

SOME PROBLEMS OF TOOL LIFE INVESTIGATIONS

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(Received November 27, 1964)

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The accurate determination of tool life represents an important problem in economic cutting. In the course of the experiments conducted to discover the correlation between tool life and cutting conditions, several hundreds of tons of material are all over the world annually cut. General and direct utilization of the results of experiments conducted at different locations by means of different methods is usually not feasible, particularly as there appear significant discrepancies between these experimental results. The main reason of these differences could be attributed to the diversity of experimental conditions.

On the proposal submitted by the United States Standard Bureau, there was elaborated an international standard projection facilitating the widespread utilization of the results of cutting experiments conducted in different locations [1]. This standard might specify the conditions of conducting tool life experiments.

Within the activity of the Department of Machine Technology of the Budapest Technical University, there are also investigations conducted to determine the factors affecting the results of tool life experiments. The present paper deals with some of the investigations on *tools* pointing out certain methodological problems to be taken into consideration in course of the preparation of the international standard referred to above.

The investigations described by the present paper concern turning and milling. In course of these experiments, to clarify the problem under investigation, a total of 53 tool life tests have been performed by cutting over 1 ton of material. Due to the wide extent of the investigations, the paper wishes only to publish some of the results, to promote the reproductivity of the tests, to describe the test conditions and, by possibly avoiding any text-book characteristics, mainly to issue the documentation supporting the conclusions arrived at.

The primary objective of the experiments has been to study the influence exerted on the experimental results by tool preparation. Thus, in the present

paper mainly methodological problems are dealt with. The other conclusions arrived at by means of the experiments conducted will be discussed in a following paper.

1. Test materials, tools, machine tools

The *material* used for turning experiments was C-35 grade steel. This material for experimental purposes was produced with increased care. Samples were of a size of $\varnothing 300 \times 2000$ mm.

The chemical composition and strength characteristics of the material were as follows:

C = 0.30%, Mn = 0.66%, Si = 0.29%, P = 0.015%, S = 0.016%, Cr = 0.13%, $\sigma_B = 56$ kp/mm², $\sigma_F = 34$ kp/mm², $\delta_{10} = 17$ per cent, HB = 167 kp/mm². The hardness variation of test samples did not exceed a maximum of HB = 11 kp/mm², permissible according to the specifications of the respective Hungarian machinability standard [2].

Steel blocks of C-45 grade and 110 × 110 × 600 mm dimensions were used for milling experiments. The chemical composition and strength characteristics of this material was the following:

C = 0.45%, Mn = 0.8%, Si = 0.15%, P = 0.05%, S = 0.04%, Cr = in traces, $\sigma_B = 71$ kp/mm², HB = 197 kp/mm².

The tool used in turning experiments included a shank with a mechanical tip mounting having high speed steel tips.

In order to develop this shank of mechanical tip mounting, certain pre-tests were performed [3]. On grounds of the experiences gathered through these pre-tests, the shank illustrated by Fig. 1 could be produced.

The tip (1) rests on the ground surface of the shank (2). Clamping of the tip is done by means of the chip breaker (3) adjustable in two stages. The construction of this component ensures the clamping of the tip along an edge (three point contact). The clamping element (4) securing the chip breaker is similarly developed to have a three point contact. Continuous tip readjustment is effected by means of a screw (5). Tips are mounted into the holder at a setting angle of $K = 45^\circ$. In the course of the experiments, the secondary cutting edge angle amounted to $\tau = 15^\circ$.

For tip material, R-3 grade high speed steel was used. Tips have been made of 22 × 12 mm bands to 10 × 20 × 35 mm size (Fig. 2). The chemical composition of the tips involved C = 0.7%, Cr = 5%, W = 17%, Mo = 0.7%, V = 1.2%. Oil cooled quenching started at 1280° C following a salt bath heating. Tempering was performed at a temperature of 580° C in a chamber type electric furnace with a holding time of twice an hour each.

