INTERNATIONAL STANDARD

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Tool life testing in milling —

Part 2 :
End milling

Essai de durée de vie des outils de fraisage —

Partie 2 : Fraisage combiné

Reference number
ISO 8688-2 : 1989 (E)

Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 8668-2 was prepared by Technical Committee ISO/TC 29, *Small tools.*

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

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Annexes

Tool life testing in milling —

Part 2 : End milling

0 Introduction

Procedures and conditions for tool-life testing with single-point turning tools are the subject of ISO 3685. Successful application of ISO 3685 resulted in requests for similar documents relating to other commonly used cutting methods.

This part of ISO 8688 has been developed on the initiative of the International Institution for Production Engineering Research (CIRP) and applies to end milling operations with high-speed steel tools, as illustrated in figures 1, 2 and 3, which represent a major manufacturing activity.

The recommendations contained in this part of ISO 8688 are applicable in both laboratories and factories. They are intended to unify procedures in order to increase the reliability and comparability of test results when making comparison of cutting tools, work materials, cutting parameters or cutting fluids. In order to achieve as far as possible 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 establishing recommendable 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 part of ISO 8688 have been designed for end milling tests using steel and cast iron workpieces of normal microstructure. However, with suitable modifications, this part of ISO 8688 can be applied to end milling tests on, for example, other work materials or with cutting tools developed for specific applications.

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

NOTE — This part of ISO 8688 does not constitute acceptance tests and should not be used as such.

1 Scope and field of application

This part of ISO 8688 specifies recommended procedures for tool-life testing with high-speed steel tools used for end milling of steel and cast iron workpieces. It can be applied to laboratory as well as to production practice.

This part of ISO 8688 establishes specifications for three types of end milling tests as follows :

a) slot milling (see figure 1);

b) end milling in which the tool periphery is used predominantly (see figure 2);

c) end milling in which the end teeth of the tool are used predominantly (see figure 3).

The cutting conditions in end milling may be considered under two categories as follows :

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 part of ISO 8688 considers only those recommendations concerned with testing which results predominantly in tool wear.

Testing for the second group of conditions given above is currently under study.

For each of these test types, recommendations are made concerning the following : workpiece, tool, cutting fluid, cutting conditions, equipment, assessment of tool deterioration and tool life, test procedures, recording, evaluation and presentation of results.

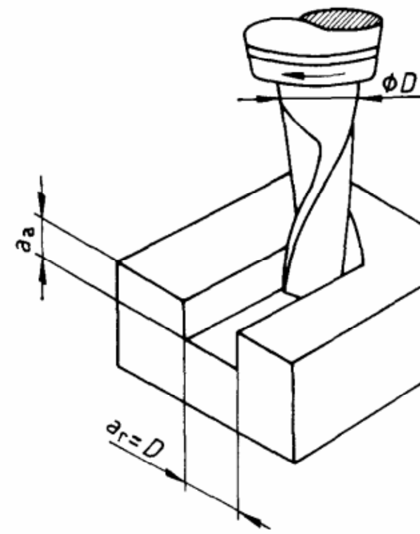
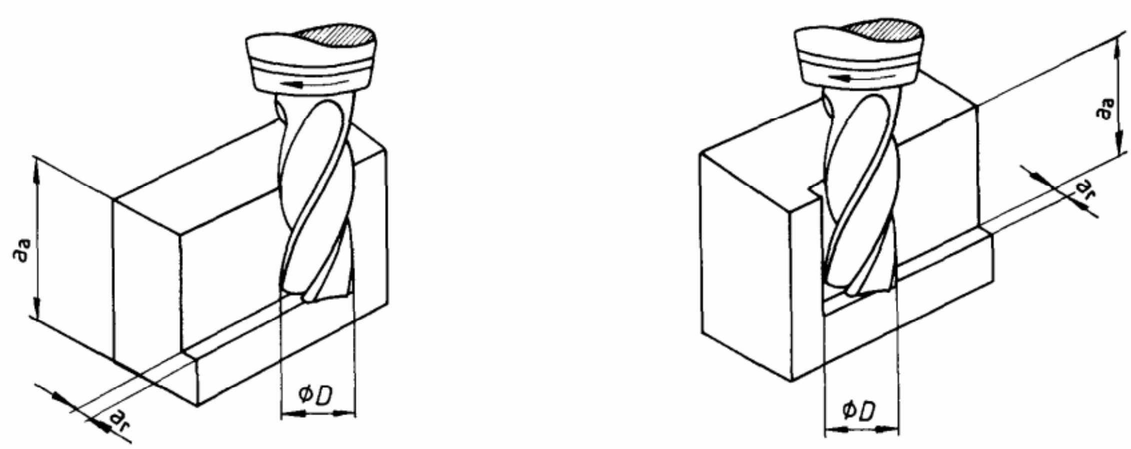


Figure 1 — Slot milling



a) Up milling

b) Down milling

Figure 2 — End milling ($a_a > a_r$)

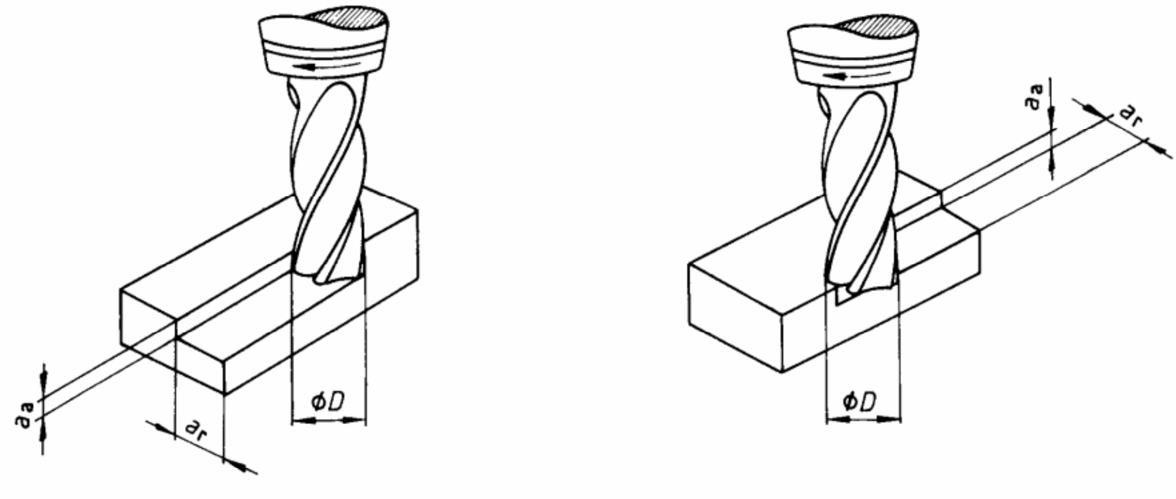


Figure 3 — End milling ($a_a < a_r$)

2 References

ISO/R 185, *Classification of grey cast iron.*

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

ISO/R 683-3, *Heat-treated steels, alloy steels and free-cutting steels — Part 3 : Wrought quenched and tempered unalloyed steels with controlled sulphur content.*

ISO 1641-1, *End mills and slot drills — Part 1 : Milling cutters with parallel shanks.*

ISO 1701, *Test conditions for milling machines with table of variable height, with horizontal or vertical spindle — Testing of the accuracy.*

ISO 2854, *Statistical interpretation of data — Techniques of estimation and tests relating to means and variances.*

ISO 3002-1, *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 3685, *Tool-life testing with single-point turning tools.*

ISO 4957, *Tool steels.*

ISO 5414-1, *Tool chucks (end mill holders) with clamp screws for flatted parallel shank tools — Part 1 : Dimensions of the driving system of tool shanks.*

ISO 5414-2, *Tool chucks (end mill holders) with clamp screws for flatted parallel shank tools — Part 2 : Connecting dimensions of chucks.*

3 Workpiece

3.1 Work material

In principle, testing bodies are free to select the work 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, steel C45 according to ISO/R 683-3 or cast iron grade 25 according to ISO/R 185, is recommended. More detailed specifications of these materials are given in annex A.

Within the specification, materials may vary with a resulting affect on machinability. To minimize such problems, the provision of a work material in compliance with stricter specifications shall be discussed with the supplier.

Information concerning the work material such as grade, chemical composition, physical properties, microstructure, complete details of the processing route of the work material (e.g. hot rolled, forged, cast or cold drawn) and any heat treatment should be reported in the test report (see 9.3.1 and annex A).

The hardness of the prepared workpiece shall be determined on one end of each test piece over the testing zone on the cross-section (see 9.3.1). For the recommended workpiece sections, the hardness indentations shall be placed along the centre-line of the zone parallel to the longest edge. The minimum number of test points shall be five; one on the centre, one near each edge and one on either side of the centre point between the centre and the edge points (see figure 4).

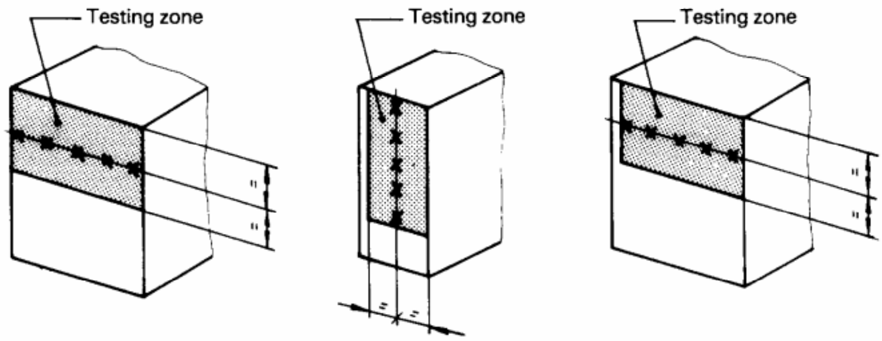


Figure 4 — Hardness testing

For workpieces which are cut from larger billets or for which hardness variation might be expected to be significant, additional hardness measurements should be taken to ascertain that the hardness values fall within the prescribed limits. The location of such measurement points and the method of measuring should be reported in the test report.

