THE APPLICATION OF ELECTROCHEMICAL GRINDING IN TOOLMAKING

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Introduction

The electrochemical grinding process is particularly useful for sharpening tools with soldered carbide tips; as another example, the production of flat, cylindrical and other shaped surfaces has recently been reported [1], [2]. Electrochemical grinding is furthermore advantageous for a large volume of stock metal to be removed when mechanical removal would cause mechanical stresses. These problems are especially relevant to a slender and pretreated work, like a pull broach.

Electrochemical plunge-in-grinding is now an economical means to manufacture cutting tools from the solid. Investigations aimed at developing the tool engineering have been carried out at the Department of Production Engineering, Technical University, Budapest.

There have been two main objectives:

— determination of the field of application of the electrochemical grinding method, and

— establishment of its limits.

Electrochemical plunge-in-grinding tests were made on specimens similar in geometry to the actual cutting tools. These model cutting tools imply the same production problems as do the real ones.

Experimental manufacture model tools of carbide

The greatest problem in test manufacturing cylindrical specimens has been found to be the setting of the arc of contact and of the contact surface [3], [4]. Plunge-in-grinding provides, however, for the contact surface required for effective machining.

The manufacture of rectangular profile, semicircle, trapezoid and triangular has been investigated. Particular attention has been paid to the magnitude of the arc of contact as well as to the volume of the machined grooves.

The variation of contact surface and removal rate as a function of depth of cut are given in Fig. 1 for several profiles.

This preliminary estimate of the removal rate is required for setting the number of revolutions of the work. The number of revolutions influences removal rate, wheel wear, performance and cost of machining.

Fig. 2 shows experimental results for grinding a circular cylinder. In accordance with Colwell's experiments [5] the resistance and the current

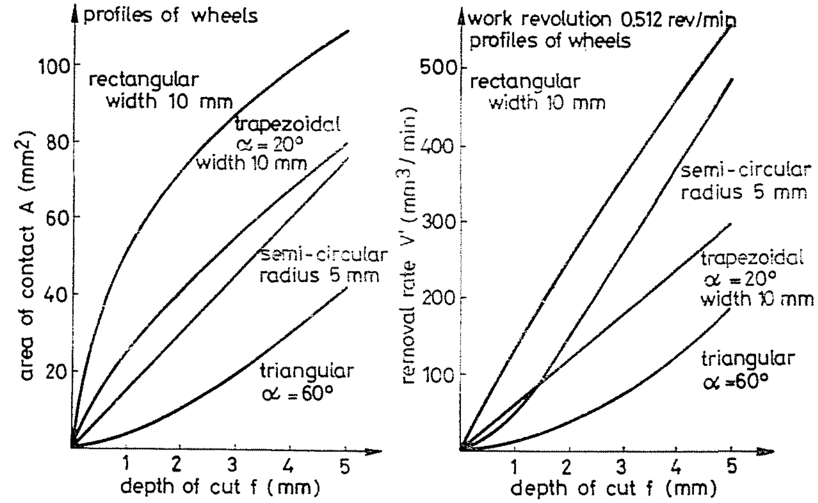

Fig. 1. Contact surface and removal versus depth of cut. Data: wheel diameter 100 mm, work diameter 35 mm

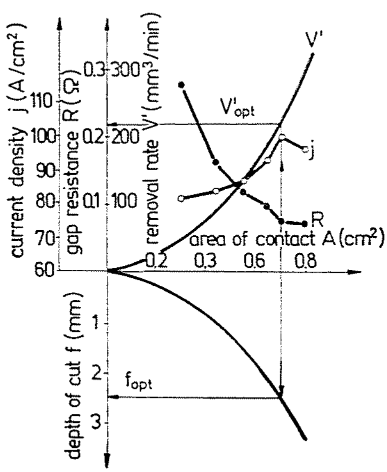

Fig. 2. Determination of optimum depth of cut and removal rate from the functions of current density and gap resistance versus area of contact and removal rate. Data: applied voltage 8 V, wheel diameter 100 mm, width 10 mm, work diameter 35 mm, 0.12 rpm, material P20 carbide

density of the gap were taken as characteristics of the process. The same results were obtained in other works [4], [6].

