HIGH PRESSURE WATER - and ELECTROEROSION CUTTING OF NIOBIUM

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The progress in the production of high purity niobium on a technical scale during the last years is remarkable. For new projects the manufacturing of superconducting cavities with Nb RRR > 300 has become possible. Such materials are very sensible to small changes of impurity content (especially of interstitial impurities) and to crystalline defects. For instance the grinding of the niobium sample by insufficient cooling leads to a strong absorption of hydrogen and subsequently to decreasing of RRR /1/. The mechanical deformation also decreases the RRR of Nb /2/.

Therefore it is important to check different technological methods of mechanical treatments of metals. The cutting of niobium sheets with high pressure water jet or elecroerosion seems to protect the RRR. This processing allows to manufacture complicated form profiles at good cooling. Some results about the influence of high pressure water cutting and electroerosion cutting on the RRR and surface status of niobium are shown below.

The high pressure water cutting was carried out by Flow Europe GmbH (Darmstadt, Mr. Girard) , Metafot Mikro-Mechanik (Wuppertal, Mrs. Schemann), B&R Water Cut (Geesthacht, Mr. Britzke). The cutting is usually carried out by application of 3000-4000 bar pressure, about 1mm focus nozzle with using roughly 50% abrasive powder in the water. The electroerosion cutting was carried out by H. Doering Werkzeugbau (Hamburg, Mr. Mohr), Ansaldo Energia (Genua, Mr. Gagliardi).

Several samples from Nb_{300} with the dimensions 2,8x1,5x80 mm were cut out on the inside of the sheets (2 mm distant from edge) for measurements of RRR. For comparison some specimens of the same sheet (cutting of the 5 mm width bar with the hit scissors, and then milling of the specimen at a very good cooling at the lowest treating speed) were prepared previously according to the proved traditional methods. The data of RRR measurements are shown in table 1.

Table 1. Comparison of the RRR values of Nb300 samples prepared by different procedures

Water cutting		Electroerosion		Milling	
Comment	RRR	Comment	RRR	Comment	RRR
Nb sheet	349	Nb sheet	372	Nb sheet	368
E.b.welding	254	E.b.welding	245	E.b.welding	257
E.b.welding	277	E.b.welding	256	E.b.welding	282
6mm far away	312	6mm far away	272	E.b.welding	248
12mm far away	332	12mm far away	290	Nb sheet	375

The obtained results allow to decide that the RRR is not essentially damaged during high pressure water- and electroerosion cutting. The differences of the RRR values for specimens produced by three different methods are rather small and more likely caused by Nb sheets' RRR differences. This means that the bulk of the samples is not damaged. However, the RRR measurement is not sufficient for a conclusion about surface damaging and pollution of Nb. An additional investigation is necessary. All the more the high pressure water cut samples have quite a rough surface and after electroerosion cutting the surface changes the colour.

The metallographic investigations of the surface structure of niobium after high pressure water cutting were accomplished by the "Universität der Bundeswehr". The applied parameters are to be extracted from table 2.

Table 2 Cutting parameters of the company Flow Europe

Constant parameters for all experiments:

Pressure	3800 bar
Focus nozzle diameter	1 mm
Abrasive grain size	80 MESCH(0,25-0,18mm)
Distance to the material	3 mm

Changeable parameters:
cutting velocity v, amount of the abrasive powder M

Cut	RRR60		RRR300	
	v, mm/min	M, g/min	v, mm/min	M, g/min
1	100	250	100	500
2	200	250	300	500
3	300	250	500	500
4	400	250	500	250
5	500	250	300	250
6	1000	250	100	250
7	800	250		
8	600	250		

In figure 1 it is schematically shown how the cutting took place and how the specimens for the structure researching were selected. Two sorts of material, Nb60 and Nb300, were investigated. From the material Nb60 the cutting edges 2 and 3, from the material Nb300 the cutting edges 1,2,4 and 5 (Fig. 1) were used. In addition to the manufacturing a stereo microscopic survey of the cutting edges and surfaces was made. Moreover the roughness measurements onto the cutting surface were made for Nb300.