The deviation in hardness within one batch of material should be as small as possible. A realistic value for the reference materials given in annex A and similar materials is ± 5 % of the arithmetic mean value.

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 materials to cover their needs.

3.2 Dimensions

3.2.1 The recommended workpiece for end milling (see 9.3.1) shall be a bar or billet of rectangular cross-section with a minimum width of 2 times the cutter diameter (50 mm min. for D = 25 mm) and a minimum length of 10 times the cutter diameter (250 mm min. for D = 25 mm) but preferably with a recommended length of 20 times the cutter diameter. The actual length should be reported.

The maximum and minimum values of height and width may be determined according to the number of tests to be made and the need for uniform material properties. These dimensions should be restricted to ensure adequate stability during machining. The actual dimensions shall be reported.

3.2.2 For cast material, the dimensions of the parallelepiped shall be chosen to obtain the required metallographic structure.

4 Tool : Cutter

In principle, testing bodies are free to select the cutter according to their own interests. However, in order to increase the comparability of results between testing bodies, the use of a slot drill 25 mm in diameter is recommended for slot cutting tests (see figure 1) and a four-fluted end mill 25 mm in diameter is recommended for end milling tests (see figures 2 and 3).

Any deviation from the recommended cutter should be reported.

4.1 Dimensions and tolerances

The dimensions of the recommended cutter shall be in accordance with ISO 1641-1. The main dimensions of the recommended cutter are given in figures 5 and 6.

The deviation between individual tools used in the same testing sequence should be kept to a minimum (see 4.2 and 9.3).

4.2 Tool geometry

4.2.1 It is recommended that all cutting tests in which the tool geometry is not the test variable be conducted using the cutting tool geometry given in table 1.

The cutting tool angular geometry designations are in accordance with ISO 3002-1 (see figure 7).

The deviation between individual tools used in the same testing sequence should be kept to a minimum. This means that smaller tolerances than those given in table 1 are recommended. This applies especially to the primary clearance angle α_{o1}.

The provision of tools with closer geometrical tolerances should be discussed with the supplier.

4.2.2 In cutting tests, in which the tool geometry is the test variable, all the tools shall be manufactured together in the same batch of steel from the same charge (heat) and using the same heat treatment.

The deviation between individual tools used in the same test sequence should be kept to a minimum.

The provision of tools fulfilling this demand should be discussed with the supplier.

4.3 Tool conditions

In order to avoid regrinding problems it is recommended to use new tools only. However, if the effects of regrinding are being investigated, the diameter of the tool should not be reduced below 90 % of the original tool diameter, and for such tests the actual diameter should be reported in the test report.

The surface roughness R_a of the face of the tool shall not exceed 1,25 µm. For the flank this limit is 0,8 µm. The surface roughness R_a is measured in accordance with ISO 468.

4.4 Tool material

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 interests. However, in order to increase the comparability of results between testing bodies, the use of one of the following reference tool materials is recommended : uncoated high-speed steel, non-cobalt alloyed (S2 and S4) or cobalt alloyed (S8 and S11), in accordance with ISO 4957. Whenever possible, supplies of tools from the same batch should be requested.

The provision of a reference tool material of stricter specifications for machining tests should be discussed with the supplier in order to guarantee as much uniformity of the tool as is practical (see 4.2.2). These reference tool materials should not have any coating or surface treatment.

If the tool material is the test variable, the material classification and as many characteristics as possible shall be reported.

The presence of any coating or surface treatment shall be reported in detail.

4.5 Mounting of the tool

The end mill or slot dril shall be mounted in a chuck with dimensions in accordance with ISO 5414-1 and ISO 5414-2. The cutter shall be securely fastened in the chuck and the runout of the cutter shall be carefully checked at the cutting edges (on the mounted tool). The maximum value of the runout at any point at the cutting edges shall not exceed the following values :

— radial runout : 50 µm

— axial runout : 30 µm

The values of runout specified above can be achieved using standard tools and chucks mounted on conventional machines.

For testing conditions, using the lower value of feed per tooth (see tables 2 and 3), efforts should be made to select tools and chucks to minimize the actual values of runout. The actual runout shall be measured and recorded.

Dimensions in millimetres

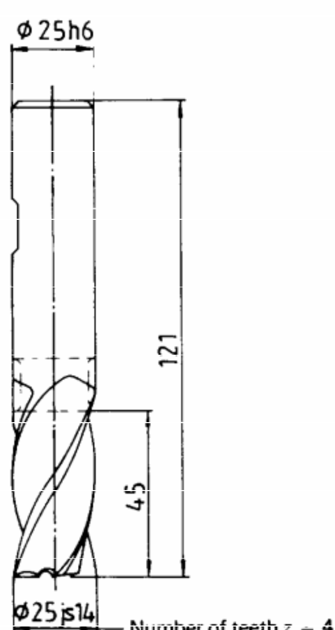


Figure 5 — End mill
(see ISO 1641-1)

Dimensions in millimetres

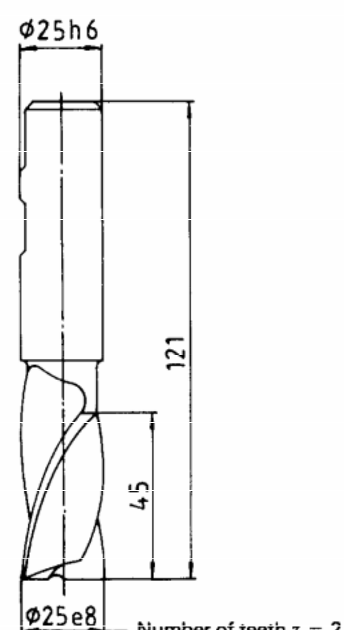


Figure 6 — Slot drill
(see ISO 1641-1)

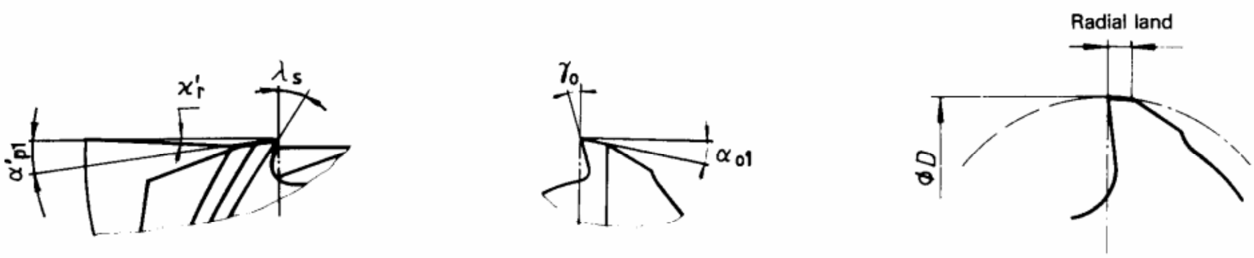


Figure 7 — Tool geometry

Table 1 — Tool geometry and tolerances for end mills and slot drills

Symbol	Terminology according to ISO 3002-1	Terminology in common use	Geometry and tolerances	
			End mills	Slot drills
λ_s	Tool cutting edge inclination	Helix angle	30° ± 2°	30° ± 2°
$\varkappa'_r$	Tool minor cutting edge angle	Minor cutting edge angle	1° ± 0,5°	1° ± 0,5°
γ_o	Tool orthogonal rake	Radial rake angle	12° ± 3°	12° ± 3°
α_{o1}	Tool orthogonal clearance, first flank	Primary clearance angle, face cutting edge	8° ± 2°	8° ± 2°
α'_{p1}	Tool minor cutting edge back clearance, first minor flank	Primary clearance angle, end cutting edge	7° ± 1°	7° ± 1°
		Radial land, mm	—	0,2 max.
		Radial runout, µm	18	8
		Axial runout, µm	18	18
		Corner chamfer (45°) or radius, mm	0,3 ± 0,1	0,12 ± 0,03

5 Cutting fluid

Cutting fluid shall be used when cutting steel. When cutting cast iron, the use of cutting fluid is not recommended. The cutting fluid shall be clearly specified. This specification should include, for example, the trade-mark or composition of the active elements, the actual concentration, the hardness of the water (when used as a diluent), or 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, the flow-rate and the reservoir temperature should be reported.

6 Cutting conditions

The recommended cutting data (see tables 2 and 3) have been chosen and combined in order to correspond to and to emphasize the milling principles dealt with in this part of ISO 8688 (see figures 1, 2 and 3). Up milling (feed motion opposite to the peripheral movement of the tool) as well as down milling (feed motion in the same direction as the peripheral movement of the tool) are considered.

6.1 Recommended cutting conditions

The cutting conditions for all tests in which the feed per tooth f_z, the axial depth of cut a_a or the radial depth of cut a_r are not the prime test variables, shall be selected from tables 2 and 3.

Table 2 — Recommended cutting conditions for slot milling

Cutting condition		I	II
Axial depth of cut a_a	mm	12,5	20
Radial depth of cut a_r	mm	25[1)]	25[1)]
Feed f_z	mm/tooth	0,08	0,125

1) Diameter of the slot drill.

