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Tool life testing in milling —

Part 1 : Face milling

Essai de durée de vie des outils de fraisage —

Partie 1 : Surfaçage

Reference number
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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 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 8668-1 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 1 : Face 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 face milling operations with carbide tools, as illustrated in figure 1, 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 face milling tests using steel and cast iron workpieces of normal microstructure. However, with suitable modifications, this part of ISO 8688 can be applied to face 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 cemented carbide tools used for face milling of steel and cast iron workpieces. It can be applied to laboratory as well as to production practice.

The cutting conditions in face 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.

This part of ISO 8688 establishes specifications for the following factors of tool-life testing with face milling tools in accordance with figure 1: workpiece, tool, cutting fluid, cutting conditions, equipment, assessment of tool deterioration and tool life, test procedures, recording, evaluation and presentation of results.

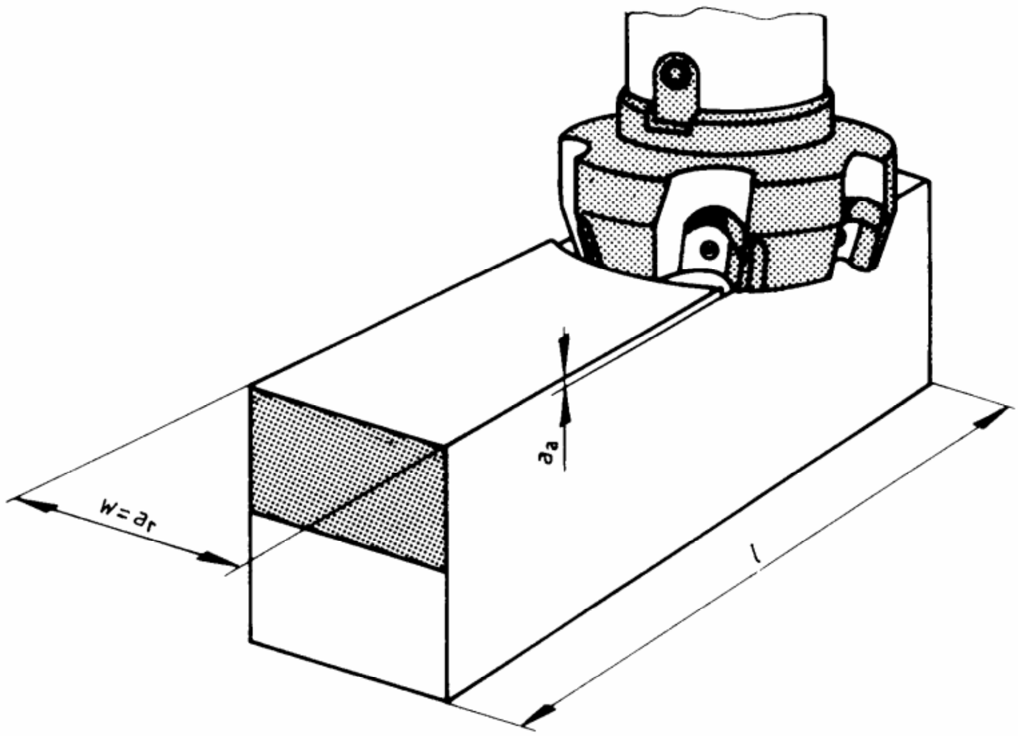


Figure 1 — Face milling — Milling operation

2 References

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

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

ISO 513, *Application of carbides for machining by chip removal — Designation of the main groups of chip removal and groups of application.*

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 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 3365, *Indexable hardmetal (carbide) inserts with wiper edges, without fixing hole — Dimensions.*

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

ISO 6462, *Face milling cutters with indexable inserts — Dimensions.*

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 2).

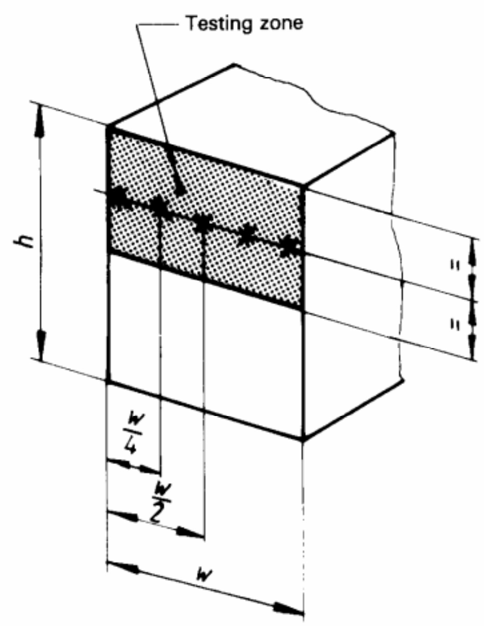


Figure 2 — Hardness testing

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 face milling (see 9.3.1) shall be a bar or billet of rectangular cross-section with a width of 0,6 times the cutter diameter (75 mm for D = 125 mm), see 6 3, and a minimum length of 3 times the cutter diameter (375 mm for D = 125 mm).

The maximum and minimum heights of a workpiece 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 face milling cutter 125 mm in diameter and with 6 equispaced inserts is recommended. 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 6462. The main dimensions of the recommended cutter body are given in figure 3.

Although testing bodies are free to select inserts according to their own interests, it is recommended that indexable carbide inserts mounted in the recommended body are SPAN1203 EDR according to ISO 3365. The dimensions of the recommended inserts are given in figure 4. The deviation between individual inserts used in the same testing sequence should be kept to a minimum (see also 4.2).

The tolerances of the recommended tool complete with recommended inserts are given in figure 3 (see also 4.5 concerning the cutting edge runout).

4.2 Tool geometry

It is recommended that all cutting tests in which the tool geometry is not the test variable be conducted using the cutting tool geometry shown in figures 3 and 4.

The cutting tool angular geometry designations are in accordance with ISO 3002-1.

The deviation between the geometry of individual inserts used in the same testing sequence should be kept to a minimum.

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

4.3 Cutting edge and insert surface

The form and method of preparing the cutting edges of the insert may significantly affect the results. It is therefore important that the geometric features are accurately measured and recorded together with the configuration and direction of grinding marks.

Where cutting edge preparation is not a test variable, the face of the insert to be used in testing should have a land of 0,2 ± 0,05 mm width, which gives a negative normal rake of 20° ± 2° (measured on the insert). The wiper edge of the insert, which in use will be parallel to the machined surface, should be as sharp as possible and there should not be a land on the tool face associated with this wiper edge (see 9.3.2).

Dimensions in millimetres

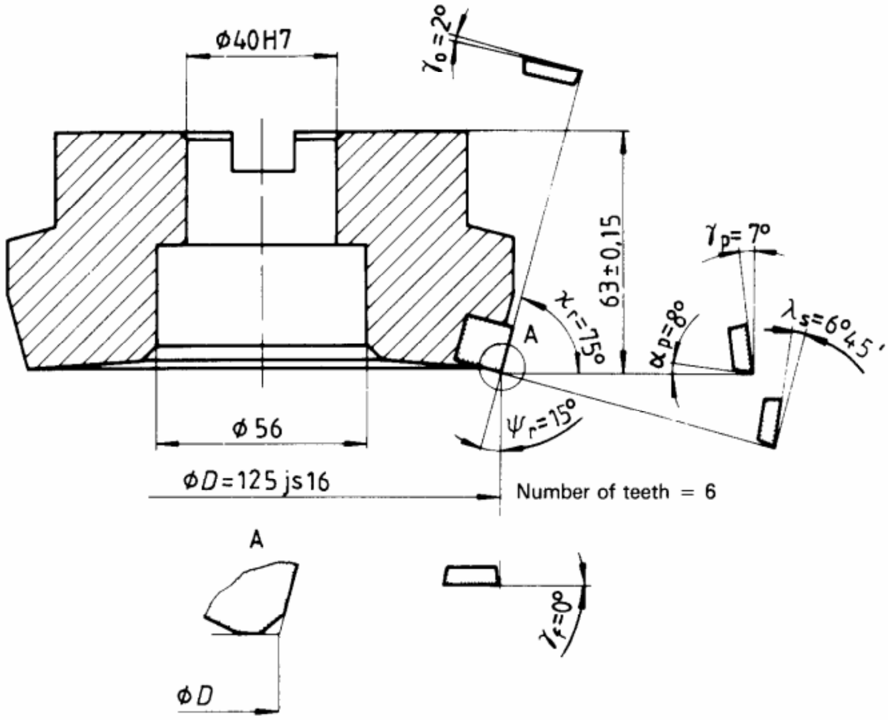


Figure 3 — Face milling cutter with hardmetal indexable inserts
(see ISO 6462, style B, ϕ D = 125 mm)