Milling experiments involved the employment of five-edge end cutters of 16 mm diameter made of R-3 grade high speed steel. The chemical composition of the cutters contained C = 0.7 per cent, Cr = 5 per cent, W = 17

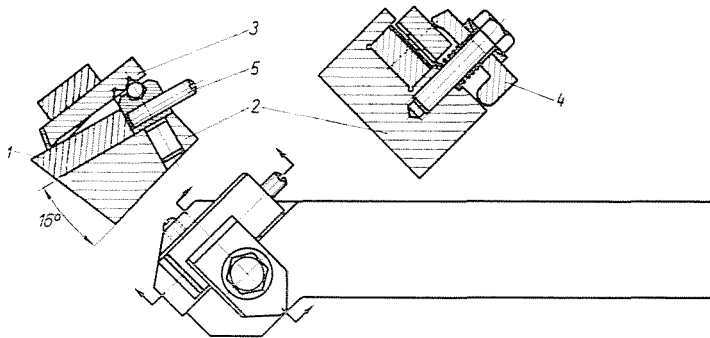


Fig. 1

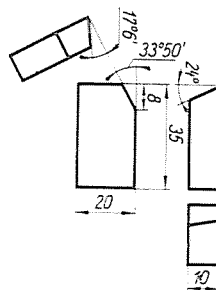


Fig. 2

per cent, V = 1.2 per cent, and Mo = 0.3 per cent. Factory heat treatment of the cutters followed standard specifications [4].

The machine-tool which was made use of for turning experiments was represented by an EU-500 type infinitely variable speed lathe (centre height 250 mm, centre distance 2000 mm, engine output 14 kW).

Milling experiments employed a VF-21 type vertical milling machine (plate dimensions: 1350 × 300 mm, engine output 6 kW).

2. Turning experiments

The experiments intended to determine how a slight difference of the material or cutting characteristics of tips would affect cutting test results.

For experimental purposes 49 tips of identical material were prepared by simultaneous heat treatment and also identically machined. Particular

attention was paid to ensure identical grinding conditions in order to eliminate the influence of this factor during the investigations.

The adaptability of tips for cutting experiments is usually tested in several ways [5]. For the present experiments adaptability was evaluated by means of hardness measurements and surface turning investigations as well as by performing structure tests on a number of tips.

In course of hardness studies, Rockwell hardness measurements were made at three different points on the surface of each tip. Tips having a hardness value of 61 to 63 HR_c and no heat treatment deficiencies which were apprehensible by visual inspection were qualified acceptable as far as hardness was concerned. According to this classification, 26 tips proved suitable for cutting experiments.

The experiences collected so far indicated that hardness does not give unequivocal informations on the cutting ability of tips. For this reason, surface turning examinations were conducted representing the second phase of the qualification process. (This test is suggested by the Soviet workability standard [6] as a short tool life test process.)

For this test, a steel disc of $\varnothing 260 \times 200$ mm dimensions made of A-42.11 type material ($\sigma_B = 44$ kp/mm²) was manufactured with a bore having a diameter of 40 mm drilled into its centre. Using the experimental tips, the disc was turned from out of this bore toward its periphery (depth of cut = 1.5 mm, feed = 0.5 mm/rev, speed = 200 rpm). The cutting capacity of tips was characterized by the diameter making the tip edge burn off this being due to the cutting speed.

Results of the hardness measurement and surface turning studies are summarized in Fig. 3.

The diagram of Fig. 3 reveals, and the experimental results hitherto obtained indicate (such as [5]) that there is no unequivocal correlation existing between tip hardness and cutting properties as was determined by surface turning.

Following the hardness measurement and surface turning test, the tips were separated into groups of 2–5 each with similar characteristics. The tips of some of these groups were for the production of microsections. The reverse of each tip was ground then subjected to electrolytic polishing cauterization, and the surfaces thus prepared were photographed with a 320-times magnification.

The evaluation of the photographs revealed that, with respect to structure, not greater than relatively minor differences are found to exist among tips pertaining to the same category by hardness and surface turning burn-off diameter. The experiments demonstrated that from among the tips classified into the same category by the preceding two tests, those of more uniform structure exhibited better cutting properties.

According to the threefold classification performed to evaluate the cutting characteristics of tips, the creation of adequate categories appeared feasible with the values characterizing the properties of each group which were, however, different as compared to one another. The tips thus classified were used for straight turning experiments. The following paragraphs introduce the results of these tests.

