parallel to the circumference, see Fig. 5.159.

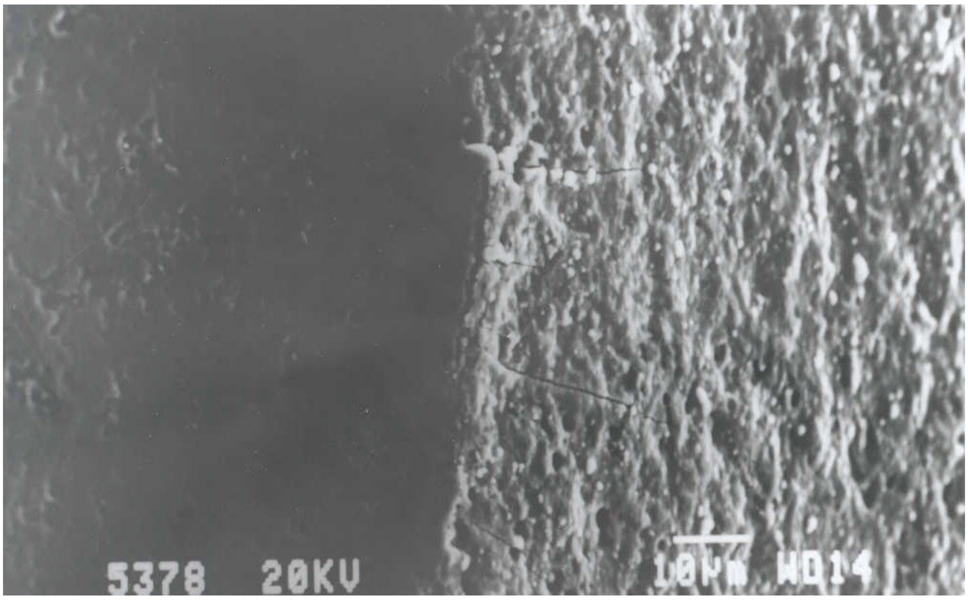


*Fig. 5.159: Cracks due to Rockwell indentation on the coatings from supplier 3*

Spectra (i), (j) and (k) showed that the coating was intact. The EDS analysis taken at the centre of the indentation is shown in spectrum (i) where the TiN appeared to be pushed down but revealing the $Al_2O_3$ underneath it, due to the thinness of the TiN coating.

Spectrum (j) from the small region which chipped showed a higher Al peak than spectrum (i) which indicates that Al is exposed. Spectrum (k) was taken at the edge of the indentation where cracks are most likely to occur, but the spectrum is the same as the one from inside the indentation.

The small chipped areas were found between cracks, see Fig. 5.160.

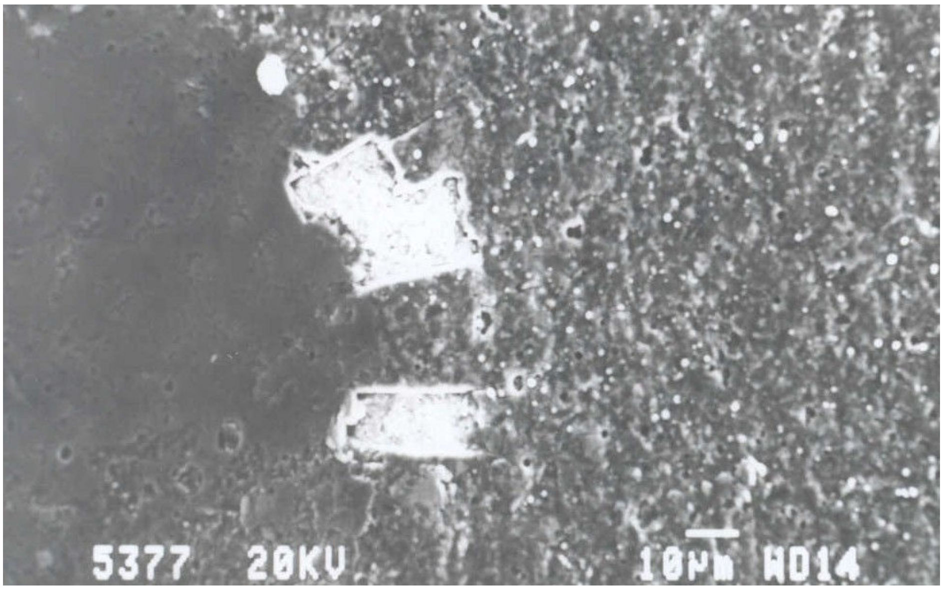


*Fig. 5.160: Chipped areas due to Rockwell indentation on the coatings from supplier 3*

