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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.

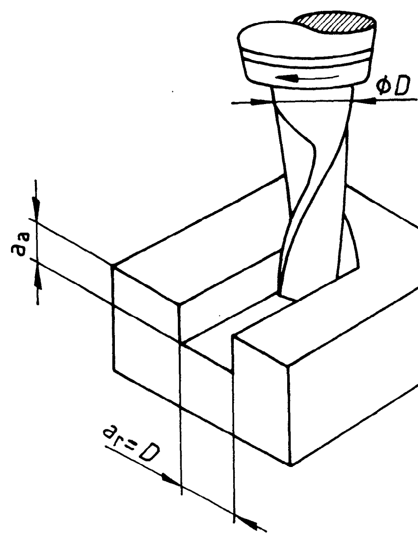
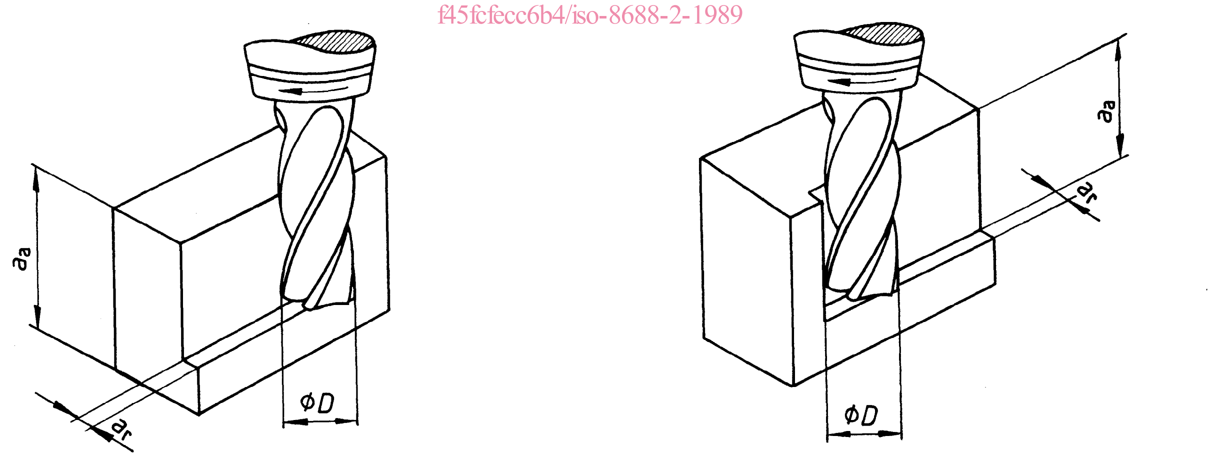


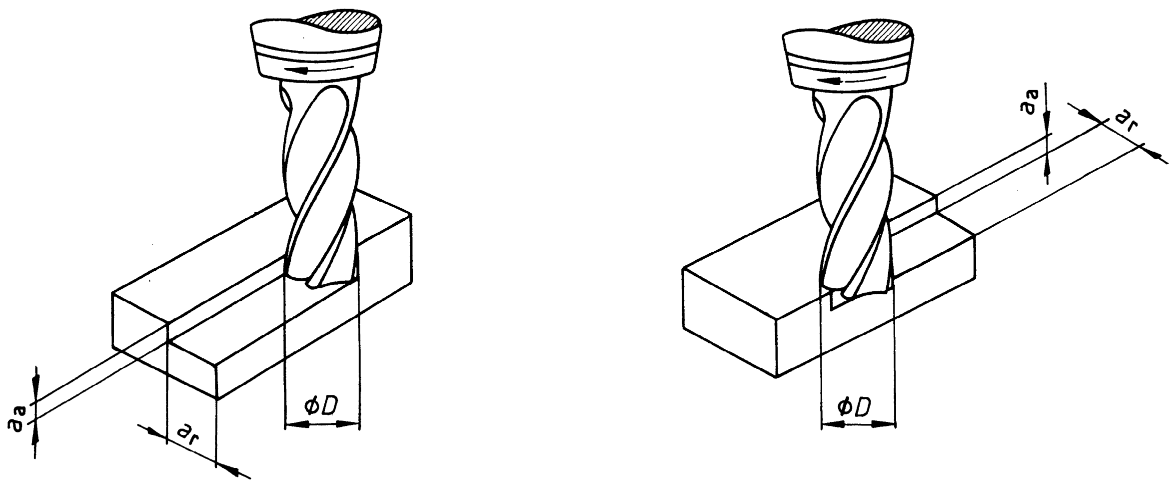
Figure 1 — Slot milling



a) Up milling

b) Down milling

Figure 2 — End milling ($a_a > a_r$)



a) Up milling

b) Down milling

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).