Table 3 — Recommended cutting conditions for end milling

Cutting condition		I	II	III	IV
		$a_a > a_r$ (see figure 2)		$a_a < a_r$ (see figure 3)	
Axial depth of cut a_a	mm	20	20	12,5	12,5
Radial depth of cut a_r	mm	2,5	2,5	20	20
Feed f_z	mm/tooth	0,08	0,125	0,08	0,125

The tolerance on the axial depth of cut and the radial depth of cut shall be ± 5 %.

6.2 Other cutting conditions

In cases where the feed, the axial depth of cut or the radial depth of cut are the test variables, all data shall be clearly specified. It should be noted, however, that the cutting conditions shall be chosen to be compatible with the cutting tool, the machine tool, the clamping device, etc., in order to obtain reliable test data.

In cases where the cutting conditions indicated in tables 2 or 3 cannot be achieved, other values as close as possible to those indicated may be used. Other cutting conditions should be limited to the minimum values given in table 4.

The maximum radial depths of cut a_r for end milling should be limited to $0{,}8D$[1)].

Table 4 — Minimum limits of cutting conditions

Cutting condition		Slot milling	End milling
Minimum feed per tooth f_z	mm	0,05	0,05
Minimum axial depth of cut a_a	mm	2	2*
Minimum radial depth of cut a_r	mm	–	2**

* For $a_a < 0{,}25D$ the value of a_r should be at least $0{,}25D$.

** For $a_r < 0{,}25D$ the value of a_a should be at least $0{,}25D$.

6.3 Cutting speed

The cutting speed is the peripheral speed of the cutting tool determined at the nominal diameter (see figures 5 and 6). The average cutting speed should be measured with the tool under load at cutting conditions representative of the test conditions to take account of any losses resulting from the cutting action.

It is suggested that the desired cutting speed be established from a preliminary test (see 9.2). An appropriate cutting speed can be found in machining data handbooks. For the reference workpiece materials and the reference cutting tool this speed will be approximately 30 m/min for high-speed steel S2 and S4, and approximately 35 m/min for S8 and S11.

A relatively small change in cutting speed will significantly affect tool life, e.g. a change of ± 5 % may result in an approximate doubling or halving of tool life.

7 Tool deterioration and tool-life criteria

7.1 Introduction

In practical workshop situations the time at which a tool ceases to produce workpieces of the desired size or 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 the useful tool life. However, the reasons for which tools may be considered to have reached the end of their useful tool life will be different in each case depending on the cutting conditions, etc.

1) D is the diameter of the cutter (equal to 25 mm for a standard cutter, i.e. a_r max. = 20 mm).

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

In order to produce test values which are reliable and comparable with test values produced from a variety of sources, it is necessary to identify and classify tool deterioration phenomena in accordance with 7.3 and to recommend those, together with their limiting values, which should be used to determine the end of useful tool life in accordance with 7.4.

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

This part of ISO 8688 recommends that tool deterioration in the form of wear be used for determining tool life. Since other modes of tool deterioration may determine the end of useful tool life, the definitions given in 7.2 take into account cracks, chipping and deformation.

Each type of deterioration will progress or occur in a variety of ways depending on the cutting conditions. Where more than one form of deterioration becomes measurable, each should be recorded, and when any one of the deterioration phenomena limits has been attained, the end of tool life has then been reached.

The numerical value of tool deterioration used to determine tool life governs the quantity of testing material required and the costs of testing.

If the limiting value if 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 deterioration development under the test conditions.

Many types of tool deterioration phenomena are listed in this clause. Some of them may occur only occasionally under the testing conditions recommended in this part of ISO 8688.

7.2 Definitions

For the purposes of this part of ISO 8688, the following definitions apply.

7.2.1 tool deterioration : All changes in a cutting part of a tool caused by the cutting process.

Two major classes of tool deterioration are distinguished, i.e. tool wear and chipping.

7.2.1.1 tool wear : Change in shape of the cutting part of a tool from its original shape, resulting from the progressive loss of tool material during cutting.

7.2.1.2 brittle fracture (chipping) : Occurrence of cracks in the cutting part of a tool followed by the loss of small fragments of tool material, resulting from crack initiation during cutting.

7.2.2 tool deterioration measure : Quantity used to express the magnitude of a certain aspect of tool deterioration by a numerical value.

Example :

— The width of a flank wear land VB 1 (see 7.3.1.1).

7.2.3 tool-life criterion : Predetermined value of a specified tool deterioration measure or the occurrence of a specified phenomenon.

Example :

— The width of a flank wear land VB 1 = 0,3 mm (see 7.4.1).

7.2.4 tool life T_c : Total cutting time of the cutting part required to reach a specified tool-life criterion (see 7.5).

7.3 Tool deterioration phenomena

Wear on end milling cutters and slot drills is illustrated in figure 8.

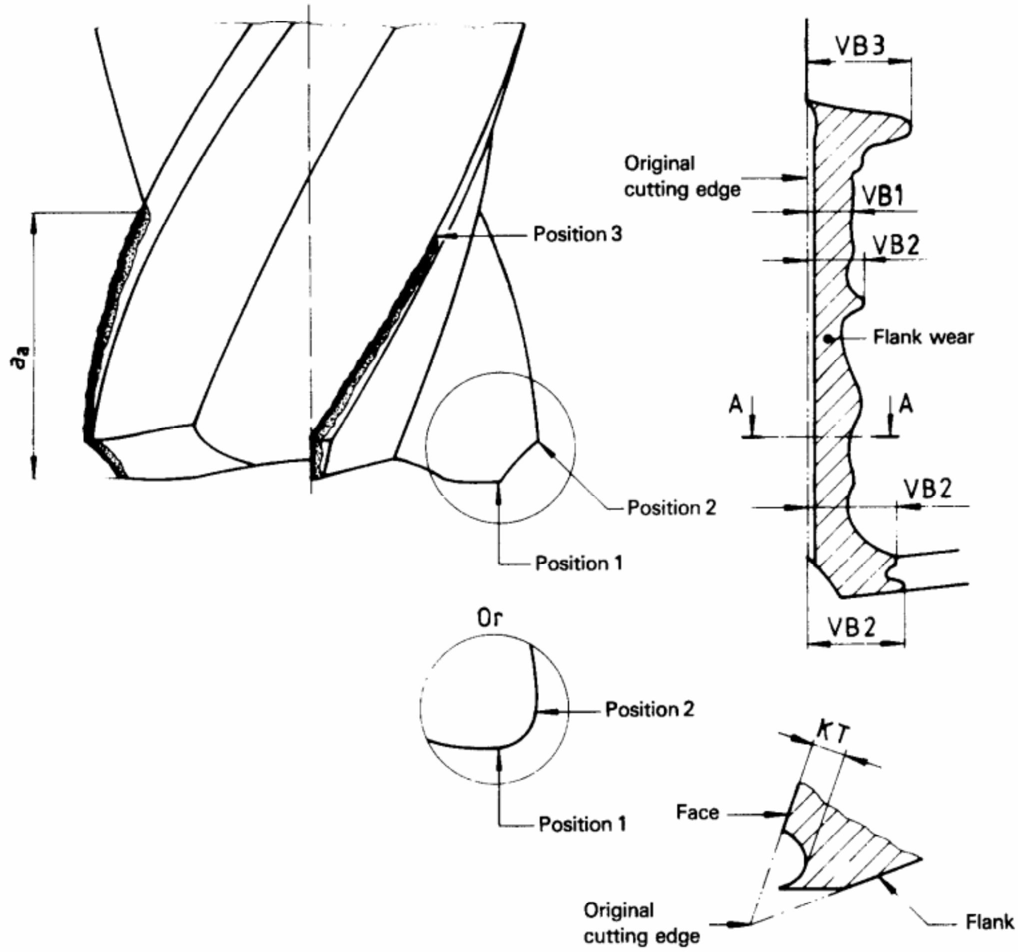
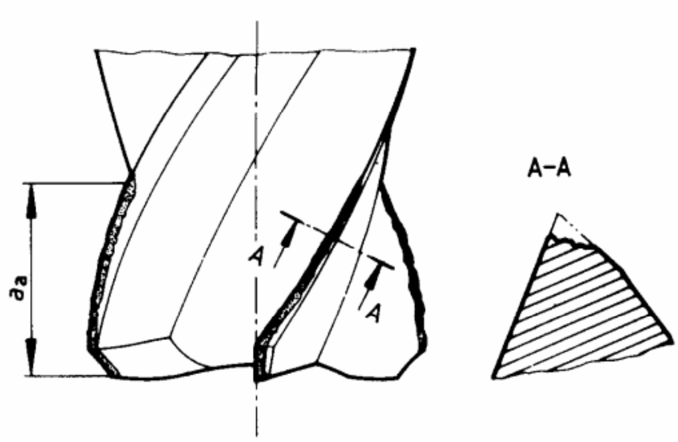


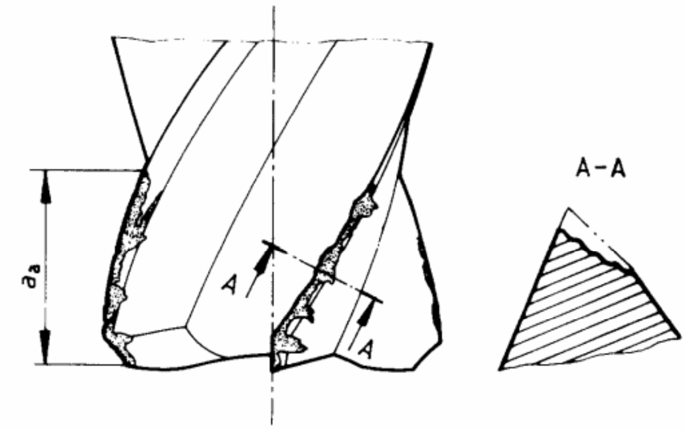
Figure 8 — Wear on end milling cutters and slot drills

7.3.1 flank wear (VB) : Loss of tool material from the tool flanks during cutting which results in the progressive development of a flank wear land.

