INTERNATIONAL STANDARD

ISO 3685

Second edition
1993-11-15

Tool-life testing with single-point turning tools

Essais de durée de vie des outils de tournage à partie active unique

Reference number
ISO 3685:1993(E)

Contents

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Annexes

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 3685 was prepared by Technical Committee ISO/TC 29, *Small tools*.

This second edition cancels and replaces the first edition (ISO 3685:1977), of which it constitutes a technical revision.

Annexes A, B, C, D, E, F and G form an integral part of this International Standard. Annex H is for information only.

Introduction

The adoption by both industry and testing bodies of the recommendations contained in ISO 3685:1977 created a demand for the publication of similar recommendations for other commonly used cutting processes.

Tool-life testing in milling is covered in ISO 8688-1:1989 and ISO 8688-2:1989. During the final stages of their preparation, it was recognized that there was a need to update the recommendations for single-point turning tools.

This International Standard contains recommendations which are applicable in both laboratories and manufacturing units. These recommendations are intended to unify procedures in order to increase reliability and comparability of test results when making comparisons of cutting tools, work materials, cutting parameters or cutting fluids. In order to come as close as possible to these aims, recommended reference materials and conditions are included and should be used as far as is practical.

In addition, the recommendations can be used to assist in finding recommended cutting data or to determine limiting factors and machining characteristics such as cutting forces, machined surface characteristics, chip form etc. For these purposes in particular, certain parameters, which have been given recommended values, may have to be used as variables.

The test conditions recommended in this International Standard have been designed for turning tests using steel and cast iron workpieces of normal microstructure, with solid high-speed steel tools or tools with cemented carbide or ceramic indexable inserts. However, with suitable modifications, this International Standard can be applied, for example, to turning tests on other work materials or with cutting tools developed for specific applications.

The specified accuracy given in the recommendations should be considered as a minimum requirement. Any deviation from the recommendations should be indicated in detail in the test report.

Tool-life testing with single-point turning tools

1 Scope

This International Standard specifies recommended procedures for tool-life testing with high-speed steel, cemented carbide and ceramic single-point turning tools used for turning steel and cast iron workpieces. It can be applied in laboratory testing as well as in production practice.

In turning, cutting conditions may be considered under two categories:

a) conditions as a result of which tool deterioration is due predominantly to wear;

b) conditions under which tool deterioration is due mainly to other phenomena such as edge fracture or plastic deformation.

This International Standard is solely concerned with recommendations for testing which results predominantly in tool wear.

Testing for the second category of conditions above is to be subject to further study.

This International Standard establishes specifications for the following factors of tool-life testing with single-point turning tools: workpiece, tools, cutting fluid, cutting conditions, equipment, assessment of tool deterioration and tool life, test procedures and the recording, evaluation and presentation of results.

Further general information is given in annex A.

NOTE 1 This International Standard does not constitute an acceptance test and should not be used as such.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 185:1988, *Grey cast iron — Classification.*

ISO 229:1973, *Machine tools — Speeds and feeds.*

ISO 468:1982, *Surface roughness — Parameters, their values and general rules for specifying requirements.*

ISO 513:1991, *Application of hard cutting materials for machining by chip removal — Designation of the main groups of chip removal and groups of application.*

ISO 683-1:1987, *Heat-treatable steels, alloy steels and free-cutting steels — Part 1: Direct-hardening unalloyed and low-alloyed wrought steel in form of different black products.*

ISO 841:1974, *Numerical control of machines — Axis and motion nomenclature.*

ISO 883:1985, *Indexable hardmetal (carbide) inserts with rounded corners, without fixing hole — Dimensions.*

ISO 1940-1:1986, *Mechanical vibration — Balance quality requirements of rigid rotors — Part 1: Determination of permissible residual unbalance.*

ISO 2540:1973, *Centre drills for centre holes with protecting chamfer — Type B.*

ISO 3002-1:1982, *Basic quantities in cutting and grinding — Part 1: Geometry of the active part of cutting tools — General terms, reference systems, tool and working angles, chip breakers.*

ISO 4957:1980, *Tool steels.*

ISO 5610:1989, *Single-point tool holders for turning and copying, for indexable inserts — Dimensions.*

ISO 9361-1:1991, *Indexable inserts for cutting tools — Ceramic inserts with rounded corners — Part 1: Dimensions of inserts without fixing hole.*

ISO 9361-2:1991, *Indexable inserts for cutting tools — Ceramic inserts with rounded corners — Part 2: Dimensions of inserts with cylindrical fixing hole.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 tool wear: The change of shape of the tool from its original shape, during cutting, resulting from the gradual loss of tool material or deformation.

3.2 tool wear measure: A dimension to be measured to indicate the amount of tool wear.

3.3 tool-life criterion: A predetermined threshold value of a tool wear measure or the occurrence of a phenomenon.

3.4 tool life: The cutting time required to reach a tool-life criterion.

4 Workpiece

4.1 Work material

In principle, testing bodies are free to select the work materials according to their own interests. However, in order to increase the comparability of results between testing bodies, the use of one of the reference materials, steel C 45 in accordance with ISO 683-1 or cast iron grade 25 in accordance with ISO 185, is recommended. Detailed specifications of these materials are given in annex B. Within these specifications, materials may vary with a resulting effect on machinability. To minimize such problems the provision of a closer specified work material should be discussed with the supplier.

It is recommended that information concerning the work material such as grade, chemical composition, physical properties, microstructure, hardness, complete details of the processing route of the work material (e.g. hot rolled, forged, cast or cold drawn) and any heat treatment be given in the test report (see 4.2 and annex B).

In order to be able to compare results over reasonably long periods of time, it is recommended that testing bodies procure sufficiently large quantities of reference work material to cover their long term needs.

4.2 Standard conditions for the workpiece

All mill scale or casting skin shall be removed by clean-up cuts before testing, except when the effect of the scale is being tested.

The plastic formed surface of the shoulder, i.e. "the transient surface", and any other burnished or abnormally work-hardened surface on the workpiece which can come in contact with the test tool shall be removed with a sharp clean-up tool prior to testing in order to reduce as much as possible the residual sub-surface deformations due to the previous test. However, this does not include removal of the normally work-hardened surface on the test bar produced by the previous passes of the tool.

The length/diameter ratio of the workpiece shall be not more than the minimum ratio at which chatter occurs. The test shall be stopped when chatter occurs. A length/diameter ratio greater than 10 is not recommended.

The hardness of the work material shall be determined over the complete cross-section of one end of each test bar or tube.

Where hardness variations are expected to be significant, measurements shall be taken to ascertain that values fall within the prescribed limits.

The locations of measurement points and the method of measurement should be noted in the test report. It is recommended that the deviation within one batch of material be as small as possible. A realistic hardness value for the reference materials and similar materials is $\pm$ 5 % of the mean value.

The cutting test shall be conducted only in the range of diameters where the hardness lies within the limits given by the original hardness specification.

Quantitative metallography (as regards microstructure, grain size, inclusion count, etc.) of the work material is recommended but when this is not practical, photomicrographs shall be included in the test report. The magnification shall be in the range $\times$ 100 to $\times$ 500.

In machining tests carried out on production components, the fixing devices normally employed in the process shall be utilized.

The chuck and the spindle shall be stable and well balanced (for a method of evaluating the balance, see ISO 1940-1). When fixing the workpiece between a chuck or a faceplate and a centre, special care shall be taken to prevent any bending loads on the workpiece.

For diameters above 90 mm, the use of a faceplate is recommended.

A centre hole of 6,3 mm diameter with 120° protecting chamfer, in accordance with ISO 2540, is recommended.

5 Tools

In principle, testing bodies are free to select testing tools according to their own interests. However, in order to increase the comparability of results between testing bodies, the use of one of the reference tool shapes and tool materials, as specified hereafter, is recommended.

5.1 Tool materials

In all cutting tests in which the tool material is not itself the test variable, the investigation shall be conducted with an appropriate reference tool material to be defined by the testing body.

In principle, testing bodies are free to select the tool materials according to their own interest. However, in order to increase the comparability of results between testing bodies, the use of one of the reference materials, specified in this subclause, is recommended.

Within these specifications, tool materials may vary with a resulting effect on performance. To minimize such problems, the provision of a closely specified tool material should be discussed with the supplier to ensure as much uniformity as is practical.

In order to be able to compare results over reasonably long periods of time, it is recommended that testing bodies procure sufficiently large quantities of reference tool materials to cover their long term needs.

Reference tool materials should not have any coating or surface treatment.

If the tool material itself, coating or surface treatment is the test variable then the material classification, physical properties, microstructure hardness and processing route should be reported in detail.

5.1.1 High-speed steel

The high-speed steel reference tool material should be uncoated non-cobalt alloyed (S 2 and S 4) or cobalt alloyed (S 8 and S 11) all of which conform to ISO 4957.

5.1.2 Sintered carbide

The sintered carbide reference tool material shall belong to the ISO groups of application P 10 for machining steel or K 10 for machining cast iron in accordance with ISO 513.

Since carbide grades for the same group of application can vary between producers and are unlikely to be comparable, it is recommended to select a particular supplier's grade as a reference grade.

5.1.3 Ceramics

These shall be of commercially available grades and the composition and physical properties shall be noted in the test report in as much detail as possible.

The reference ceramics shall be

a) Al_2O_3-based, with min. 70 % Al_2O_3 and additions of other hard materials such as ZrO_2, titanium carbide (TIC) or titanium nitride (TIN);

b) Si_3N_4-based, with min. 90 % Si_3N_4 and additions of Y_2O_3 and/or Al_2O_3.

5.1.4 Other tool materials

When the tool material is the test variable, the material classification and, if possible, the chemical composition, hardness and microstructure shall be noted in the test report.

5.2 Tool geometry

5.2.1 Cutting tool geometry

The cutting tool geometry is defined in accordance with ISO 3002-1.

Figure 1 illustrates those angles which are necessary to define the orientation of the cutting edges, face and flank of a single-point cutting tool.

5.2.2 Standard tool geometry

All cutting tests in which the tool geometry is not the test variable shall be conducted using one of the tool geometries given in table 1. In the case of sintered carbide and ceramic tools, these shall be of the clamped insert type. Brazed or adhesive-bonded insert tools shall not be used as reference tools.

The tool shall be set on the machine correctly. This is accomplished by setting the corner on centre and setting the tool shank perpendicular to the axis of rotation of the workpiece. For carbide cutting tools used for machining steel and similar alloys only, the cutting edge shall have a radius r_n such that,

$$\text{if } r_\varepsilon = 0{,}4 \text{ mm, then } r_n = 0{,}02 \text{ mm to } 0{,}03 \text{ mm;}$$

$$\text{if } r_\varepsilon > 0{,}4 \text{ mm, then } r_n = 0{,}03 \text{ mm to } 0{,}05 \text{ mm.}$$

The conditions of the cutting edge for ceramics shall be in accordance with the magnified view in figure 1. r_n values shall be those obtained by grinding and shall be noted in the test report.

All other cutting tools shall be used with the normally sharp edge produced by the grinding or finishing operations indicated in 5.3.5.

Dimensions in millimetres

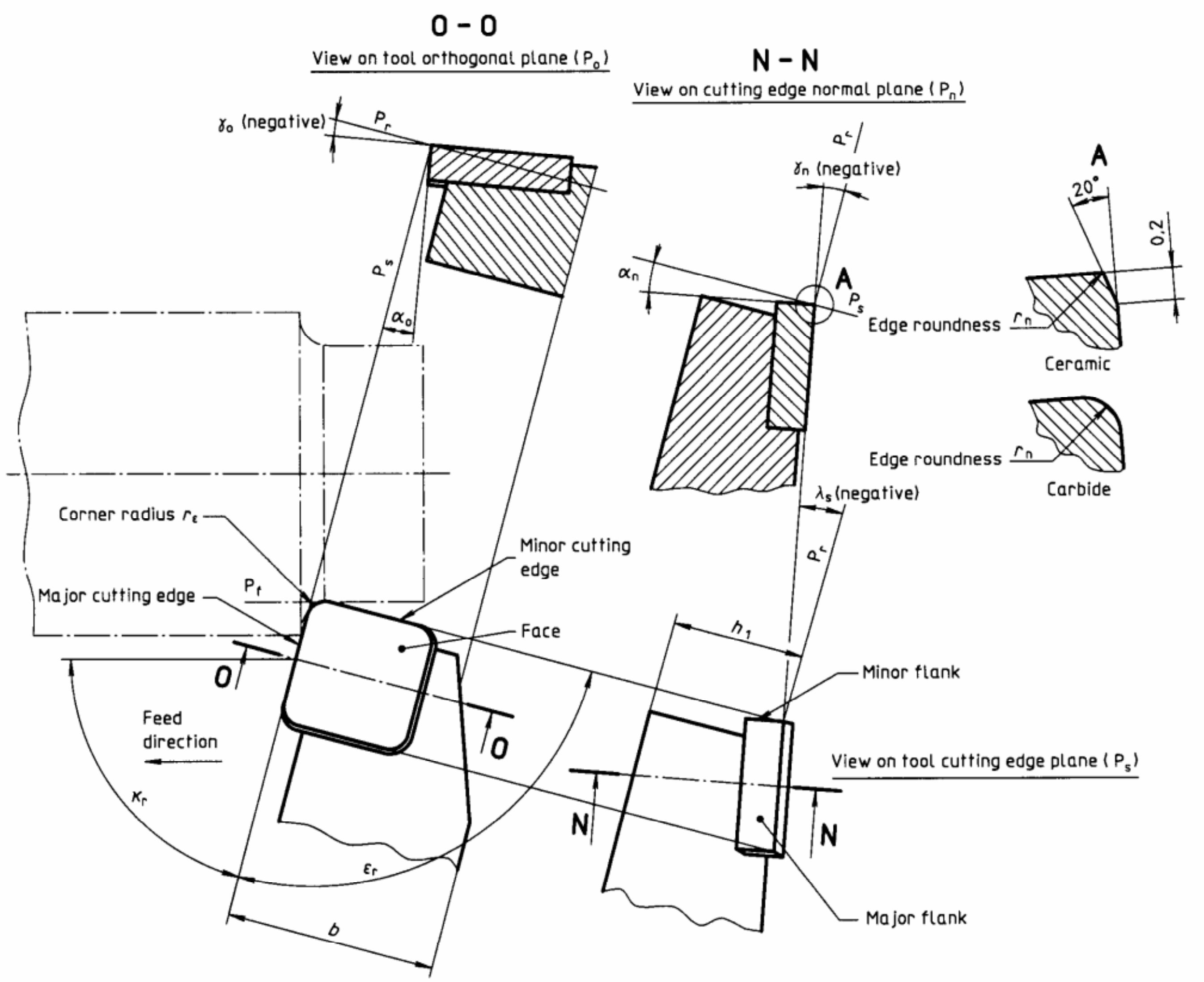


Figure 1 — Illustration of tool angles

Table 1 — Standard tool angles

Angles in degrees

Cutting tool material	Rake[1)] γ	Clearance[1)] α	Cutting edge inclination λ_s	Cutting edge angle κ_r	Included angle ε_r
High-speed steel	25	8	0	75	90
Sintered carbide	+6	5	0	75	90
	−6	6	−6	75	90
Ceramic	−6	6	−6	75	90

1) The tool rake and tool clearance angles may be measured in either the cutting edge normal plane (P_n) or the tool orthogonal plane (P_o). The appropriate subscript shall be added to γ and α to denote the plane of measurement, i.e. γ_n or γ_o and α_n or α_o.

5.2.3 Other tool geometries

Alloys unusually difficult to machine, such as nickel base and refractory materials, may require a departure from the standard tool geometry, but such a departure shall only be made when it is impossible to employ the standard tool geometry. In such a case or where tool geometry is the test variable, the following information shall be indicated in the test report:

a) values of the tool angles and the corresponding working angles (specified for the condition where the feed speed is zero as shown in table 1);

b) condition of the cutting edge: normally sharp, rounded to a specified radius or chamfered (the widths and angles of any lands on the face or flank).

5.3 Standard conditions for the tool

5.3.1 Tool type and size

A straight roughing tool shall be used.