d) Cutting Tool Inserts from Supplier 4

Figure 5.161 shows a micrograph of a Rockwell indentation on a supplier 4's insert and spot analysis spectra from the points which are connected to the spectra by lines.

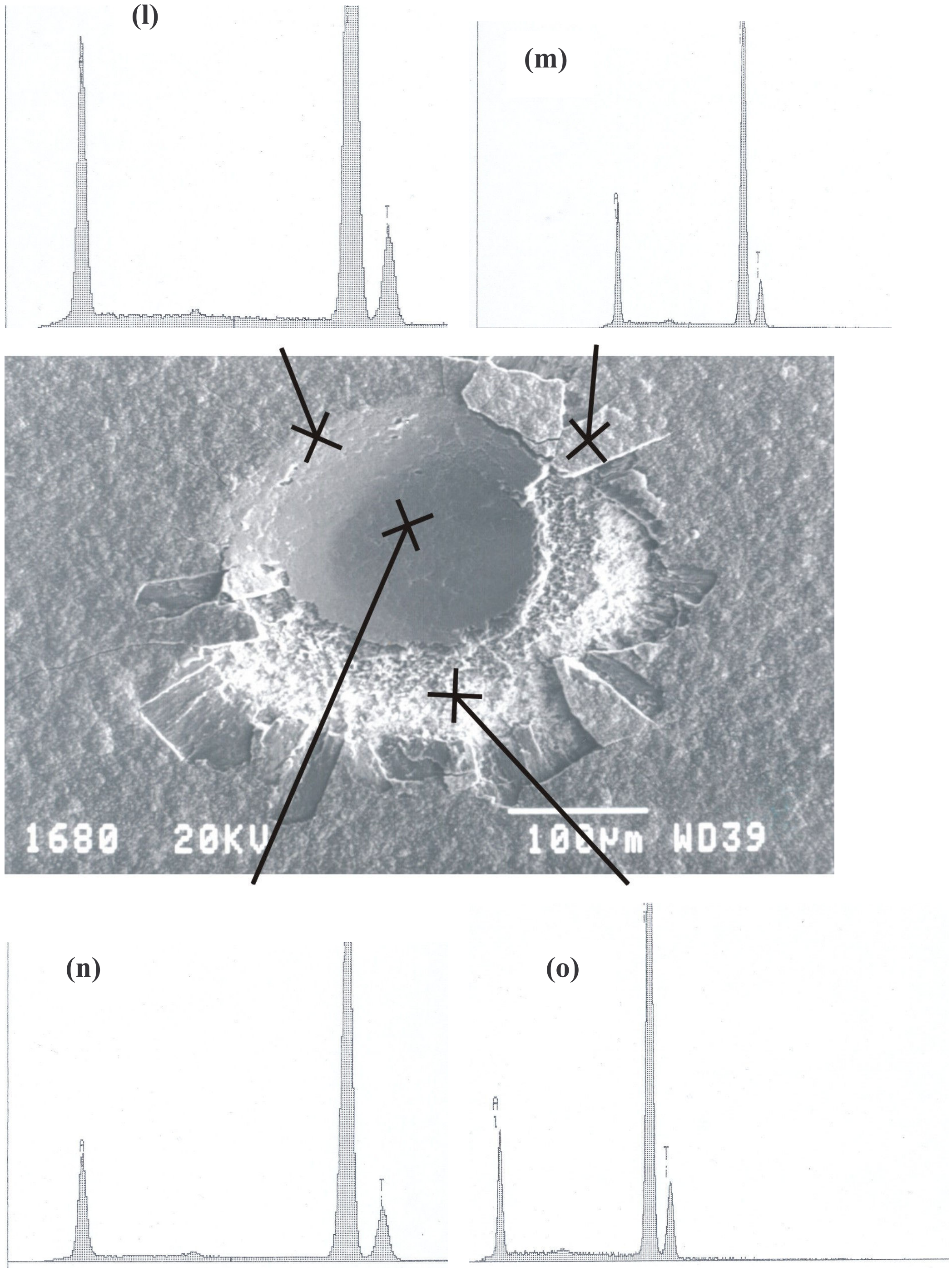


*Fig. 5.161: Rockwell indentation of system "substrate/coating" from a supplier 4's insert and EDS spectra from the spots indicated by the crosses*

The annular region in supplier 4's coating consisted of a finely fragmented area around the indentation and an area with radial cracks surrounding the fragmented region. The cracks were parallel and regular and could be seen inside and parallel to the circumference.

Spectrum (l) is taken at the edge of the indentation where the EDS analysis revealed Al. Spectrum (m) is from a spot on the cracked region where the coating was broken but had not fallen off. In spectrum (o) from the finely fragmented annular region, the TiN had probably partly fallen off and uncovering the $Al_2O_3$ and possibly also the TiCN. The centre of the indentation in spectrum (n) showed the TiN coating pushed down with some $Al_2O_3$ detected.