The optimum depth of cut can be determined from Fig. 2 for given process variables. The experimental results show an optimum in the curves of current density and gap resistance to exist at the removal rate and contact area pertaining to the optimum depth of cut. From Fig. 2 the optimum depth of cut is $f = 2$ to 2.5 mm, with a removal rate of $V_{opt} = 250$ mm^3/min. For such a small diameter of work, $d = 35$ mm, this result can be regarded as promising.

The experiments have been performed as usual, namely changing, one of the process variables, the rest kept constant. This procedure, however, makes heavy demand on time and materials. To decrease the time of experiments, the process of "continuous cut" has been introduced, increasing the depth of cut uniformly as a function of time. The machined surface is an Archimedean spiral.

In the experiments, the relationship between the number of revolutions and the diameter of the work, and also the feed have been considered in terms of the consumed power for cutting and the current.

The results obtained from "continuous cut" are seen in Fig. 3. It is remarkable that the increase of the depth of cut is limited by the power of the grinding spindle. Increase in the depth of cut causes a corresponding increase in power and decrease in current.

For higher numbers of revolution, i.e. greater feed rate, the power limit is at a lower value of depth of cut. For a constant depth of cut a higher number of revolutions reduces the working gap involving a higher current intenity. Of course, the change of the depth of cut and the diameter, were also found to affect the removal rate.

For a constant depth of cut, a higher rate of power consumption pertains to a bigger diameter, thus, to a higher removal rate. It is remarkable that the value of depth of cut is lower for the "continuous cut" than for the step-by-step cut. This is likely to be attributed to the elastic strain of the cutting system, although further investigation is necessary.

The current density vs. depth of cut is shown in Fig. 4. The functions of current density are seen to have an optimum for small diameters. For larger diameters the existence of an optimum can only be guessed since the power of grinding spindle limits further investigation.

Some experiments have been done on electrochemical plunge-in-grinding for different shapes by step-by-step cut, since it has been shown before that, though the process of continuous cut is much quicker, it can even be proceeded to a lower depth of cut.

Fig. 5 shows the results of power and current as a function of depth of cut. In the case of a constant depth of cut, however, the highest power

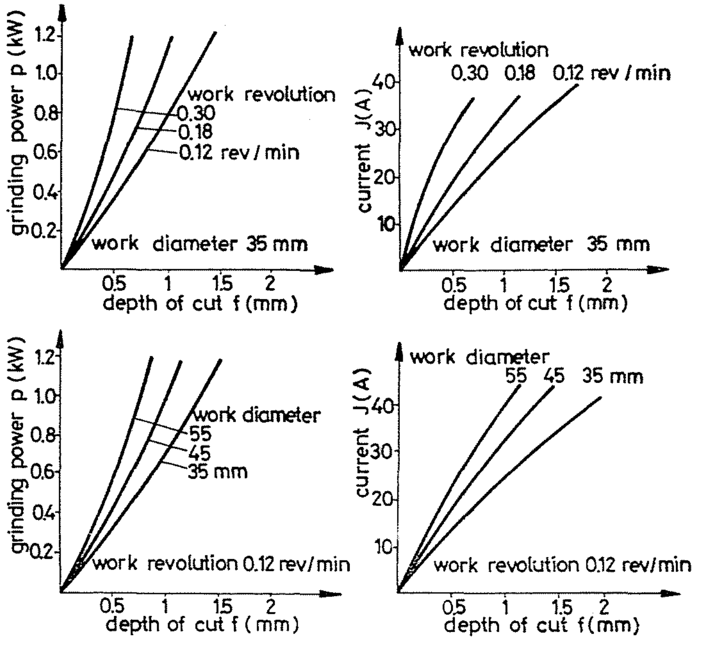

Fig. 3. Grinding power and current versus depth of cut obtained from "continuous cut'. Data: feed rate 3.15 mm/rev, applied voltage 8 V, work material P20 carbide, wheel diameter 100 mm, width 10 mm

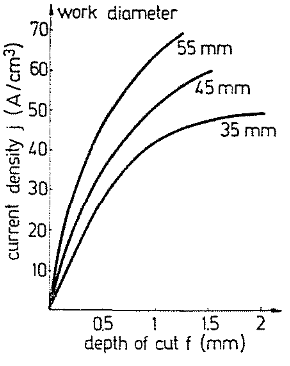

Fig. 4. Current density versus depth of cut obtained from "continuous cut". Data: applied voltage 8 V, feed rate 3.15 rpm, work material P20 carbide, wheel diameter 100 mm, width 10 mm, 0.12 rpm

consumption pertains to semicircular profile. On the other hand, the current in the gap is the highest for a trapezoidal profile.