The cutting structure of the Nb300 is presented in figure 2. The photos show that the deformation area near the cutting edges is rather small. By using a low cutting velocity the deformation is approximately only 5µm. The deepenings, which are observed from time to time, are obviously caused by transversally flying particles. The thermal influence onto the cutting edges of niobium is not determined.

The stereo microscopic photos of the cutting surface for the Nb60 are represented in figure 3a and for the Nb300 in figure 3b respectively. The roughness measurements were accomplished according to DIN 4762 and DIN 4768 norms /3/. The ten point height of irregularities (R_z), the arithmetical mean deviation of the profile (R_a) and the mean height of profile irregularities (R_t) were determined.

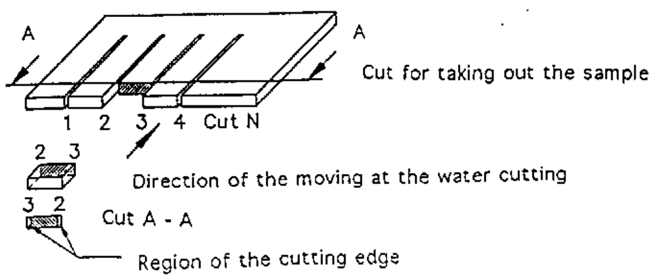


Fig. 1 Taking out the samples for metallographical investigations of the cutting edges

$$R_z = \frac{\sum_{i=1}^{5}|y_{p_i}| + \sum_{i=1}^{5}|y_{v_i}|}{5}$$

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i|$$

$$R_t = \frac{1}{n}\sum_{i=1}^{n}|y_{p_i}| + \frac{1}{n}\sum_{i=1}^{n}|y_{v_i}|$$

y_{p_i} - the height of the i-st highest profile's hill
y_{v_i} - the depth of the i-st deepest profile's valley
n - number of the separate profile deviations.

The results of the roughness measurements are given in diagrams 4 and 5. It could be easily seen that at the lowest velocity of cutting (about 100 mm/min) the roughness is the smallest. The doubling of the abrasive amount in the water has only a very slight influence onto the roughness. Only at a cutting velocity of 300 mm/min this influence becomes appreciable.
The results of the gas analysis of some of the water cut and electroerosion samples Nb300 prepared for the RRR measurements deserve to be mentioned.

Table 3a. Comparison of the gas content in Nb300 samples prepared by

different cutting procedures (after degreasing)

Sample	C, ppm	H, ppm	O, ppm	N, ppm	RRR
		water cutting			
WC		1	67 96	7 11	275
		milling			
7./95		1	32 19	8 8	265
		electroerosion			
1./95		9	522 535	13 13	286