The Al/Ti ratio seems to be minimum in spectrum (n), therefore the Al peak is probably due to the extreme thinness of the TiN coating. In spectra (m) and (o) the Al/Ti is not much higher than in spectrum (n), indicating that despite fragmentation and cracking most of the TiN coating did not fall off. The highest Al/Ti ratio was found in spectrum (l).

When the sample was tilted by 45 ° to the electron beam, a lip could be identified which was larger than that of the indentation on the coatings from supplier 3, see Fig. 5.162. (The lip is in focus in Fig. 5.162 while the original surface is out of focus because it is at a lower level.)

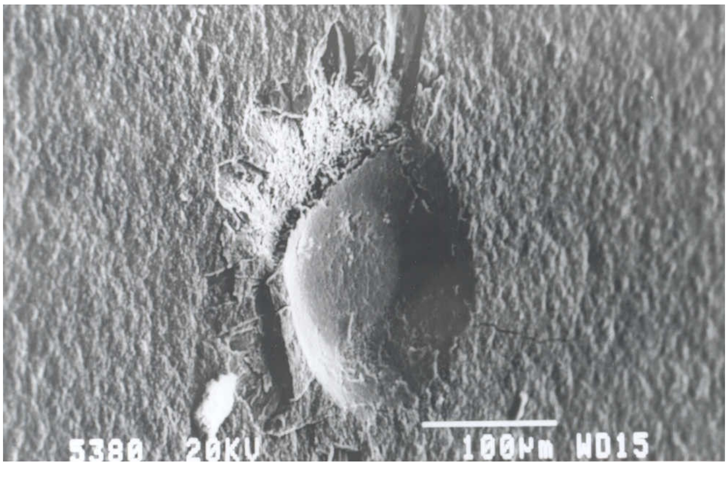


*Fig. 5.162: Rockwell indentation on the coatings from supplier 4*

e) Cutting Tool Inserts from Supplier 5

Figure 5.163 shows a micrograph of a Rockwell indentation on a supplier 5's insert and spot analysis spectra from the points which are connected to the spectra by lines.