A characteristic value for the electrochemical efficiency is that of the current per unit power. The functions $I/P = f(f)$ have been plotted in Fig. 6.

For electrochemically grinding a trapezoidal profile, the power consumption referred to the output proportional to the electrochemical efficiency

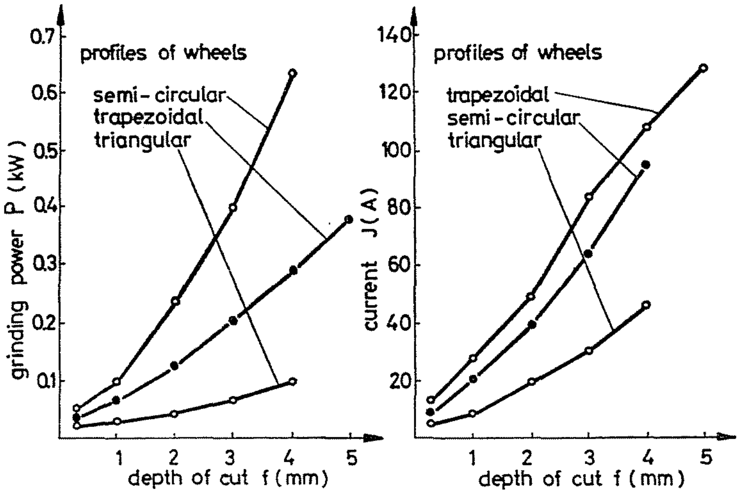

Fig. 5. Grinding power and current versus depth of cut for different profiles. Data: applied voltage 8 V, wheel diameter 100 mm, work diameter 35 mm, 0.12 rpm, material P20 carbide

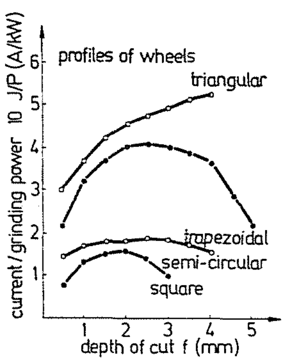

Fig. 6. Current per grinding power versus depth of cut for different profiles. Data: work material P20 carbide, 0.12 rpm, work diameter 27 mm, applied voltage 8 V

was the most favourable in the range of $f = 2$ to 3 mm. For the triangular profile the curve tended to an optimum. When machining semicircular profile, the optimum slightly varied in the range of $f = 1$ to 3 mm.

The efficiency of the electrochemical grinding process expressed by the ratio of the electrochemically removed material to the total stock removal, is not easy to determine in practice. In view of the function $I/P = f(f)$ giving a similar indication, the introduction of this index number for the electrochemical grinding process seems to be justified.

Investigations of the stock removal involved measurements of accuracy and surface roughness.

Some characteristic concentric diagrams are shown in Fig. 7.