The shank cross-section $h_1 \times b$ for tool holders, in accordance with ISO 5610, shall be

25 mm × 16 mm for solid high-speed steel tools;

25 mm × 25 mm for carbides; and

32 mm × 25 mm for ceramics.

The distance from the corner of the tool to the front of the lathe tool post holder (overhang) shall be 25 mm.

Sintered carbide inserts shall be 12,7 mm square and with a thickness of 4,76 mm for negative rake and 3,18 mm for positive rake (see ISO 883).

Ceramic inserts, in accordance with ISO 9361-1 and ISO 9361-2, shall be 12,7 mm square and with a thickness of 4,76 mm.

5.3.2 Tolerances

Tolerances for all tool angles shall be ± 0,5° (30′) for the complete cutting tool.

The angle between a tangent to the rounded corner and the major or minor cutting edges at the point where these blend shall not be greater than 5° (see figure 2).

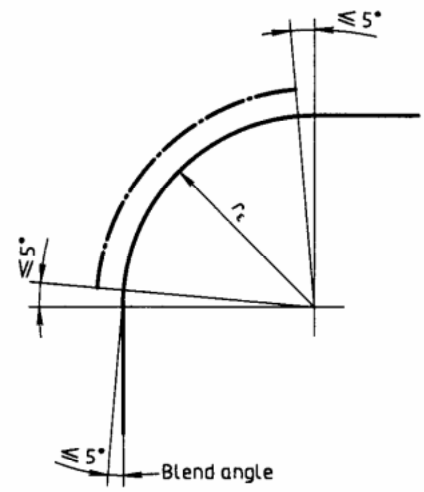


Figure 2 — Details of rounded corner

The tolerance for the corner radius (r_ε) shall be $\pm 0,1 \times r_\varepsilon$.

The tolerance on parallelism between the tool reference plane P_r and the tool back plane P_p (see ISO 3002-1:1982, subclauses 4.1.1 and 4.1.3) and the fixed setting axes X_m and Z_m (see ISO 3002-2:1982, subclause 2.2) of the machine tool, shall be ± 0,5°. In practice, this requirement is met when the corner is on centre within ± 0,25 mm and the infeed of the tool past a stationary reference point produces a deviation of the top surface (parallel to the supporting plane) and the side surface (parallel to the plane P_p) of the tool shank not in excess of ± 0,4 mm per 50 mm of infeed motion (see figure 3).

The tolerances of sintered carbide and ceramic inserts shall correspond to ISO 1832 class G, except as indicated above.

5.3.3 Tool finish

The roughness, R_a, of the face and flank of the tool shall not exceed 0,25 µm (measured in accordance with ISO 468).

The deviation from flatness of the supporting face of an insert, except in the immediate vicinity of its edges, shall not exceed 0,004 mm.

The cutting edge on high-speed steel tools shall have neither burrs nor feather edge. These may be removed by careful light honing of the face and flank surfaces of the tool.

Each cutting edge to be used in testing shall be examined at a minimum magnification of × 10 for visual defects such as chips or cracks. These defects shall be corrected if possible, otherwise the tool shall not be used.

5.3.4 Tool holders for inserts

For cutting tests, tool holders shall meet the following conditions.

The geometry shall be as indicated in table 1.

The tolerance on the angles for tool holder plus inserts shall be ± 0,5° (30′) and for the tool holder alone ± 0,2° (12′).

Dimensions in millimetres

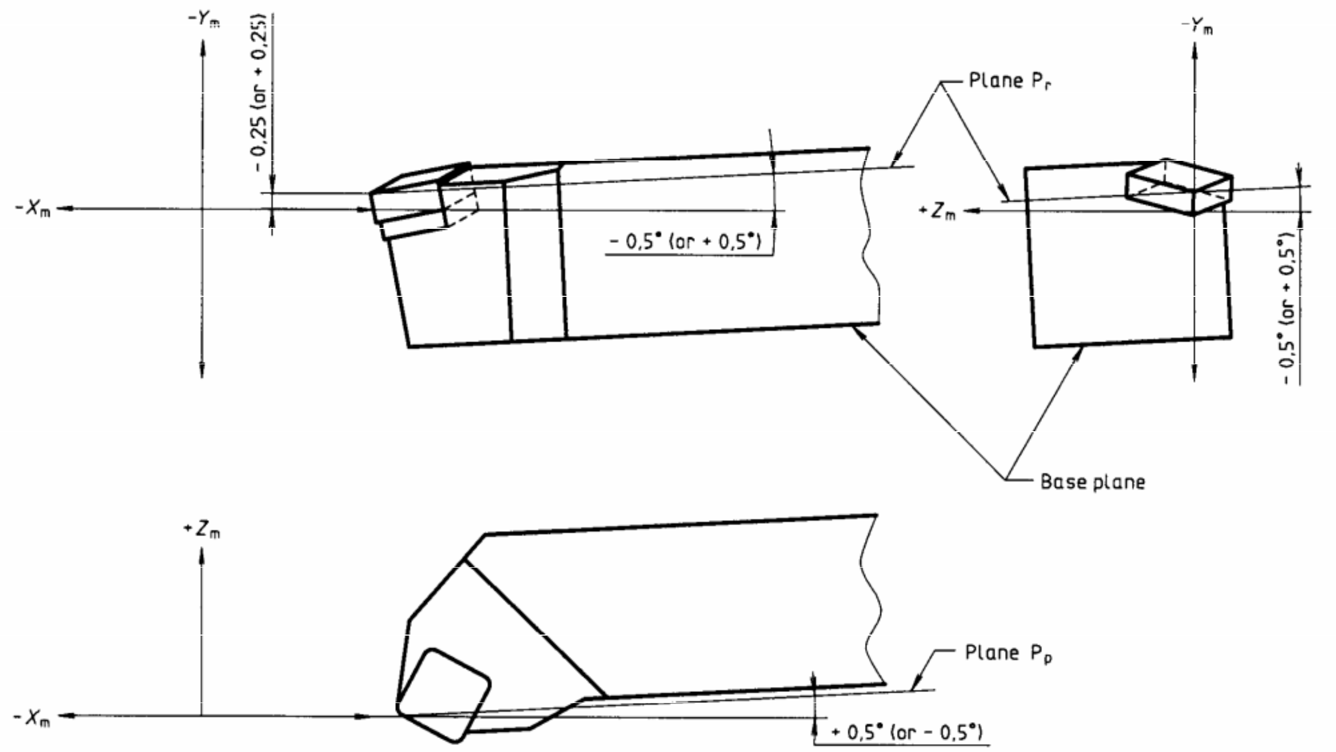


Figure 3 — Tolerance on parallelism

The angle for locating the indexable insert in the tool holder shall be as specified in figure 4.

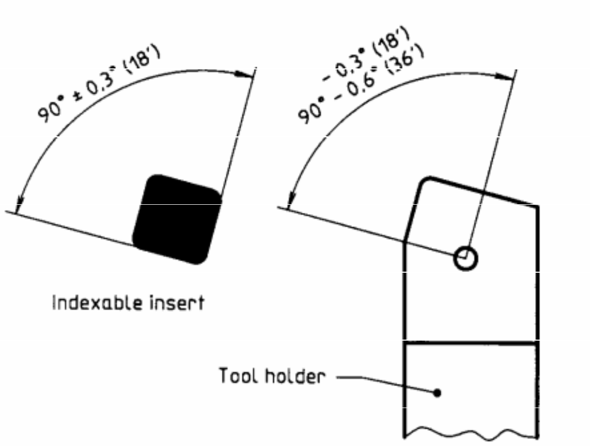


Figure 4 — Tolerances on squareness of insert and tool holder location

The tool holder material shall be steel with a tensile strength not less than 1 200 N/mm^2 (1 200 MPa).

The flatness of the base of the tool holder shall be within 0,1 mm over the length and width of the tool holder.

The faces on the tool holder or the shim supporting the insert shall be flat to within 0,01 mm.

The underside of the indexable insert shall not project over the supporting face of the tool holder by more than 0,3 mm (see figure 5).

The chip breaker height and chip breaker distance and the method of clamping the insert shall be noted in the test report. (See 5.3.7.)

5.3.5 Tool grinding of high-speed steel

The sequence of operations, types of grinding wheel, cutting data and recommended procedures should be obtained from the grinding wheel manufacturers.

For tools having a positive rake, each subsequent corner shall be lower than the preceding one. The decrease in tool corner height shall not exceed 5 mm, otherwise a new rake face shall be ground at the original height.

The cutting direction of the active periphery of the grinding wheel should be approximately perpendicular to the tool major cutting edge and in a direction away from the major cutting edge across the tool surface being ground.

Dimensions in millimetres

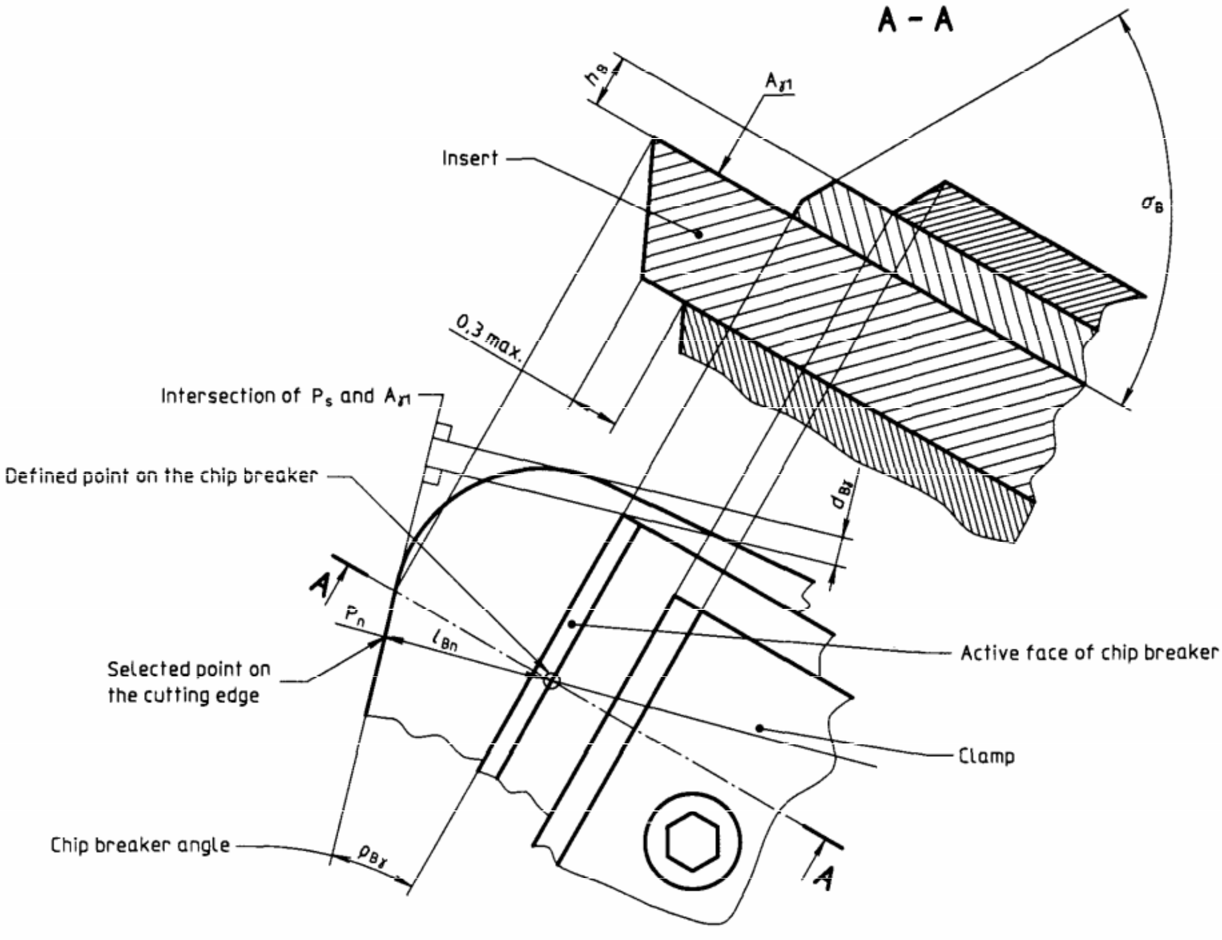


Figure 5 — Illustration of insert overhang and chip breaker

When using a plain grinding wheel the direction of feed motion may be either in the same direction or opposite to the cutting direction of the wheel relative to the surface being ground.

There is a danger of overheating, especially when the grinding machine does not permit a perfect control of depth setting and feed. Overheating is usually followed by oxidation colours but when colours are not obvious, overheating may still influence the hardness. Therefore, a hardness check shall be made.

After grinding, the hardness of the tool shall be measured on the flank or face as near as possible to the cutting edge. The hardness shall correspond to the previously measured hardness of the tool material. If this hardness value is not obtained after grinding, further grinding or cutting back shall be performed until the desired hardness is achieved.

The profile of the tool shall be restored after testing as shown in figures 1 and 2 and table 1.

When regrinding, the tool shall be ground back at least 2 mm beyond the wear marks. The tool geometry has to be maintened as specified in figures 1 and 2 and table 1. Care shall be taken to ensure that the tool corner has not been displaced sideways.

5.3.6 Carbide, ceramic

These inserts shall be used in the manufacturer's delivery condition and shall not be reground.

5.3.7 Chip breaker

A chip breaker shall not be used on high-speed steel tools unless the chip breaker is itself a test variable or if chipbreaking is necessary. The use of a chip breaker is permissible when testing with sintered carbide and ceramic tools. A chip breaker is often required when using these tool materials as a safety factor.

The chip breaker, if used, shall rest flat on the indexable insert. The deviation in flatness of the face of the chip breaker in contact with the insert shall not exceed 0,004 mm.

The chip breaker angle $\varrho_{B\gamma}$ (see figure 5) is the angle between the line of intersection of the chip breaker and the tool face and the straight portion of the major cutting edge. The angle $\varrho_{B\gamma}$ can be varied with different work piece materials so that an acceptable chip form is achieved and in order to guide the chip direction to or from the work piece, see ISO 3002-1:1982, subclause 7.5. The chip breaker wedge angle (σ_B), i.e. the angle between the active face of the chip breaker and the tool face shall be between 55° and 60°.

The chip breaker distance l_{Bn} shall be chosen so that an acceptable chip form is achieved (see figure 5). The actual chip breaker distance shall be noted in the test report.

For ceramic tools, the distance l_{Bn} may not be too small with regard to the risk for crushing the edge.

NOTE 2 Particular attention should be paid to the fact that the crater can be different when turning with or without a chip breaker.

6 Cutting fluid

Cutting fluid shall be used when cutting steel workpieces with high-speed steel tools unless the high-speed steel tools are being tested to catastrophic failure (see 8.2.1).

When cutting steel workpieces with carbides or ceramics cutting fluid normally should not be used.

When cutting cast iron the use of cutting fluids is not recommended.

The cutting fluid shall be clearly specified either by trademark or composition of the active elements, the actual concentration, hardness of water (when used as a diluent) and the pH value of the solution or emulsion.

When using cutting fluid the flow should "flood" the active part of the tool. The flow-rate should not be less than 3 l/min or 0,1 l/min for each cubic centimetre per minute of metal removal rate, whichever is the larger. The orifice diameter, flow-rate and reservoir temperature should be noted in the test report.

7 Cutting conditions

7.1 Standard cutting conditions

For all tests in which feed, f, depth of cut, a_p, or corner radius, r_ε, are not the prime test variables, the cutting conditions shall be one or more of the combinations listed in table 2.

Table 2 — Standard cutting conditions

Cutting condition	A	B	C	D
Feed, f, mm/rev	0,1	0,25	0,4	0,63
Depth of cut, a_p, mm	1	2,5	2,5	2,5
Corner radius, r_ε, mm	0,4	0,8	0,8	1,2

The tolerance on feed shall be $^{+3}_{-2}$ % (in accordance with ISO 229).

The tolerance on depth of cut shall be ± 5 %.

The edge geometry on corner radius is defined in 5.3.2.

NOTE 3 Designations in accordance with ISO 3002-3 have been used.