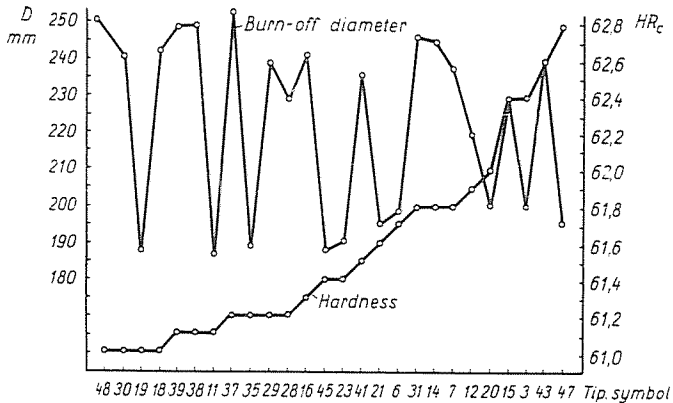


Fig. 3

2.1. Experiments to determine optimum cutting angles

The experiments involved cooling with 10 per cent cutting oil emulsion in a quantity of 10 dm³/min used as cooler.

Tool wear was determined by back wear and crater wear measurements. Back wear and crater width dimensions were measured by means of a shop microscope of 15-times magnification. Crater depth was checked by using a dial gauge of 0.001 mm accuracy converted just for this purpose. In evaluating the experimental results, back wear magnitude was reckoned with as a basis for all turning experiments.

To determine optimum relief angle, first the 3 tips for each group were selected. Grinding of these tips involved identical conditions, a rake angle of $\gamma = 16^\circ$, a nose radius of $r = 1$ mm, and relief angles of $\alpha = 6^\circ$, 8° , and 10° , respectively, for the different categories. Depth of cut for both categories was $f = 1.5$ mm, and feed $e = 0.5$ mm/rev. Experiments in the first category used a speed of $v = 65$ m/min whereas those of the second group $v = 75$ m/min. Tool life was determined in each case on the basis of the wear curve.

Experimental results are shown in Fig. 4. The diagram of Fig. 4 shows that, among the three different relief angles, $\alpha = 6^\circ$ ensured maximum tool life if cutting with either of the two speeds.

Now experiments were conducted to test the data of the first experimental category by using three tips belonging to the same class. Each tip performed four tests cutting with relief angles $a = 4, 6, 8,$ and 10° , respectively. The experimental results are shown in Fig. 5.

According to Fig. 5, relief angle of $a = 6^\circ$ appears as optimum again with the absolute value of the tool life measured; however showing significant differences.

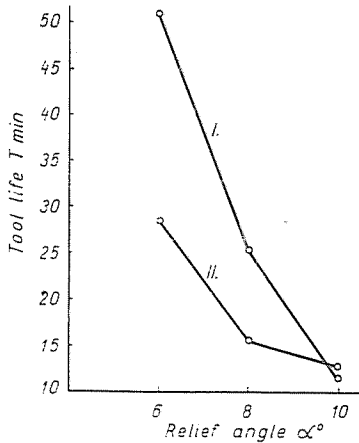


Fig. 4

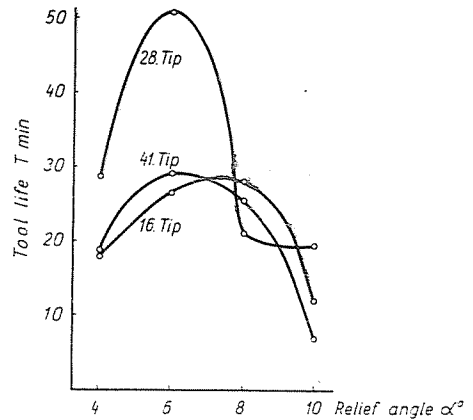


Fig. 5

With respect to the fact according to which there is only the determination of one single extreme value aimed at when conducting experiment to determine optimum relief angle, the tips qualified and grouped as described above appear suitable for this purpose.

The conclusions referred to by the previous paragraphs are supported by a number of investigations conducted earlier in studying this problem.

Investigations similar to those explained above have been carried out to determine optimum *rake angle*. First there were four tips used for cutting in each category with the data pertaining to experimental group I. ($a = 6^\circ$). Tips taken from the different categories were ground with rake angles $\gamma = 10^\circ, 12^\circ, 14^\circ,$ and 16° , respectively.

The experimental results are presented in Fig. 6. This reveals that optimum rake angle is, according to either of the curves, at $\gamma = 12^\circ$.

Now test using four tips were made having the tips ground with rake angles of $\gamma = 10^\circ, 12^\circ, 14^\circ,$ and 16° in sequence, cutting with the data obtained through the first experimental series. The curves plotted by means of these experimental results are shown in Fig. 7. These again demonstrate $\gamma = 12^\circ$ as optimum.