Dimensions in millimetres

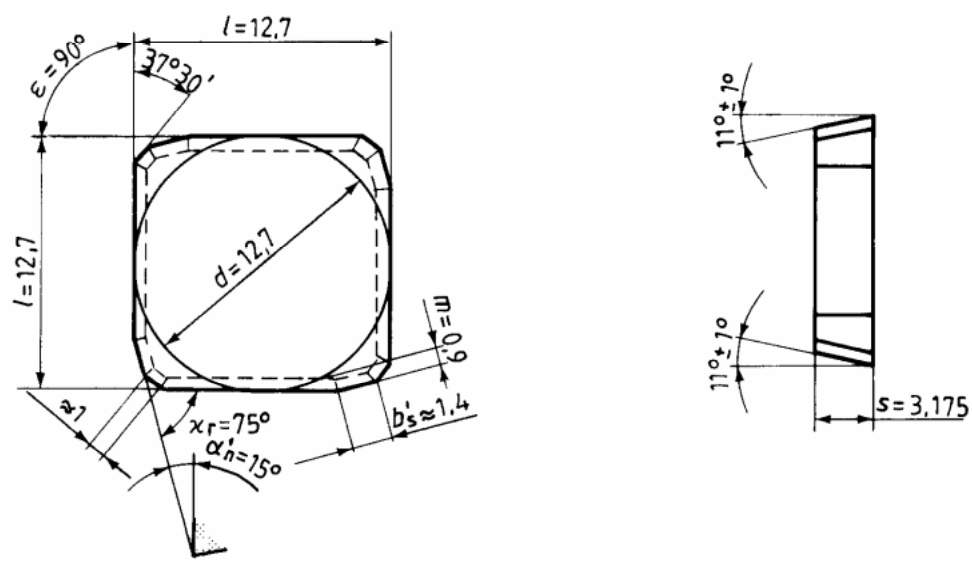


Figure 4 — Square indexable hardmetal inserts
(see ISO 3365, designation SPAN1203 EDR)

The land, if any, on the tool face associated with the major cutting edge may be parallel to the cutting edge or tapered, i.e. with a width increasing with the distance from the tool corner. If the land is tapered, the maximum width within the active part of the major cutting edge should not exceed 0,2 mm and the amount of taper should be reported. The grinding direction used for producing the land should be reported.

The surface roughness R_a of the insert surfaces should not exceed 0,25 µm (measured in accordance with ISO 468).

The deviation in flatness of the supporting surface of an insert should not exceed 0,004 mm.

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 hardmetal grade for group of application P25 for milling steel and K10 for milling cast iron in accordance with ISO 513. In addition, the use of hardmetal from a reference stock is recommended in order to cover the need for comparison of results over a sufficiently long period of time. It is recommended that a sufficient stock of tool material be kept.

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 cutting edges as is practical.

Since hardmetal grades for the same ISO group of application vary between producers and to a lesser extent between batches, the performance of newly bought inserts should be calibrated against that of inserts for which the characteristics are known.

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 cutter used for face milling tests shall be mounted directly in the machine spindle. The cutter and spindle mounting surfaces shall be cleaned and free from all burrs. The cutter shall be securely fastened to the spindle and the runout of the cutter shall be carefully checked at the cutting edges.

The maximum values of runout shall be as follows :

- radial runout : 100 µm
- axial runout : 50 µm

Between consecutive cutting edges the values of radial runout should not exceed 50 µm. The actual runout for each cutting edge considered should be measured and recorded.

The values of runout specified above can be achieved using standard inserts and cutters mounted on conventional machines. However, since runout of cutting edges may influence the wear of individual edges, especially for testing conditions using the two lower values of recommended feed per tooth (see table 1), efforts should be made to reduce the actual values of runout as much as possible by selective mounting of the inserts in the body.

5 Cutting fluid

Normally, tests should be carried out without the application of a cutting fluid. However, if circumstances require the use of a cutting fluid, the fluid used should 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.

In these cases, the flow of cutting fluid 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

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 table 1.

Table 1 — Recommended cutting conditions

Cutting condition		I	II	III	IV
Axial depth of cut a_a	mm	2,5	2,5	2,5	4
Radial depth of cut[1] a_r	mm	0,6 D[2]			
Feed f_z	mm/tooth	0,125	0,2	0,315	0,5

1) In this particular case, the depth is equal to the width of the workpiece.

2) D = diameter of the milling cutter.

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

6.2 Other cutting conditions

In those cases where the indicated feed values are not practical, other values as close as possible to those indicated may be used. In such cases the axial depth of cut should be

either $a_a = 2{,}5$ mm

or $a_a = 8f_z$

whichever is the larger.

In cases where the feed, the depth of cut or the width of workpiece 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.

It should be noted that feeds of less than 0,1 mm per tooth or greater than 0,8 mm per tooth and depths of cut smaller than 2 mm or greater than 8 mm may result in modes of tool deterioration other than those recommended as criteria in this part of ISO 8688 and should therefore not be used.

6.3 Location of the cutter

For face milling tests, the cutter axis should preferably travel along the centre-line of the workpiece. In order to avoid the danger of edge fracture as the insert exits from the workpiece, it is permitted to alter the cutter position in relation to the centre-line of the workpiece in the direction away from the exit edge of the workpiece. If it is desired to locate the axis of the cutter to give a predominantly down-mill condition or a predominantly up-mill condition, the location of the cutter axis with respect to the workpiece centre-line should be recorded. However, it should be recognized that certain conditions of predominantly up-milling may result in adverse insert exit from the workpiece with significant cutting edge fracture and associated short tool life (see clause 1, second condition). The actual location of the cutter relative to the workpiece should be reported (see annex C).

6.4 Cutting speed

The cutting speed is the peripheral speed of the cutting tool determined at the nominal diameter (see figure 3). 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 180 m/min.

A relatively small change in cutting speed will significantly affect tool life, e.g. a change of ± 10 % 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.

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. To aid both test reporting and the interpretation of test reports, a coded classification system is recommended to give a detailed description of the form of deterioration (see 7.3).

Many types of tool deterioration phenomena are listed in this clause and in table 2. 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.

Three major classes of tool deterioration are distinguished, i.e. tool wear, brittle fracture and plastic deformation.

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 : 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.

7.2.1.3 plastic deformation : Distortion of the cutting part of a tool from its original shape without initial loss of the tool material during cutting (see 7.3.7).

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

Examples :

— The width of a uniform flank wear land VB 1 (see 7.3.2.1).

— The number of comb cracks CR 1 (see 7.3.5.1 and 7.5.4).

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

Examples :

— The width of a uniform flank wear land VB 1 = 0,35 mm (see 7.4.1).

— Cracking becomes visible.

7.2.4 tool life T_c : Total cutting time of the tool required to reach a specified tool-life criterion.