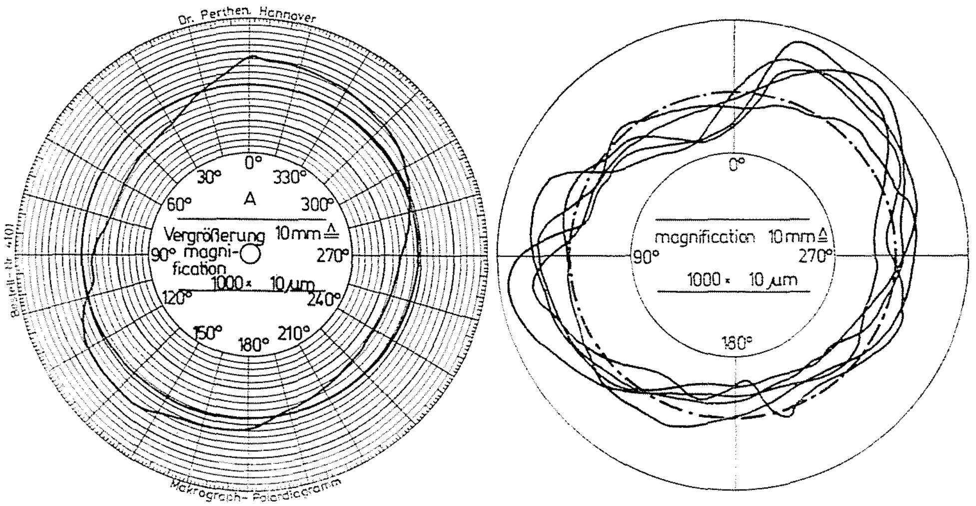

Fig. 7. Concentric diagrams obtained for cylindrical plunge-in-grinding

The greatest deviation from the reference circle is $+10$ μm -14 μm, and the smallest is $+4$ μm $-$ 10 μm. Superposition of the concentric diagrams shows clearly that the error of concentricity is regular, coming from two sources;

— the features of machining and

— the run-out of the main spindle.

Features of machining as a source of error can be overcome, if the work is ground by double turn. In Fig. 7 a concentric diagram is seen, taken from a surface machined by this method.

For this method, the error of concentricity is ± 8 μm which, in practice, equals the error of the main spindle. The accuracy of the electrochemical grinding is substantially determined by the machining system.

Measured values of the surface roughness are in the range of $R_a = 0.57$ to 1.31 μm. As an advantage, the specimens were exempt of mechanical scratches. The surface roughness may be improved e.g., by diamond grinding.

The purpose of experiments has been stated to produce surfaces similar to the envelope surfaces of cutting tools. Such models made from carbide are seen in Fig. 8.

The material of the specimens is P20, complying ISO standards, of a starting diameter $\varnothing 30$ mm. The grooves have been made in one turnaround of the work. Grooves with profiles of trapezoidal, semicircular, rectangular and triangular have been thread grooves made on the first specimen.

The set number of revolutions is $n = 0.12$ rpm. The second specimen is the model of the cutting and burnishing tooth of a broach.

A thread of M26$\times$2 has been made on the third specimen in one turn-

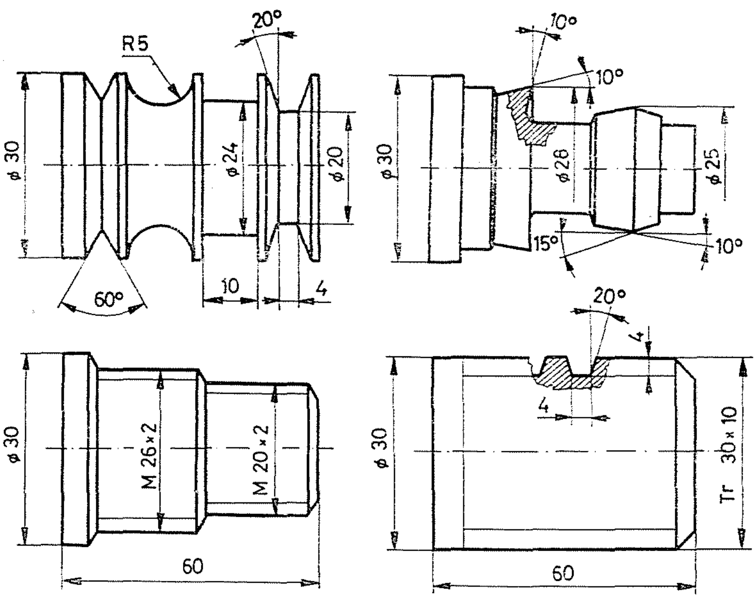

Fig. 8. Carbide test specimens, P20

around of the work. For the thread of M20×2, the diameter ∅20 mm has been ground first, and the thread has been made on the surface by setting the total depth of cut.