As a result of the experiments carried out to determine optimum angles, that conclusion may be arrived at according to which, if only the *optimum* angle determination is to be accomplished, the tests may be performed by using either the tip category selected on the basis of hardness measurements and surface turning qualification studies each having the tip ground at a different angle, or a single tip qualified as suitable for each test to cut with all experimental angles consecutively.

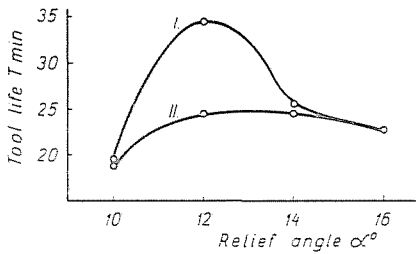


Fig. 6

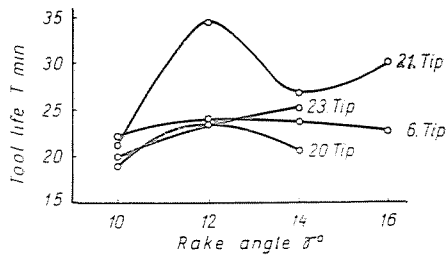


Fig. 7

Figures 4 to 7 indicate that tests performed according to selection by hardness measurements or surface turning, with a standard deviation for hardness and surface turning values as accepted for the present experiments, do not establish a unequivocal mathematical correlation between tool life and angles. These problems of the investigations as well as other conclusions of the present study will be dealt with in another paper.

2.2. Examination of cutting speed and feed effects

In studying the effects exerted on tool life with cutting speed and feed, each tip performed a complete continuous experimental sequence, that is, there were as many as four experimental points determined (according to the calculations completed previously, for the evaluation of the experimental results carried out at least so many measurements are required). Tip grinding involved a relief angle of $\alpha = 6^\circ$, a rake angle of $\gamma = 12^\circ$, and a nose radius of $r = 1,5$ mm. Experimental depth of cut amounted to $f = 2$ mm.

Of the experiments conducted to study cutting speed effects, the measurement results obtained by using tips marked 15 and 43, respectively, are presented for comparison. These tests involved a feed of $e = 0,5$ mm/rev. Results are illustrated in Fig. 8.

Fig 8. indicates that tip 43 ensures, under identical cutting conditions, a longer tool life than tip 15 does. This result is verified by hardness measurement and surface turning data: tip 15 exhibited an average hardness of 62,4 HR_C and a burn-off diameter of 230 mm, while tip 43 a hardness of 62,6

HR_c and a burn-off diameter of as much as 241 mm. These data as well as the information obtained for other tips evaluated in detail in a subsequent paper prove that tips unequivocally qualified as more appropriate by hardness and surface turning measurements give more adequate cutting results as well,

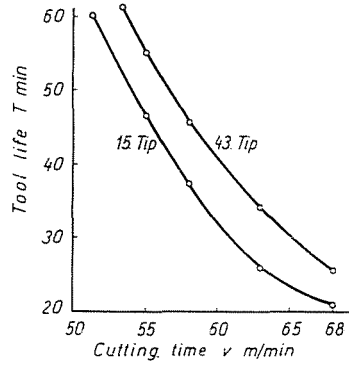


Fig. 8

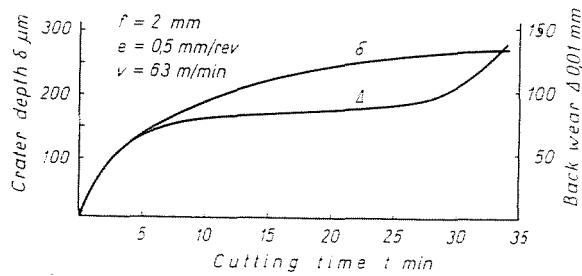


Fig. 9

No.	D_1 mm	D_2 mm	f mm	e mm/f	q mm ²	n f/min	v m/min	t min	Δ 0,01 mm	δ 0,001 mm	c 0,01 mm
1	162	158	2	0.5	1	124	63.1	2	38	30	153
2	162	158	2	0.5	1	124	63.1	4	60	75	178
3	158	154	2	0.5	1	127	63	9	77	182	211
4	158	154	2	0.5	1	127	63	14	82	208	237
5	158	154	2	0.5	1	127	63	19	84	255	244
6	158	154	2	0.5	1	127	63	24	89	261	254
7	158	154	2	0.5	1	127	63	29	99	240	254
8	158	154	2	0.5	1	127	63	34	134	272	263
9	158	154	2	0.5	1	127	63	37			