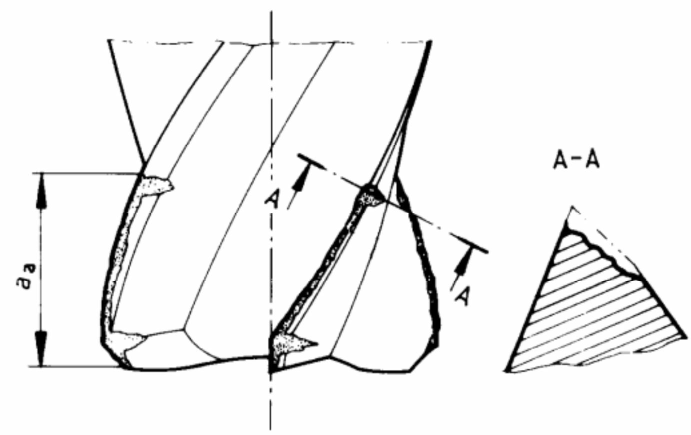
7.3.1.1 uniform flank wear (VB 1) : Wear land which is normally of constant width and extends over those portions of the tool flanks adjoining the entire length of the active cutting edge.



7.3.1.2 non-uniform flank wear (VB 2) : Wear land which has an irregular width and for which the profile generated by the intersection of the wear land and the original flank varies at each position of measurement.

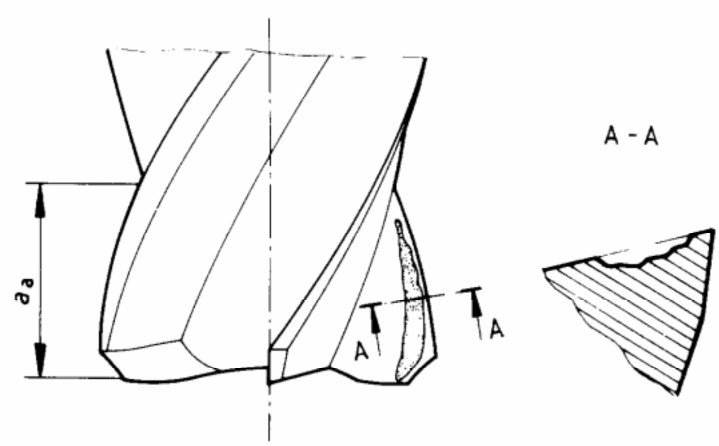


7.3.1.3 localized flank wear (VB 3) : Exaggerated and localized form of flank wear which develops at a specific part of the flank (see figure 8, positions 1, 2 or 3).

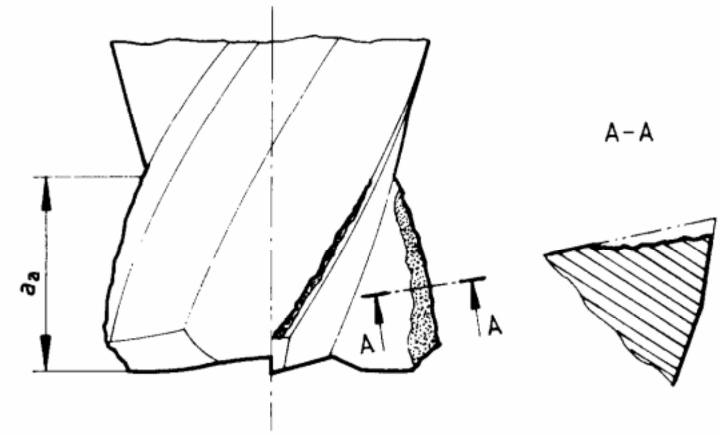


7.3.2 face wear (KT) : Gradual loss of tool material from the tool face during cutting.

7.3.2.1 crater wear (KT 1) : Progressive development of a crater oriented approximately parallel to the major cutting edge and with a maximum depth some distance away from the major cutting edge.

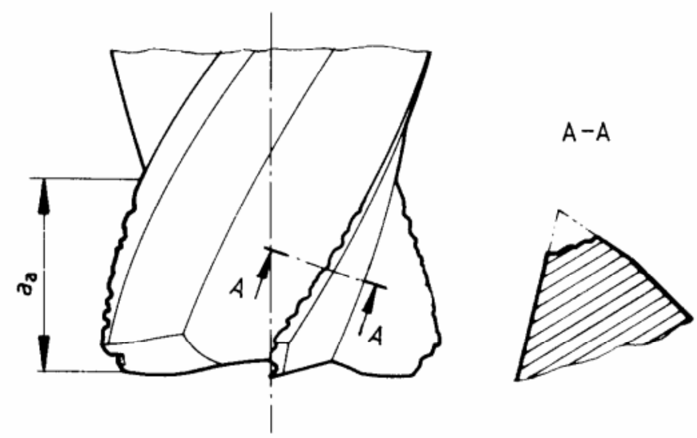


7.3.2.2 stair-formed face wear (KT 2) : Form of face wear in which the maximum depth of the wear scar, measured perpendicular to the tool face, occurs at the intersection of the wear scar with the tool major flank.

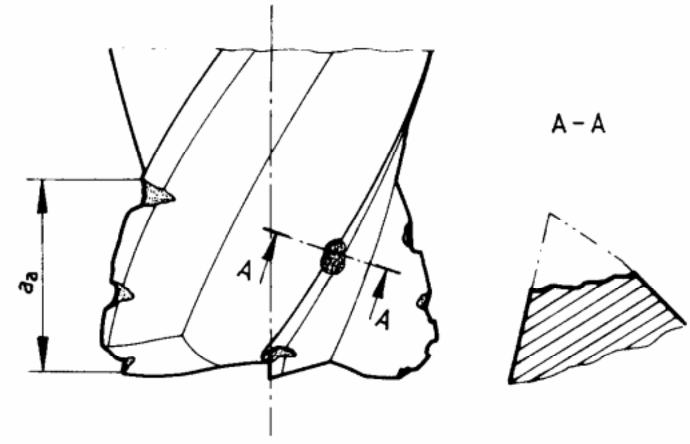


7.3.3 chipping (CH) : Edge deterioration where parts of the edge break away.

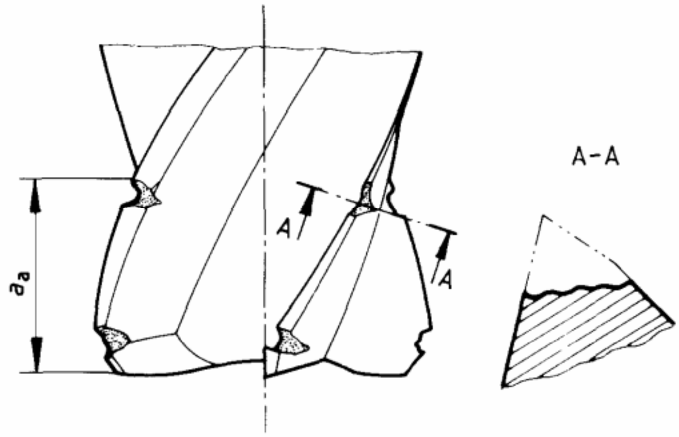
7.3.3.1 uniform chipping (CH 1) : Loss of tool fragments of approximately equal size along the cutting edges, which significantly influences the uniformity of the width of the flank wear land.



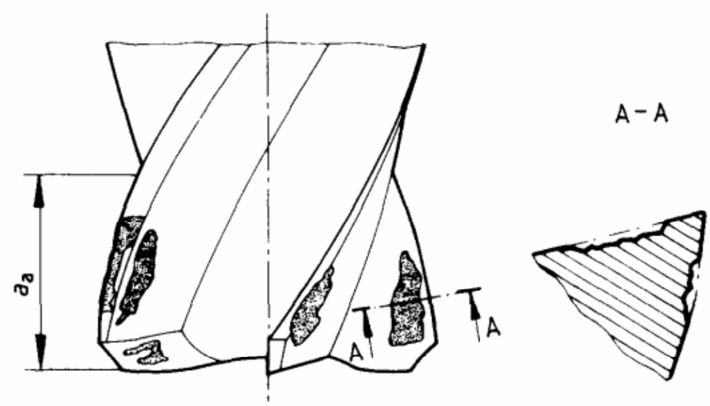
7.3.3.2 non-uniform chipping (CH 2) : Chipping which occurs mostly in connection with cracks at a small number of positions along the active cutting edges but with no consistency from one cutting edge to another.



7.3.3.3 localized chipping (CH 3) : Chipping which occurs consistently at certain positions along the active cutting edge.

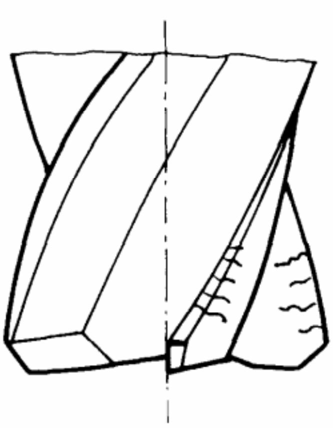


7.3.4 flaking (FL) : Loss of tool fragments in the form of flakes from the tool surfaces. This phenomenon is most frequently observed when coated tools are used but may also be observed with other tool materials.