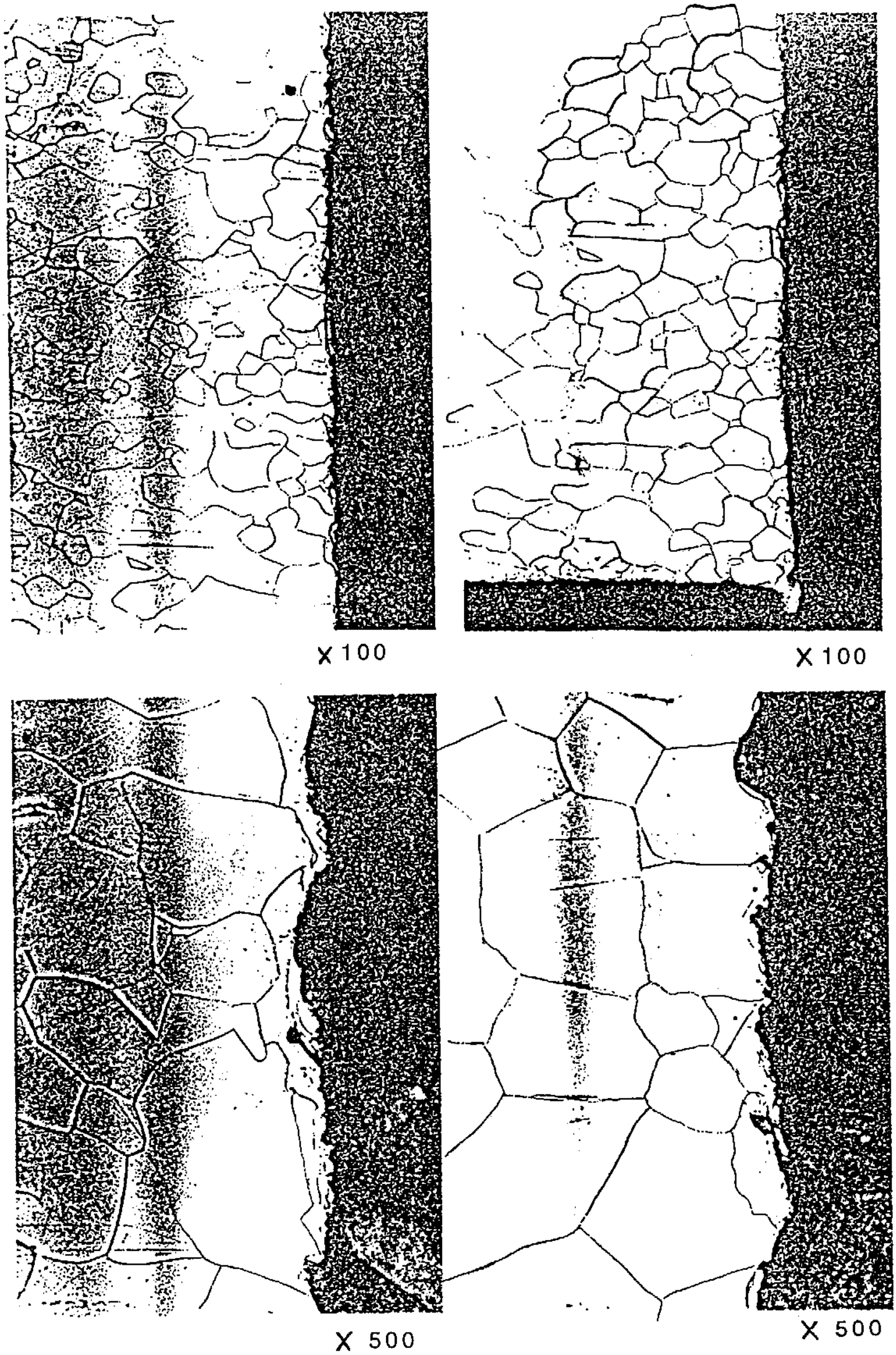


Fig. 2 Cutting edge of Nb RRR 300 (cut1)

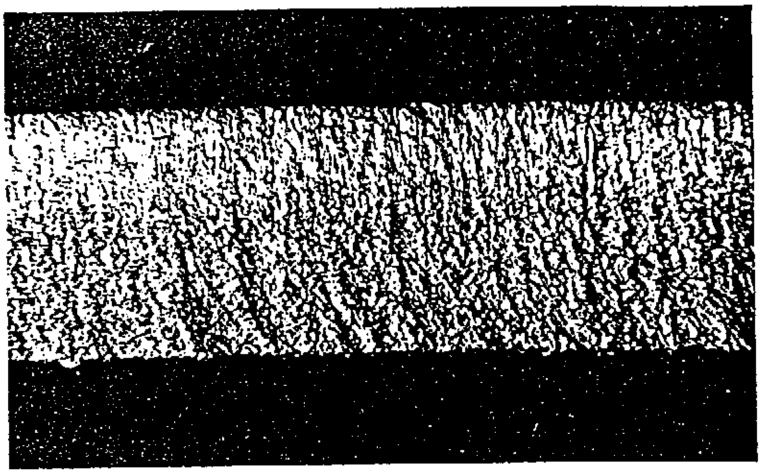


Fig. 3a Cutting surface of Nb60 (x 15)