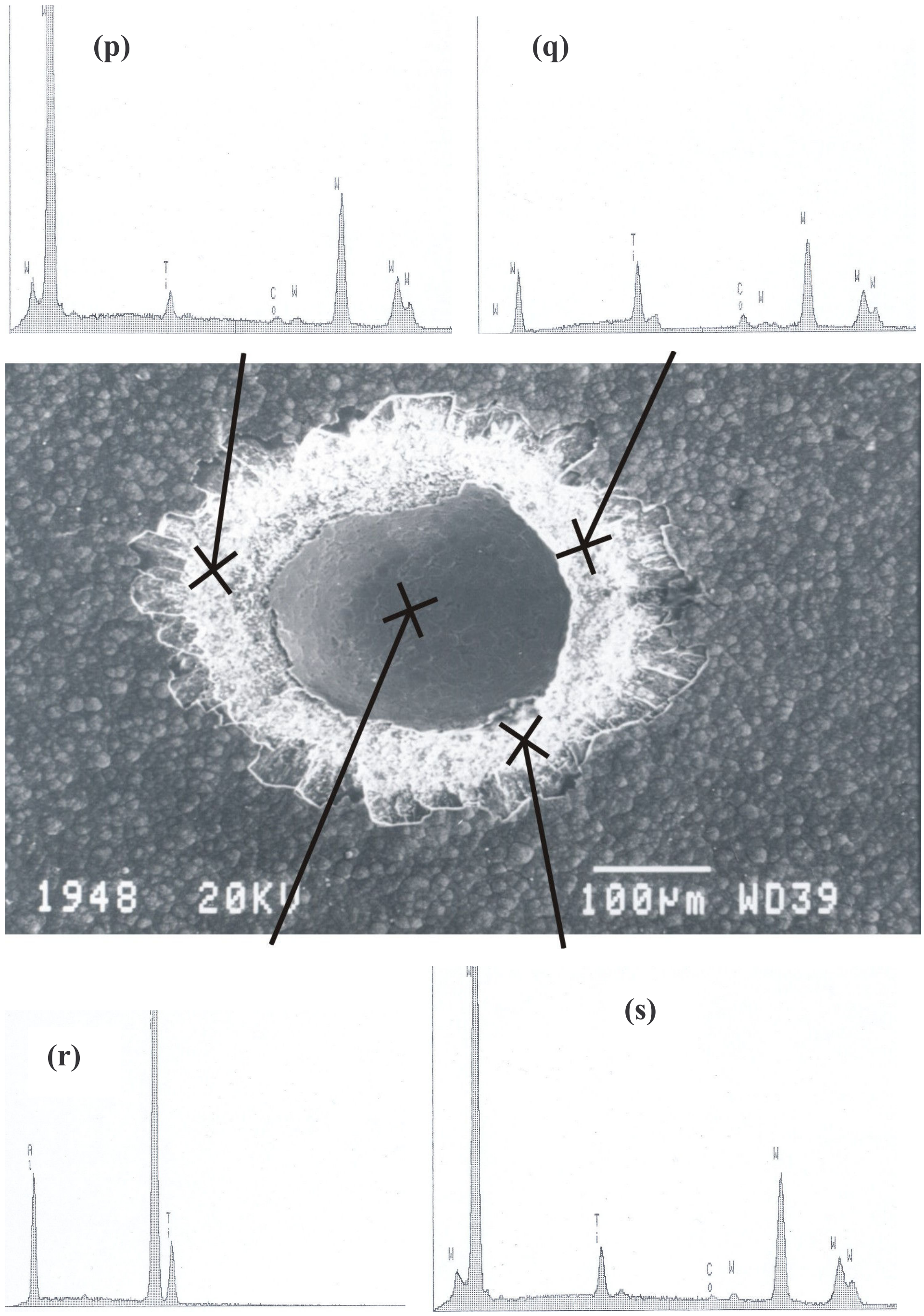


*Fig. 5.163: Rockwell indentation of system "substrate/coating" from a supplier 5's insert and EDS spectra from the spots indicated by the crosses*

The indentation on a cutting tool insert from supplier 5 showed a thick finely fragmented annular area around the indentation and, around that, a region with radial cracks. Those cracks were not long but many.

The centre of the indentation in spectrum (r) revealed Ti and Al as the TiN was pushed down without removing it, the $Al_2O_3$ layer underneath being revealed probably because of the thinness of the TiN coating. Spectra (p), (q) and (s) showed that the substrate was visible among the coating fragments in larger or smaller amounts depending on the area and that the TiN and $Al_2O_3$ layers were both removed (if $Al_2O_3$ was absent, and thus removed, also TiN must have been removed). Therefore this coating did not adhere to the substrate after cracking.

f) Summary of Rockwell Indentation Features

Table 5.40 lists features of the flaking of the coating of the cutting tool inserts from the five different suppliers and indicates if the substrate was exposed by the Rockwell indentation.