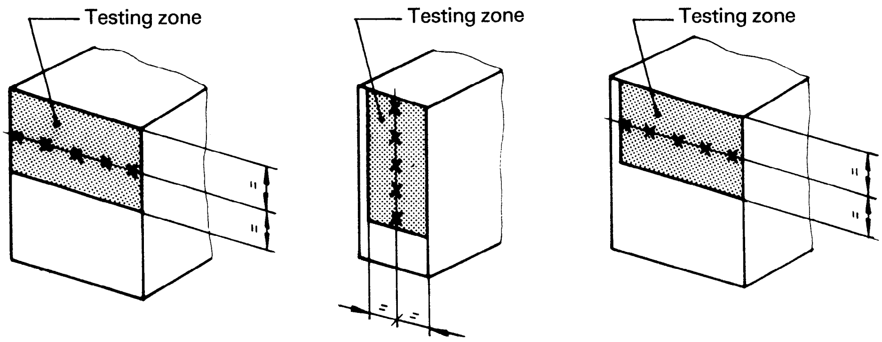


Figure 4 — Hardness testing

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

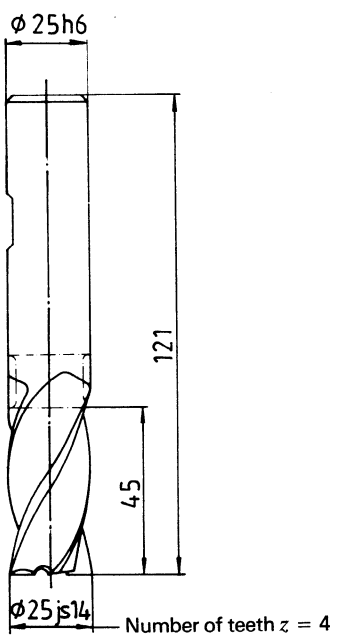


Figure 5 — End mill
(see ISO 1641-1)

Dimensions in millimetres

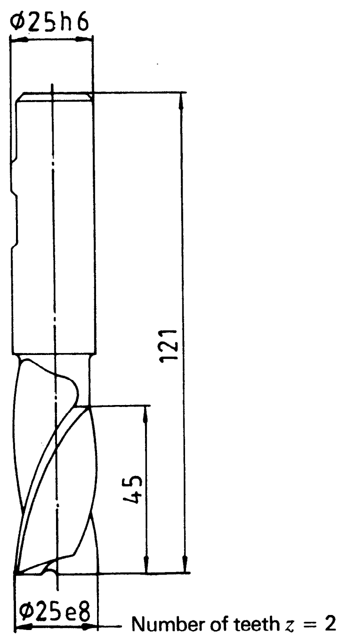


Figure 6 — Slot drill
(see ISO 1641-1)

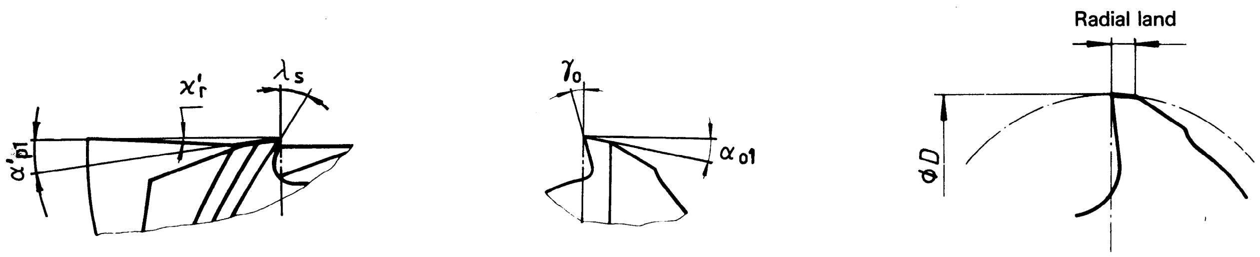


Figure 7 — Tool geometry

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).