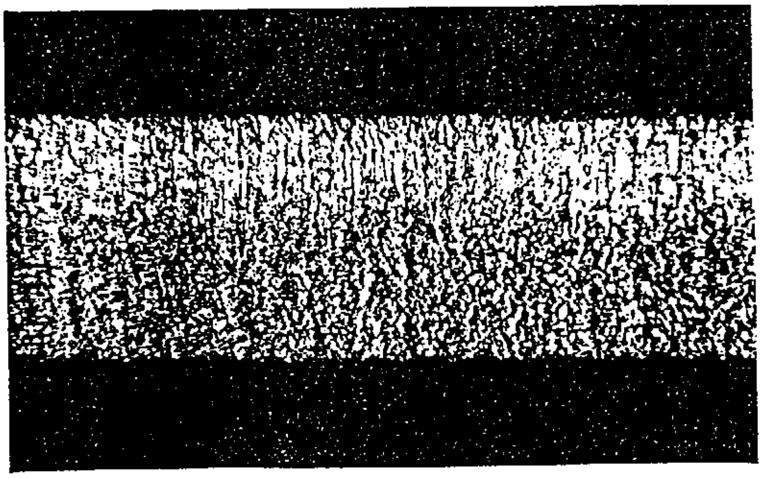
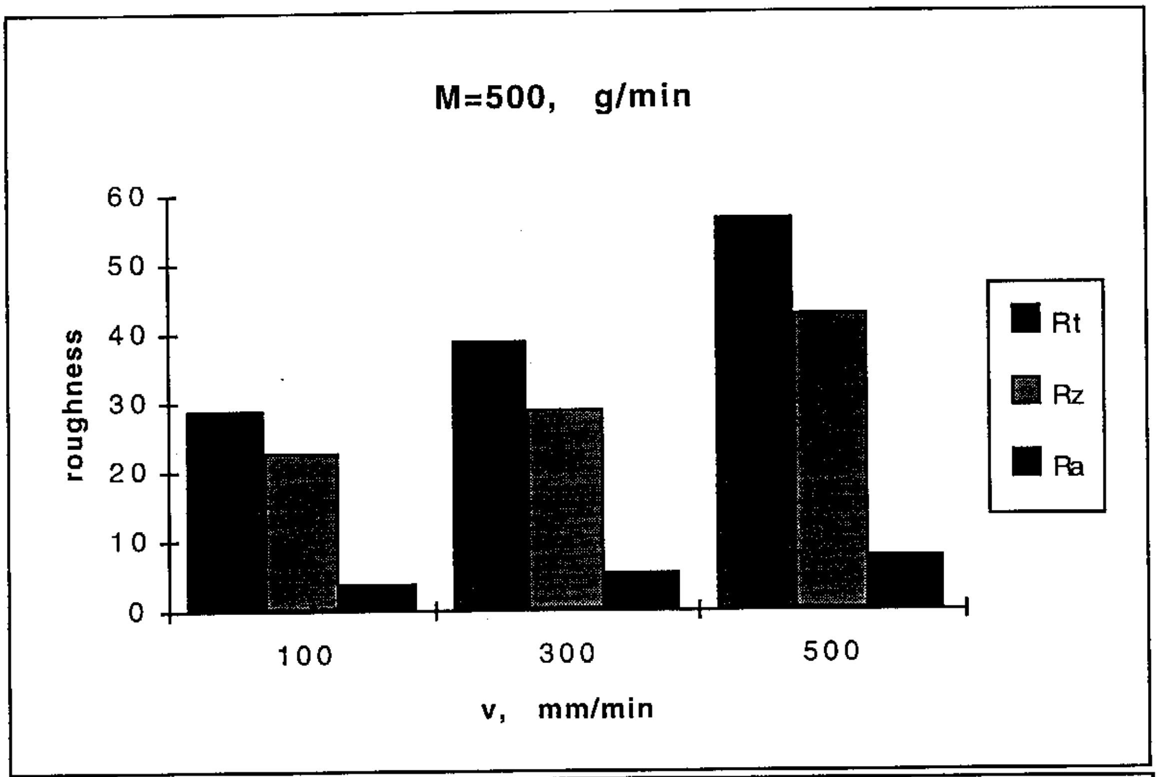


Fig. 3b Cutting surface of Nb300 (x 15)