*Table 5.40: Features of Rockwell indentations on cutting tool inserts from the five suppliers*

| **Cutting tool insert** | **Flaking of coatings** | |
|---|---|---|
| | **Exposure of substrate** | **Description** |
| Supplier 1 | Yes | Substrate visible among fragments in the finely fragmented annular region |
| Supplier 2 | No | Coating was lost under indenter |
| Supplier 3 | No | Almost no flaking observed |
| Supplier 4 | No | Substrate was not visible, even among the fine fragments in the annular region |
| Supplier 5 | Yes | Substrate was visible among the fine fragments in the annular region |

The substrate was exhibited around indentations on cutting tool inserts from suppliers 1 and 5 while around the indentations on the cutting tool inserts from suppliers 2 to 4 the substrate was not uncovered.

Different Al amounts were found by doing EDS spot analysis on the centre of the indentations on the coatings from supplier 2 to 5. Figure 5.164 shows a representative spectrum each of the EDS spot analyses on the centre of the Rockwell indentations.

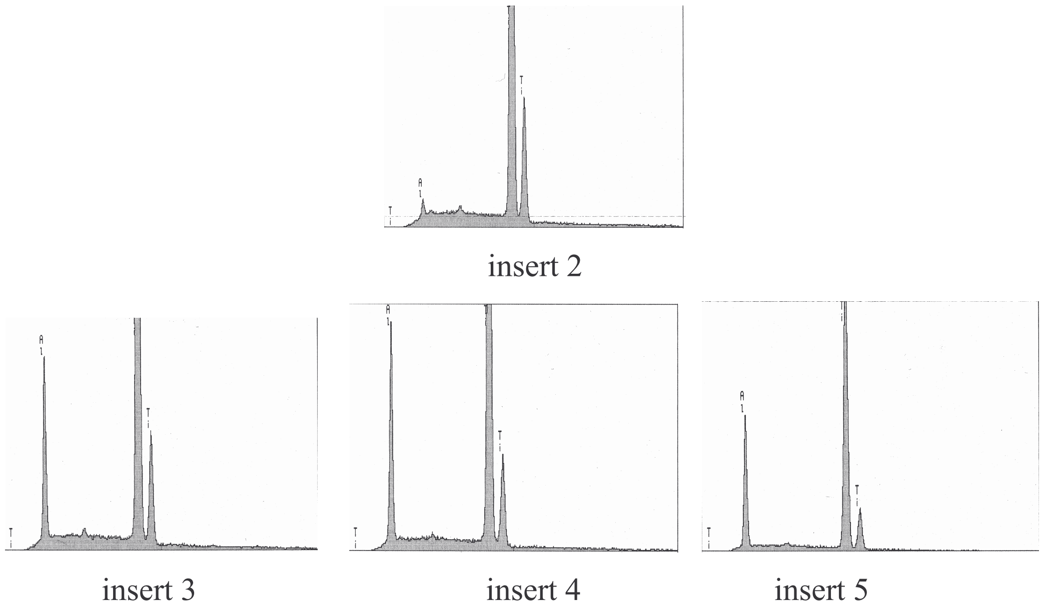


*Fig. 5.164: EDS spectra on the centre of a Rockwell indentation on the coatings from supplier 2 to 5*

The Al detected was much lower in the inserts from supplier 2 compared to the inserts from suppliers 3 to 5 (the inserts from supplier 1 did not contain Al), see the Al/Ti $K_{\beta}$ peak ratios in Table 5.41.

*Table 5.41: Al/Ti $K_\beta$ ratios from EDS spectra on the centre of a Rockwell indentation on the coatings from supplier 2 to 5*

| **Cutting tool insert** | **Al/Ti $K_\beta$** |
|---|---|
| Supplier 2 | 0.22 |
| Supplier 3 | 1.63 |
| Supplier 4 | 2.36 |
| Supplier 5 | 3.13 |

The Al/Ti $K_\beta$ ratio from the inserts from supplier 2 is below one, while those from the inserts from suppliers 3 to 5 are above one. That phenomenon is still unexplained, although one wonders if the stopping power of the TiCN layer in the coating of the inserts from supplier 2 is related to the adhesion between the TiCN and the $Al_2O_3$ layers. The adhesion between substrate and whole coating in the inserts from supplier 2 seemed to be good, contrary to the bad adhesion between the TiCN and $Al_2O_3$ coating layer.