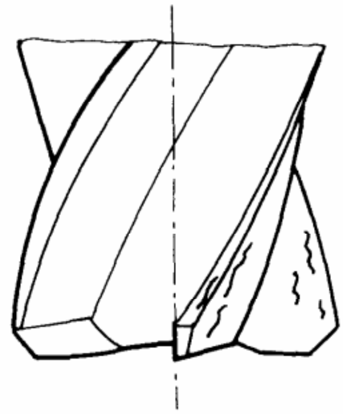


7.3.5 cracks (CR) : Fracture of the cutting tool material which does not immediately cause loss of tool material.

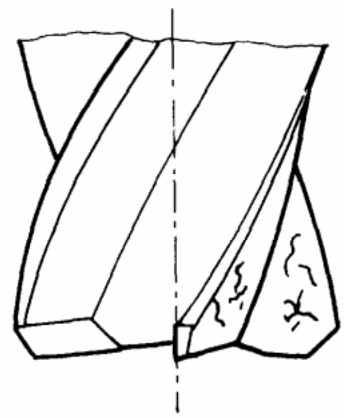
7.3.5.1 comb cracks (CR 1) : Cracks which appear on both the tool face and the tool flank and are oriented approximately perpendicular to the major cutting edge.



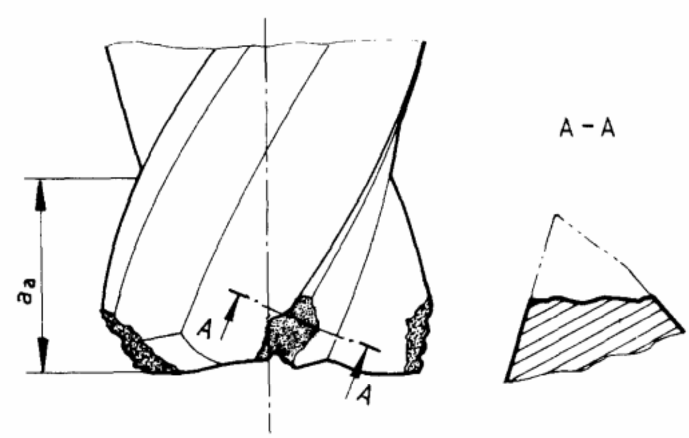
7.3.5.2 parallel cracks (CR 2) : Cracks which appear on the tool face or the tool flank and which are oriented approximately parallel to the major cutting edge.



7.3.5.3 irregular cracks (CR 3) : Cracks which sometimes appear on the tool face and on the tool flank and which are irregularly oriented.



7.3.6 catastrophic failure (CF) : Rapid deterioration to complete failure of the cutting part.



7.4 Tool deterioration phenomena used as tool-life criteria

In order to be able to determine tool life and to compare the influence of different test parameters it is necessary to select one defined type of deterioration of the cutting part as a criterion.

The tool-life criterion can be a predetermined numerical value of any type of tool deterioration which can be measured. Where more than one form of deterioration becomes measurable, each should be recorded and when any one of the deterioration phenomena limits has been attained, the end of tool life has been reached.

The type of deterioration 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. The type and value of the criterion used shall be reported.

7.4.1 Recommended tool-life criteria

Tool-life criteria which can be defined as a predetermined numerical value of specific types of tool wear are recommended.

A certain width of the flank wear land (VB) is the most commonly used criterion.

The following tool life end points are recommended :

- Uniform wear : 0,3 mm averaged over all teeth.
- Localized wear : 0,5 mm max. on any individual tooth.

NOTES

1 Often the maximum localized wear occurs at a position on the flanks adjacent to the work surface during cutting.

2 Variations in the primary clearance angle α_{01}, within the limits specified in table 1, may affect the width of the flank wear land significantly and should therefore be minimized.

7.4.2 Other tool-life criteria

In cases where none of the recommended criteria applies, it may be possible to obtain meaningful data by using one of the following criteria.

- A certain depth of the face wear (KT) is sometimes used as a criterion.
- Chipping (CH) is a criterion which may be used.
- When chipping occurs it is to be treated as localized wear using a VB 3 value equal to 0,5 mm (see figure 8) as a tool-life end point.
- Chipping (CH) in a very heavy form and flaking (FL) are forms which exceptionally could be used as criteria.

Catastrophic failure (CF) can occur inadvertently and should not be used as a primary criterion for the tool-life end point.

Cutters with small diameters (usually less than 12 mm) sometimes break owing to clogging or increasing wear of various types before wear measurements can be recorded. This type of deterioration is not recommended as a tool-life criterion.

7.5 Assessment of tool deterioration

Measurement of tool wear and brittle deterioration using appropriate equipment (see 8.2 and 9.3.5) at intervals determined by the test plan (see 9.2) should be recorded on the data sheets and plotted on diagrams (see 10.4 and annex B).

When there is evidence of built-up-edge (BUE), built-up-layer (BUL), or other debris of work material on the surface of the cutting tool, such observations should be reported since accurate measurement of the deterioration phenomena may be impeded by such deposits. Although mechanical techniques for the removal of deposits from tool surfaces are not recommended, it may be permitted to remove BUE or BUL using a soft material such as a "thumb nail", piece of plastic or wood, with a minimal risk of damaging the tool. Chemical etching may be used only when the cutting tool material is very different from the work material. If deposit removal is undertaken, the method used shall be reported in detail.

7.5.1 Measurement of flank wear (VB)

Flank wear measurement is carried out parallel to the surface of the wear land and in a direction perpendicular to the original cutting edge, e.g. the distance from the original cutting edge to that limit of the wear land which intersects the original flank. Although the flank wear land on a significant portion of the flank may be of uniform size, there will be variations in its value at other portions of the flanks depending on the tool profile and edge chipping (see 7.3). Values of flank wear measurements shall therefore be related to the area or position (see figure 8) along the cutting edges at which the measurement is made (see 7.2 and 7.3).

7.5.2 Measurement of face wear (KT)

Face wear KT 1 is evaluated by the crater depth which is measured from the original face of the tool in a direction perpendicular to the original face. Since the depth of the crater will vary along its length, the position of the depth measurement in relation to the original cutting edge should be recorded together with the position of the section considered for measurement in relation to some reference point on the tool faces (see 7.2 and 7.3.2.1).

Face wear KT 2 is measured as the distance between the worn edge and the original cutting edge in a direction perpendicular to the original face (see 7.2 and 7.3.2.2).

7.5.3 Assessment of chipping (CH)

Chipping should be measured both on the flank and on the face parallel and perpendicular to the original cutting edge. The position along the cutting edge where chipping occurs should be indicated.

7.5.4 Assessment of cracks (CR)

Cracking is evaluated by counting the cracks (observed at a magnification of 8X) and by measuring the minimum distance between two consecutive cracks. The position of the cracks should be reported.

8 Equipment

8.1 Machine tool

The milling machine on which the tests are to be conducted shall have sufficient power and physical capacity, be of stable design and be in such condition that abnormal vibrations or deflections are not observed during the test. Cutting conditions which cause chatter should not be used. However, if chatter does occur it may be reduced significantly or eliminated by a small change in cutting speed without varying other cutting parameters.

The spindle axis orientation, vertical or horizontal, shall be recorded.

The accuracy of the milling machine shall be in accordance with ISO 1701.

The feed speed under load shall be constant.

The traverse required for a test should not exceed 0,75 times the limit of motion of the axis.

8.2 Other equipment

Table 5 lists equipment which is necesary and recommended for carrying out the tests specified in this part of ISO 8688.

Table 5 — Equipment necessary for measurements in the end milling tests

Clause	Minimum equipment	Recommended equipment
3 Workpiece		
Dimensions	Graduated rule	Sliding calliper
Hardness	Hardness tester	Hardness tester
4 Cutter		
Dimensions	Sliding calliper	Micrometer, 0-25
Roughness	Roughness standard	Surface tester
Defects	Magnifier, having a minimum magnification of 8X	Toolmakers' microscope
Runout	Dial indicator	Dial indicator, graduated to 0,001 mm
Hardness		Hardness tester
5 Cutting fluid		
Concentration		Refractometer
Flow	Graduated vessel and stop-watch	Graduated vessel and stop-watch
(pH value)	1)	pH meter
(Temperature)		Thermometer
6 Cutting conditions		
Feed speed	Stop-watch	Stop-watch
Spindle speed	Tachometer	Tachometer
Depth and width of cut	Sliding calliper	Sliding calliper
7 Tool deterioration		
Flank wear, face wear, chipping and flaking	Toolmakers' microscope, dial indicator with a contact point 0,2 mm in diameter	Toolmakers' microscope, profile recorder and special device for mounting the tools under the microscope
10 Evaluation of results		Programmable calculator

1) Use freshly diluted cutting fluid.

9 Procedure

9.1 Purpose

The main purpose of the test may be the comparison (or ranking) or work materials, tool materials, tool geometries or cutting fluids. Other purposes may include the establishment of data useful for making cutting condition recommendations, the study of machining characteristics such as forces exerted on the tool, machined surface characteristics or chip form. However, for these purposes certain recommendations given in this part of ISO 8688 may have to be modified to suit the specific requirements or aims of the test. Such modifications shall be reported.

9.2 Planning

Planning of the test programme should take into consideration which of the following types of tests should be used to achieve the purpose of the test.

— Type A : One single test point for a particular combination of test variables.

This type of test is intended for the determination of, for example, differences between two or more batches of work materials, groups of tools, etc. (see 10.3.1).

— Type B : One vT curve, with the cutting speed as a variable for a particular combination of other cutting variables (see 10.3.2).

— Type C : Tool life as a function of cutting speed and feed (see 10.3.3).