Fig. 10

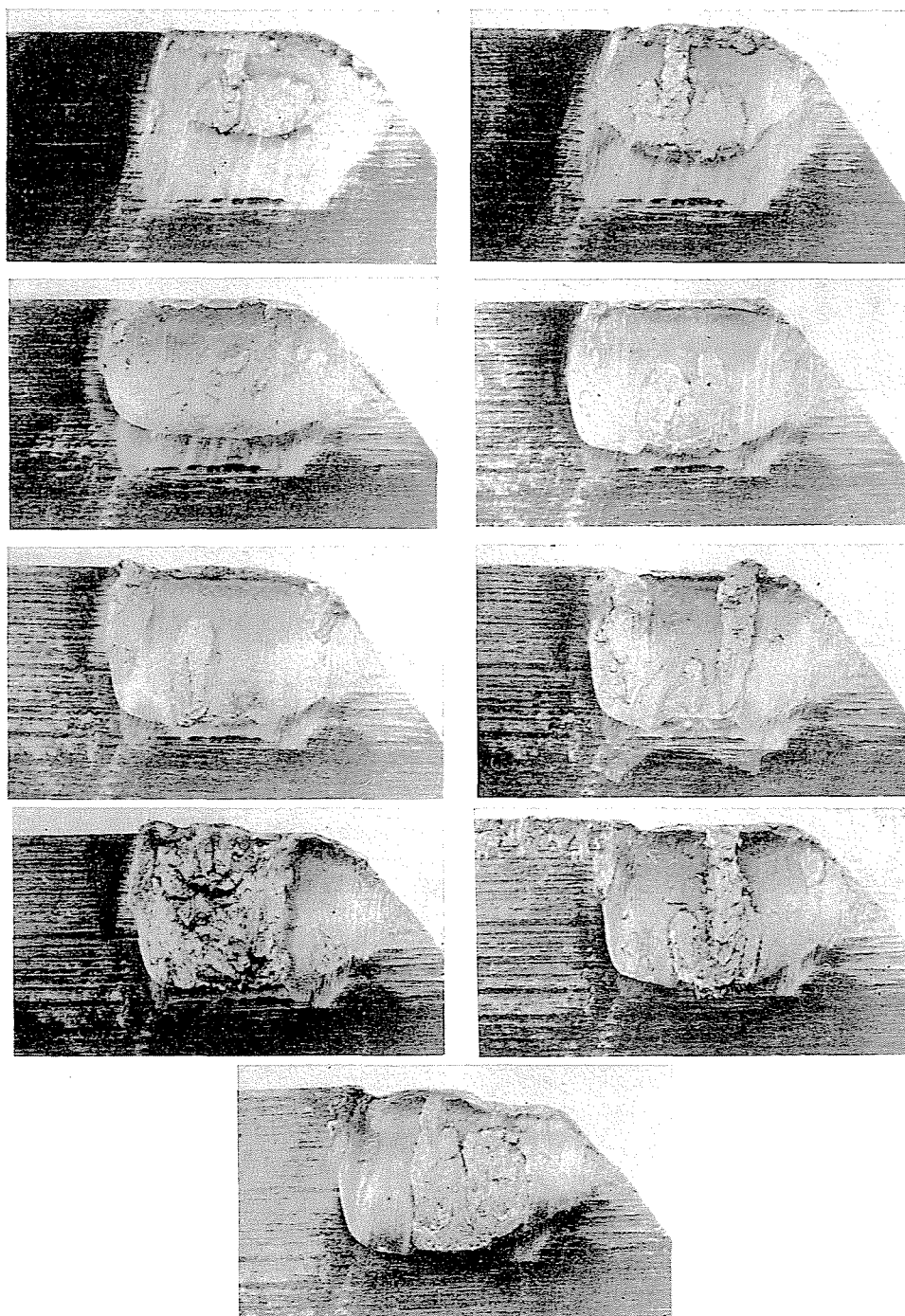


Fig. 11/a. Crater wear development: I — 2 min, II — 4 min, III — 9 min, IV — 14 min, V — 19 min, VI — 24 min, VII — 29 min, VIII — 34 min, IX — 37 min after cutting