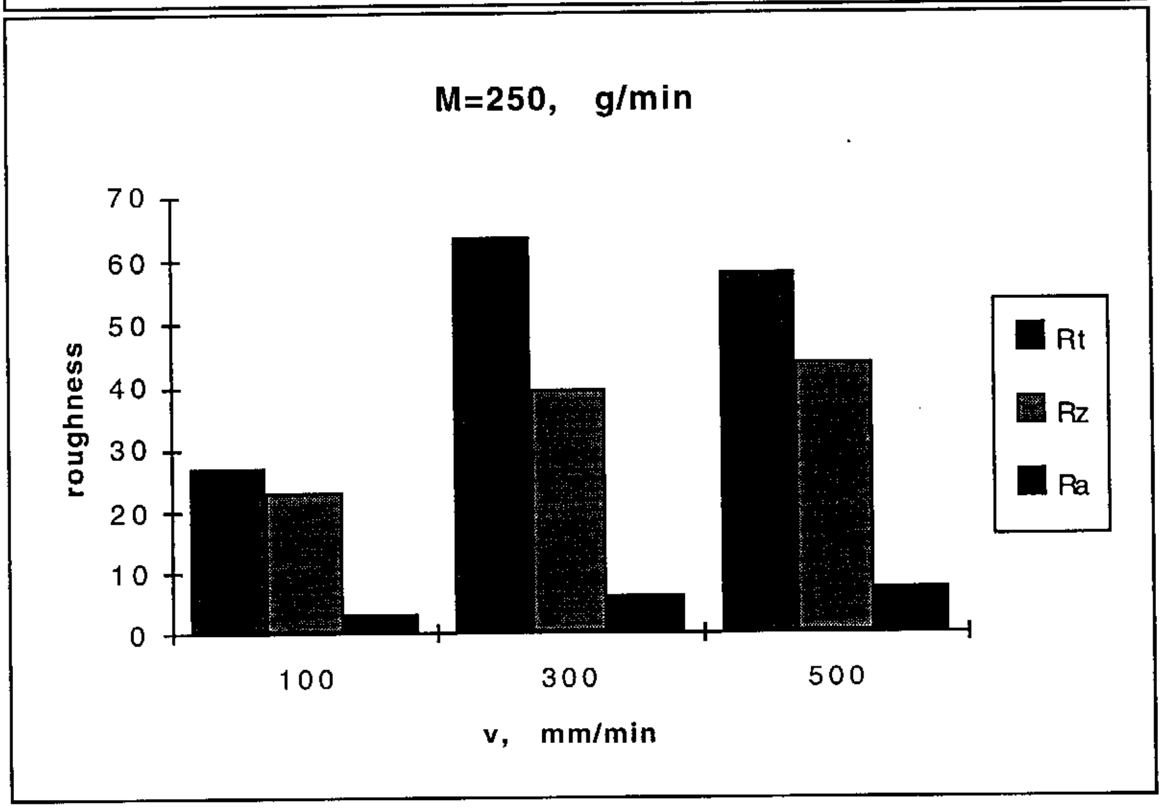


Fig. 4 Roughness of Nb 300 for different water cutting velocities

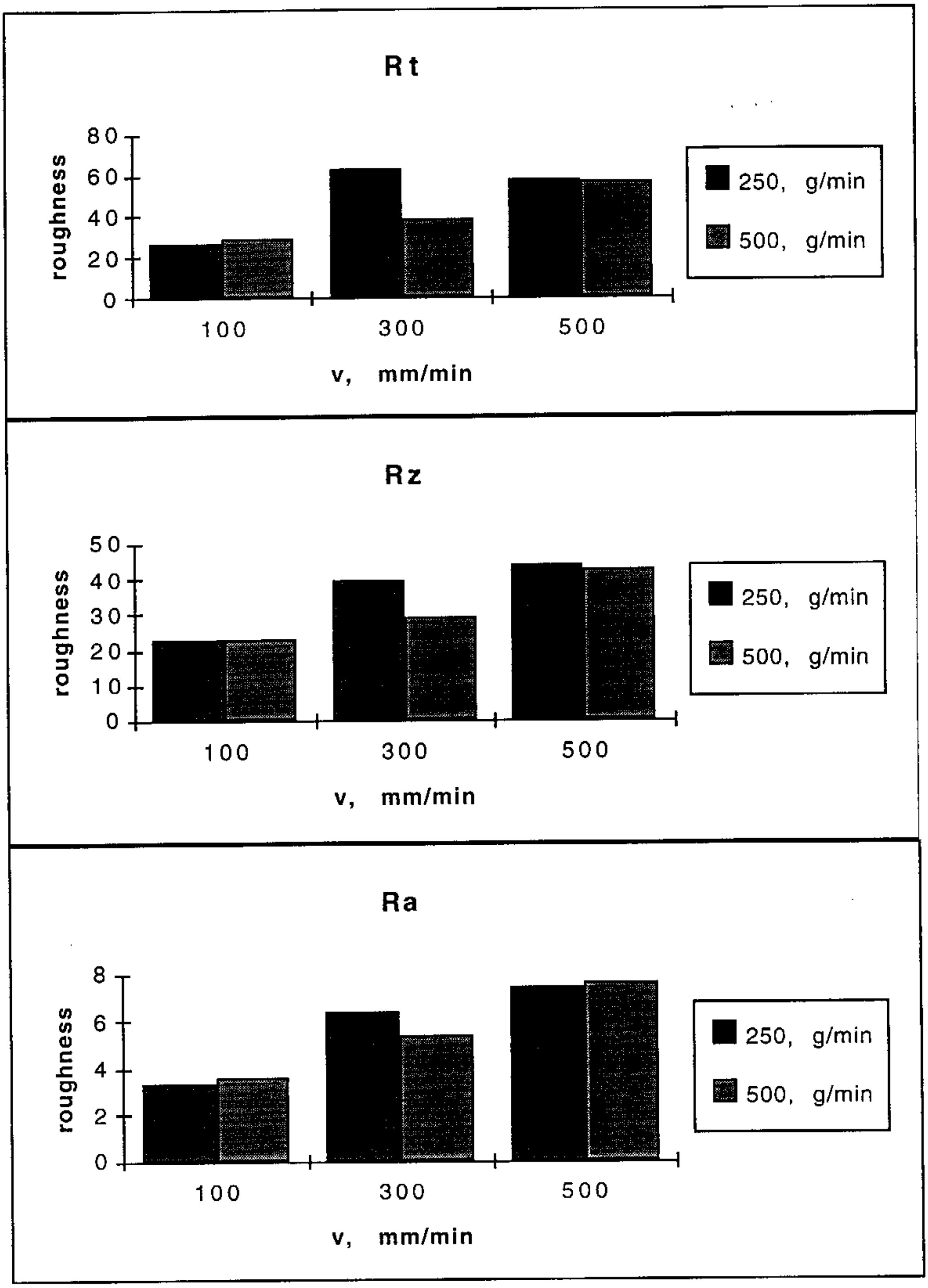


Fig.5 Influence of abrasive amount on the roughness of Nb 300

Table 3b Comparison of the gas content in Nb300 samples prepared by different cutting procedure (after 20 µm etching)

Sample	C, ppm	H, ppm	O, ppm	N, ppm
water cutting				
WC		1	9 12	3 7
milling				
7./95	1	1	8 11	9 6
electroerosion				
1./95	2	6 7	6 8	7 3

These results in comparison with standard gas contents for milled Nb300 samples are shown in table 3 a,b.

The gas analysis of the water cut samples demonstrates huge oxygen content which can be interpreted as due to some particles of the abrasive powder remaining on the rough sample surface after having been used for water cutting. This point is confirmed by the gas analysis on the sample after etching of 20 µm material surface (table 3a). In this case the oxygen content is reduced to a normal value which usually can be seen in Nb300. This means, one has to be careful when using the Nb sample after water cutting for the heat treatment (electron beam welding, annealing and so on). Anyway it is necessary to subject the samples to the same etching procedure as after grinding (removing about 20-30 µm material from the surface).