7.2 Other cutting conditions

When it is not possible to choose one of the standard cutting conditions, or when the feed, the depth of cut or the corner radius is the test variable, it is recommended that only one parameter be altered at a time and that the values chosen be at the intersection of designated feeds and depths of cut within the triangular areas shown in figure 6. The limits of the triangular areas are defined in table 3.

Table 3 — Limits of other cutting conditions

Minimum depth of cut	2 times corner radius[1)]
Maximum depth of cut	10 times feed
Maximum feed	0,8 times corner radius

1) A smaller depth of cut may make measurements of tool wear more difficult and less accurate.

7.3 Cutting speed

The cutting speed, in metres per minute (m/min), shall be determined on the surface of the workpiece to be cut, i.e. the work surface and NOT on the diameter resulting from the cut, i.e. the machined surface. Furthermore, the cutting speed shall be measured after the tool has engaged the workpiece to take into account any loss of cutting speed resulting from the cutting action.

At least four different cutting speeds shall be chosen for each cutting condition, except for ceramics, when a limitation to three speeds is practical with regard to the material consumption. In general, the cutting speeds shall be chosen such that the tool life at the highest speed is not less than 5 min, for ceramics not less than 2 min.

When machining expensive materials, a shorter tool life may be chosen, but shall not be less than 2 min.

In order to obtain adequately spaced points on the cutting speed tool-life curve, it is recommended that successive cutting speeds bear a ratio which will result in an approximately double tool life. The ratios can be chosen from a geometrical series of preferred numbers given in ISO 3 and/or ISO 229.

As a guideline, the following speed ratios can be used:

high-speed steel tool: 1,06

carbide tools: 1,12

ceramic: 1,25

8 Tool-life criteria and tool wear measurements

8.1 Introduction

In practical/workshop situations, the time at which a tool ceases to produce workpieces of the desired size and surface quality usually determines the end of useful tool life. The period up to the instant when the tool is incapable of further cutting may also be considered as useful tool life. However, the reasons for which tools may be considered to have reached the end of useful tool life will be different in each case depending upon cutting conditions etc.

To increase reliability and comparison of test results, it is essential that tool life is defined as the total cutting time of the tool to reach a specified value of tool-life criterion.

Depending on where at the cutting edges the deterioration occurs different values can be accepted.

This International Standard recommends that tool deterioration in the form of wear shall be used for determining tool life.

Where more than one type of wear becomes measurable, each type should be recorded and when any one of the wear phenomena limits has been attained, then the end of tool life has been reached.

The numerical value of tool wear used to determine tool life governs the quantity of testing materials required and the costs of testing. If the limiting value is too high, the cost of establishing results may exceed the worth of these results. If the limiting value is too low, the established result may be unreliable since it may be determined during the initial stages of wear development under the test conditions.

8.2 Tool-life criteria

The type of wear that is believed to contribute most to the end of useful tool life in a specific series of tests shall be used as a guide to the selection of one of the tool-life criteria specified hereafter. The type and value of the criterion used shall be noted in the test report. If it is not clear which type of wear will predominate, it is possible to use either two criteria, resulting in two v_c-T_c curves, or a mixed criterion, resulting in a broken v_c-T_c curve (see figure 7).

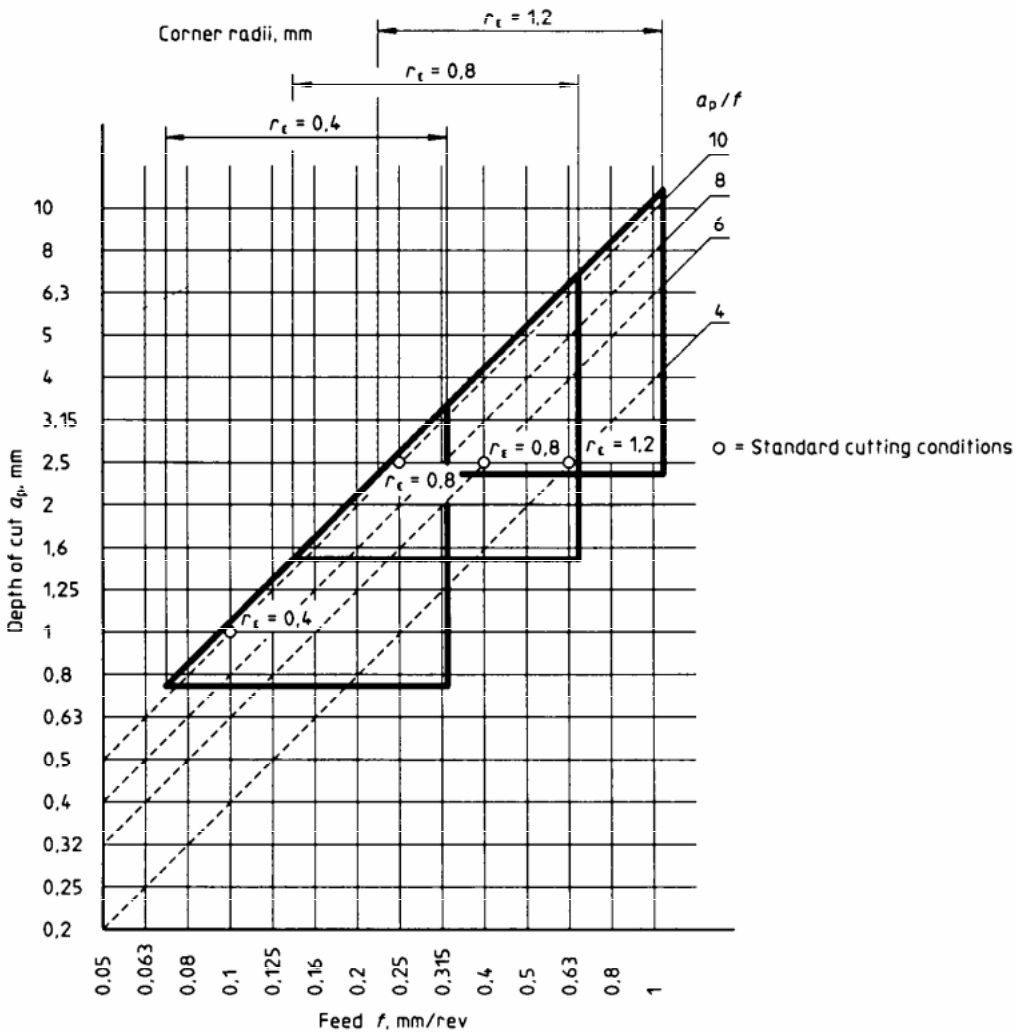


Figure 6 — Limits of cutting conditions

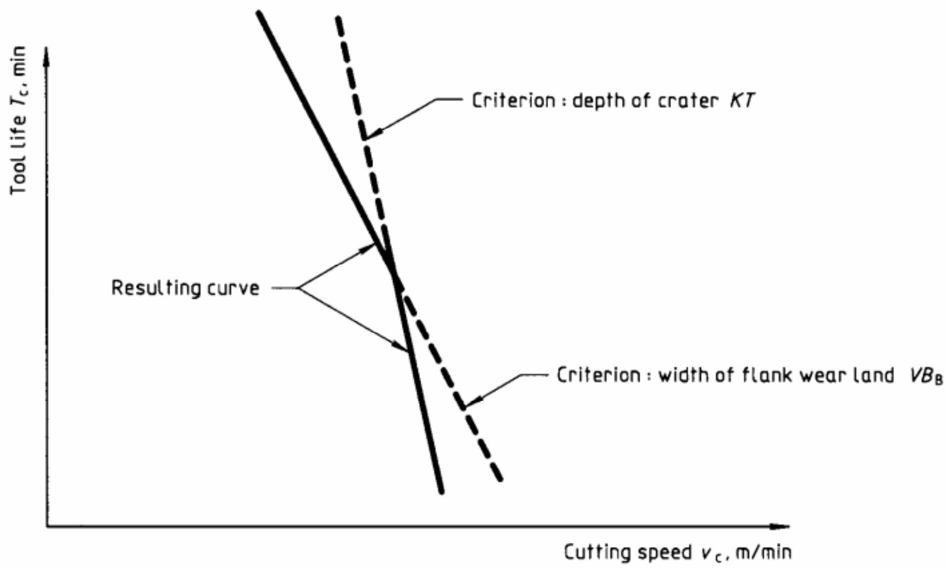


Figure 7 — Broken v_c-T_c curve, combined flank and crater wear (Logarithmic scales)

8.2.1 Common criteria for high-speed steel tools (see figure 8)

The criteria most commonly used for high-speed steel tools are as follows:

a) the maximum width of the flank wear land VB_B max. = 0,6 mm if the flank wear is not regularly worn, scratched, chipped or badly grooved in zone B;

b) the average width of the flank wear land VB_B = 0,3 mm if the flank wear land is considered to be regularly worn in zone B;

c) catastrophic failure.

8.2.2 Common criteria for sintered carbide tools (see figure 8)

The criteria most commonly used for sintered carbide tools are as follows:

a) the maximum width of the flank wear land VB_B max. = 0,6 mm if the flank wear land is not regularly worn in zone B;

b) the average width of the flank wear land VB_B = 0,3 mm, if the flank wear land is considered to be regularly worn in zone B;

c) the depth of the crater KT given, in millimetres, by the formula

$$KT = 0{,}06 + 0{,}3f$$

where f is the feed expressed in millimetres per revolution. For standard feeds, this leads to the values of KT given in table 4 when KT applies as a criterion.

Table 4 — Values of KT

Feed f, mm/rev.	0,25	0,4	0,63
Crater depth KT, mm	0,14	0,18	0,25

d) the crater front distance reduces to a value of KF = 0,02 mm (see figure 8);

e) the crater breaks through at the minor cutting edge, causing a poor finish of the machined surface.

NOTES

4 It should be recognized that notch wear is normally due to chemical action and occurs outside the area of physical contact between tool and workpiece both along the major cutting edge and to a lesser extent along the minor cutting edge. In both instances notch wear affects both the face and the flank simultaneously.

5 Notch wear, which in some cases can cause catastrophic failure, should be distinguished from abrasive wear VB_A which occurs along the cutting edge coincident with the work surface. Notch wear is often caused by work hardening effects in the workpiece by the previous pass of the tool.

Dimensions in millimetres

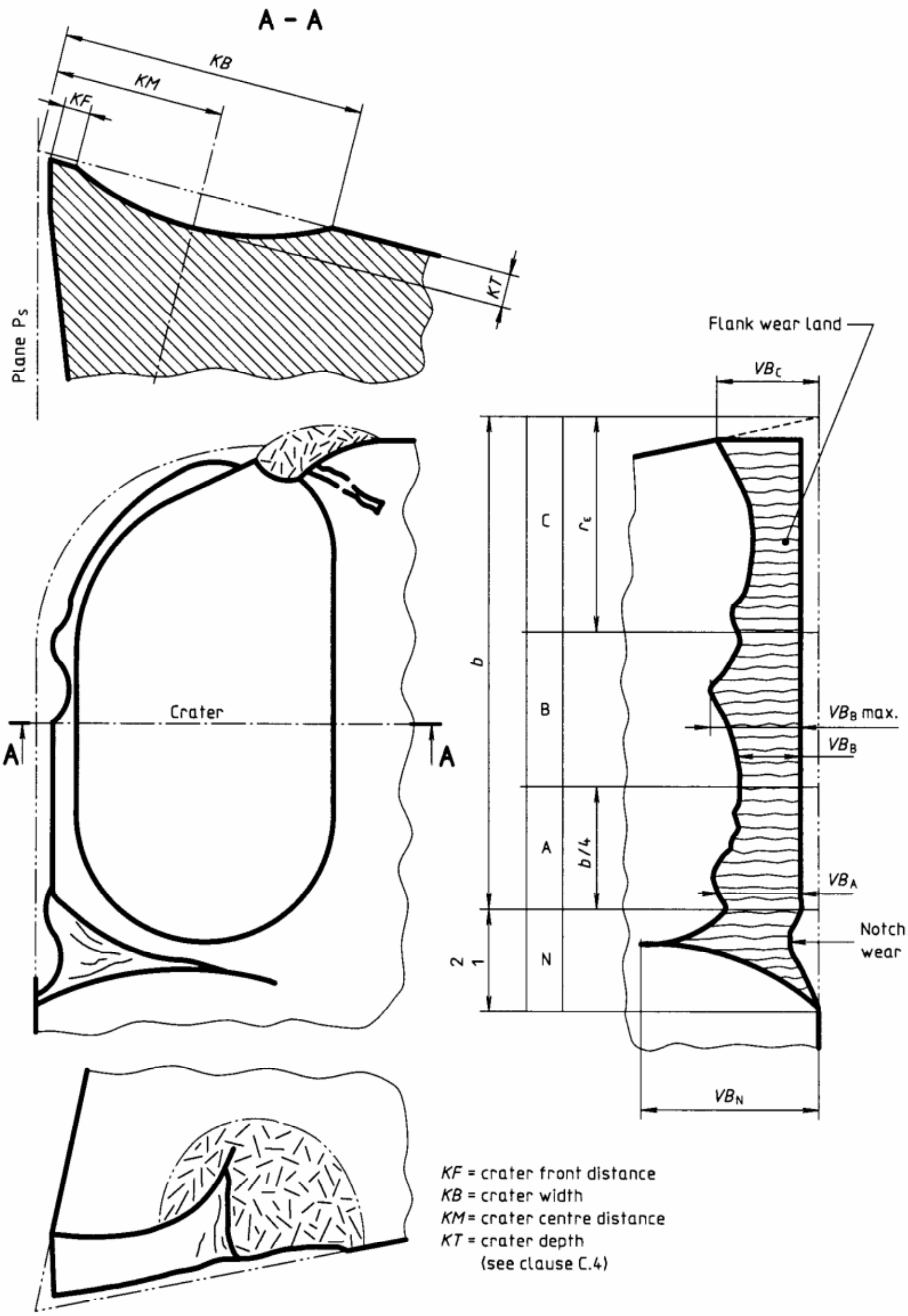


Figure 8 — Some types of wear on turning tools

8.2.3 Common criteria for tools of ceramics (see figure 8)

The criteria most commonly used for ceramics are as follows:

a) the maximum width of the flank wear land VB_B max. = 0,6 mm if the flank wear land is not regularly worn in zone B;

b) the average width of the flank wear land VB_B = 0,3 mm if the flank wear land is considered to be regularly worn in zone B.

8.2.4 Other criteria

The criteria specified in 8.2 are usually sufficient when turning steel and cast iron.

The reasons for the selection and choice of other criteria for special cases are discussed in annex C.

8.3 Tool wear measurements

Particles adhering to the flank directly under the wear land can give the appearance of a larger width of the wear land. Also a deposit in the crater results in lower values of the crater depth. Loose material shall be removed carefully but chemical etchants shall not be used except at the end of the test.

For the purpose of the wear measurements, the major cutting edge is considered to be divided into four zones as shown in figure 8.

Zone C is the curved part of the cutting edge at the tool corner.

Zone B is the remaining straight part of the cutting edge between zone C and zone A.

Zone A is the quarter of the worn cutting edge length b farthest away from the tool corner.

Zone N extends beyond the area of mutual contact between the tool and workpiece for approximately 1 mm to 2 mm along the major cutting edge. The wear is of notch type.

The width of the flank wear land VB_B shall be measured within zone B in the tool cutting edge plane P_s[1] perpendicular to the major cutting edge. The width of the flank wear land shall be measured from the position of the original major cutting edge.

The crater depth KT shall be measured as the maximum distance between the crater bottom and the original face in zone B.

Further details are given in annex C.

9 Equipment

9.1 Machine tool

The lathe on which the test is carried out shall be of stable design and in such good condition that no tendencies to vibrations or abnormal deflections can be observed under the test conditions (balance quality grade G 6.3 in accordance with ISO 1940 is recommended).

The machine tool used for testing shall be equipped with an infinitely variable speed spindle drive covering the range of spindle speeds to be used.

This is particularly important in turning in order to be able to maintain the same cutting speed as the diameter of the workpiece is reduced by successive cuts.

Furthermore, a variable speed drive allows precise predetermination of cutting speeds and reduces the time required to obtain the data for a complete tool life curve.