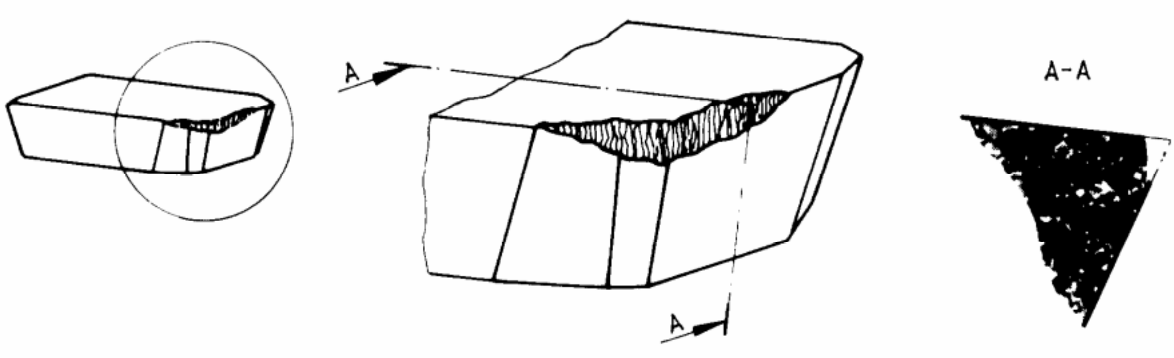
7.3 Tool deterioration phenomena

7.3.1 Coding system for tool deterioration and tool wear

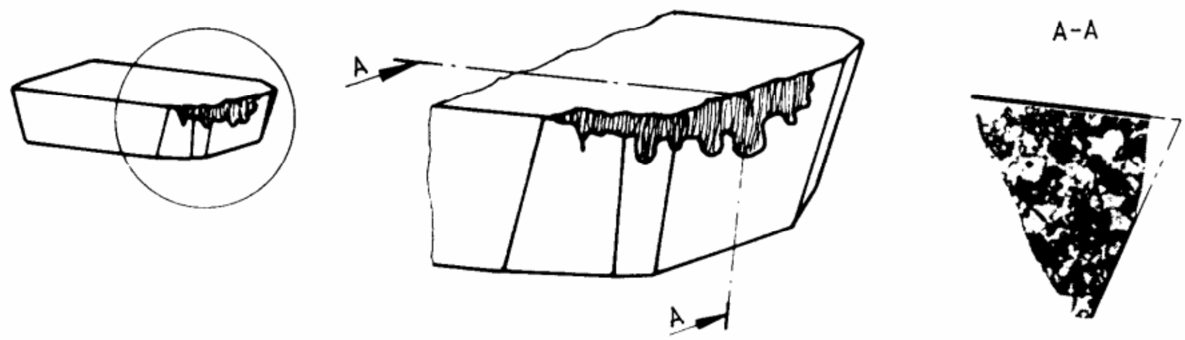
In practice, different types of deterioration will occur together during machining. It is desirable, therefore, to be able to give information concerning deterioration in a meaningful manner. Table 2 gives recommendations for and illustrations of a coding system to describe deterioration phenomena observed at each stage of measurement during testing, thus reducing the risk of misinterpretation of lengthy written descriptions and minimizing the number of illustrations required in a test report.

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

7.3.2.1 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.



7.3.2.2 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.

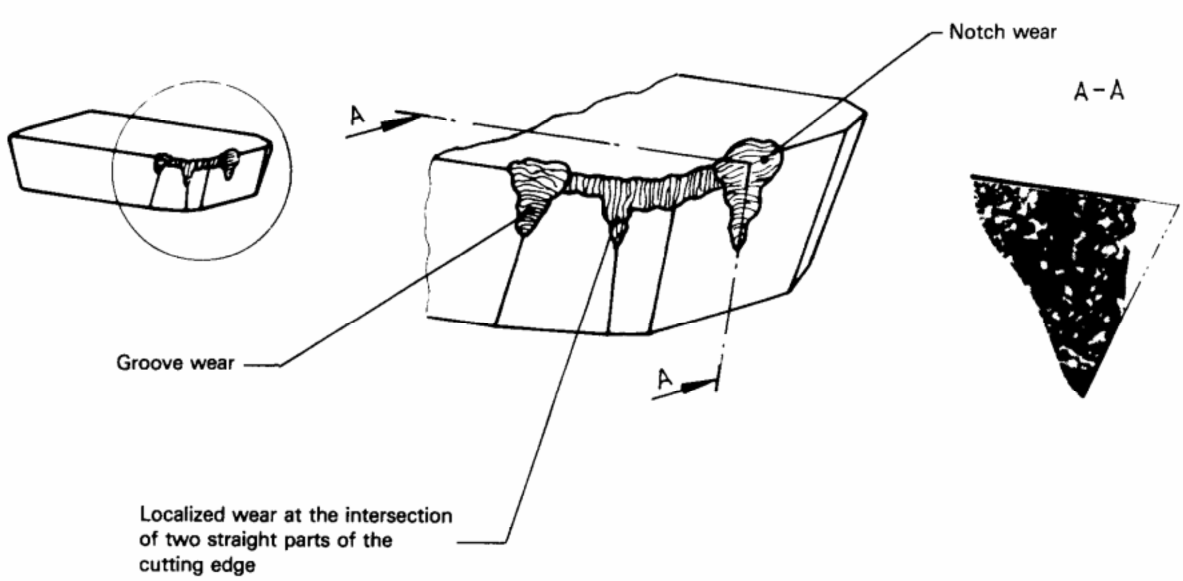


7.3.2.3 localized flank wear (VB 3) : Exaggerated form of flank wear which develops at localized points on the flanks (see figure 5, points P_1 to P_2 and P_f or zone A_1).

One special form of this type of flank wear is **notch wear** which develops on that part of the major flank adjacent to the work surface during cutting.

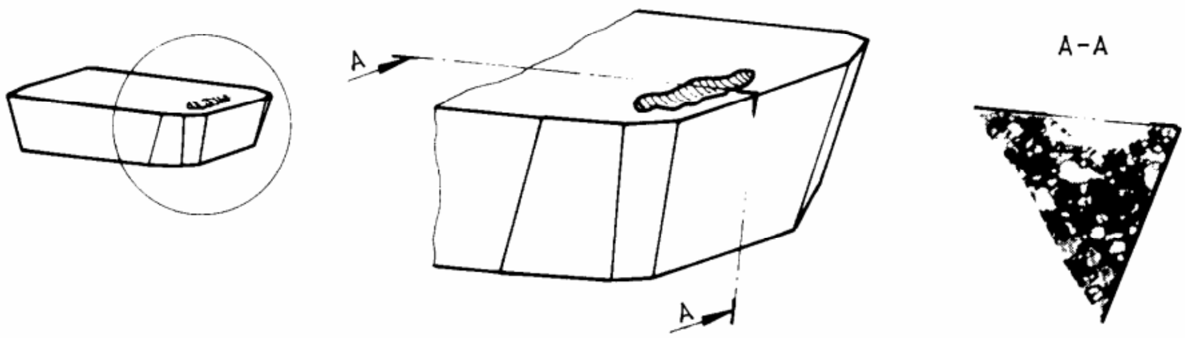
Another special form of this type of flank wear is **groove wear** which develops on that part of the minor flank adjacent to the machined surface during cutting.

A third special form of localized flank wear occurs sometimes at the point of intersection of two straight parts of the cutting edge.

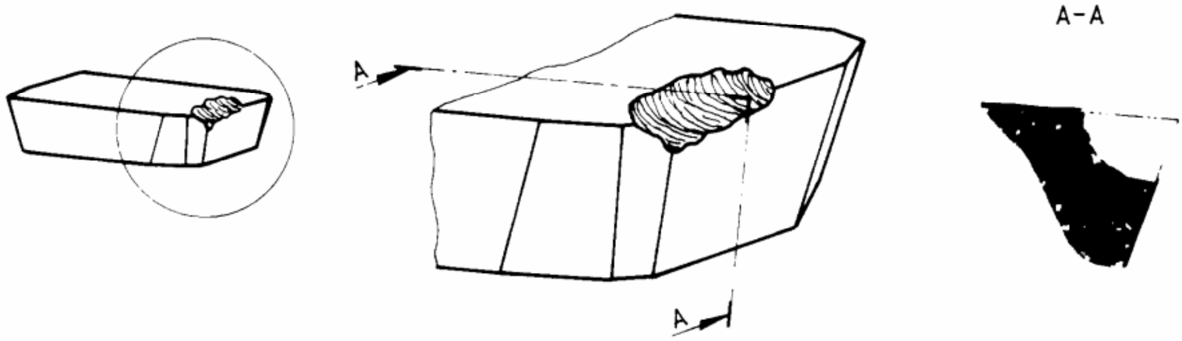


7.3.3 face wear (KT) : Gradual loss of tool material from the tool face during cutting.

7.3.3.1 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. Under certain circumstances the crater may break off from the tool face to intersect the tool major flanks.

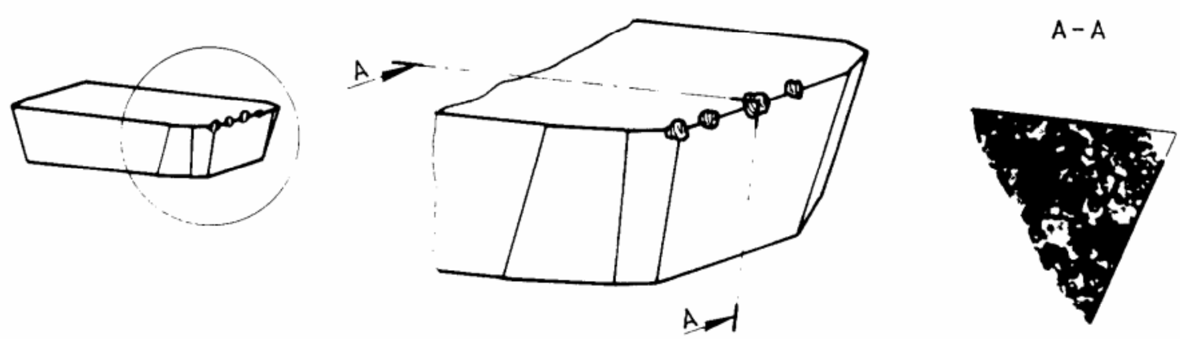


7.3.3.2 stair-formed face wear (KT 2) : Form of a face wear in which the maximum depth of the wear scar, measured perpendicular to the tool face, occurs at the intersection of the wear scar with the tool major flank.