The fourth specimen is trapezoidally threaded. The thread has the dimension of Tr30×10, and it has also been made by setting the total of the depth of cut at once. These results vote for the manufacture of small- diameter specimens from the solid by electrochemical grinding, and also show that the process of electrochemical plunge-in-grinding can be utilized for manufacturing carbide tools.

Manufacture of broach models from high-speed-steel

The purpose of investigation was to manufacture the broach model seen in Fig. 9, and to prove the applicability of the electrochemical grinding in this field. The material of the specimens was R6 high-speed-steel* in pretreated state, its hardness was 62—64 HRC, and its dimensions ∅27×345 mm. The first series of experiments concerned the possibility of electrochemical form grinding of hardened high-speed steel by metal bond grinding wheel. According to recent results [7], Al_2O_3 metal-bond grinding wheels are

* Composition: C 1.0—1.1%, Cr 3.0—3.6%, V 2.1—2.5%, W 8.5—9.5%, Mo 3.8—4.3%, Co 7.5—8.5%, Si 0.45%, Mn 0.45%.

useful for the electrochemical grinding of alloy steels. In our previous work, diamond grit wheels were succesfully used for surface grinding high-speed-steels [8].

In the investigations a generator voltage of $U = 8$ V and a number of revolutions $n = 0.12$ rpm have been set, thus the time of machining one groove was 8.5 min. The number of revolutions was increased in the preliminary investigations, but because of the rapid "sludging" of electrolyte, most of the recent experiments have been performed at $n = 0.12$ rpm.

In the experiments the maximum and optimum depths of cut have been determined. The depth of cut has been changed by increments of $\Delta f = 0.5$ mm. The investigation showed the electrochemical grinding of high-speed-steel to be satisfactory. The grinding is free of sparking, except for depths of cut $f > 5$ mm, when slight mechanical sparking arose. For voltages over 8 V electric sparking occurred. This caused an increased wear of the grinding wheel and deterioration of surface roughness.

The experiments on material removal showed no mechanical traces to arise on the ground surface at the depth of cut $f = 5$ mm.

For the process variables $f = 5$ mm, $d = 27$ mm, $b = 100$ mm, $n = 0.12$ mm, the arc of contact is $a = 11.8$ mm at a removal rate of approximately $V' = 420$ mm^3/min. While working out one groove, 3500 mm^3 of stock goes into solution, of a wet volume of some 1000 cm^3. It is not surprising that quick sludging of electrolyte has been observed. Using thickened electrolyte saturated by iron hydroxide, an increased electric sparking occurred. The total required depth of cut of $f = 5$ mm, can only be set with a new electrolyte. In making the broach model, the depth of groove has been determined at 4 mm.

Grooves have been worked out in two cuts. The total groove can be made in many combinations, thus the first and the second depth of cut have been determined. The function of current versus depth of cut has simultaneously been determined.

The scheme of cuts and the function of current versus depth of cut obtained from the experiments are seen in Fig. 10 where

$$f = f_1 + f_2 = 4 \text{ (mm)}.$$

In the extreme positions

$$f_1 = 0, \quad f_2 = 4$$
$$f_1 = 4, \quad f_2 = 0.$$

The curves of f_1 and f_2 are of the opposite slope. It is reasonable to set the distribution of cut at the point of intersection of the two curves. To reach this conclusion, the working-out of the broach grooves has been performed