9.2 Other equipment

The following equipment is needed for specific measurements and shall be of sufficient resolution to discriminate the tolerances specified in this International Standard

— a device for measuring tool geometry accurately;

— a profile projector for inspection of the tool corners;

— a stopwatch for recording the cutting time;

— a toolmaker's microscope, or a microscope equipped with a filar eyepiece, for measuring flank wear;

— a dial indicator with a contact point approximately 0,2 mm in diameter for measuring crater depth;

— an X - Y table is recommended to obtain more accurate tool wear measurements;

— a profile recorder if registration of the crater profile is desired;

— hardness testing equipment for the determination of hardness of the workpiece and the tool;

— a portable roughness measuring apparatus for measuring workpiece roughness while the workpiece is mounted on the lathe;

— an instrument for measuring cutting speed;

1) The tool cutting edge plane P_s is the plane containing the major cutting edge and the assumed direction of primary motion.

- a slide caliper for measuring workpiece diameter and for setting the chip breaker distance;
- equipment for measuring the flow-rate of cutting fluids (this can be done by measuring the time to fill a barrel of known volume).

10 Tool-life test procedure

It is only possible to describe tool-life test procedure in general terms, as conditions will vary with each situation.

The method to follow is the same as that used for good machine tool operation, except that great care and observation must be exercised and that certain measurements must be taken.

Most details of the measurements and the precautions to be taken have already been covered elsewhere in this International Standard.

Before starting the test, ascertain that the lathe, workpiece and tools fulfil all the requirements of this International Standard. Complete the data sheet "General conditions" (see annex D).

The machine shall be set to the required cutting conditions. If necessary, a preliminary tool-life test as described in annex E shall be carried out.

Tool wear measurements shall be made at suitable intervals. All data shall be recorded on the "Wear versus time measurements" data sheet as shown in annex D. The readings shall be plotted on a tool wear (ordinate) versus time (abscissa) diagram (see figures 9 and 10).

Such diagrams shall show at least five experimental points for each curve so that the time at which the value that is selected as the tool-life criterion is reached can be assessed with sufficient accuracy.

Under no circumstances shall the tool life be determined by extrapolating the tool wear versus time diagram.

Finally, the results of a series of tests shall be recorded on the "Tool life versus cutting speed diagram" data sheet as shown in annex D.

The evaluation of the tool-life data is dealt with in clause 11.

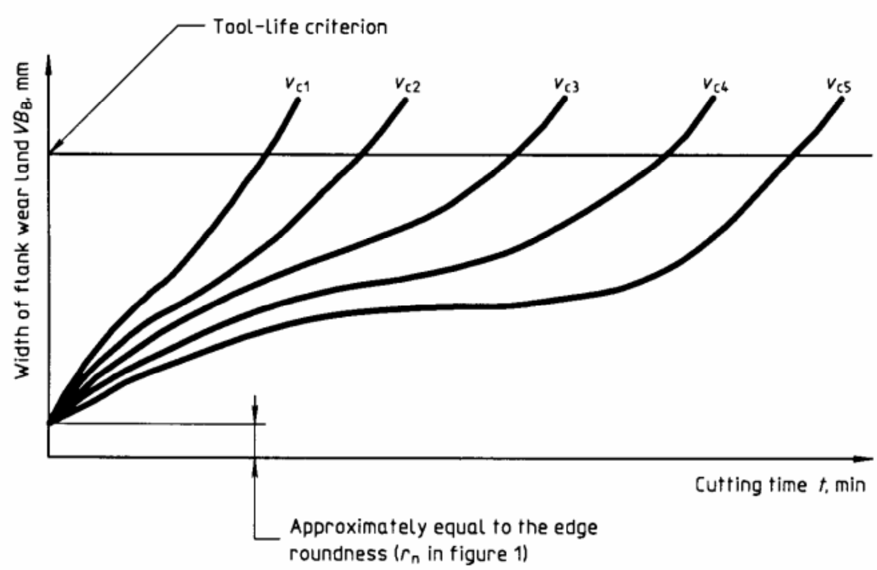


Figure 9 — Development of flank wear for different cutting speeds, v_{c1}-v_{c5} (Linear scales)

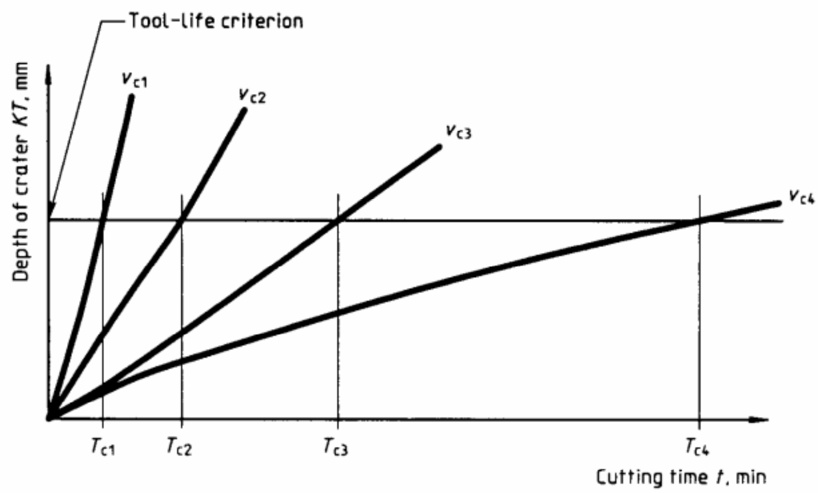


Figure 10 — Development of crater depth for different cutting speeds, v_{c1}-v_{c4} (Linear scales)

11 Recording and reporting results

11.1 Tool-life tests

11.1.1 Tool life as a function of cutting speed

Flank wear versus time measurements taken at several cutting speeds will provide curves as shown in figure 9. Corresponding curves will be obtained in measuring cratering as shown in figure 10, surface roughness, etc.

If catastrophic failure is used as a criterion, the tool life, T_c, is plotted directly against the cutting speed, v_c, which will provide tool-life curves.

Plotting the co-ordinates (v_{c1}, T_{c1}), (v_{c2}, T_{c2}), etc., obtained from figures 9 and 10 on a double logarithmic cutting speed versus tool-life diagram (same module along both axes) will produce a v_c-T_c curve as shown in figures 11 and 12.

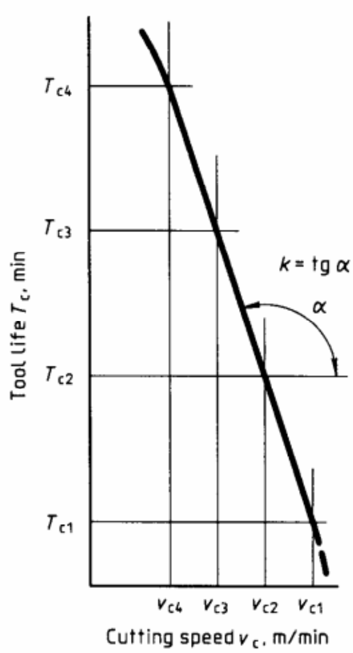


Figure 11 — v_c-T_c **curve based on figure 9**
(Logarithmic scales)

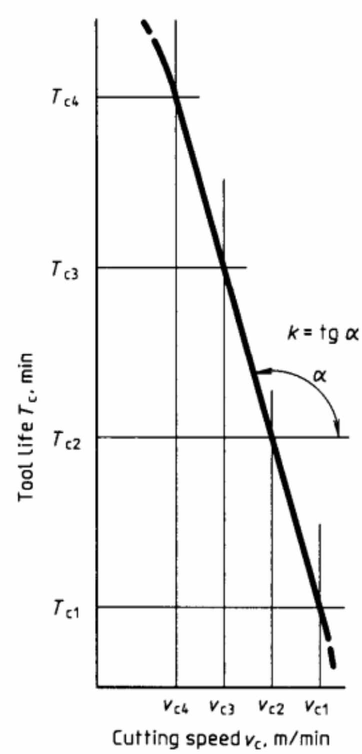


Figure 12 — v_c-T_c **curve based on figure 10**
(Logarithmic scales)

These v_c-T_c curves may be considered linear within a certain speed range. The equation for this linear portion of the curves is written:

$$v_c \times T_c^{-1/k} = C$$

where

v_c is the cutting speed, in metres per minute;

T_c is the tool life, in minutes;

$k = \text{tg}\ \alpha$ (as shown in figures 11 and 12) defines the slope of the tool-life curve;

$C =$ constant.

The values of k and C in the above equation shall be given in the test report. Methods for the determination of k and C are given in 11.3.

If the flank wear criterion is reached before that of the crater wear or vice versa, a v_c-T_c curve may be drawn according to figure 7. It should be observed that usually the v_c-T_c curve determined by cratering is steeper than the curve determined by flank wear.

11.1.2 Tool life as a function of spindle speed

In production it is sometimes suitable to plot the combinations of revolutions and number of workpieces produced for a specific criterion of tool wear on a double logarithmic diagram as shown in figure 13. This diagram can be used in the same way as a v_c-T_c diagram.

11.1.3 Tool-life tests at a single speed

In certain circumstances, tests at a number of cutting speeds cannot be carried out. In such a case, the tool life is expressed in minutes or alternatively as the number of workpieces produced at a single chosen speed.

The evaluation of such tests is explained in annex F.

11.2 Data sheets and diagrams

11.2.1 General

No standard data sheets are specified. However, suggested layouts are given in annex D, but these are not suitable for computer evaluation.

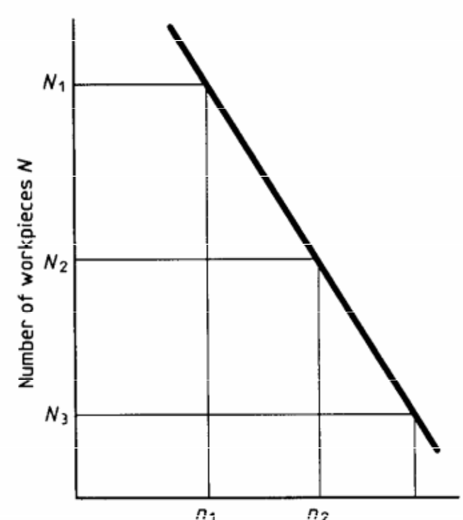
Three different data sheets are suggested:

a) "General conditions", data sheet which covers all the basic data for a complete series of tests;

b) "Wear versus time measurements" data sheet, which covers all the details of a single tool-life test;

c) "Tool life versus cutting speed diagram" data sheet, for recording the results of a number of tool-life tests carried out at a range of cutting speeds.

All information shown on the sample data sheets shall be included in any other data sheet compiled.



NOTE — Further information is given in annex E.

Figure 13 — Diagram showing the number of workpieces produced as a function of spindle speed
(Logarithmic scales)

11.2.2 "Wear versus time measurements" data sheet

Information recorded in the "Remarks" column on data sheet b) in 11.2.1 shall include the following:

a) the chipforms obtained (see annex G);

b) the progressive readings of Brinell hardness of the workpiece as its diameter is reduced by successive cuts;

c) the orifice diameter, flow-rate and reservoir temperature of the cutting fluid supply and fluid pressure if possible.

11.2.3 "Tool life versus cutting speed diagram" data sheet

The tool-life curve shall be plotted on standard log-log graph paper with the same module in both directions (83,33 mm modules if possible).

The abscissa shall be the cutting speed v_c, expressed in metres per minute.

The ordinate shall be the tool life T_c, expressed in minutes, or the number of workpieces N.

The following pertinent data shall be shown in the heading of the graph:

a) the date;

b) the work material specification;

c) the hardness or the physical properties of the work material;

d) the tool material used and hardness in the case of high-speed steel;

e) the tool geometry (data given in the following order γ_n, α_n, λ_s, κ_r, ε_r, r_ε, r_n, and chip breaker);

f) the cutting fluid;

g) the feed;

h) the depth of cut;

i) the criterion of end point of tool life;

j) all other data pertinent to the test.

11.3 Evaluation of tool-life data

11.3.1 General

Any evaluation of tool-life test data becomes useless if precautions are not taken during the experiment to ensure that the observations obtained are really independent of all factors other than those which are being investigated, and that the tests are carried out in a random sequence.

The constants of the Taylor tool-life equation

$$v_c \times T_c^{-1/k} = C$$

can be estimated from tool-life tests either by a simple graphic method, described in 11.3.2 or by a mathematical method, described in 11.3.3. If the latter is used, it is possible to obtain a measure for the dispersion as well as for the significance and the confidence interval limits, as described in 11.3.4 and 11.3.5.

11.3.2 Evaluation "by eye"

With evaluation "by eye" it is possible to estimate the constants C and k quickly with an accuracy that is acceptable in many cases. However, it should be borne in mind that evaluation "by eye" is not objective, as it is unlikely that two individuals would arrive at exactly the same result. Further details are given in annex F.

11.3.3 Evaluation by calculation

Linear regression analysis is an objective method of fitting a straight line through a number of observations. The line is fitted by the method of least squares which requires that the sum of the squares of the deviations between the observation points and the line be minimized. The method is described in annex F.

11.3.4 Statistical considerations on the goodness of fit of the v_c-T_c curve

11.3.4.1 Dispersion

All experimental observations are concerned with dispersion. One way of indicating the dispersion is by the determination of residual variation about the regression line, which is the mean square deviation of the observed $\log T_c$ values from the value according to the regression line. Further details are given in annex F.

11.3.4.2 Significance

If the observed relation between the variables T_c and v_c is not to be considered as only a result of chance, the residual variation should be small in relation to the total variation of the T_c values due to regression. Further calculation methods are shown in annex F.

Annex A
(normative)

General information

The objective of this International Standard is to provide standard conditions and procedures for conducting tool-life tests with single-point tools in turning so that

— results from different sources can be compared;

— dispersion of the test results will be kept to a minimum.

Aims of such tests may be

— determination of machining properties or work materials;

— comparison of tools (material, geometry, etc.);

— comparison of cutting fluids;

— determination of recommendable cutting data.

In this International Standard, certain items are standardized (for example, standard tool geometries and standard cutting conditions). The term "standard" is used for quantities the values of which can be measured and expressed in physical units, one or more of the values being chosen as standard. In tool-life testing there are also variables like work material, tool material and type of cutting fluid the properties of which may be important for machining but cannot be easily expressed in physical units. Here, a detailed description containing chemical composition, manufacturing procedure, etc. is needed. Therefore, the term "reference" is introduced. The tool-life criteria are divided into "common" criteria and "other" criteria, as it is impossible to standardize them all. For practical reasons and for reasons of comparability, the "common" criteria specified in this International Standard are preferred, but in some situations "other" criteria may be more appropriate. In such cases annex C should serve as a guide.

Although the reference materials are described in detail, differences in behaviour in cutting may be noticed when another batch is taken of the same nominal material. The only real solution for this problem would be an international "material bank" in which very large amounts of very rigidly controlled materials would be kept for calibration purposes. This idea has been considered but cannot be realized.

A major problem in drafting this International Standard was that an International Standard with only one or very few conditions gives very good comparability but little freedom to adopt the test circumstances to wider use.

If more conditions (for example feeds, tool geometries) are standardized, a greater chance exists that a case comparable with a particular type of production is covered, but it would be unlikely that data of this case are available for comparison. If, for instance, it is required to test the machining properties of work materials in order to obtain information for the purchasing, work preparations and other departments, this can be done in most cases by the use of one of the standard cutting conditions, standard tool geometries, common tool-life criteria, the reference tools and the reference cutting fluid. Then the results will be comparable with those obtained elsewhere. In many cases it will be necessary to deviate from this International Standard. For instance, work materials very different from the non-alloyed steels and cast irons, which are the work materials most commonly used in the tests described in this International Standard, may make it necessary to use a non-reference tool material, and perhaps the standard tool geometry will also not be the best choice. If deviations are necessary, it is advisable to follow this International Standard when possible.

Annex B
(normative)

Reference work materials

B.1 Steel

The steel reference material shall be a hot-rolled medium-carbon steel of the following composition corresponding to steel C 45 E4, in conformance with ISO 683-1.

C %	Si %	Mn %	S %	P %
0,42 to 0,50	0,10 to 0,40	0,50 to 0,80	0,035 max.	0,035 max.