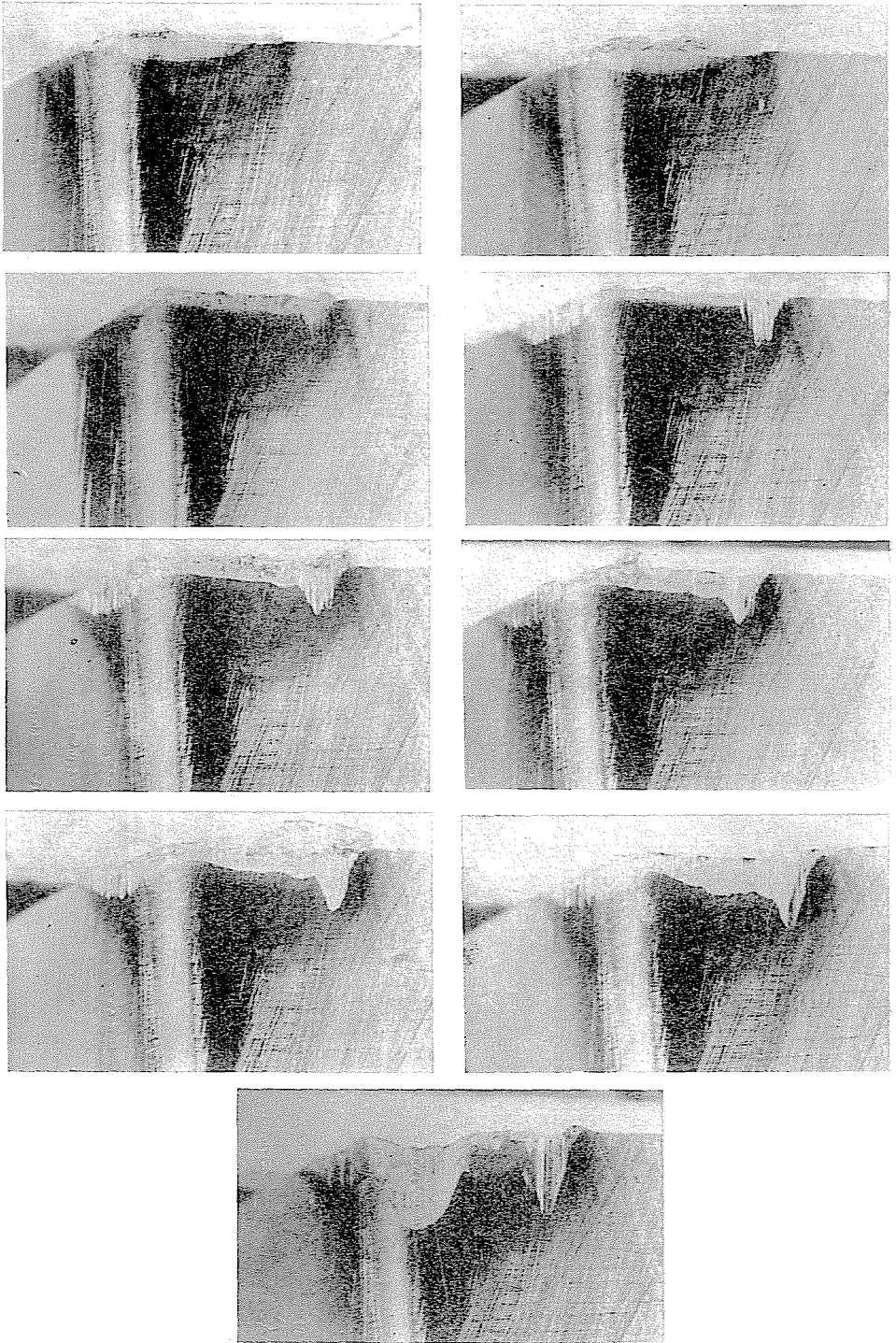


Fig. 11/b. Back wear development: I — 2 min, II — 4 min, III — 9 min, IV — 14 min, V — 19 min, VI — 24 min, VII — 29 min, VIII — 34 min, IX — 37 min after cutting

and, therefore, the accomplishment of these tests should be definitely taken into consideration by any international standard specifying qualification test requirements.