5.7.1.2 Classification of Failure Modes

The Rockwell indentations were classified by examining the cracking and flaking of the coating around the indentations. According to Su *et al.* [Su, 2003], only plastic deformation (without cracking) around the indentation is regarded as "good adhesion", "fair adhesion" shows only fine fragmentation of the coating around the indentation, and "poor adhesion" is present when radial cracks accompany a large area of annular detachment around the indentation, see Fig. 5.165.

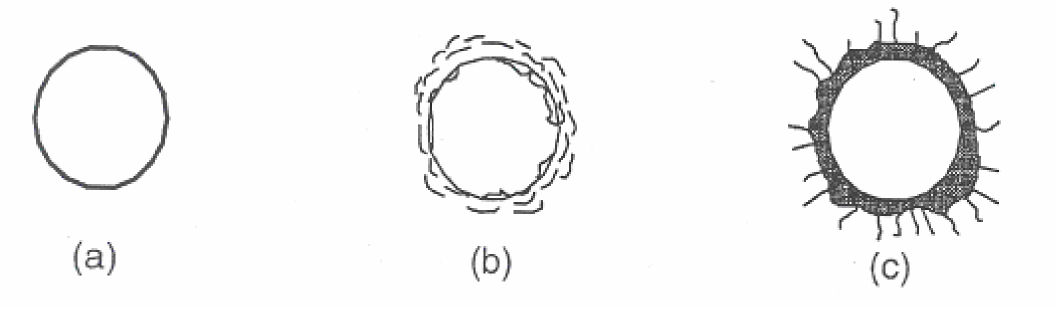


*Fig. 5.165: Failure modes for coatings, as classified into three groups [Su, 2003]*

Four indentations were made on the coatings of the cutting tool inserts from suppliers 1 to 5 under an applied load of 60 kgf, differently from the applied load of 150 kgf which was used by Su *et al.* [Su, 2003]. As explained in section 5.7.1.1, the 60 kgf load was chosen after trial tests.

After the indentations were made, the tool inserts were examined and compared in the SEM. The cutting tool inserts from each supplier showed reproducible patterns. Figures 5.166 to 5.170 show three indentations on the coatings from the inserts from each supplier and these micrographs were used to classify the adhesion of the coatings to the substrate.