It is recommended to use mean values, if possible.

The presence of the following elements in excess of the maximum values given below shall disqualify the steel as a reference test material.

Ni = 0,20 %

Cr = 0,15 %

Mo = 0,05 %

V = 0,02 %

Cu = 0,20 %

The steel shall be dioxidized with aluminium and the minimum aluminium content shall be 0,01 % and the maximum aluminium content shall be 0,03 %. Special deoxidants shall not be used.

The nitrogen content, being to some extent dependent on the steelmaking source, shall be as follows:

Source	Nitrogen content %
Open hearth or oxygen convertors	0,003 to 0,006
Arc, single slag	0,004 to 0,008

It will be necessary to analyse the steel for nitrogen. The steel shall satisfy ISO 683-1 delivery condition 1 (chemical analysis only). The limits of the elements and deoxidation practice shall be discussed with the steelmaker and analysis of C, Si, Mn, Ni, Cr, Mo, P, S, V, Cu, Al and N requested at the time of the order.

In order to reduce dispersion of test results, attempts should be made to obtain material in which the actual composition is within closer limits than indicated above.

The microstructure shall be specified and recorded.

For the recommended reference work material the minimum initial test bar diameter shall be 90 mm. The actual initial diameter shall be reported. If other work materials are being tested, it can be necessary to use smaller diameters in order to achieve a homogenous structure in the zone to be tested. If required cutting speeds, or for reasons of stability, bigger diameters would be needed, it is recommended to use tubes with a wall thickness of maximum 40 mm.

Test bars or tubes after being cut to length (see 4.2 "length/diameter ratio") shall be normalized to a hardness within the range specified in ISO 683-1.

For testing purposes where the work material is not the test variable, it is recommended that the hardness should fall within closer tolerances than those indicated in ISO 683-1. The actual hardness values and points of measurement should be recorded and reported (see 4.2).

B.2 Cast iron

The cast iron reference material shall be supplied to ISO 185, grade 25.

The microstructure throughout the entire volume of each cast iron test bar shall consist essentially of a matrix of 100 % pearlite with flake graphite within the following specification:

— free iron carbide: 0 %

— free ferrite: 5 % max.

— steadite (iron-iron phosphide eutectic): 5 % max.

— graphite: flake graphite only

— pearlite: balance

For testing purposes where the work material is not the test variable it is recommended that the hardness values should fall within closer tolerances than those indicated in ISO 185. The actual hardness values and points of measurement should be recorded and reported (see 4.2).

B.3 Other work materials

Where the work material is not one of the reference materials, the grade, chemical composition, physical properties, microstructure and complete details of the processing route of the work material (for example hot-rolled, forged, cast or cold-drawn) and any heat treatment shall, if possible, be noted in the test report.

Annex C
(normative)

Tool wear and tool-life criteria

C.1 General

The aim of tool-life testing is to determine experimentally how one or more factors affect the useful life of cutting tools.

The reason why the useful life of a cutting tool should be considered to be ended is often different in different machining operations. The most simple case that may occur is that the tool becomes completely useless.

In most cases, the tool wears gradually and the work done by the tool becomes less satisfactory, for instance the roughness of the machined surface becomes too high, cutting forces rise and cause intolerable deflections or vibrations, the tool wear rate increases so that dimensional tolerances cannot be maintained, etc.

For reasons of comparability the determination of the end of tool life has been established.

C.2 General remark

The numerical values in this annex and in 8.2 are a reasonable compromise and apply to the cutting conditions specified in clause 7 for non-alloyed and low-alloyed steels and cast irons, with tools having the approximate characteristics specified in clause 5. (As an example, the presence of sintered-in chipbreaking grooves or special surface treatments may influence the wear behaviour significantly and make the assessment of the amount of wear more difficult.) In circumstances which differ greatly from those specified, it may be necessary to select other values for the tool-life criteria. In such cases, values being either 50 % lower or 50 % higher than the indicated values are recommended. Under no circumstances should the tool life be assessed by extrapolating the wear versus time graph.

C.3 Wear of the major flank

C.3.1 Flank wear

This is the best known type of tool wear (see figure 8). In many cases the flank wear land has a rather uniform width along the middle portion of the straight part of the major cutting edge. The width of the flank wear land is relatively easy to measure. The growing width of the flank wear land leads to a reduction in the quality of the tool. All cutting tool materials normally have a high initial rate of flank wear which usually decreases considerably after a short time of cutting, unless excessive cutting speeds are used (see figure 9). The flank wear of high-speed steel frequently develops differently from the wear of sintered carbide and ceramic tools.

High-speed steel tools may have prolonged periods of very little measurable increase of flank wear. This phenomenon occurs especially at low cutting speeds when machining ductile materials. At higher cutting speeds the increase of flank wear of all cutting tool materials is usually approximately uniform (see figure 9) subsequent to the initial high wear rate. The final portion of the flank wear versus time graph often shows an accelerated rate of wear which leads to catastrophic failure. The width of the flank wear land VB_B max. (see figure 8) is a suitable tool wear measure and a predetermined value of VB_B max. is regarded as a good tool-life criterion.

Too low a value would cause more dispersion of results since the initial high wear rate would have too much influence.

Too high a value would be costly and may not be reached in all tests.

An irregularly worn flank is often caused by chipping of the cutting edge and is therefore dealt with in C.6.2.

C.3.2 Notch wear

This is a special type of combined flank and face wear which occurs adjacent to, but outside, the point where the major cutting edge intersects the work surface, and may under certain circumstances make the change of tools necessary (see 8.2.2). The profile and the length of the wear notch VB_N (see figure 8) depend to a great extent on the accuracy of repeated depth settings.

For these reasons the notch wear is excluded from the evaluation of the width of the flank wear land (see 8.3). In special cases where the notch wear is predominant over all other tool wear phenomena, the length of the wear notch may be used as the tool wear measure. In such cases the value for VB_N may be used as the tool-life criterion.

C.4 Wear of the face

Crater wear is the most commonly occurring type of face wear.

The depth of the crater KT (see figure 8) may be used as a tool wear measure and a predetermined value of KT may be selected as a tool-life criterion. Crater wear is more important for carbide tools than for ceramic and high-speed steel. Recommended values are given in 8.2.2.

The position of the crater relative to the cutting edge has also some importance. A deep, wide crater far away from the cutting edge can be less dangerous to the tool than a less deep, narrow crater close to the cutting edge.

The distance from the front edge of the crater to the major cutting edge is sometimes a useful criterion which if limited can eliminate catastrophic failure.

This is one of the reasons why the values for KT as a tool-life criterion are given in relation to the feed. For special purposes, the crater centre distance KM and the crater width KB may be measured as additional information. However, they should not be used as tool-life criteria.

The crater centre distance KM (the distance between the original major cutting edge and the deepest point of the crater) is measured in zone B parallel to the face and perpendicular to the major cutting edge (see figure 8).

The crater width KB (the distance between the original major cutting edge and the rear side of the crater) is measured parallel to the face in zone B and perpendicular to the major cutting edge (see figure 8). As the crater centre distance KM depends not only on feed but also on work material and tool material, the crater ratio K ($K = KT/KM$) is sometimes calculated. A chosen value may then be used as the tool-life criterion and the value K approximately 0,1 is recommended.

C.5 Wear of the minor flank

In turning, the machined surface is shaped mainly by the tool corner and the minor cutting edge. This means that any change of the tool corner as a result of wear has an effect on the machined surface.

In finish turning with small feeds, one or more grooves are often found in the minor flank after a period of cutting. These grooves cause increased roughness of the machined surface. A direct evaluation of this type of tool wear is difficult but its effect may be assessed by the measurement of the roughness of the machined surface. A certain value of the roughness may be used as the tool-life criterion. Surface roughness is a common criterion for finish turning and the following R_a values, in micrometres, in accordance with ISO 468, are preferred:

0,4; 0,8; 1,6; 3,2; 6,3; 12,5.

Oxidation of the minor flank often leads to the destruction of the tool when turning with carbide tools at sufficiently high temperatures caused by high feeds and high cutting speeds. In such cases the tool may become useless because of oxidation of the minor flank before the criteria $VB_B = 0,3$ mm or the recommended value of KT are reached. In such cases, the sudden deterioration of the machined surface caused by the destruction of the minor flank has to be used as the tool-life criterion.

In general this happens quite suddenly, otherwise a certain deterioration has to be taken as a criterion.

C.6 Various other phenomena

C.6.1 Deformation of the tool corner

This can lead to destruction of high-speed steel and carbide tools when cutting conditions are severe.

Ceramics do not deform plastically under practical cutting conditions.

Deformation of the tool corner should not itself be used as a tool-life criterion; however, deformation will in most cases lead to a more rapid occurrence of catastrophic failure of high-speed steel tools and it makes the consequences of oxidation of carbide tools more severe. It can happen that cutting conditions are so severe that deformation starts immediately after the tool starts cutting. In such cases the tool life is usually very short. This is why it is recommended in 7.3 that tool life should be not less than 5 min for normal materials or not less than 2 min for expensive materials.

C.6.2 Chipping

The chipping of fine particles from the cutting edge and thermal cracking (frequently met in interrupted cuts) is important with brittle tool material. The amount of chipping and thermal cracking is evaluated to a certain extent by the maximum width of the flank wear land VB_B max. (see figure 8). Therefore the value VB_B max. = 0,6 mm is indicated in 8.2 as a tool-life criterion.

C.6.3 Premature failure

All abnormally quick, and therefore unreliable and unpredictable, modes of tool failure and heavy deformations which end tool life immediately can be caused by a hard spot in the work material or an accident in the operation of the machine tool. One tool of a series can break, chip badly, deform or otherwise fail unpredictably. The occurrence of premature failure disqualifies the test, unless special cases arise where premature failure is more frequent than wear and the other criteria are seldom reached.

This may be the case when machining very hard and heterogeneous work materials with brittle tool materials and delicate tool shapes. In such cases it is recommended that more experimental points be used to determine the v_c-T_c curves.

C.6.4 Catastrophic failure

The rapid deterioration of the cutting edge after a period of successful cutting under the combined action of load and increasing temperature is a reliable criterion for high-speed steel tools and is therefore indicated in 8.2.1. It may also be used in cases of testing carbide and ceramic tools under severe metal cutting conditions, but this is not recommended.

C.6.5 Preliminary failure

This phenomenon, sometimes observed prior to the catastrophic failure of high-speed steel tools, is evidenced by a shiny, burnished appearance of the machined surface and the transient surface, usually during a few revolutions of the workpiece. This may occur seconds before catastrophic failure or as early as half of the tool life. Preliminary failure shall not be used as a tool-life criterion and cutting shall be continued until one of the preferred tool-life criteria is reached. The instant of preliminary failure shall be recorded.

C.7 Surface roughness, cutting forces and temperature

Surface roughness is a common criterion for finish turning.

A major increase of cutting forces and temperature with cutting time is sometimes used as the basis for a tool-life criterion in scientific research and in adaptive control systems.

This is not covered in this International Standard. Surface roughness, forces and temperature may be measured as additional information.

Chip formation is normally not recommended for determining tool life. Chip form, however, is useful as a "control instrument" as described in annex G.

Annex D
(normative)

Data sheets

Data sheets

Company	**General conditions**	Reg. No. .... Order No. ....
Date	Ordered by	Performed by ....

Aim of the test

....

....

Test material

Designation	Manufacturer .... Country													Charge No. ....
Analysis %	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	V				Al_{tot} .... %
Standard														O .... %
Charge														N .... %
Test bars														H_2 .... %

Slag analysis and inclusions	SiO_2	Al_2O_3	FeO	MnO	Inclusions (Type, size, etc.)
					....
	CaO	MgO	TiO_2	Cr_2O_3	....
					....

Treatment of ingot (ingot size, rolling, etc.) ....

Heat treatment			Structure ....
Mechanical properties	$R_{p0,2}$ .... N/mm²	Brinell hardness	Additional data
	R_{eH} .... N/mm²	Ball diameter .... mm	....
	R_{eL} .... N/mm²	Load .... N	....

Tools

Manufacturer .... Country		Tool material ....
Sintered carbide ☐	Insert (designation)	Group of application (ISO 513) ....
Ceramic: Al_2O_3-type ☐ Si_3N_4-type ☐	Toolholder (type and designation)	
High-speed steel	Composition	Hardness ....
	Heat treatment	Designation of tool ....
	Grinding method	

Tool geometry	γ_n = ...	λ_s = ...	ε_r = ...	r_n = ...	$\rho_{B\gamma}$ = ...
	α_n = ...	κ_r = ...	r_ε = ...		l_{Bn} = ...

Lathe

Manufacturer	Type	No.	Year of manufacture ....
Rated output[1)] .... kW	Height of centres .... mm	Maximum distance between centres .... mm	Machine conditions as for record No. ....
Machine mounting (bolted down, etc.)		Infinitely variable speed	Yes ☐ No ☐

Miscellaneous ....

Fixing device

The following fixing device is used: Chuck ☐ / Chuck centre ☐ / Centres ☐	Other device (description) ....

Cutting fluid

Cutting fluid used Yes ☐ No ☐	Type	Designation or analysis	Pressure	Temperature	Volume .... l/min

Miscellaneous

1) If possible, the values of the cutting power, P_c, and/or the working power, P_e, (in accordance with ISO 3002-4) should be measured and recorded.

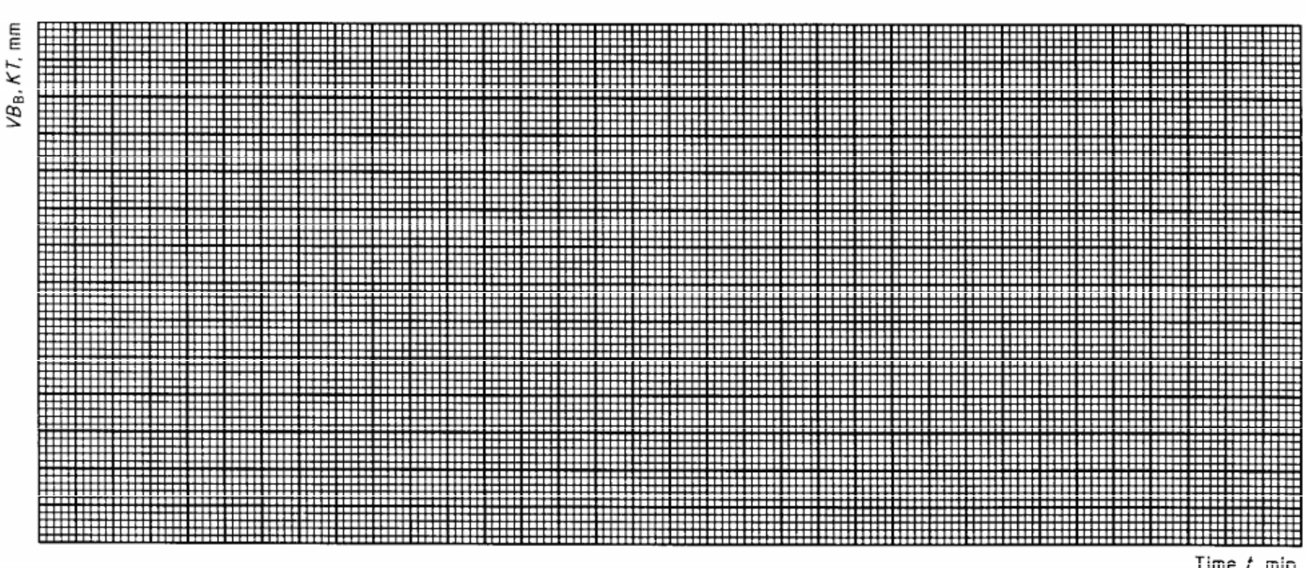
Company	Wear VB_B, KT versus time t measurement				Reg. No. .... Order No. ....
Date............	Ordered by............			Performed by	
Test bars, tool and cutting data					
Insert or tool No............ / Edge No............	Rough diameter ....mm	Diameter before machining ....mm	Length of workpiece ....mm	Machined zone ....mm	Chipbreaker
Feed f ....mm/rev	Depth of cut a_p............mm		Cutting speed v_c............m/min		height .... / distance ....
Miscellaneous............					