— Type D : Tool life as a function of cutting speed, feed, and axial and radial depths of cut (see 10.3.3).

— Type E : Machining characteristics such as cutting forces, machined surface and chip formation.

When planning the tests outlined above, the likely scatter in test results and the need for a minimum number of tests, which may be determined from previous experience or from statistical considerations (see clause 10), should be considered.

Care should be exercised when assessing the material quantity requirements for completing the entire test programme (see tables 6 and 7). Guidance in the selection of the cutting speed range, the feed values and the desirable time intervals between successive assessments of the amount of tool deterioration, taking into account the expected progression of tool deterioration, may be obtained from preliminary tests.

Table 6 — Approximate mass of material removed for each single test run using the recommended criteria under the recommended test conditions for slot milling

Cutting condition			I	II
Axial depth of cut a_a		mm	12,5	25
Radial depth of cut a_r		mm	25	25
Feed f_z		mm/tooth	0,08	0,125
Approximate mass of material removed (to achieve recommended tool-life criterion)	speed, 30 m/min	kg/test run	7	15
	speed, 35 m/min		3	6

Table 7 — Approximate mass of material removed for each single test run using the recommended criteria under the recommended test conditions for end milling

Cutting condition			I	II	III	IV
Axal depth of cut a_a		mm	25	25	12,5	12,5
Radial depth of cut a_r		mm	2,5	2,5	20	20
Feed f_z		mm/tooth	0,08	0,125	0,08	0,125
Approximate mass of material removed (to achieve recommended tool-life criterion)	speed, 30 m/min	kg/test run	3	4	11	15
	speed, 35 m/min		2	2	4	6

9.3 Preparation of material, tools and equipment

Prior to the commencement of any single experiment constituting part of a test programme the following preparatory steps should be taken.

9.3.1 Workpiece

All types of surface scale should be machined away. Individual specimens of appropriate size should be cut from the bars or billets and clearly stamped to identify the parent bar or billet, and the position and orientation within that bar or billet originally occupied by the specimen.

Visual inspection and hardness tests should be carried out on each test piece and details recorded before commencing the cutting test (see 3.1). Where a specimen has been used previously, the machined surface generated under the test conditions may have to be considered as "scale" and removed by clean-up cuts with a fresh tool before a new experiment is started.

9.3.2 Tool geometry and cutting edges

Tool geometry should be inspected and recorded (see 4.2, 4.3 and 7.4.1). The cutting edges should be marked, inspected and compared with recommended cutting edge conditions at a minimum magnification of 8X and checked for cutting defects such as burn marks, chipping and cracking. The cutting edges shall have neither burrs nor feather edges. The defects shall be corrected, if possible; otherwise the tool shall not be used.

9.3.3 Tools and tool holders

The chuck should be checked for damage. The machine spindle and chuck should be cleaned immediately prior to mounting the chuck. The axial and radial runout of the tool should be measured, after it has been mounted in the chuck, using an indicator, graduated to 0,001 mm and having a flat anvil, and the values recorded for each edge. Recommended limiting values of runout are given in 4.5.

9.3.4 Machine tool

Since spindle speeds and feed speeds quoted on machine tools may be nominal values, the actual spindle speeds and feed speeds should be measured and recorded under load conditions which are representative of the test conditions. Before any testing is commenced, the machine tool should be warmed up by running the spindle for a minimum period of 30 min at a speed of 0,7 times the maximum available spindle speed or at the speed to be used in the test. At 5 min intervals during this period the feed motion should be engaged to cause an axis movement at least equal to that required for the test, in the region to be used for testing, and the axis then returned at rapid traverse.

Clamping devices should be checked to ensure the best possible workpiece stability.

9.3.5 Equipment for assessment of tool deterioration

The availability and quality of suitable equipment for measuring tool deterioration phenomena should be ensured (see 8.2). This information should be recorded on suitable data sheets (see annex B).

9.3.6 Personnel

Machine operators and other persons involved in the test programme should be adequately instructed as to the purposes of the tests and the test procedure.

9.4 Test techniques

Complete information concerning the tests should be recorded on suitable test data sheets (see annex B).

Before starting the actual tests, a check should be made to ensure that the cutting conditions have been chosen to be compatible with the cutting tools, the tool holder, the machine tool, the clamping device, etc., and that the estimated tool life will be obtained.

Tool or spindle overhang should be kept to a minimum.

Successive passes should always be made in the same feed direction and the tool should be returned to the starting point for a pass, ensuring that there is no possible contact between the cutting edges and the workpiece during the return motion.

Successive cuts in the same slot, in the axial direction of the tool, should not be allowed and for slotting tests (see figure 1) the slot should not be allowed to break out from the workpiece.

The walls between slots shall have a thickness equal to a quarter of the depth of cut and shall be not less than 3 mm.

The length of the pass is considered to be equal to the length of the workpiece or, if this is not relevant, the cut length corresponding to the feeding distance with the tool in full engagement with the workpiece.

Prior to commencing a new test run, the workpiece shall be "cleaned up" using a fresh tool (see 9.3.1).

9.5 Measurements and recording of tool deterioration

At time intervals determined by the test plan all edges should be examined. Measurements of tool deterioration should be carried out and the observations recorded on the data sheets together with details of any deterioration (see annex B).

These measurements should be made with the tool mounted in the machine (see 7.1 and 7.2). The measurements should be made on the most deteriorated edge. It may be acceptable to measure the cutter after removal from the machine tool spindle, provided that the cutter can be reinserted in the spindle and realigned in the same position after measurement.

The tool deterioration measurement values should be treated in accordance with clause 10.

10 Evaluation of results

10.1 General considerations

The evaluation of deterioration test results from end milling with multitoothed tools should be undertaken using the following guidelines.

— The aim of the test shall be established in accordance with clause 0 or 9.1.

— The test results should be obtained from a properly planned test programme (see 9.2).

— The principles for test techniques should be applied (see 9.4).

10.2 Treatment of test values/observations

The individual edges of the same tool used in a given test run are not independent of each other. Consequently, the test values from measurements or other observations of tool deterioration on individual edges shall be regarded together as the result of a specified test run with one tool.

In tests where a specific type of deterioration is expected and measured or studied (see 7.3 to 7.5) any early or sudden occurrence of an unexpected deterioration phenomenon shall be carefully observed and recorded. If this unexpected deterioration is likely to have an influence on the test results, the test run shall be disregarded in the calculations of the total result.

Unexpected and very serious deteriorations should normally cause a rejection of the test run. The reasons shall be investigated. In the case of repeated failure, a change of the test conditions shall be considered.

10.3 Number of test runs

Regardless of the purpose of the test or the type of test undertaken (see 9.1 and 9.2) the accuracy of the results which can be achieved or might be desired is always a function of the number of test runs.

The desired accuracy of the test results shall be balanced against the limitations given by the consumption of material, tools, time and money (see 7.5).

For the study of machining characteristics such as chip formation, surface characteristics, etc. (test type E, see 9.2), one test run of limited size for each test condition will normally be sufficient.

When comparing cutting tool materials, cutting fluids, etc. (see 9.1), experienced personnel may be able to establish with sufficient accuracy the significance of differences in the test results from a very small number of test runs.

For test procedures the purpose of which is to determine the tool life, edge deterioration phenomena are measured directly (see 7.4.1 and 7.5) or indirectly by observations of surface finish, dimensions of the workpiece or other machining results.

In these cases a number of test runs for each cutting condition is recommended to give an acceptable accuracy from a practical point of view and from the basis of experience and statistical considerations.

10.3.1 Test type A

For test type A (see 9.2) a minimum of three repeated test runs is needed. However, if the differences between batches of materials, groups of tools, etc. are small, the use of the statistical methods given in annex C will show that more test runs may be needed in order to determine whether the results are significant.

10.3.2 Test type B

To plot the tool life (see clause 7) as a function of the cutting speed (vT diagram) it is necessary to have at least five data points corresponding to five cutting speed values (see figure 9).

Starting with a cutting speed giving a tool life of not less than 5 min, the cutting speed should be decreased for each data point, if possible using a constant ratio such that the maximum tool life during testing is not less than 25 min.

A tool life of less than 5 min will be unreliable. However, a tool life in excess of 25 min may be costly in terms of material and time.

The actual cutting speeds used depend on the speeds available on the machine tool and the requirement for stable cutting, and they should be reported.

Two or more types of deterioration may occur in the same test. If it is not clear which type of deterioration will dominate, it is possible to use two (or even more) criteria (I and II in figure 10). This can be carried out in two different ways as follows.

a) Determination of the tool life for criterion I for all tests in a specific series and subsequent determination of the tool life for criterion II, also for all tests in the series.

When tool life is plotted for both criteria as a function of a variable (e.g. the cutting speed) then two different curves will be obtained (see the example given in figure 10).

b) Combined criteria are adopted and, in this case, the tool life will be considered to be ended when either criterion I or criterion II is reached. When tool life is plotted as a function of a variable (e.g. the cutting speed) this will usually result in a "broken" curve (see the example given in figure 10).