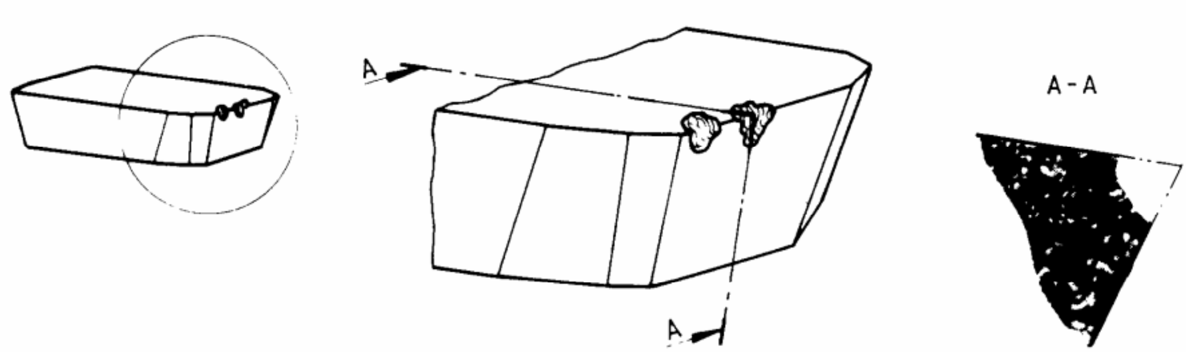


7.3.4 Chipping (CH)

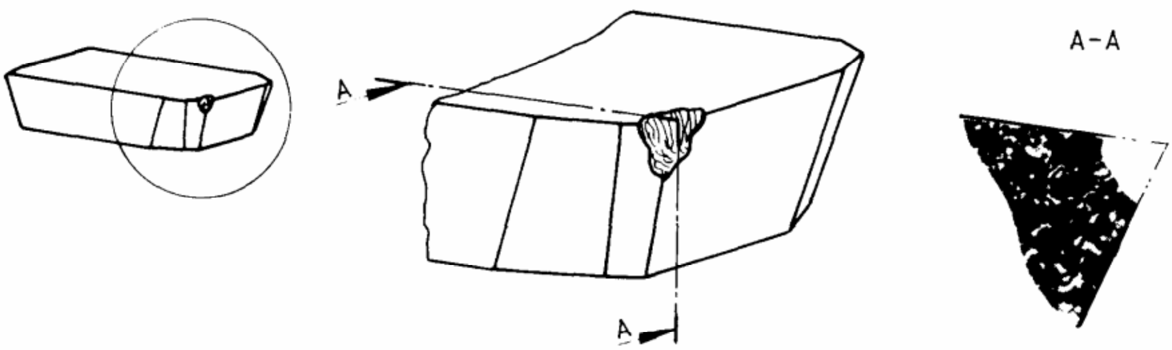
7.3.4.1 uniform chipping (CH 1) : Loss of tool fragments of approximately equal size along the cutting edges, which significantly influences the uniformity of the width of the flank wear land.



7.3.4.2 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.



7.3.4.3 localized chipping (CH 3) : Chipping which occurs consistently at certain positions along the active cutting edge (or in zone A_0 in figure 5).

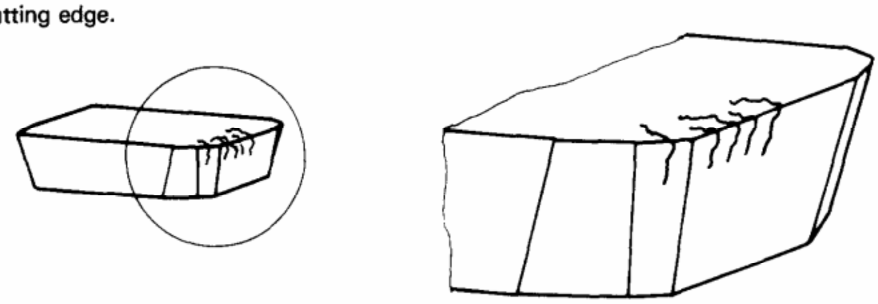


7.3.4.4 chipping of the non-active part of the major cutting edge (CH 4) : Chipping, which occurs outside the active part of the cutting edge, due to chip hammering.

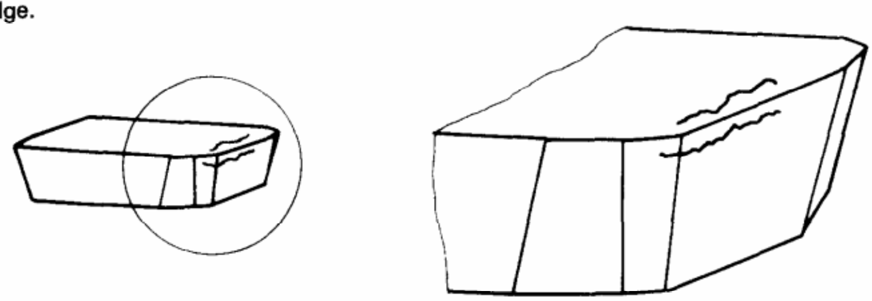
7.3.4.5 brittle edge failure : Disappearence of the major part of the active cutting edge which makes it impossible to continue cutting.

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

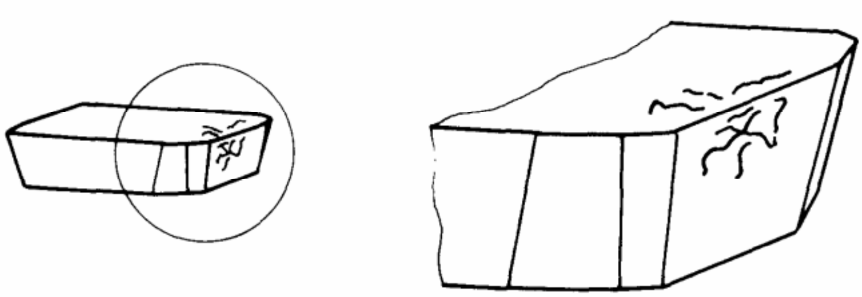
7.3.5.1 comb cracks (CR 1) : Cracks which appear on both the tool face and the tool flank and are oriented approximately perpendicular to the major cutting edge.



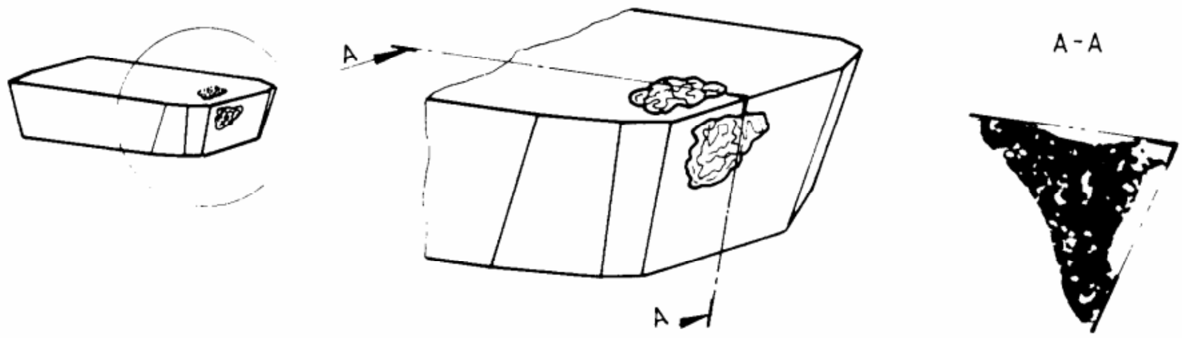
7.3.5.2 parallel cracks (CR 2) : Cracks which appear on the tool face or the tool flank and which are oriented approximately parallel to the major cutting edge.