In order to characterize the magnitude of results deviations, the cutting speed ensuring a tool life of 60 min is introduced here: it amounts to $v_{60} = b = 51.7$ m/min for tip 15, and to $v_{60} = 53.7$ m/min for tip 43. This difference is less than 4 per cent which is within the range of deviations in tool life measurement results. At the same time, this low deviation refers to what is permissible for hardness measurement and surface turning experiments as well.

Among the methodological conclusions arrived at by turning tests, the evaluation of the tool wear process should also be taken into account here.

In course of these experiments, back wear, crater width and depth sizes have been measured. The obtained wear curves show back wear and crater depth characterizing wear development. Crater width does not give information on wear development as accurately as the others do.

As the documentation of the conclusions drawn, the results of an experiment performed by means of tip 43 will be published here as an example. Fig. 9 presents the wear curves plotted through back wear and crater depth measurements while Fig. 10 shows the measurement data of the report prepar-

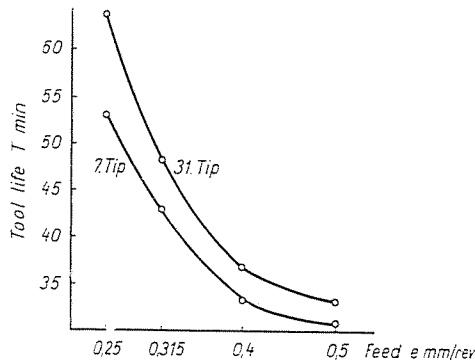


Fig. 12

ed in course of the experiments in question. These data show that the magnitude of crater width (c) did not significantly change in the course of cutting. Fig. 11/a presents the photographs illustrating the face while Fig. 11/b those showing the back of the tool. These photos show that back wear development permits correct conclusions to be drawn concerning tool wear extent. For this reason as well as due to the simplicity of the back wear measurement process it is suggested that tool life measurements are to be performed by back wear.

Of the experiments carried out to study feed effects, the results obtained by using tips No 7 and 31, respectively, are presented in Fig. 12. These experiments involved a cutting speed of $v = 55$ m/min.

Tip 7 displayed an average hardness of 61.8 HR_C and a burn-off diameter of 238 while tip 31 a hardness of similarly 61.8 HR_C with, however, a burn-off diameter of 246 mm. Thus, according to Fig. 12, the quality difference disclosed by surface turning was also shown by the experimental results. Tip 31 also proved better than tip 7 according to structure examinations.

3. Milling experiments

The aim of these experiments was to analyse the influence exerted by *tool grinding quality* on tool life.

Experimental tools were selected from a bunch manufactured for commercial purposes. Tools had been ground by the bunch in a quality conforming to standard specifications.

Cutting was performed with cooling by means of a 20 per cent cutting oil emulsion as cooler in a quantity amounting to 5 dm³/min. Cutting with each milling tool involved the following data: speed $n = 600$ rpm, cutting speed $v = 30.2$ m/min, feeding speed $v_e = 78$ mm/rev, feed per tooth $e_z = 0.026$ mm/tooth, cut width milled $b = 16$ mm, cut depth $f = 5$ mm. In the course of these experiments, wear was measured along the face and side edges, respectively, of the cutter with the magnitude of back wear determined by using a shop microscope of 15-times magnification. Each measurement included the plotting of 10 wear curves: 5 curves representing the wear shown by the 5 face edges, and 5 illustrating that of the 5 side edges.

Following the completion of the first experimental sequence, that of the regrinding of the cutters was performed by using the same machine, tool, and technological data as used prior to the beginning of the first test series. Regrinding was performed, however, individually and with much greater care than in the first case. There could be no significant difference observed between the two grindings, by means of routine measurements on the cutters, the milling characteristics of the cutters, however, appeared much improved after the second more careful one.

Now some wear curves will be presented to illustrate the experimental results.

Fig. 13 shows the wear curves obtained by the test performed subsequently to the regrinding of one of the cutters. Fig. 13/a illustrates side edge wear while Fig. 13/b that of the face edges. Each curve represents the wear of a single edge. The difference between the wear of individual edges is relatively small which might be attributed to careful grinding. It could be demonstrated experimentally [7] that, in the case of less carefully executed grinding,

significant differences due to edge eccentricity and structural changes which take place during grinding may be encountered.