Application of the same gas analysis procedure to the electroeroded samples has shown that after simple surface degreasing the oxygen and hydrogen content are very high (about 530 ppm and 13 ppm respectively). Removing of 20 µm material from the cutting surface reduces the oxygen content to the normal value (< 10 ppm). Although the hydrogen value is reduced after etching too, its concentration remains rather high, 6-9 ppm, which means hydrogen penetrates deeply enough into Nb during the electroerosion cutting. The RRR is not very sensitive concerning small changes of hydrogen content. At the same time hydrogen plays a very important role in definite cases (for example hydrogen decease). The hydrogen pollution by electroerosion cutting must be taken into account and if it is crucial the hydrogen has to be removed by additional annealing. The reason for colour changing due to electroerosion cutting obviously is the surface contamination with some elements from filament and vicinity. From the auger

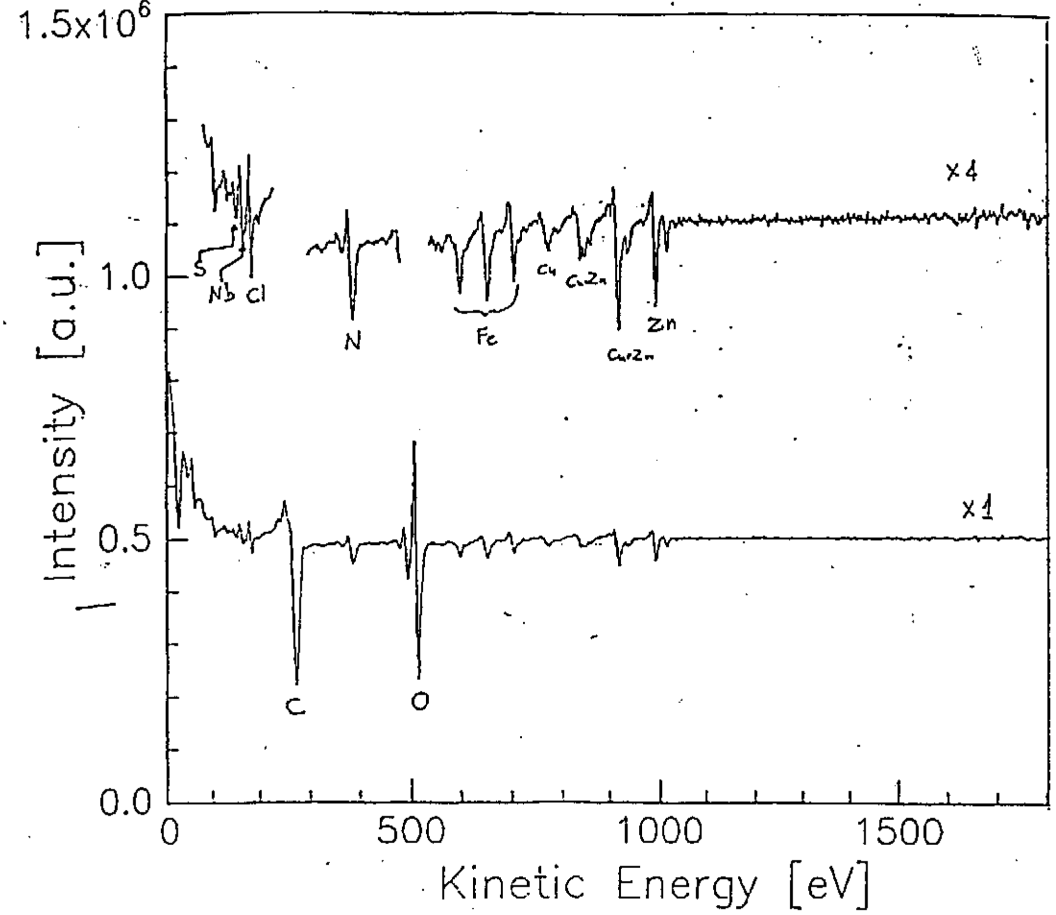


Fig. 6a Auger spectra of electroeroded Nb300 after degreasing

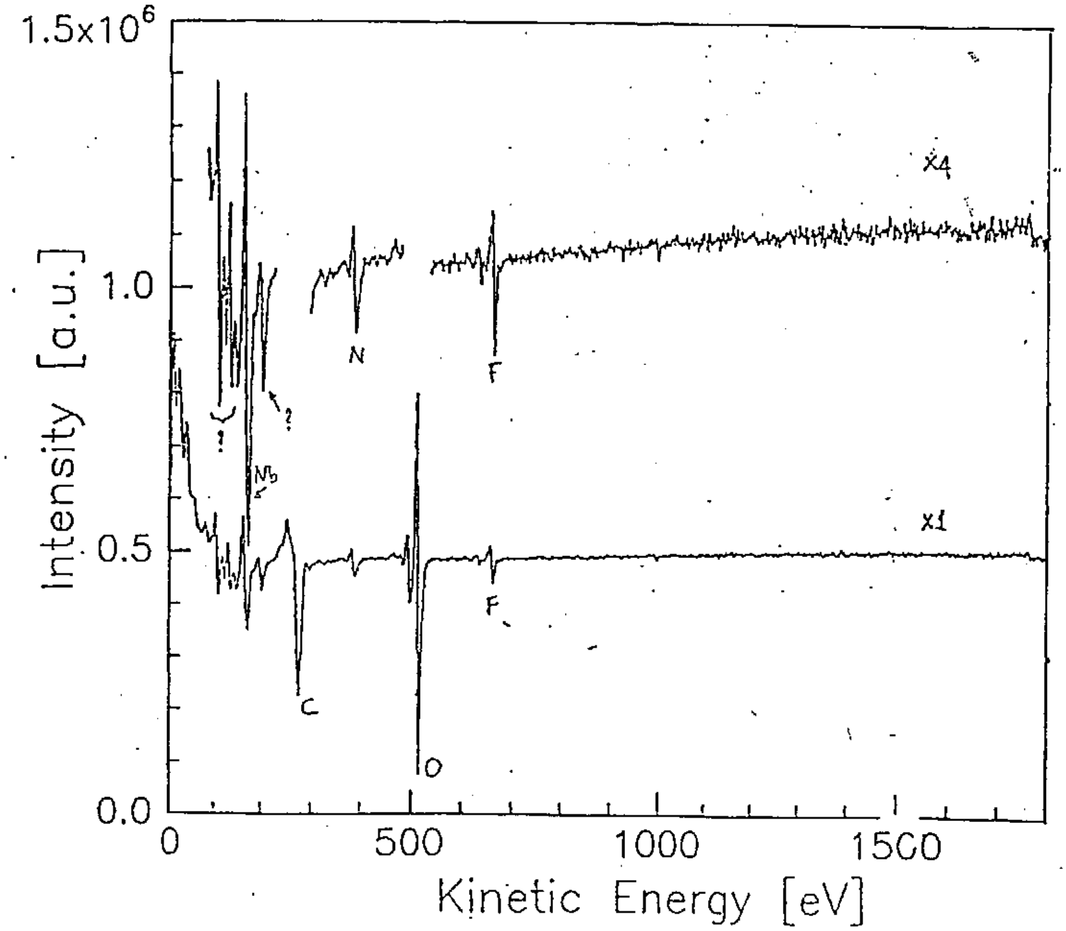


Fig. 6b Auger spectra of electroeroded Nb300 after etching (1:1:4, 1min)

spectroscopy results /4/ the presence of oxygen, carbon, iron, copper, zinc and other elements can be seen (hydrogen contamination is not visible by this experiment) (Fig. 6a). These contaminations basically deposit directly on the surface and disappear after light etching (Fig. 6b).

It is worth remarking in conclusion that high pressure water- and electroerosion cutting side by side with milling in principle can be regarded as acceptable procedures. When selecting a concrete procedure the advantages and disadvantages of each of them have to be considered (table 5).

Table 5. Advantage and disadvantage of cutting procedures

	Advantage	Disadvantage
Milling	cheap accessible	making of only a simple shape quality is worker dependent small oxygen surface contamination
Water Cutting	making of complicated shape high cutting speed quality is worker independent	rather rough surface, size tolerance not ever sufficient oxygen surface contamination rather expensive
Electroerosion	making of complicated shape good size tolerance quality is worker independent	oxygen surface contamination hydrogen bulk contamination surface pollution rather expensive small cutting speed

Acknowledgments

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