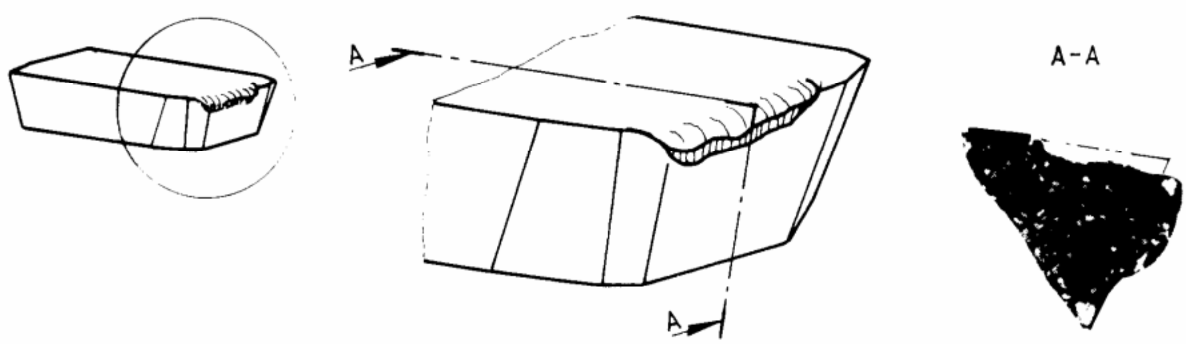
7.3.5.3 irregular cracks (CR 3) : Cracks which sometimes appear on the tool face and on the tool flank and which are irregularly oriented.

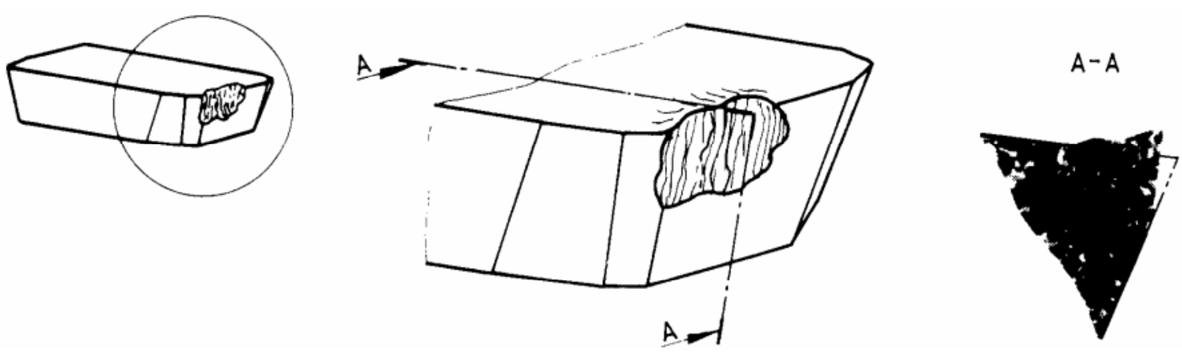


7.3.6 flaking (FL) : Loss of tool fragments in the form of flakes from the tool surfaces. This phenomenon is most frequently observed when coated tool inserts are used but may also be observed with other tool materials.

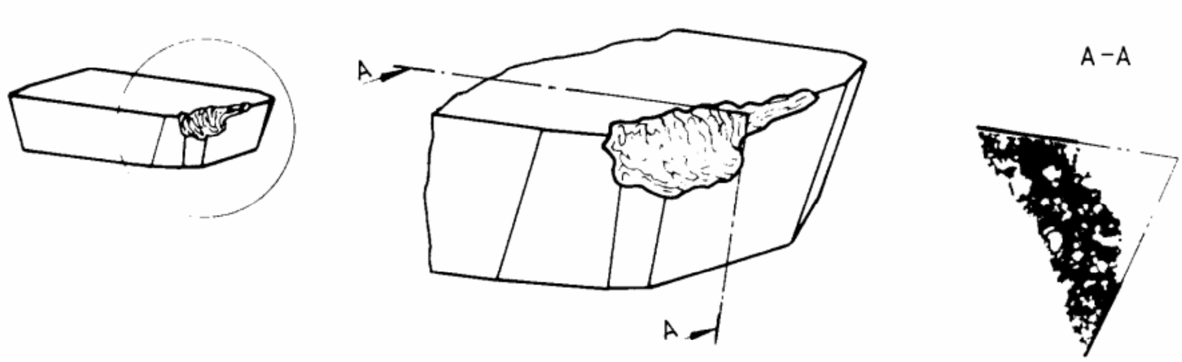


7.3.7 plastic deformation (PD) : Distortion of the cutting part of a tool from its original shape without initial loss of tool material.





7.3.8 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 (see table 2).

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.

A certain depth of the crater on the tool face (KT 1) or the height of the stair step (KT 2) is sometimes used as a criterion.

The numerical value of tool deterioration used to determine tool life governs the quantity of testing material required and 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 deterioration development under the test conditions. To satisfy the testing requirements for the majority of users of conventional steels and cast irons a set of three limiting values for each deterioration criterion is specified (see table 2).

The numerical values for the various tool deterioration measurements indicated under the heading "Tool-life criteria" are to be used as follows :

— Normal (N) : The values under this heading apply to the cutting conditions indicated in clause 6 on work materials similar to the reference work materials specified in annex A and with tool characteristics similar to those indicated in clause 4. The values selected are a reasonable compromise between reliability, costs of testing and normal deterioration intensity. Normally one of the numerical values will be reached before total destruction of the cutting parts occurs.

— Large (L) : The values under this heading give more information about the capability of a tool under certain conditions of testing. The use of these values is especially recommended in cases where the full potentials of the cutting parts and the cause of final destruction are to be assessed and where costs of higher material consumption are not prohibitive.

— Small (S) : The values under this heading give less information about the capability of a tool under the conditions of testing. The use of these minimum values is allowed only in cases where the costs of material consumption are very high as may be the case with very wear-resistant cutting tools or very expensive work materials. The adoption of values smaller than the smallest values specified in this part of ISO 8688 is not recommended.

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.

— Chipping (CH, in the moderate form A or B, see table 2) is a criterion which may be used.

— Cracking (CR) is a common phenomenon and may sometimes be used as a criterion.

— Chipping (CH) in the heaviest form (see table 2), flaking (FL), plastic deformation (PD) and catastrophic failure (CF) are forms which exceptionally could be used as criteria.

For complete reporting, especially when edge failure or some other form of deterioration renders the tool useless for cutting, it is recommended that complete details of the deterioration are recorded in the data sheet (see annex C) according to the descriptions, codes and values contained in table 2 and the positions along the cutting edges represented in figure 5.

7.5 Assessment of tool deterioration

Measurement of tool wear and brittle deterioration using appropriate equipment (see 8.2 and 9.3.7) 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 C).

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 major flank may be of uniform size, there will be variations in its value at other portions of major and minor 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 5) 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). Normally the section is taken at a position corresponding to the mid-depth of cut and perpendicular to the major cutting edge.

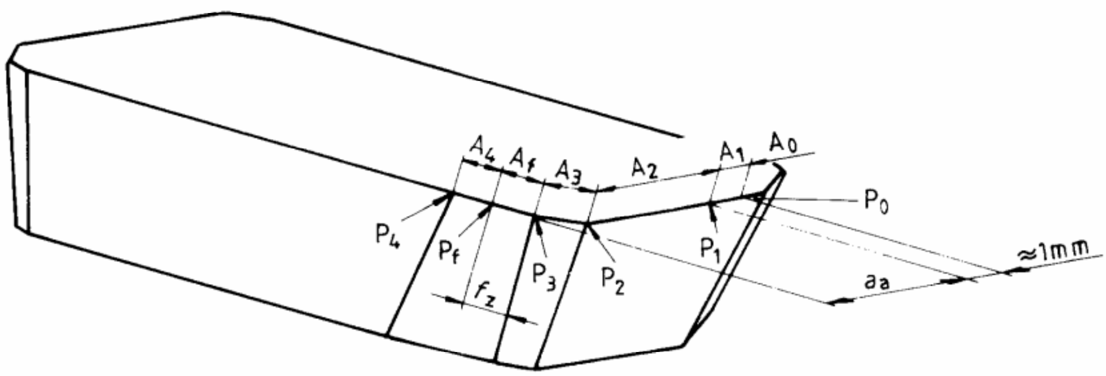
Face wear KT 2 is measured as the distance between the worn edge and the original cutting edge (see 7.2 and 7.3).

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 zone in which chipping occurs should be indicated in accordance with the coding system given in figure 5.

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 using the coding system given in figure 5.



This coding system includes

- code A, which refers to areas;
- code P, which refers to points;
- indexes, which refer to positions.