Fig. 14 presents the wear curves obtained for two experiments conducted by using one and the same tool. The first line (I) indicates the average side

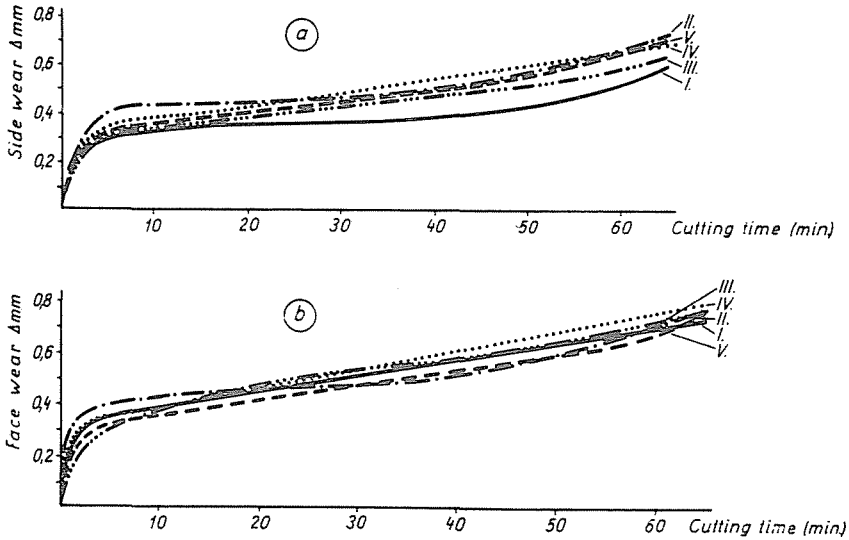


Fig. 13

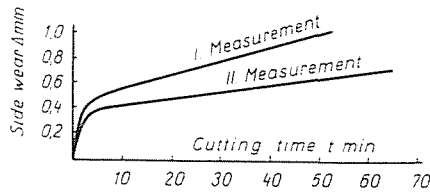


Fig. 14

wear developed after the first grinding, whereas the second line represents those measured subsequently to the second grinding operation. It is seen that wear is much lower following the more careful second grinding than after the first one.

4. Conclusions

The aim of the experiments was to contribute testmethodological data to the international tool life standard. In the present paper, some problems in tool preparation are being dealt with. As a result of the conducted investigations, the following conclusions may be drawn:

1. Experimental tool quality should be checked by hardness measurement and abbreviated turning tests (such as surface turning). For hardness measurements, the limit values beyond which tips qualify as unsuitable for experimental purposes must be determined. The value 66 to 67 HR_c proposed by the United States standard draft (1) appears to be exaggerated. For practical purposes, the value of 63 HR_c seems more reasonable as a directive. The hardness deviation of 1 HR_c referred to by the United States standard draft proved to be a realistic value according to the investigations carried out by this Institute.

Tools qualified by hardness tests as adequate should be subjected to short turning tests as well. For this purpose, the surface turning technique is suggested. This test, however, requires the determination of the sample material and cutting conditions as specified by international agreement. In order to avoid any waste of material, a depth of cut amounting to $f = 1.5$ mm is recommended for test purposes. In addition, test performance without cooling is proposed.

Tool structure examination may be suggested as a supplementary test. According to the gathered experiences this test generally supplies congruent results to the joint data given by hardness measurement and surface turning studies.

2. For tool preparation, grinding conditions must be accurately specified. To facilitate the numerical evaluation of grinding quality, in addition to back and face surface roughness the specification of the edge roughness value also appears reasonable.

3. To the investigations described in the present paper cooling was employed. Control experiments demonstrated that minor variations of cooler quality and cooling techniques affected experimental results to a significant extent. Test performance, therefore, requires either a method without cooling or, if adapting industrial practices, the highly accurate specification of cooling conditions.

4. To evaluate tool wear, back wear measurements are suggested. This method of measurements made at different points the comparison most possible.

5. When describing the experimental process, the detailed specification of experimental conditions had been also referred to. However, the present paper discussed these experiments with respect only to the tool and, also from this viewpoint, only with a minor field covered, omitting a number of theoretical problems which will be dealt with in another paper. In specifying experimental conditions, the interactions of tool and material must be taken into account, and qualification tests should be carried out as well. (According to informations obtained, such investigations have been conducted at the Aachen Technical College.)

Summary

The present paper deals with the problem of tool life test preparations. The effect of adequate tool preparation on experimental results is discussed. The investigations conducted are described in detail, and conclusions are drawn with respect to the influence exerted by tool quality differences on tool life.

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