Test values

Measurement	Time	Diameter	Flank wear				Cratering		Chip form	Remarks
	t	D	VB_B	VB_B max.		1)	KT	1)		
No.	min	mm	mm	zone	mm		mm			
0			—	—	—	—	—	—	—	
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										

Tool-life criterion	1) If other wear measure is applied	Is chipforming affected by chipbreaker? Yes ☐ No ☐

The scales of the two axes shall be adapted to the values obtained.



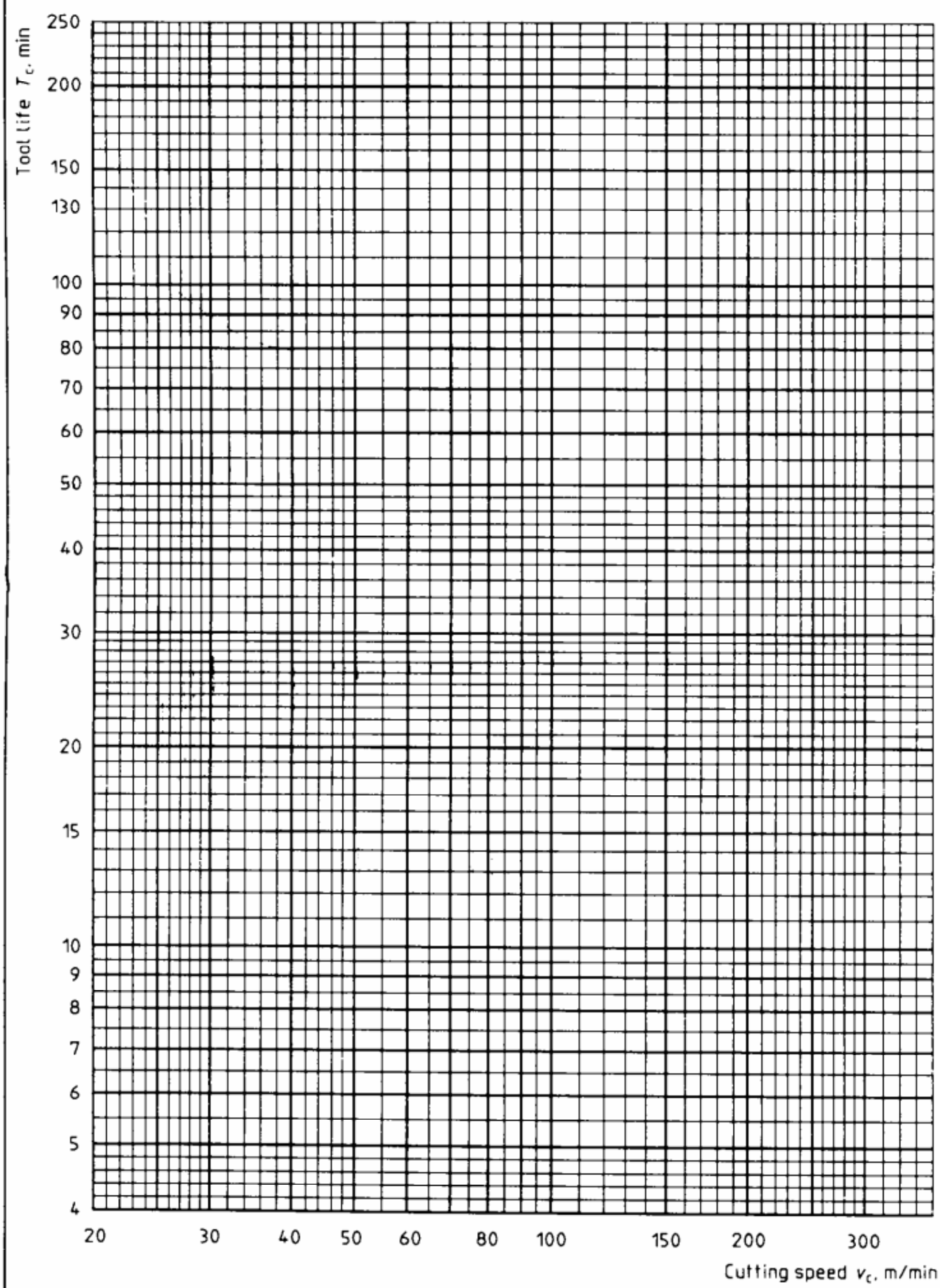
Company	**Tool life T_c versus cutting speed v_c diagram**	Reg. No. .... Order No. ....
Date	Ordered by	Performed by ....

Main data

Test material	Tool material	Tool designation	Feed f	Depth of cut a_p
....	....	....	.... mm/rev	.... mm

Tool geometry	γ_n = ...	α_n = ...	λ_s = ...	κ_r = ...	ε_r = ...	r_ε = ...	Cutting fluid ....

Remarks ....



Test values

Sheet No.	Tool-life criterion	Cutting speed v_c m/min	Tool life T_c, min	
			Mean value	Standard deviation

Remarks ....

Annex E
(normative)

Preliminary tool-life test

It is recommended that a preliminary tool-life test be carried out in order to determine a cutting speed which will result in a reasonable tool life and avoid inordinately time-consuming cuts.

A cut should be taken with the machine set at an arbitrarily selected low cutting speed and, if necessary, the chip breaker distance should be adjusted until an acceptable chip form is obtained. The period of time over which the cut is taken should be short, and will probably vary between individual cases. The tool should then be examined for indications of failure, and if none appear, a further cut should be taken with the cutting speed increased. This procedure should be repeated until the tool has failed.

A tool-life point thus obtained should not be recorded in the test report; however, it is valid in establishing the correct operating level. The cutting time taken during the test at the lower speeds is an insignificant portion of the life of the cutting tool when operating at the speed at which the tool failure occurred.

The cutting speed for the first tool-life tests is determined by estimating the slope, k, of the tool-life curve.

Using a log-log graph paper (module 83,33 mm recommended), a line having an estimated slope can be drawn through the tool-life point obtained in this preliminary test.

This line can then be used to determine the cutting speed for the first tool life desired. This cutting speed can also be calculated by using the tool-life equation in the following formula:

$$v_{c2} = v_{c1}\left(\frac{T_{c1}}{T_{c2}}\right)^{-1/k}$$

A reasonable estimate of the slope of the tool-life line for flank wear for different cutting tool materials is given below.

— High-speed steel: $k = -7$, but values between -12 and -5 can be obtained;

— Carbide: $k = -4$, but values between -6 and $-2{,}5$ can be obtained;

— Ceramics: $k = -2$, but values between $-2{,}5$ and $-1{,}25$ can be obtained.

Values near the initial estimated values are frequently found when cutting reference work material with reference tools.

The cutting speed thus chosen will rarely yield the tool life selected; however, it will provide a reasonable cutting speed at which the test may be started. With some experience the preliminary test can be omitted.

Annex F
(normative)

Evaluation of tool-life data

F.1 General

It should be noted that the symbols N, X, Y, $\overline{X}$, $\overline{Y}$, σ and σ^2 used previously for the work relative to tool-life testing with single point turning tools have been replaced by n, x, y, $\overline{x}$, $\overline{y}$, s and s^2 respectively in accordance with ISO 3534.

F.2 Evaluation "by eye"

Procedure and calculation

A log-log graph paper of equal scale moduli shall be used with the tool life T_c (dependent variable) on the vertical scale and the cutting speed v_c (independent variable) on the horizontal scale.

All observations of v_c and T_c for the particular tool-life criterion shall be plotted with the exception of obviously false data. Errors frequently occur by averaging the results of observations at one speed prior to plotting on the double logarithmic graph.

The best straight line shall be fitted to the graph of $\log T_c$ against $\log v_c$. Theoretically, the line should be drawn in such a manner that the sum of the squares of the vertical distances between the line and the actual points is estimated, by eye, to be as small as possible.

The constant k can be easily obtained from the slope of the line, or from two sets of observations (v_c, T_c) through which the line actually passes.

$$k = \frac{\log\ T_{c2} - \log\ T_{c1}}{\log\ v_{c2} - \log\ v_{c1}}$$

The constant C can be read directly from the graph as the cutting speed for a total life of 1 min.

Alternatively, C may be calculated from

$$C = v_{c1} \times T_{c1}^{-1/k}$$

EXAMPLE

In a series of tool-life tests with carbide P 30 tools on a normalized 0,45 % steel with feed F = 0,25 mm/rev., depth of cut a_p = 2,5 mm, corner radius r_ε = 0,8 mm and tool orthogonal angle γ_o = 6°, the following results were obtained:

Number of test	Cutting speed, v_c m/min	Tool life, T_c, min	
		Criterion KT = 0,14 mm	Criterion VB_B = 0,3 mm
1	180	10	17,5
2	160	18,5	24
3	140	24	30
4	140	20	26
5	125	36	40
6	160	13	17
7	125	44	51
8	180	8	15,5
9	160	15,5	22
10	125	40	47
11	140	25	36
12	180	6,5	12,5

NOTE 6 The work material and the tool material were not identical in all respects to the reference materials described in this International Standard.

Determine the constants of the tool-life equation.

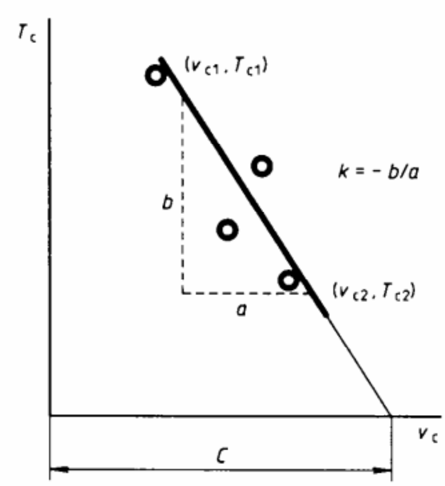


Figure F.1 —
(Logarithmic scales)

Solution:

The experimental points are plotted as shown in figure F.2. One line is plotted for the criterion $VB_B = 0,3$ mm and another line for the criterion $KT = 0,14$ mm. The constants are obtained graphically and are indicated in the figure.

F.3 Evaluation by calculation

F.3.1 Regression analysis

Regression analysis is a statistical method which helps to fit the best line to a given set of data, instead of simply drawing a line by eye. This method determines the equation of that straight line from which the sum of the squared distances, or deviations, of all plotted points in a particular direction becomes a minimum.

In this particular work, it is assumed that $\log T_c$ is a linear function of an independent variable $\log v_c$; the deviations are thus measured in the $\log T_c$ or vertical direction.

The logarithmic transformation from T_c and v_c to $\log T_c$ and $\log v_c$ results in the regression analysis being calculated for deviations from $\log T_c$ instead of T_c. This distinction leads to a small underestimation of the level of the line, as shown in figure F.3.

In practice, the difference between a tool life calculated for T_c and a curve calculated for $\log T_c$ is very small in comparison with the scatter about the curve.

F.3.2 Calculations

For the calculations, the computation schedule shown in table F.1 may be used. Columns 1, 2 and 3 are completed initially by the insertion of the observed v_c and T_c values for all the experimental results taken. Only undoubtedly false results should be omitted.

The following notation is used:

n: number of experimental observations
x: $\log v_c$
y: $\log T_c$

Columns 4 and 5 of table F.1 are completed by simply taking logarithms of v_c and T_c. The summation of both the x and y values is then obtained and their mean values $\bar{x}$, $\bar{y}$, computed from:

$$\bar{x} = \frac{\sum x}{n} \text{ and } \bar{y} = \frac{\sum y}{n}$$

Transformation of the Taylor tool-life equation together with suitable choice of axes gives the following formula:

$$y = a + k(x - \bar{x})$$

where

$$a = k(\bar{x} - \log C)$$
$$= \bar{y}$$

and

$(\bar{x}, \bar{y})$ are the co-ordinates of the centroidal point.

It is necessary to find the values of C and k such that the sum of the squares of the y residuals is a minimum. An outline for the calculation is given in table F.1.

The constant k, which is the tangent of the angle between the regression line and the X-axis, is given by

$$k = \frac{\sum xy - \left[\left(\sum x \cdot \sum y\right)/n\right]}{\sum x^2 - \left(\sum x\right)^2/n}$$

The products xy are tabulated in column 6 of table F.1 and their summation obtained. The separate values of $\sum x$ and $\sum y$ are obtained from columns 4 and 5 respectively. The product $\sum x \cdot \sum y$ is then divided by n.

In column 7 the sum of squares $\sum x^2$ is calculated. Then from column 4 the sum $\sum x$ is obtained, squared and divided by n.

NOTE 7 $\sum x^2$ is not the same as $\left(\sum x\right)^2$.

Finally, the constant C is calculated from

$$\log C = \bar{x} - \bar{y}/k$$

EXAMPLE

Calculate the constants k and C in the Taylor tool-life equation for the observations presented in the example given in table F.2.

Solution:

A simple graph of tool life against cutting speed is made on log-log paper as indicated in figure F.2. The graph shows that there is good reason to assume that the tool life follows the Taylor equation. Thus, it is reasonable to compute the constants k and C by means of regression analysis.

The calculations are shown in table F.4 for the criterion $KT = 0,14$ mm. The results are shown in figure F.3.

F.4 Statistical considerations on the goodness of fit of the v_c-T_c curve

F.4.1 Dispersion

The residual variation is calculated according to

$$s_r^2 = \frac{\sum y^2 - \bar{y}\sum y - k\left(\sum xy - \frac{\sum x \cdot \sum y}{n}\right)}{n-2}$$

For the computation, the computation schedules shown in tables F.1 and F.2 are used. Begin with the computation of the square sum $\sum y^2$ in table F.1. Transfer this square sum from table F.1 to part 1 of table F.2, as well as $\bar{y}$, $\sum y$, κ, $\sum xy$, $\sum x \cdot \sum y / n$. Continue with computation of s_r^2 according to the formula given in part 1 of table F.2.

F.4.2 Significance

Calculations

For the calculations, use the computing scheme shown in table F.2. The following have to be calculated:

a) The mean square sum due to deviation from the regression line (= residual variation) as described in F.4.1 (use part 1 of table F.2.)

b) The mean square sum due to variation explained by regression

$$s_R^2 = k\left(\sum xy - \sum x \cdot \sum y / n\right)$$

This quantity has already been calculated as a partial result in part 1 of table F.2.

c) The ratio s_R^2 / s_r^2

Choose the confidence level necessary (for example 90 %) and read from Fischer's F-table the F-value for the number of degrees of freedom (d.f.) equal to 1 and $n - 2$. The ratio s_R^2 / s_r^2 should be greater than the F-value in the F-table. If this is not the case, the observed relationship should be regarded as a chance result.

F.5 Confidence interval limits for the v_c-T_c curve

F.5.1 Confidence interval limits for the complete line

Calculations

Use the computation schedule shown in table F.3. Proceed as follows:

a) Write in the head of table F.3 the quantities obtained in tables F.1 and F.2. Choose the desired level of confidence. Read in Student's t-table the two-sided t-value for the number of degrees of freedom equal to $n - 2$.

b) The confidence interval for the complete line is calculated from the following formula:

$$y = \bar{y} + k(x - \bar{x}) \pm$$

$$\pm\, t s_r \sqrt{\frac{1}{n} + \frac{(x-\bar{x})^2}{\sum x^2 - \left(\sum x\right)^2 / n}}$$

The first two terms of this formula represent the regression line itself. The last term is an expression for the size of the confidence interval, that is, the complete range between the confidence limits.

Table F.3 part 2, indicates the order of the calculations required. Values for $t s_r$ (column 1) and $1/n$ (column 2) are first obtained. A series of x values is then chosen (column 3) followed by the completion of columns 4, 5 and 6.

Column 6 gives the confidence interval on either side of the regression line for the chosen confidence level.

F.5.2 Confidence intervals for the constants, a, C and k

Calculation

The confidence interval for k is obtained from

$$k_m = k \pm \frac{t s_r}{\sqrt{\sum x^2 - \left(\sum x\right)^2 / n}}$$

Table F.3 suggests a method for recording the values obtained. Input data may be obtained from part 1 of table F.3.