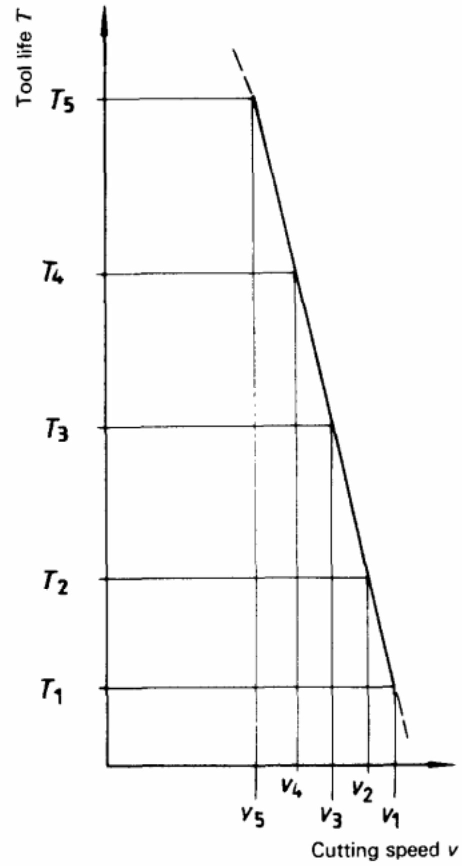


Figure 9 — Example of a *vT* curve (logarithmic scales)

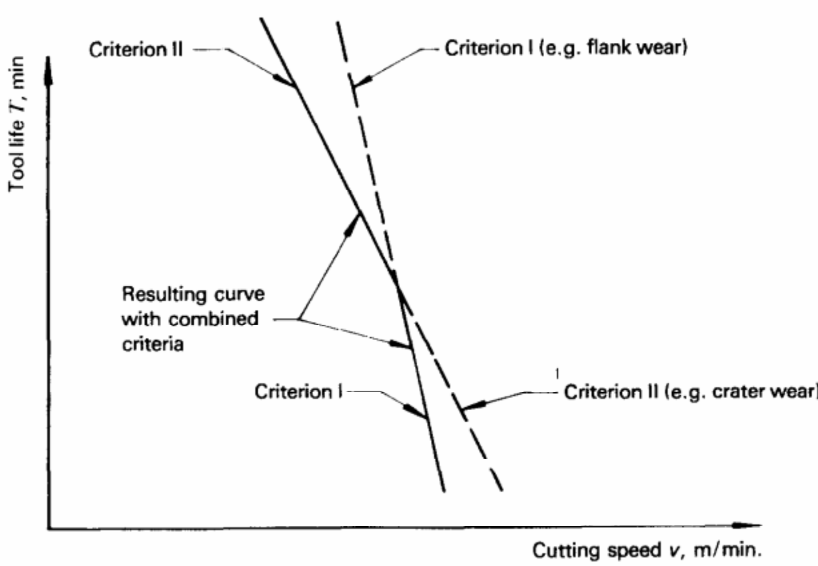


Figure 10 — Set of two *vT* curves resulting from the use of two different criteria and a "broken" *vT* curve resulting from the use of combined criteria (logarithmic scales)

10.3.3 Test types C and D

For test type C (see 9.2) the minimum number of data points is seven, obtained in seven test runs. For test type D (see 9.2) the minimum number of data points is nine, obtained in nine test runs.

10.4 Diagrams

Tool deterioration values of any type (see 7.3) obtained in a test run and treated as a group of dependent values from all the edges on the same cutter can be plotted over the effective cutting time (see 9.5). The data points on the curve may be the individual measurement values (see figure 11), the arithmetic mean values (see figure 12) or the maximum and minimum values (see figure 13). The arithmetic mean values and the maximum and minimum values are calculated statistically as described in annex C.

The tool life is obtained from the point or the field of intersection of the curves mentioned above and the horizontal line representing the limiting deterioration value determined as the "tool-life criterion" (see 7.4.). For repeated test runs, the tool life values can be treated statistically to calculate the arithmetic mean value, the standard deviation, the maximum and minimum values and the confidence interval.

Figures 11, 12 and 13 show a variety of curves which intersect the tool-life criterion level. It is essential, when plotting tool life against any cutting parameter or when reporting tool-life values, that it is made clear whether tool life is based on the values from one single test run, from the arithmetic mean value of a number of test runs or from the statistically determined maximum or minimum value.

Tool-life values obtained as described above can be plotted against any independent factor, e.g. cutting speed (see 9.2, types B, C or D), in order to give a *vT* diagram (see figure 9). It is common to plot *vT* diagrams with logarithmic scales. The *vT* curve thus obtained will, under normal conditions, be represented by a straight line. This line should be fitted to the data points in such a manner that the sum of the squares of the vertical distances between the line and the actual points is as small as possible. Experienced personnel may well be capable of constructing a line through the test points "by eye" with sufficient accuracy. Guidance on statistical calculations for this purpose are found in ISO 3685, and other references are given in clause 2.

It should be noted that the deterioration may change in character when cutting properties are changed, e.g. an increase in cutting speed. Consequently any diagram representing tool life as a function of changing cutting data shall be based on one specified deterioration phenomenon and one tool-life criterion. If this is not possible, the actual conditions shall be specially recorded.

10.5 Statistical interpretation

The use of statistical methods in the evaluation of test results from cutting operations needs great care with regard to the number of test values and the quality of the test results. If these demands cannot be met, statistical methods should not be used.

Guidelines for statistical calculations of arithmetical mean values, standard deviations, maximum and minimum values and confidence intervals are given in annex C.

The determination of significant differences between results from two or more cutting conditions is also described as an example in the same annex. The recommended calculation method is based on Student's *t* distribution.

Guidelines for the statistical calculations which can be used for determining tool-life diagrams of type B, C or D (see 9.2) are found in ISO 3685 and other references given in clause 2 and in the bibliography.

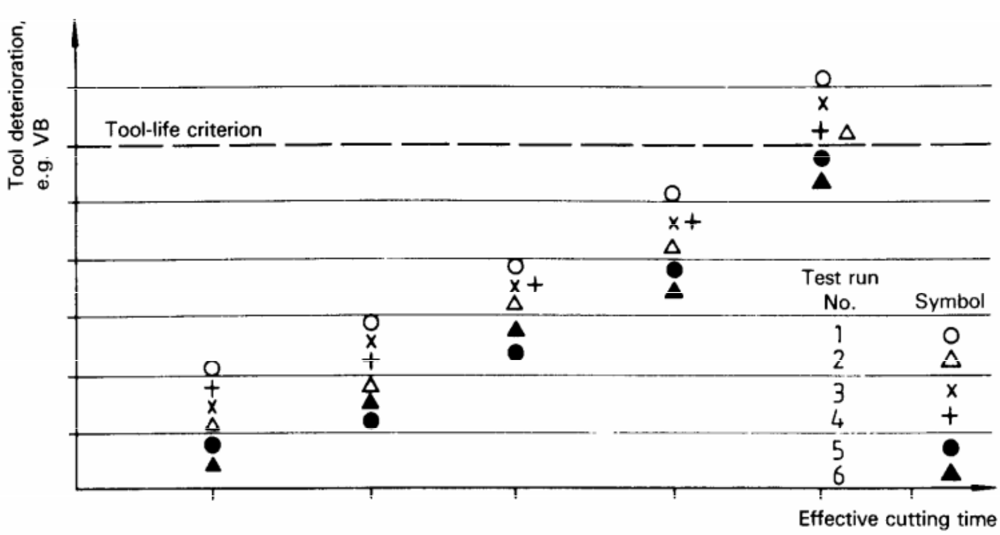


Figure 11 — Tool deterioration values for a number of test runs plotted against cutting time

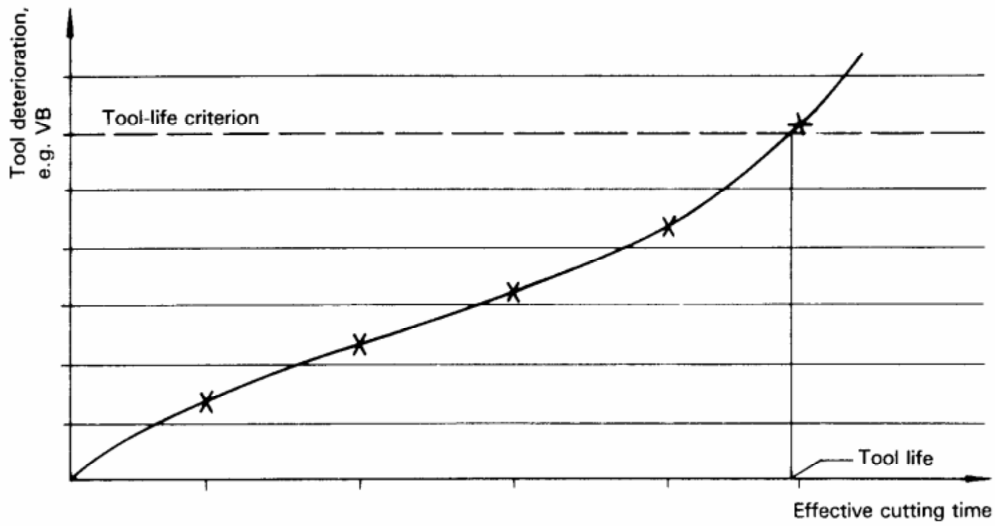


Figure 12 — Arithmetical mean values of tool deterioration for a number of test runs plotted against cutting time

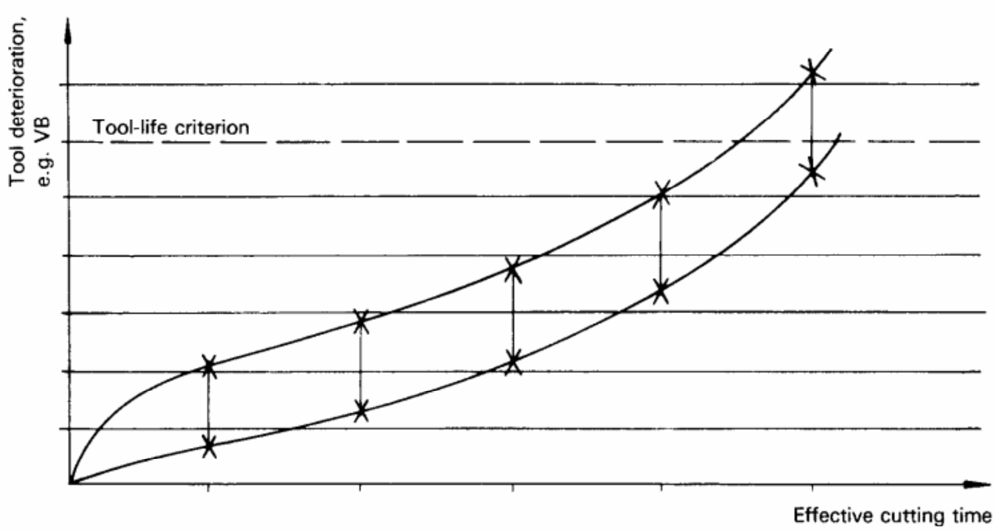


Figure 13 — Maximum and minimum tool deterioration values observed for the 95 % confidence level from a number of test runs plotted against cutting time

Annex A

Reference work materials

(This annex forms an integral part of the standard.)