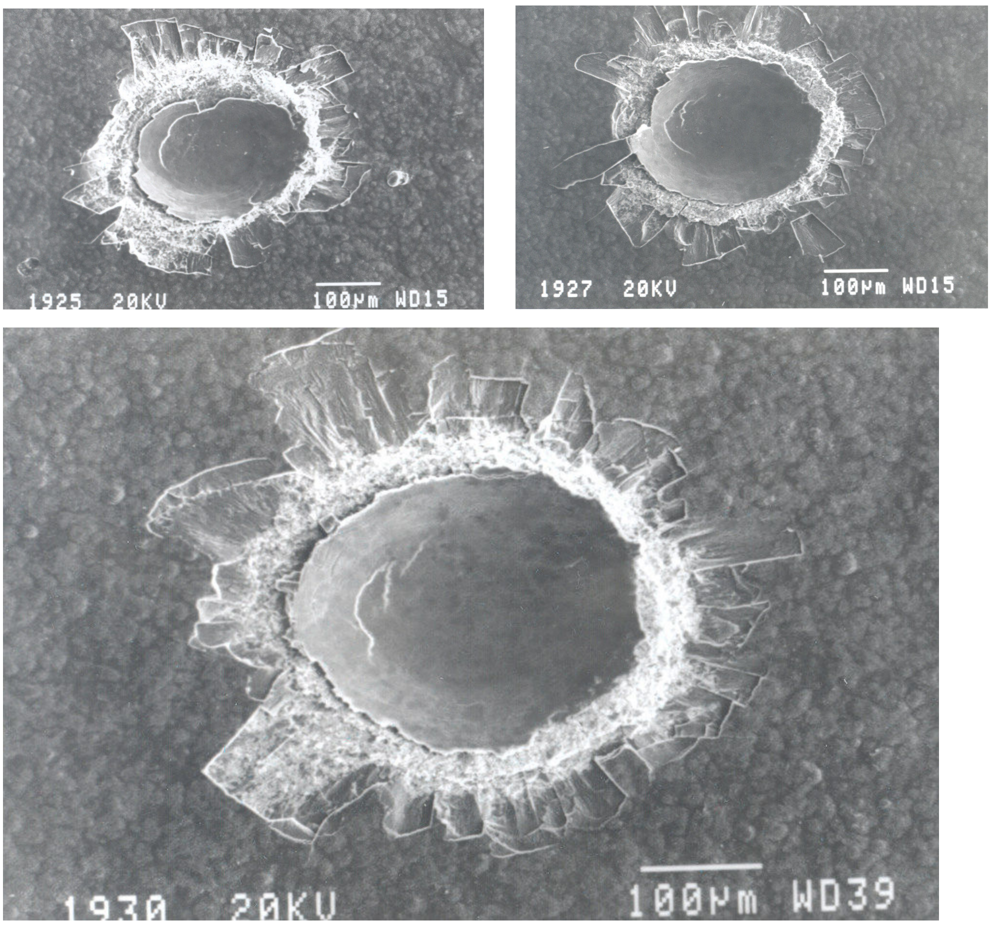


*Fig. 5.166: Rockwell indentations on the coating from an insert from supplier 1*