The confidence interval for the constant a is obtained from

$$a = \bar{y} \pm \frac{ts_r}{\sqrt{n}}$$

and a substitution in equation

$$\log C = \bar{x} - \bar{y}/k$$

Corresponding limit values for log C and finally C may be obtained. Again, table F.3 suggests a method for recording the values obtained.

EXAMPLE

Obtain a measure for the dispersion about the regression line treated in the example given in F.3.2. Also carry out a test of significance and set up confidence interval limits.

a) Dispersion

The calculations are shown in table F.5 part 1.

b) Significance

The calculations are shown in table F.5, parts 2 and 3. When the F-value is taken from the table of the F-distribution, note that the degree of freedom is $n - 2$ for the smaller sum of squares and 1 for the greater sum of squares and thus the correct F-value is taken from the $n - 2$ row and the first column.

As the variance ratio = 131 and F = 4,96, there exists a high degree of significance.

c) Confidence interval limits

1) Confidence interval limits for the line as a whole

The calculations are shown in table F.6. The results can be shown graphically. Note that if a log-log paper with scale modulus 100 mm is used, then x = 2,25 corresponds to a distance of 225,5 mm from x = 0,0 (v_c = 1 m/min). Thus, a confidence interval width of Δy = 0,082 corresponds to a distance (above or below the mean regression line) of 8,2 mm.

In figure F.3 the regression line with confidence intervals limits corresponding to a confidence level of 95 % is shown.

2) Confidence interval for k

The calculations are shown in part 3 of table F.6.

3) Confidence interval for C

In part 4 of table F.6, the minimum and the maximum values are shown.

F.6 Evaluation of tool-life tests at a single speed

Calculations

From the observed number n of T_c-values, the mean value $\bar{T}_c$ should be calculated as:

$$\bar{T}_c = \sum T_c/n = \frac{T_{c1} + T_{c2} + T_{c3} + T_{c4} + ... + T_{cn}}{n}$$

Moreover if:

a) the observations are statistically independent;

b) randomization has been carried out;

then the sample of the observed T_c-values may be regarded as drawn from a population with normally distributed T_c-values. (Sometimes a normal distribution[2)] may be obtained by taking log T_c-values instead of the T_c-values.)

The confidence interval for the calculated mean tool life $\bar{T}_c$ can be obtained from

$$T_c = \bar{T}_c \pm s\frac{t}{\sqrt{n}}$$

where s is the standard deviation of the n observed values of tool life.

$$s = \sqrt{\frac{\sum(T_c - \bar{T}_c)^2}{n - 1}}$$

and t denotes Student's t-value for $n - 1$ degrees of freedom for the desired level of confidence $1 - \alpha$ % (see table F.7).

EXAMPLE

The difference between the wear resistance of two tool materials was investigated by practical industrial tests in a machine-tool group, where three machine tools of the same model and year of manufacture were in use under identical cutting conditions.

As the material for the workpieces was delivered from more than one stock, it was decided to divide the material up into 20 lots. The order of the machining of each lot was determined by means of a table of random numbers. The workpieces were then machined with tool bits made of materials A and B, and the number of workpieces that could be machined by each tool edge was recorded. (The tool-life criterion was VB_B = 0,8 mm.)

2) Use a test of normality to make sure.

The following tool-life data were obtained:

Tool life (Number of workpieces for each tool edge)	Number of observed tool lives	
	Material A	Material B
14	4	
15	5	
16	6	1
17	15	6
18	10	18
19	16	20
20	18	20
21	10	14
22	8	8
23	5	8
24	2	4
25	1	2
Sum n =	100	101

Solution and discussion

The mean tool life for tool material A is

$$\bar{T}_{cA} = \frac{14 \times 4 + 15 \times 5 + 16 \times 6 + ...}{4 + 5 + 6 + ...} = 19{,}0$$

The mean tool life for tool material B is

$$\bar{T}_{cB} = 20{,}0$$

The standard deviation for material A is

$$s_A = \sqrt{\frac{4(14-19)^2 + 5(15-19)^2 + ...}{4 + 5 + 6 + ... - 1}} = 2{,}5$$

and for steel B

$$s_B = 2{,}0$$

The confidence interval for material A is (with a confidence level of 95 %)

$$T_{cA} = 19{,}0 \pm 1{,}984 \times 2{,}5/\sqrt{100} = 19{,}0 \pm 0{,}5$$

For material B the corresponding interval is

$$T_{cB} = 20{,}0 \pm 0{,}4$$

The confidence interval is less than the difference between the mean tool lives for the tested materials.

Thus, the mean tool life for material B is greater than that for material A under the test conditions. If there is no factor other than tool material that might explain the test result, it is justified to generalize that the tool material B has a greater wear resistance than material A, under conditions similar to those of the test.

However, in this case the formulation of the text of the problem indicates that there exist some factors (besides tool material) that might result in a difference in tool life in the two sets of observations. These factors are the machine tools involved, their operators and the order of testing A and B. If the influence of these factors had been controlled, for example by randomization, the above conclusion could have been drawn.

EXAMPLE

The difference in the wear resistance of two kinds of high-speed steel tool materials was investigated. For this purpose, the number of workpieces produced by one tool until tool failure occurred was recorded for a number of tools made from both kinds of high-speed steel.

All workpieces were identical and made from cold-drawn steel bars from one delivery. As there might be some influence of variation of the properties of the work material between the bars, tools were changed in a random sequence each time a workpiece was finished. All tests were carried out by the same operator on a semi-automatic lathe with a constant spindle speed.

This means that these results do not necessarily apply when cutting conditions, tool geometry or work material are changed.

In order to achieve reasonably safe production, tools made of material A should be changed after 12 products have been made. For tool material B this number is 15. Approximately 20 % of the tools will fail before this number is reached.

If tools are changed after 11 and 14 products respectively, the risk of early failure is reduced to about 10 %.

Tool material A			
Tool number	**Tool life** T_c	$T_c - \bar{T}_c$	$(T_c - \bar{T}_c)^2$
1	15	1,5	2,25
2	10	− 3,5	12,25
3	17	3,5	12,25
4	14	0,5	0,25
5	13	− 0,5	0,25
6	11	− 2,5	6,25
7	14	0,5	0,25
8	12	− 1,5	2,25
9	16	2,5	6,25
10	13	− 0,5	0,25
11	12	− 1,5	2,25
12	14	0,5	0,25
13	15	1,5	2,25
14	13	− 0,5	0,25
$n = 14$	$\sum T_c = 189$	$\sum(T_c - \bar{T}_c)^2 = 47,50$	

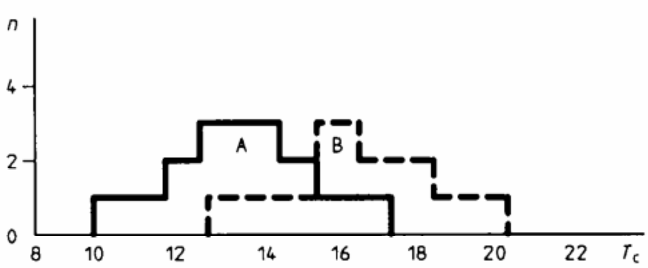
$$\bar{T}_c = \frac{\sum T_c}{n} = \frac{189}{14} = 13,5$$

$$s = \sqrt{\frac{\sum(T_c - \bar{T}_c)^2}{n-1}} = \sqrt{\frac{47,50}{13}} = 1,91$$

Tool material B			
Tool number	**Tool life** T_c	$T_c - \bar{T}_c$	$(T_c - \bar{T}_c)^2$
1	14	− 2,6	6,76
2	18	1,4	1,96
3	17	0,4	0,16
4	13	− 3,6	12,96
5	16	− 0,6	0,36
6	18	1,4	1,96
7	17	0,4	0,16
8	20	3,4	11,56
9	16	− 0,6	0,36
10	16	− 0,6	0,36
11	15	− 1,6	2,56
12	19	2,4	5,76
$n = 12$	$\sum T_c = 199$	$\sum(T_c - \bar{T}_c)^2 = 44,92$	

$$\bar{T}_c = \frac{\sum T_c}{n} = \frac{199}{12} = 16,6$$

$$s = \sqrt{\frac{\sum(T_c - \bar{T}_c)^2}{n-1}} = \sqrt{\frac{44,92}{11}} = 2,02$$



Confidence level: 95 %

Number of degrees of freedom: $n - 1$

Material A: $n - 1 = 13$, t-value $= 2,160$

Material B: $n - 1 = 11$, t-value $= 2,201$

$$T_c = \bar{T}_c \pm \frac{ts}{\sqrt{n}}$$

$$T_{cA} = 13,5 \pm \frac{2,16 \times 1,91}{\sqrt{14}} = 13,5 \pm 1,1$$

$$T_{cB} = 16,6 \pm \frac{2,2 \times 2,02}{\sqrt{12}} = 16,6 \pm 1,3$$

Difference significant Yes ☒ No ☐

As it is felt that all factors which may affect tool life were kept under a reasonable degree of control, it is justified to conclude that tool material B has a greater wear resistance than tool material A for the conditions of these tests.

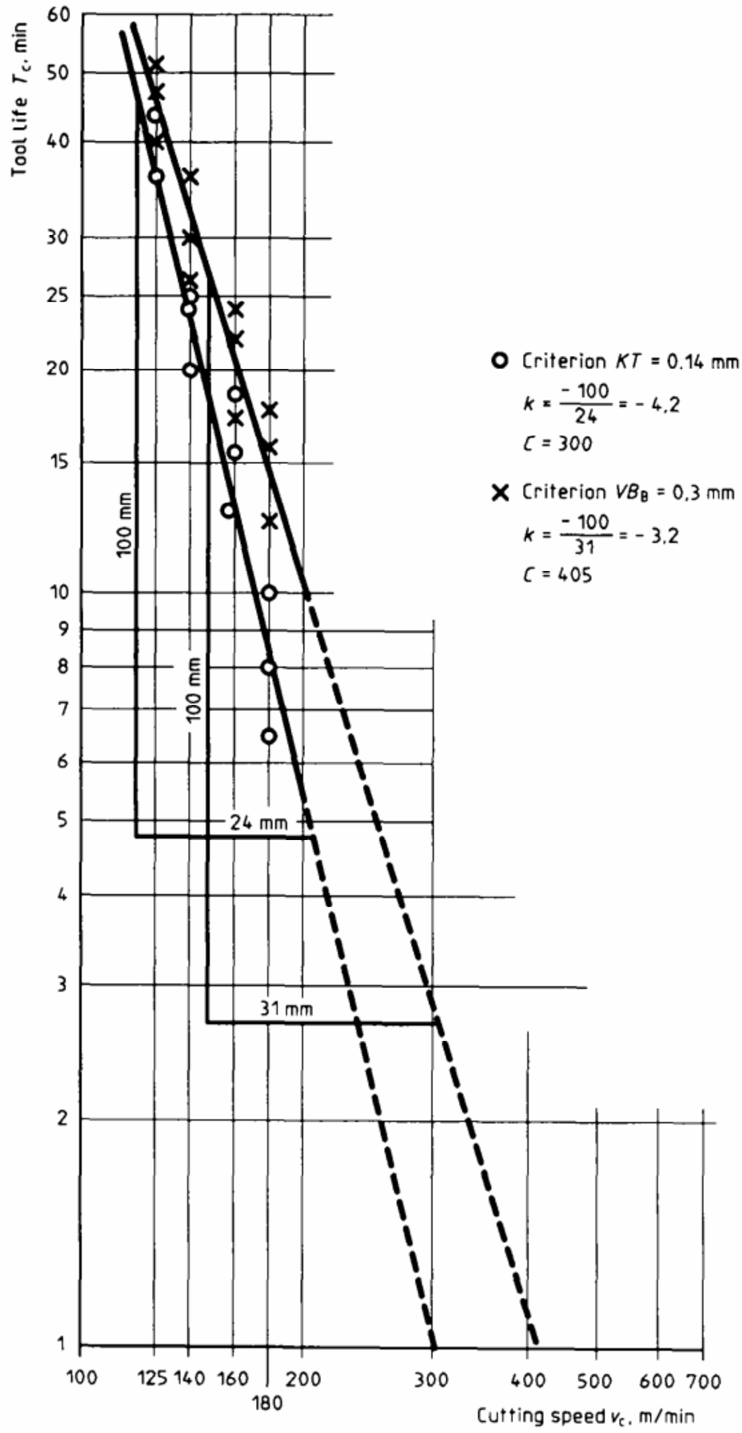
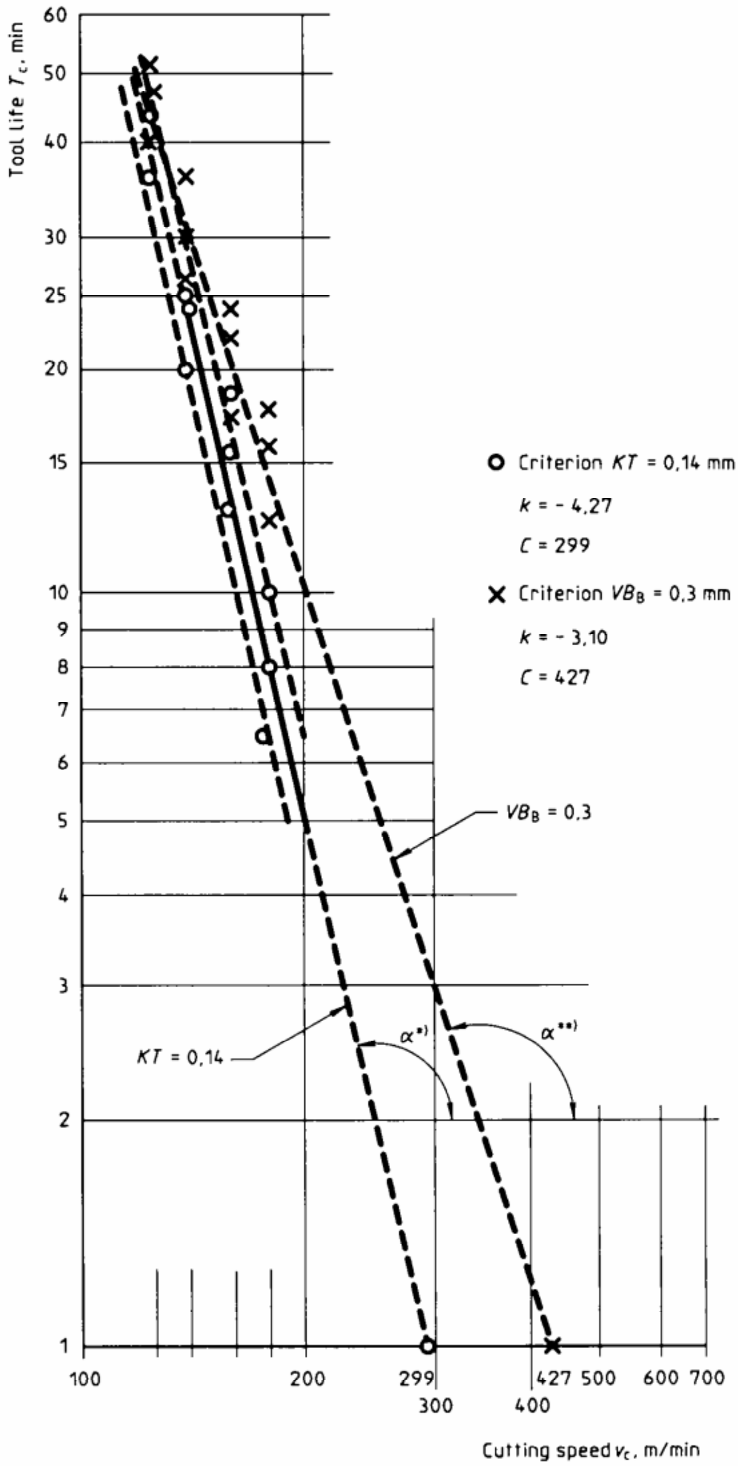


Figure F.2 — Lines fitted "by eye"



*) tg α = - 4,27
**) tg α = - 3,10

Figure F.3 — Lines with confidence interval fitted by calculation

Table F.1 — Computation schedule for calculation of regression line $y = a + k(x - \bar{x})$