A.1 Steel

The steel reference material shall be a hot-rolled medium-carbon steel of the following composition corresponding to steel C 45, in conformity with ISO/R 683-3.

C %	Si %	Mn %	S %	P %
0,42 to 0,50	0,15 to 0,40	0,50 to 0,80	0,02 to 0,035	0,035 max.

It is recommended that a steel of average composition be used 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 deoxidized with aluminium. 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, which is dependent to some extent on the steel-making process, should be as shown below.

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

The steel shall satisfy ISO/R 683-3 delivery condition 1 (chemical analysis only). The limits of the elements and the deoxidation procedure shall be discussed with the steelmaker and analyses of C, Si, Mn, Ni, Cr, Mo, P, S, V, Cu, Al and N requested at the time or order.

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

The microstructure shall be specified and recorded.

The test bars, after being cut to size, shall be normalized to a hardness within the range specified in ISO/R 683-3.

For testing purposes where the work material is not the test variable, it is recommended that the hardness should fall within stricter tolerances than those indicated in ISO/R 683-3. The actual hardness values and points of measurement should be recorded and reported (see 3.1).

A.2 Cast iron

The cast iron reference material shall be supplied in accordance with ISO/R 185, grade 25.

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

- free iron carbide : 0 %
- free ferrite : 5 % max.
- steadite (iron-iron phosphide eutectic) : 5 % max.
- graphite : flake graphite only
- perlite : balance

For testing purposes where the work material is not the test variable, it is recommended that the hardness values fall within stricter tolerances than those indicated in ISO/R 185. The actual hardness values and points of measurement should be recorded and reported (see 3.1).

Annex B
Example data sheet

(This annex forms an integral part of the standard.)

Page .... of				
End milling	Purpose of the test	**Test No.**	Date	Signature ....

Tool/Tool holder

- ☐ Slot drill ☐ End mill
- ☐ ISO 1641-1, ϕD = 125 mm
- or ☐ ....

Manufactured by ....
....

Tool material ISO 4957

- ☐ S2 ☐ S8
- ☐ S4 ☐ S11
- or ☐ .... or ☐ ....

Coating ....

Cutting edge preparation..................
....

Workpiece

Material, see specifications

- ☐ ISO/R 683-3, C45
- ☐ ISO/R 185, grade 25
- or ☐ ....

Manufactured by ....
....

Charge (heat) .... Code ....

Dimensions : Hardness : ....

h = ... mm; w : ..... mm; l : ..... mm

Workpiece No. ....

Tool holder

- ☐ ISO 5414-1 and ISO 5414-2
- or ☐ ....

Manufactured by ....

Machine tool

☐ Horizontal ☐ Vertical

Manufactured by ....
....

Model .... No. ....

Spindle power .... kW

Cutting fluid

☐ Yes ☐ No Amount .... l/min

Manufactured by ....
....

Cutting conditions

Used condition		Slot milling		End milling			
Condition No.		I	II	I	II	III	IV
Axial depth of cut a_a	mm	12,5	20	20	20	12,5	12,5
Radial depth of cut a_r	mm	25	25	2,5	2,5	20	20
Feed f_z	mm/tooth	0,08	0,125	0,08	0,125	0,08	0,125
Feed speed v_f	mm/min						
Cutting speed v_c	m/min						
Spindle revolution	r/min						

Tooth No.	Run-out axial / radial	Actual tool travel min/mm/workpiece			Actual tool travel min/mm/workpiece			Actual tool travel min/mm/workpiece			Actual tool travel min/mm/workpiece			Actual tool travel min/mm/workpiece			Actual tool travel min/mm/workpiece		
		Deterioration			Deterioration			Deterioration			Deterioration			Deterioration			Deterioration		
		Phenomenon	Position	Value	Phenomenon	Position	Value	Phenomenon	Position	Value	Phenomenon	Position	Value	Phenomenon	Position	Value	Phenomenon	Position	Value
1																			
2																			
3																			
4																			
Notes																			

Tool-life criteria		
Phenomenon	Position	Value

Evaluation : clause 10

Notes

Tool life of the cutter min/mm/workpiece
....

Annex C

Statistical calculations

(This annex forms an integral part of the standard.)

In order to compare the test results from two or more cutting conditions the first step is to determine the arithmetic mean values of the repeated test runs at each test condition. In this annex the symbol x is used to denote the test results. It could represent the tool life T, the number of parts produced U or any other test result.

The arithmetic mean value $\bar{x}$ is obtained by dividing the sum of the results from each test run $\sum_{i=1}^{n} x_i$ by the number n of test runs :

$$\bar{x} = \sum_{i=1}^{n} x_i \Big/ n$$

The standard deviation s is then calculated as the root-sum-square of all the differences between the individual values x_i from each test run and the mean value $\bar{x}$, divided by the number of test runs n minus 1.

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}}$$

The confidence interval, defined as the interval within which further test run results will be located with an assumed probability, is calculated as the arithmetic mean value $\bar{x}$ plus and minus its variation :

$$\bar{x}_{max} = \bar{x} + t \frac{s}{\sqrt{n-1}}$$

and

$$\bar{x}_{min} = \bar{x} - t \frac{s}{\sqrt{n-1}}$$

where t is a constant obtained from table 7 for the 95 %, 99 % and 99,9 % confidence levels. The t values are dependent on the number of test runs, expressed by the number of degrees of freedom in table 7.

By using the following formula, it can be determined whether there is a significant difference between the results of two test series with different cutting conditions :

$$|t_\alpha| = (\bar{x}_A - \bar{x}_B) \Big/ \sqrt{\frac{n_A \times s_A^2 + n_B \times s_B^2}{n_A + n_B - 2} \times \left(\frac{1}{n_A} + \frac{1}{n_B}\right)}$$

The value $|t_\alpha|$ obtained is then compared with the corresponding t value for the actual number of degrees of freedom and the conclusion may be made as to whether a significant difference exists at the confidence level chosen.

The letters A and B indicate the two test series.

The numerical examples illustrate the calculation methods.

Experience has shown that tool life in many cases does not follow the laws of the well-known normal distribution. It is therefore recommended to use the logarithmic values of the test results which in most cases give a normal distribution. This can be checked by the methods described in ISO 2854.

The statistical calculations described are only valid if

a) the observations are statistically independent;

b) the tests have been carried out in such a way that no systematic errors are present.

Table 7 — Student's t values for different confidence levels

Number of degrees of freedom $(n - 1)$ or $(n_A + n_B - 2)$	Student's t value		
	Confidence level		
	95 %	99 %	99,9 %
1	12,706	63,657	636,5
2	4,302 7	9,925	31,60
3	3,182 5	5,841	12,94
4	2,776 4	4,604	8,610
5	2,570 6	4,032	6,859
6	2,446 9	3,707	5,959
7	2,364 6	3,499	5,405
8	2,306 0	3,355	5,041
9	2,262 2	3,250	4,781
10	2,228 1	3,169	4,587
11	2,201 0	3,106	4,437
12	2,178 8	3,055	4,318
13	2,160 4	3,012	4,221
14	2,144 8	2,977	4,140
15	2,131 5	2,947	4,073
16	2,119 9	2,921	4,015
17	2,109 8	2,898	3,965
18	2,100 9	2,878	3,922
19	2,093 0	2,861	3,883
20	2,086 0		
30	2,042 3		
40	2,021 1		
60	2,000 3		
120	1,979 9		
∞	1,960 0		
Degree of significance	*	**	***
	Significant	Well significant	Strongly significant

Example

Test run number	Test conditions and results	
n	A	B
1	7,0	10,0
2	7,5	9,5
3	8,5	10,5
4	8,9	11,5
5	9,5	11,0
6	9,0	11,5
Arithmetic mean value $\frac{\sum x_i}{n} = \overline{x}$	8,25	10,66
Standard deviation s	0,935	0,816
Student's t value t_{95}	2,571	2,571
Confidence interval $\pm t \frac{s}{\sqrt{n-1}}$	± 1,076	± 0,939
$\overline{x}_{max} = \overline{x} + t_{95} \frac{s}{\sqrt{n-1}}$	9,326	11,605
$\overline{x}_{min} = \overline{x} - t_{95} \frac{s}{\sqrt{n-1}}$	7,174	9,728
$\lvert t_\alpha \rvert$	4,768	

Conclusion : The t_α value is greater than t for $(n_A + n_B - 2)$ at the 99 % confidence level. A strongly significant difference exists.

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Descriptors : tools, cutting tools, milling cutters, end mills, tests, determination, life (durability).

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