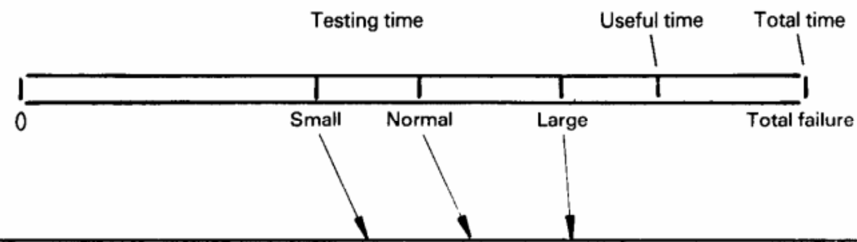
These codes and indexes shall be used in the data sheet, see the example in annex C.

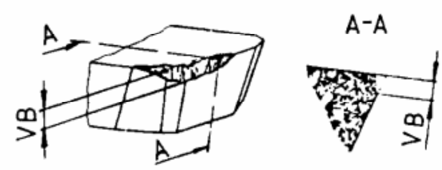
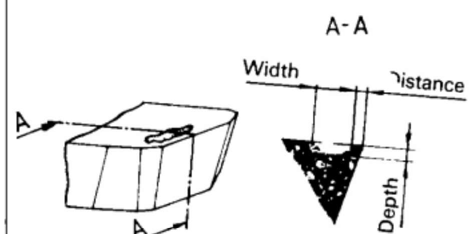
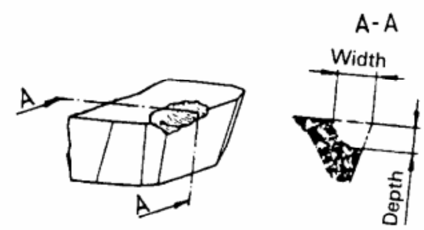
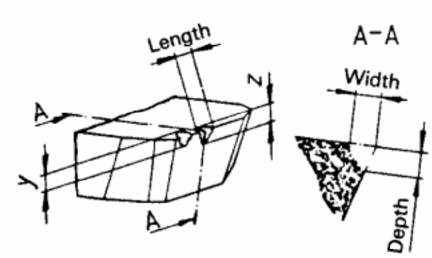
Figure 5 — Deterioration position coding system

Table 2 — Coding system

Code: Basic form / Distribution / Subdivision

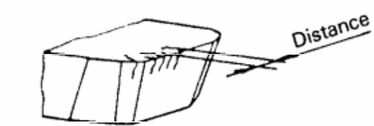
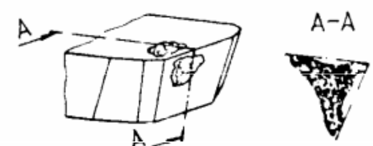
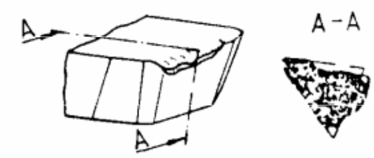
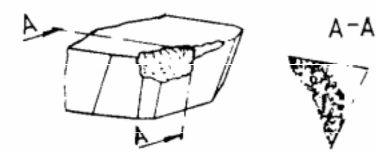
Description of tool deterioration



Code	Tool deterioration phenomena		Criteria, mm S	N	L	Illustration
VB	**Flank wear**					
1	Uniform		0,2	0,35	0,5	
2	Non-uniform		0,9	1,2	1,5	
3	Localized		0,8	1	1,2	
KT	**Face wear**					
1	Crater wear :	Depth	0,05	0,1	0,15	
		Width*	.....	.....	.....	
		Distance*	.....	.....	.....	
2	Stair forms :	Depth	0,25	0,3	0,35	
		Depth/width*	.....	.....	.....	
CH	**Chipping** (breakage)					
1	Uniform		For *y* or *z* with corresponding length values			
2	Non-uniform					
3	Localized					
		Length, mm				
A	Micro-chipping	< 0,3	0,2	0,25	0,3	
B	Macro-chipping	0,3 to 1	0,25	0,4	0,5	
C	Breakage	> 1	—	—	—	

* To be recorded.

Table 2 (*concluded*)

Code (Basic form / Distribution / Subdivision)	Description of tool deterioration: Tool deterioration phenomena	Criteria, mm: S / N / L	Illustration
CR	**Cracks**	The number of the largest cracks and the mean distance between them shall be recorded	
1	Cracks perpendicular to the edge		
2	Cracks parallel to the edge		
3	Irregular direction		
FL	**Flaking**	Could be used as criteria in exceptional cases	
PD	**Plastic deformation**		
CF	**Catastrophic failure**		

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 required spindle power and spindle torque for recommended cutting conditions are given in table 3.

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.

Table 3 — Required spindle power and spindle torque for the standardized test conditions

Cutting condition			I	II	III	IV
Axial depth of cut a_a		mm	2,5	2,5	2,5	4
Radial depth of cut a_r (equal to the width of cut)		mm	75	75	75	75
Feed f_z		mm/tooth	0,125	0,2	0,315	0,5
Minimum spindle power[1)] (at a cutting speed of 180 m/min)	Steel	kW	5	7	9	14
	Cast iron	kW	3	4	6	8
Minimum spindle torque[1)]	Steel	Nm	100	130	200	300
	Cast iron	Nm	60	80	110	160

1) The values given for spindle power and spindle torque are rounded-off values.

NOTE — It is necessary to consider the actual efficiency in order to calculate the minimum motor power. Any deviation from the recommended testing conditions, for example the use of negative rake tool geometry, may result in torque and power requirements which are higher than those quoted in table 3.

8.2 Other equipment

Table 4 lists equipment which is necessary and recommended for carrying out the tests specified in this part of ISO 8688.

Table 4 — Equipment necessary for measurements in the face milling tests

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

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 some other variable (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 table 5). 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.

The information obtained can be used to determine material quantity requirements and the total duration of the test programme.

Table 5 — Approximate mass of material removed for each single test run using the recommended criteria under the recommended test conditions

Cutting condition		i	ii	ii	iV
Axial depth of cut a_a Radial depth of cut a_r Feed f_z	mm mm mm/tooth	2,5 75 0,125	2,5 75 0,2	2,5 75 0,315	4 75 0,5
Approximate mass of material removed (to achieve recommended tool-life criterion)	kg/test run	10	15	25	55

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 fresh inserts before a new experiment is started.

9.3.2 Hardmetal inserts

Each cutting edge should be examined for defects such as cracking and chipping prior to testing using a minimum magnification of 8 X. Defective cutting edges should not be used.

9.3.3 Cutter body

The insert locations in the cutter body should be marked, checked for damaged seats, shims and wedges, and any replacements should be mounted in accordance with the tool manufacturer's recommendations (see annex B for setting instructions).

9.3.4 Insert setting, indexing and replacement

Each insert should be mounted according to the tool manufacturer's instructions. In the absence of such instructions the general principles outlined in annex B should be referred to. The position of consecutive cutting edges should be measured in the axial and radial directions (see 4.5). The values shall be recorded for each insert location (see annex B).

Inserts should be covered and protected until the face mill is mounted in the machine spindle.

9.3.5 Face mill with inserts

The machine spindle and face mill should be cleaned immediately prior to mounting the tool in the spindle. The axial and radial runout of each insert should be measured on the cutter mounted in the spindle, using an indicator graduated to 1 µm with a flat anvil, and the values recorded for each insert location. Recommended limiting values of these runout amounts are given in 4.5.

9.3.6 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.

9.3.7 Equipment for assessment of tool deterioration

The availability and quality of suitable equipment for measuring tool deterioration phenomena of the inserts both in the tool body (but removed from the machine if necessary) and removed from the tool body should be established (see 8.2). This information should be recorded on suitable data sheets (see annex C).

9.3.8 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 C).

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.

In certain cases, visual checks on inserts prior to machining may not identify defects in the inserts. In addition, the choice of the initial cutting conditions may be unsuitable. These factors taken separately or jointly may result in a form of premature failure of one or more inserts during the first few seconds of the machining time and this failure may become apparent by a change in chip formation, the start of a vibration or a change in surface finish. When there is doubt concerning the adequate performance of a tool, the test should be interrupted to permit inspection of the inserts. If one insert has failed during the first few seconds of the machining time, the failure should be recorded, the insert should be replaced, maintaining the cutting edge positional accuracy (see 4.5), and the test continued. However, if several inserts have failed, the entire set should be replaced and a new test started under different cutting conditions which are more likely to give wear characteristics of all inserts comparable with practical industrial applications.