1	2	3	4	5	6	7	8
Observation No.	v_c m/min	T_c min	$x = \log v_c$	$y = \log T_c$	xy	x^2	y^2
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
Sum			$\sum x =$	$\sum y =$	$\sum xy =$	$\sum x^2 =$	$\sum y^2 =$
			$\left(\sum x\right)^2 =$	$\sum x \cdot \sum y =$			
			$\left(\sum x\right)^2 / n =$	$\sum x \cdot \sum y / n =$			

Number of observations $n =$

$$\bar{x} = \sum x / n =$$

$$a = \bar{y} = \sum y / n =$$

$$k = \frac{\sum xy - \sum x \cdot \sum y / n}{\sum x^2 - \left(\sum x\right)^2 / n} =$$

$$= \frac{\quad - \quad}{\quad - \quad} =$$

$$= \frac{\quad}{\quad} =$$

$k = -$
$-1/k =$

$$\log \ C = \bar{x} - \bar{y}/k =$$

$$= \quad + \quad =$$

$C =$	(m/min)

Table F.2 — Computation schedule for assessment of dispersion and significance

Part 1: Mean-square sum due to deviation from the regression line (residual variation)

Read from table F.1

$\sum y^2$ =

$\bar{y}$ =

$\sum y$ =

k =

$\sum xy$ =

$\sum x \cdot \sum y / n$ =

Compute $\sum xy - \sum x \cdot \sum y / n =$

Compute residual variation

$$s_r^2 = \frac{\sum y^2 - \bar{y}\sum y - k\left(\sum xy - \sum x \cdot \sum y / n\right)}{n-2} = \frac{\qquad}{\qquad} = \frac{\qquad}{\qquad} =$$

Part 2: Mean-square sum due to variation explained by regression (explained variation)

Read from part 1

$$s_R^2 = k\left(\sum xy - \sum x \cdot \sum y / n\right) =$$

Part 3: Calculation of variance ratio and comparison with *F*-value

Source of variation	**Degrees of freedom** (d.f.)	**Mean-square sum**	**Ratio**
Regression	1	$s_R^2 =$	$\frac{s_R^2}{s_r^2} = \frac{\qquad}{\qquad} =$
Residuals	$n-2=$	$s_r^2 =$	

Confidence level: %

Read *F*-value from Fisher's *F*-table for d.f. = 1, $n-2$ =

Significant Yes ☐ No ☐

Table F.3 — Computation schedule for calculation of confidence intervals

Part 1: Input data

Read from table F.1	Read from part 1 of table F.2
$n =$ $\bar{x} =$ $\sum x^2 - \left(\sum x\right)^2 / n =$ $a =$ $k =$	$s_r^2 =$ Calculate $s_r =$
Confidence level % t-value for d.f. $= n - 2$:	

Part 2: Confidence interval length (besides mean value y)

1	2	3	4	5	6
ts_r	$\frac{1}{n}$	x	$x - \bar{x}$	$(x-\bar{x})^2 / \left(\sum x^2 - \left(\sum x\right)^2 / n\right)$	$\Delta y = ts_r \sqrt{\frac{1}{n} + \frac{(x-\bar{x})^2}{\sum x^2 - \left(\sum x\right)^2 / n}}$

Part 3: Confidence interval for k

$k_m = k \pm ts_r / \sqrt{\sum x^2 - \left(\sum x\right)^2 / n} =$

	$k_{min} =$	$k_{max} =$
$k_m =$	$(-1/k)_{min} =$	$(-1/k)_{max} =$

Part 4: Confidence interval for a and C

$a = \bar{y} \pm ts_r / \sqrt{n} =$

$a =$	$a_{min} =$	$a_{max} =$

$(\log C)_{min} = \bar{x} - \bar{y}/k_{min} =$ $=$ $C_{min} =$

$(\log C)_{max} = \bar{x} - \bar{y}/k_{max} =$ $=$ $C_{max} =$

EXAMPLES (see tables F.4 to F.6)

NOTE 8 The results of the calculations in tables F.4 to F.6 depend on the number of decimal places used and the rounding scheme used for the values. It is therefore important to note that the values and results given in these tables are only examples and are not based on the values given to three decimal places in columns 4 to 8 of table F.4.

Table F.4 — Example of calculation of regression line $y = a + k(x - \bar{x})$

1	2	3	4	5	6	7	8
Observation No.	v_c m/min	T_c min	$x = \log v_c$	$y = \log T_c$	xy	x^2	y^2
1	180	10	2,255	1,000	2,255	5,085	1,000
2	160	18,5	2,204	1,267	2,792	4,858	1,605
3	140	24	2,146	1,380	2,961	4,605	1,904
4	140	20	2,146	1,301	2,792	4,605	1,693
5	125	36	2,097	1,556	3,263	4,397	2,421
6	160	13	2,204	1,114	2,455	4,858	1,241
7	125	44	2,097	1,643	3,445	4,397	2,699
8	180	8	2,255	0,903	2,036	5,085	0,815
9	160	15,5	2,204	1,190	2,623	4,858	1,416
10	125	40	2,097	1,602	3,359	4,397	2,566
11	140	25	2,146	1,398	3,000	4,605	1,954
12	180	6,5	2,255	0,813	1,833	5,085	0,661
13							
14							
15							
Sum			$\sum x = 26{,}107\ 3$	$\sum y = 15{,}168\ 4$	$\sum xy = 32{,}820\ 6$	$\sum x^2 = 56{,}841\ 89$	$\sum y^2 = 19{,}981\ 39$
			$\left(\sum x\right)^2 = 681{,}590\ 7$	$\sum x \cdot \sum y = 396{,}007\ 2$			
			$\left(\sum x\right)^2 / n = 56{,}799\ 2$	$\sum x \cdot \sum y / n = 33{,}000\ 6$			

Criterion $KT = 0{,}14$ mm

Number of observations $n = 12$

$$\bar{x} = \sum x / n = 2{,}175\ 61$$

$$a = \bar{y} = \sum y / n = 1{,}264\ 03$$

$$k = \frac{\sum xy - \sum x \cdot \sum y / n}{\sum x^2 - \left(\sum x\right)^2 / n} = -4{,}216\ 4$$

$k = -4{,}216\ 4$
$-1/k = 0{,}237\ 2$

$$\log C = \bar{x} - \bar{y}/k = 2{,}475\ 4$$

$C = 298{,}9$ (m/min)

Table F.5 — Example of assessment of dispersion and significance

Part 1: Mean-square sum due to deviation from the regression line (residual variation)

Read from table F.4

$\sum y^2 = 19{,}981\ 39$

$\bar{y} = 1{,}264\ 03$

$\sum y = 15{,}168\ 4$

$k = -4{,}216\ 4$

$\sum xy = 32{,}820\ 6$

$\sum x \cdot \sum y / n = 32{,}000\ 6$

Compute $\sum xy - \sum x \cdot \sum y / n = -0{,}180$

Compute residual variation

$$s_r^2 = \frac{\sum y^2 - \bar{y}\sum y - k\left(\sum xy - \sum x \cdot \sum y / n\right)}{n-2} = 0{,}004\ 96$$

Part 2: Mean-square sum due to variation explained by regression (explained variation)

Read from part 1

$$s_R^2 = k\left(\sum xy - \sum x \cdot \sum y / n\right) = 0{,}763\ 5$$

Part 3: Calculation of variance ratio and comparison with F-value

Source of variation	**Degrees of freedom** (d.f.)	**Mean-square sum**	**Ratio**
Regression	1	$s_R^2 = 0{,}763\ 5$	$\frac{s_R^2}{s_r^2} = 153{,}93$
Residuals	$n - 2 = 10$	$s_r^2 = 0{,}004\ 96$	

Confidence level: 95 %

Read F-value from Fisher's F-table for d.f. = 1, $n - 2 = 10$:4,96

Significant Yes ☒ No ☐

Table F.6 — Example of calculation of confidence intervals

Part 1: Input data

Read from table F.4 $n = 12$ $\bar{x} = 2{,}175\ 61$ $\sum x^2 - \left(\sum x\right)^2/n = 0{,}042\ 69$ $a = 1{,}264$ $k = -4{,}216\ 4$	Read from part 1 of table F.5 $s_r^2 = 0{,}004\ 86$ Calculate $s_r = 0{,}069\ 71$
Confidence level 95 % t-value for d.f. $= n - 2$: 2,23	

Part 2: Confidence interval length (besides mean value y)

1	2	3	4	5	6
ts_r	$\frac{1}{n}$	x	$x - \bar{x}$	$(x-\bar{x})^2/\left(\sum x^2 - \left(\sum x\right)^2/n\right)$	$\Delta y = ts_r \sqrt{\frac{1}{n} + \frac{(x-\bar{x})^2}{\sum x^2 - \left(\sum x\right)^2/n}}$
0,155 5	0,083 3	2,255 3	0,079 69	0,150 87	0,075 2
		2,204 1	0,028 49	0,188 86	0,049 8
		2,146 1	− 0,029 5	0,028 44	0,050 1
		2,069	− 0,078 7	0,147 07	0,074 6
					Average: 0,062 4

Part 3: Confidence interval for k

$$k_m = k \pm ts_r / \sqrt{\sum x^2 - \left(\sum x\right)^2/n} = -4{,}216\ 4 \pm 0{,}155\ 5/\sqrt{0{,}042\ 09}$$

	$k_{min} = -4{,}98$	$k_{max} = -3{,}46$
$k_m = -4{,}216\ 4 \pm 0{,}768$	$(-1/k)_{min} = 0{,}201$	$(-1/k)_{max} = 0{,}289$

Part 4: Confidence interval for a and C

$$a = \bar{y} \pm ts_r / \sqrt{n} = 1{,}264 \pm \frac{0{,}155\ 5}{\sqrt{12}} =$$

$a = 1{,}264 \pm 0{,}045$	$a_{min} = 1{,}219$	$a_{max} = 1{,}309$

$(\log C)_{min} = \bar{x} - \bar{y}/k_{min} = 2{,}430$ = $C_{min} = 269{,}1$

$(\log C)_{max} = \bar{x} - \bar{y}/k_{max} = 2{,}541$ = $C_{max} = 347{,}3$

Table F.7 — t-distribution for 95 % confidence level

Number of degrees of freedom	Two-sided interval t_{95}
1	12,706
2	4,303
3	3,182
4	2,776
5	2,571
6	2,447
7	2,365
8	2,306
9	2,262
10	2,228
11	2,201
12	2,179
13	2,160
14	2,145
15	2,131
16	2,120
17	2,110
18	2,101
19	2,093
20	2,086
21	2,080
22	2,074
23	2,069
24	2,064
25	2,060
26	2,056
27	2,052
28	2,048
29	2,045
30	2,042
40	2,021
60	2,000
100	1,984
120	1,980
—	1,960

Annex G
(normative)

Chip characteristics

The chip formed during a cutting process has characteristics which are related to the work material, tool material, tool geometry, condition of the cutting edges, cutting edge position and cutting data and conditions.

For any given set of conditions, the chip formation will remain unchanged unless one of the above mentioned factors changes. Observations of chip formation can therefore be a useful indicator when attempting to reproduce test conditions used in a previous test, as an indicator of changing conditions during a given tool-life test, to indicate varying stability in the cutting conditions, as an indicator of changing machinability of the workpieces or as an indicator of unexpected edge failure.

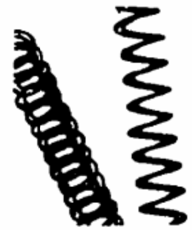
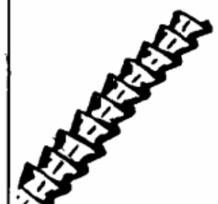
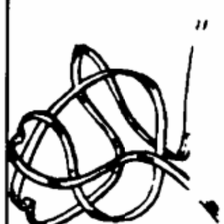
It is therefore essential to be able to report characteristics of chips and their form in a consistent manner (see "Wear versus time measurement" data sheet, annex D). Table G.1 can be used, together with information on chip cross-section and length, to define chips produced. The table also includes a numeric coding system for the more commonly observed chip types.

The basic coding system composes two digits which relate to the basic chip characteristics, i.e. 2.2 is the code to denote a short tubular chip.

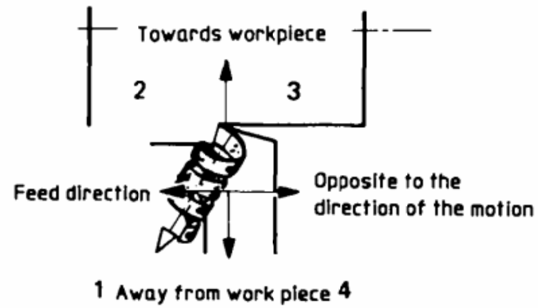
A third digit can be added to designate either the direction in which the chip flows or the mode of chip breaking, e.g. 1.3.4 would denote a "snarled ribbon chip" which flows away from the workpiece and in a direction opposite to the direction of feed motion. Code 6.1.5 would denote a "connected arc chip" which breaks against the transient surface on the workpiece.

Table G.1 is to be looked upon as an example. Regarding the fact that an almost unlimited number of various chip types can be produced, it is recommended that a classifying system is established for each actual machining process.

Table G.1 — Chip forms

1 Ribbon chips1)	2 Tubular chips1)	3 Spiral chips	4 Washer-type helical chips1)	5 Conical helical chips1)	6 Arc chips2)	7 Elemental chips	8 Needle chips
1.1 Long 	**2.1** Long 	**3.1** Flat 	**4.1** Long 	**5.1** Long 	**6.1** Connected 		
1.2 Short 	**2.2** Short 	**3.2** Conical 	**4.2** Short 	**5.2** Short 	**6.2** Loose 		
1.3 Snarled 	**2.3** Snarled 		**4.3** Snarled 	**5.3** Snarled 			

1) The direction of the chip is characterized by the third digit as follows:



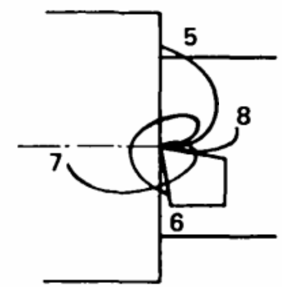
1 Away from the workpiece and in the direction of feed motion (shown in the sketch).

2 Towards the workpiece and in the direction of feed motion.

3 Towards the workpiece and opposite to the direction of feed motion.

4 Away from the workpiece and opposite to the direction of feed motion.

2) Further subdivision is characterized by the third digit as follows:



5 Broken against transient surface.

6 Broken against tool flank.

7 Broken against work surface.

8 *Broken against machined surface.*

Annex H
(informative)

Bibliography

[1] ISO 3:1973, *Preferred numbers — Series of preferred numbers.*

[2] ISO 1832:1991, *Indexable inserts for cutting tools — Designation.*

[3] ISO 3002-2:1982, *Basic quantities in cutting and grinding — Part 2: Geometry of the active part of cutting tools — General conversion formulae to relate tool and working angles.*

[4] ISO 3002-3:1984, *Basic quantities in cutting and grinding — Part 3: Geometric and kinematic quantities in cutting.*

[5] ISO 3002-4:1984, *Basic quantities in cutting and grinding — Part 4: Forces, energy, power.*

[6] ISO 3534-1:1993, *Statistics — Vocabulary and symbols — Part 1: Probability and general statistical terms.*

[7] ISO 3534-2:1993, *Statistics — Vocabulary and symbols — Part 2: Statistical quality control.*

[8] ISO 3534-3:1985, *Statistics — Vocabulary and symbols — Part 3: Design of experiments.*

[9] ISO 8688-1:1989, *Tool life testing in milling — Part 1: Face milling.*

[10] ISO 8688-2:1989, *Tool life testing in milling — Part 2: End milling.*

[11] HALD, A. *Statistical theory with engineering applications*. London, 1957.

[12] LESLIE, R.T. and LORENZ, G. *Tool life exponents in the light of regression analysis.* National Standards Laboratory. Technical Paper No. 20, CSIRO, Australia, 1964.

[13] NATRELLA, G. *Experimental statistics.* NBS Handbook 91, Washington, 1966.

UDC 621.941.025:620.178.3

Descriptors: tools, cutting tools, lathe tools, life (durability), wear, tests, cut tests, wear tests, testing conditions, reference materials, test results, technical data sheets.

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