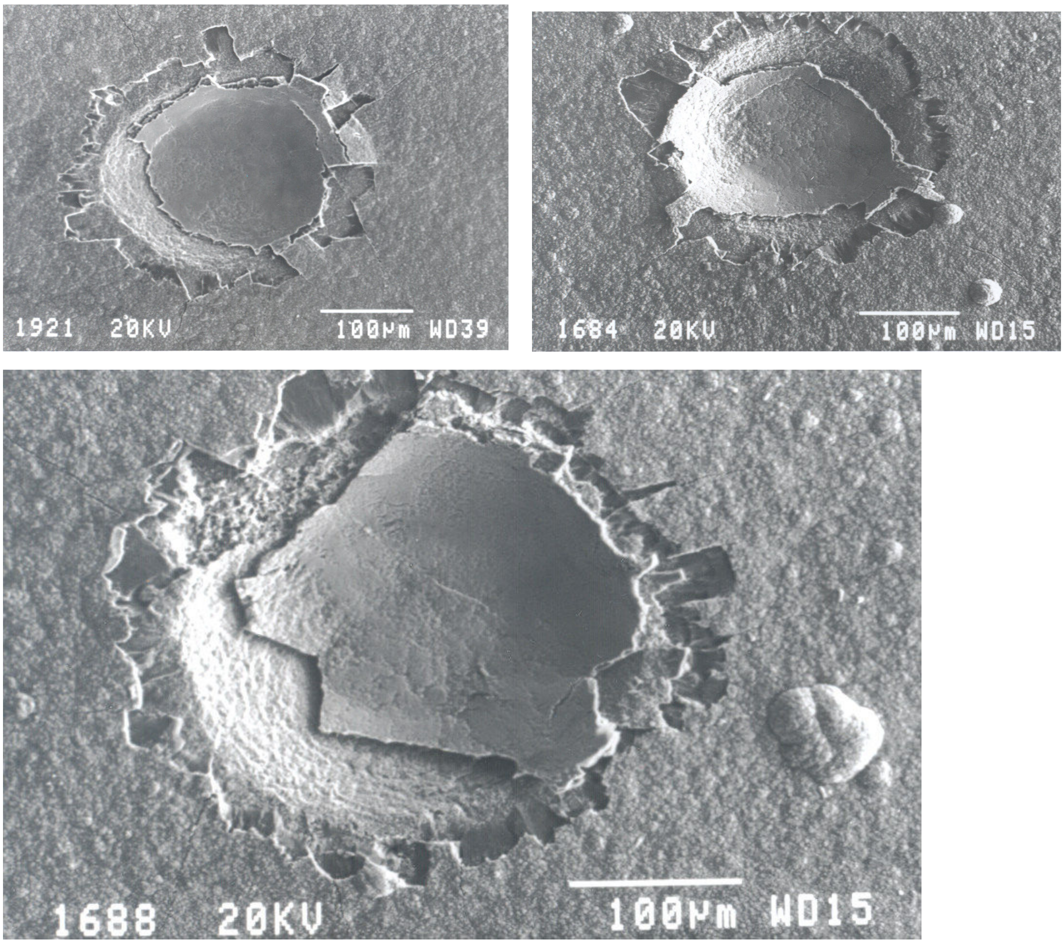


*Fig. 5.167: Rockwell indentations on the coating from an insert from supplier 2*

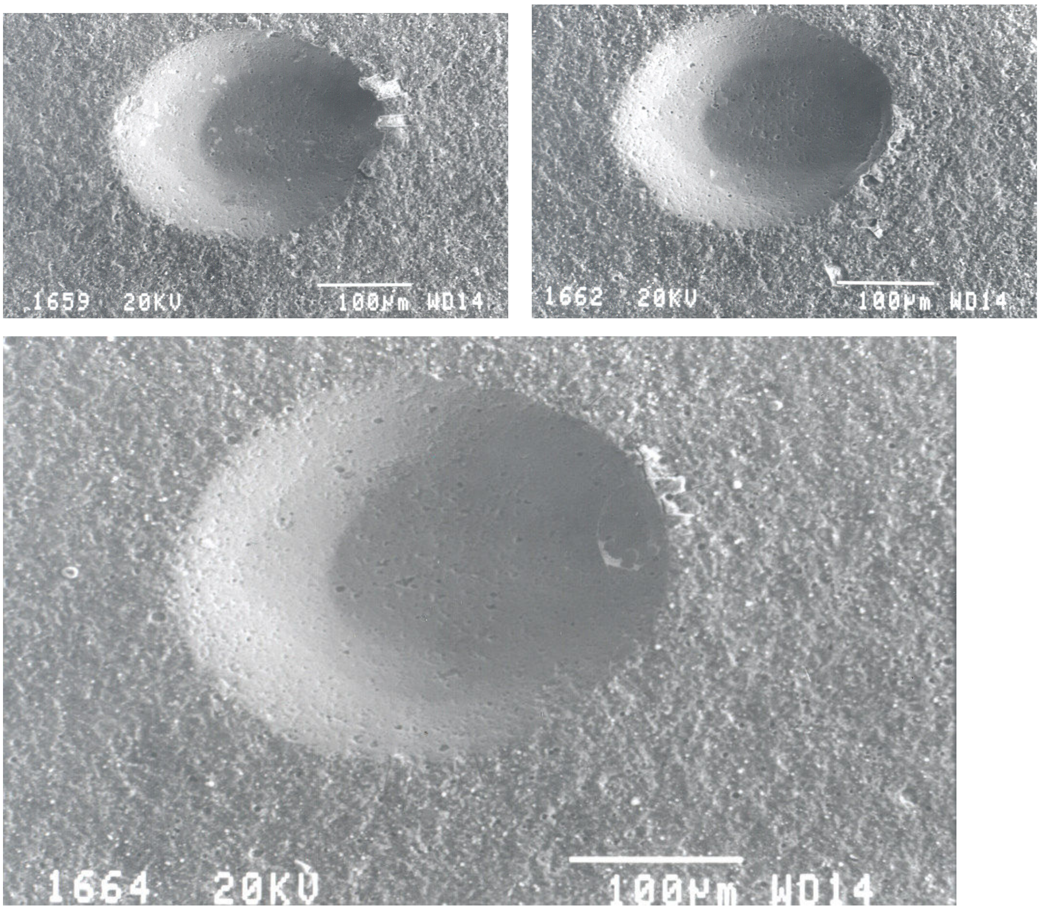


*Fig. 5.168: Rockwell indentations on the coating from an insert from supplier 3*