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 inserts and the workpiece during the return motion.

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.

Special attention shall be paid to the position of the spindle centre-line (see 6.3).

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

9.5 Measurements and recording of tool deterioration

At time intervals determined by the test plan all inserts 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 C).

These measurements should be made with the tool mounted in the machine at various positions along the cutting edges and on the face (see 7.1 and 7.2). The measurements should be made on each insert and related to both the insert position in the tool body and the appropriate corner of the insert.

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

10 Evaluation of results

10.1 General considerations

The evaluation of tool deterioration observations from face milling with multitoothed cutters 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

The individual edges mounted in the same cutter body and used in a given test run do not act independently of one another. Consequently, the test values from measurements or other observations of tool deterioration of the individual edges on identical inserts shall be considered together to be the result of a specified test run with one tool.

Because of the non-independent action of individual edges, comparative testing of inserts of different geometry or quality mounted together in the same cutter may be completely misleading and should not be attempted.

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 should normally require replacement of the actual insert. The new edge shall not be taken into consideration in the calculation of the results of the test run.

Any unexpected deterioration phenomenon shall be carefully observed and recorded. The reasons shall be investigated (see 9.4).

If several inserts fail as described above the entire test shall be neglected in the evaluation. 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 6.4 and 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 (see 7.4.1 and 7.5). 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.

These minimum numbers quoted assume the use of statistical techniques for the evaluation of the test results (see 10.5).

Since the accuracy of the test results determined by statistical analysis depends on both the number of test runs and the number of variables examined in the test plan, it is recommended that the number of test runs be four times the number of test variables. However, in order to reduce costs, the minimum number of test runs specified for test types B, C and D below can be accepted.

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 D 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 6).

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 7). 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 7).

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 7).

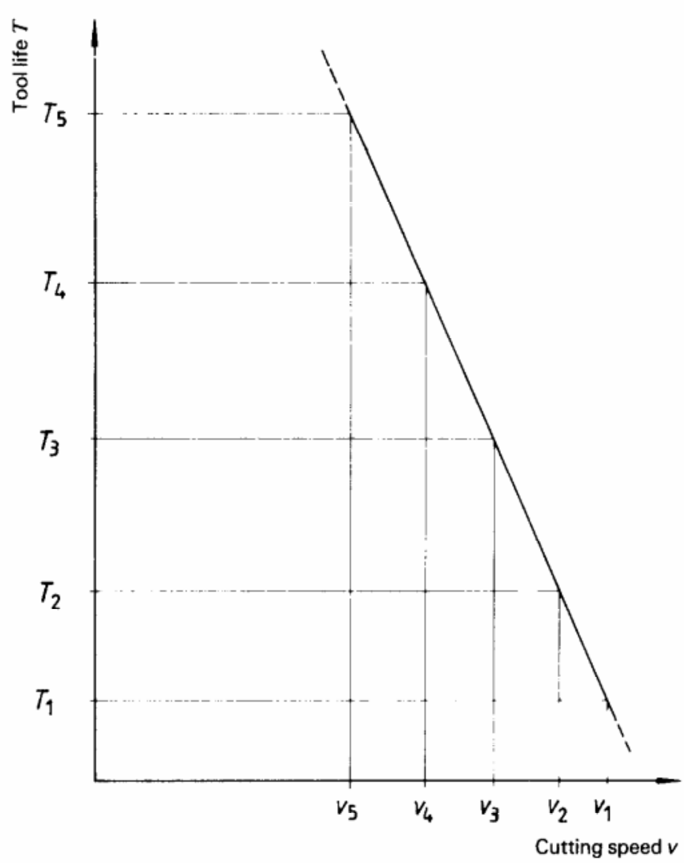


Figure 6 — Example of a *vT* curve (logarithmic scales)

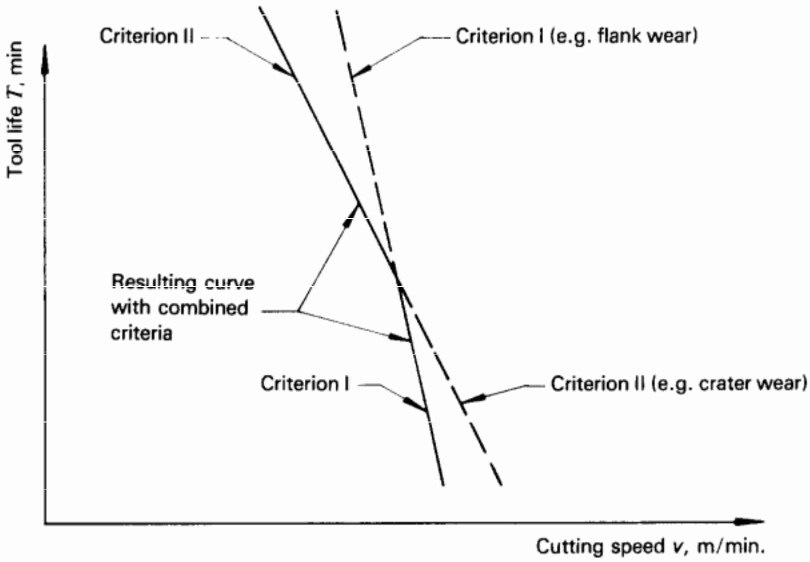


Figure 7 — Set of two vT curves resulting from the use of two different criteria and a "broken" vT curve resulting from the use of combined criteria (logarithmic scales)

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 8), the arithmetic mean values (see figure 9) or the maximum and minimum values (see figure 10). The arithmetic mean values and the maximum and minimum values are calculated statistically as described in annex D.

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 7.4.1).

Provided that the recommended number of test runs are carried out (see 10.3), the tool life values can be treated statistically so that the mean value, the standard deviation, the maximum and minimum values and the confidence intervals can be calculated.

Figures 8, 9 and 10 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 time taken for one edge to reach the limiting value of deterioration, the time taken for all edges to reach the limiting value, the time taken for the average of the values measured on all edges to reach the limiting value or 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 6). 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.

When varying the cutting conditions in order to obtain tool-life curves as mentioned above, there is a great risk of changing the type of deterioration. Thus it is necessary to note that the straight tool-life curve is relevant over its whole length only if the same tool-life criterion can be used for every combination of cutting data.

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 D.

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.

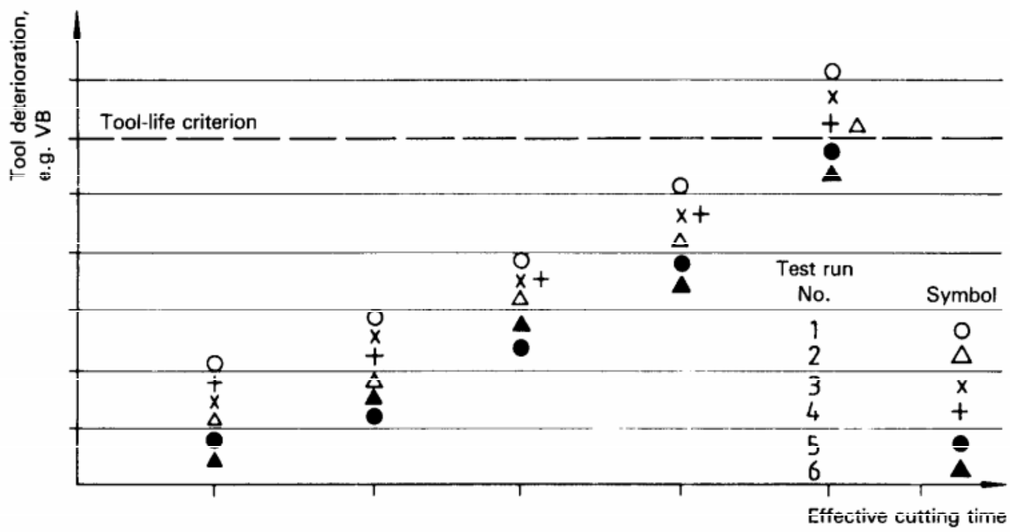


Figure 8 — Tool deterioration values for the individual edges of a milling cutter plotted against cutting time