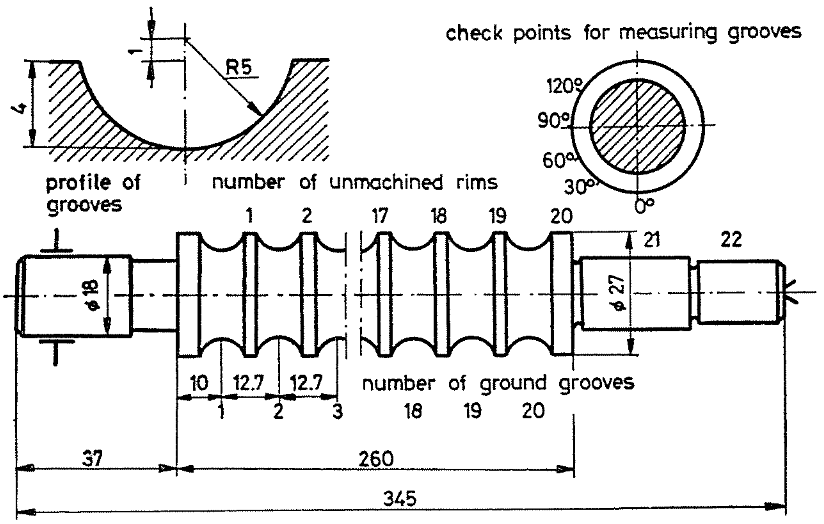

Fig. 9. Broach model made of hardened high-speed-steel grade R6

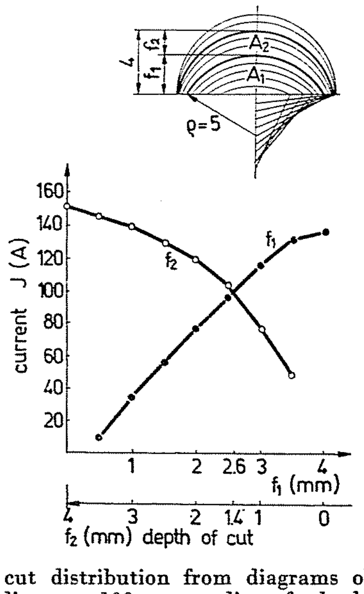

Fig. 10. Determination of cut distribution from diagrams obtained from current versus depth of cut. Data: wheel diameter 100 mm, radius of wheel profile 5 mm, work material high-speed steel, R6, hardness 64 HRC, diameter 27 mm, 0.12 rpm, applied voltage 8 V

at the values of $f_1 = 2.5$ mm and $f_2 = 1.5$ mm. The current consumption $I = 90$ to 110A, depended on the state of contamination of the electrolyte. As shown from the scheme of cut distribution in Fig. 10, for this cut distribution the same contact area and volume of stock to be removed pertain to both operations.

Although the generator capacity $I = 400$ A has not been fully utilized, the most favourable condition has been deduced from the life of the electrolyte. By setting the optimum cut distribution, the life of the grinding wheel and the surface roughness can indirectly be kept at the optimum value.

The production of the broach started from a hardened and ground stock. The dissolution of stock means that with the removal of this considerable volume of material, internal stresses are released, likely to deform the broach. The symmetric dissolution of the stock is, however, favourable from the aspect of the turnover of the stress balance.

The radial and tangential forces arising in electrochemical grinding can also deform the broach. For electrochemical grinding the cutting forces are smaller than those in any kind of mechanical grinding, so that only a low-rate deformation needs consideration. To obtain a measure of the deformation of the broach after machining, the concentricity of the unmachined rings of broach have been measured.

The measurement of concentricity aiming at the determination of deformation has mainly justified the preliminary assumption that the dissolution of stock releases stresses. The deformation increased however, with the runout of the main spindle and the contamination of the electrolyte.

Summary

Electrochemical plunge-in-grinding of small-diameter carbide specimens brought about the enveloping surfaces of the multipoint cutting tools made of solid. A model has been produced that can be considered as the cutting and burnishing rings of a multi-component broach. The experiments on optimum depth of cut, contact surface and removal rate have been performed by the methods of step-by-step and continuous cut, both in plunge-in grinding. The function $I/P = f(f)$ has been introduced as a characteristic of the quality of electrochemical process. Investigations of the material removal and the concentricity have demonstrated the electrochemical plunge-in-grinding to be useful for tool engineering.

The experiments on electrochemical plunge-in-grinding applied a broach model made of hardened high-speed steel grade R6. The rapid contamination of electrolyte required to determine the optimum cut distribution.

In the investigation on material removal, the function of current versus depth of cut has been determined. Under given conditions the greatest depth of cut was $f = 5$ mm, for higher values mechanical sparking occurred. In measuring the concentricity of the produced broach, the machining deformation has been found to be due to the dissolution of stock, the inaccuracy of main spindle and the mechanical load due to the contamination of electrolyte.

Tests on broach models made of both carbide and high-speed-steel by electrochemical plunge-in-grinding showed its being applicable in tool-making.

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