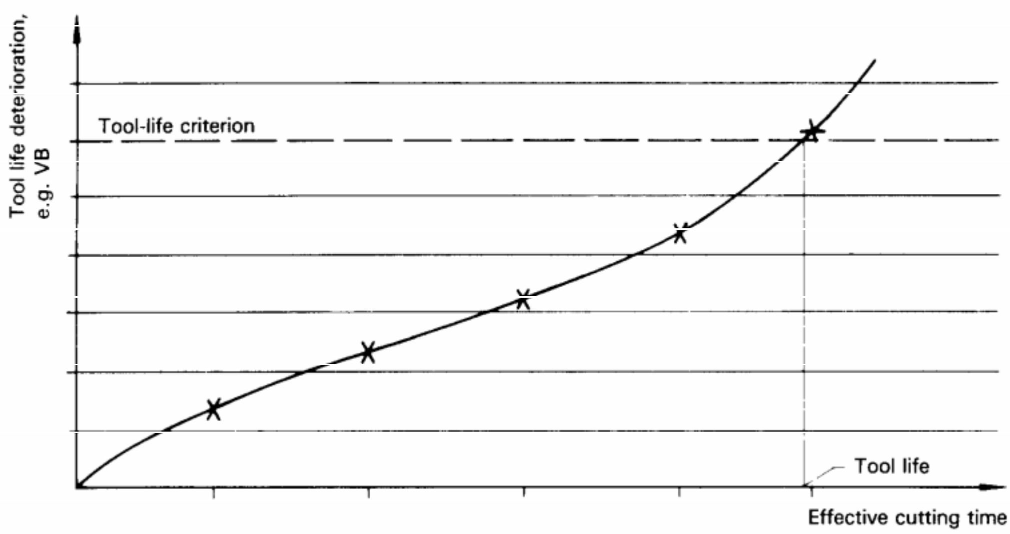


Figure 9 — Arithmetical mean values of tool deterioration plotted against cutting time

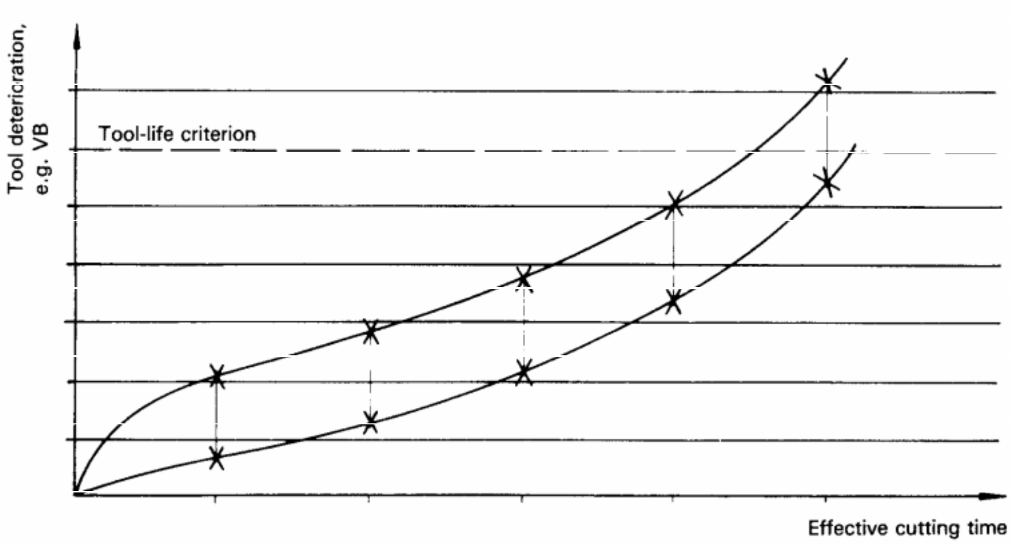


Figure 10 — Maximum and minimum tool deterioration values observed for the 95 % confidence level from measurements on individual edges of a milling cutter plotted against cutting time

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 of the 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

Tool setting

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

B.1 Introduction

Subclauses 4.5, 9.3.3, 9.3.4 and 9.3.5 give recommendations for mounting the tool and relate to cutting edge runout with the tool mounted on the machine tool spindle. It is usual, however, for face milling cutters to be set up in advance and, therefore, to be serviced in isolation from the machine tool.

The following clauses outline certain recommended procedures for setting up face milling cutters, on the basis of good engineering practice, and should be regarded as minimum requirements. In certain instances, manufacturers' instructions may be more stringent and should be followed to ensure both the accuracy and the good performance of a particular face milling cutter.

B.2 Damage and cleanness

It is essential, prior to any positioning check or resetting of inserts, that the milling cutter body surface which locates on the machine spindle and those surfaces which locate the inserts are thoroughly inspected for burrs and indentations. Any defects of such a nature should be carefully dressed using a fine hone and all resulting debris should be removed so that the body can be mounted on a surface plate or other fixture and the inserts seated properly.

For new tools, all protective coatings should be removed and for used tools all swarf and cutting fluid residues should be removed with the aid of a suitable solvent to ensure positive location on a surface plate or other fixture.

Particular attention shall be paid to the cleanness of screws, screw threads, and slots in the body and corners of any recesses in the cutter body.

B.3 Setting equipment

To check or reset a face milling cutter it is recommended that a surface plate, a dial indicator (graduated to 1/1 000 mm) fitted with a flat anvil and mounted on a rigid stand and torque wrenches be used.

B.4 Body accuracy

With the face milling cutter supported on a surface plate, the accuracy of the tool body should be established using a single "master" insert which is positioned in each insert location in turn, and the axial deviation of the cutting edge position at each insert location is then measured using the dial indicator. For this assessment it is essential that one corner of the "master" insert be labelled and its orientation maintained in each separate location; in addition, it is vital that the magnitude of the clamping force used at each location is the same.

This procedure will establish the variation in insert location surfaces which, for certain styles of cutter, may be adjusted to reduce the variations in insert positioning. For such cutters the clamping force used to fix the locating surfaces should be equal at every insert location and this force should be applied using a torque wrench in accordance with the tool manufacturer's recommended values. Careful cleaning of clamping screws and their mating screw threads prior to coating with a suitable lubricant film will assist the uniformity in clamping force.

In those cases where cutter bodies do not have the facility for insert location adjustment, the variations in insert location surfaces may be reduced by selective mounting of inserts.

B.5 Insert mounting

All inserts for mounting and the insert locations on the cutter body should be cleaned thoroughly prior to the inserts being clamped into position using a "finger-tight" clamping force. In turn, each insert clamp should then be progressively tightened to distribute evenly stesses induced in the cutter body due to clamping until the manufacturer's prescribed torque value has been reached.

Variations in cutting edge position can be determined using a surface plate, dial indicator and stand. In some cases, dependent on the quality of inserts used, the actual deviations in cutting edge position may be minimized by selective mounting such that variations in insert size combined with variations in insert location surfaces virtually cancel one another.

Annex C

Example data sheet

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

Face milling	Purpose of the test	Test No.	Page ...... of	
			Date	Signature ....

Tool

Cutter
☐ ISO 6462, type B, ϕD = 125 mm
or ☐ ....
Manufactured by ....
Insert — Grade
☐ ISO 3365/SPAN 1203 ....
or ☐ ....
Manufactured by ....
....
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. ....

Machine tool

☐ Horizontal ☐ Vertical
Manufactured by ....
....
Model .... No. ....
Spindle power .... kW

Cutting fluid

☐ Yes ☐ No Amount ... l/min
Manufactured by ....
....

Cutting conditions

Used condition						
Condition No.		I	II	III	IV	V
Axial depth of cut a_a	mm	2,5			4	
Radial depth of cut a_r	mm	0,6 D				
Feed f_z	mm/tooth	0,125	0,2	0,315	0,5	
Feed speed v_f	mm/min					
Cutting speed v_c	m/min					
Spindle revolution	r/min					
Location of cutter relative to the centre-line		On centre-line	Up-milling mm		Down-milling mm	

Tooth No.	Run-out axial	Run-out radial	Actual tool travel min/mm/workpiece .... Deterioration Code	Position	Value	Actual tool travel min/mm/workpiece .... Deterioration Code	Position	Value	Actual tool travel min/mm/workpiece .... Deterioration Code	Position	Value	Actual tool travel min/mm/workpiece .... Deterioration Code	Position	Value	Actual tool travel min/mm/workpiece .... Deterioration Code	Position	Value	Actual tool travel min/mm/workpiece .... Deterioration Code	Position	Value
1																				
2																				
3																				
4																				
5																				
6																				
Notes																				

Tool-life criteria		
Code	Position	Value

Evaluation : clause 10

Notes

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

Annex D

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 $\overline{x}$ 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 :

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

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 $\overline{x}$, divided by the number of test runs n minus 1.

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

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 $\overline{x}$ plus and minus its variation :

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

and

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

where t is a constant obtained from table 6 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 6.

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 :

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

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 6 — 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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