University of Southern Queensland

Faculty of Engineering and Surveying

Research and Development of

Multi Purpose Carbide End mill

A dissertation submitted by

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In fulfillment of the requirement of

Courses ENG4111 and 4112 Research Project

Towards the degree of

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Abstract

In the metal cutting industry, End mill cutter plays an important role in cutting metal to obtain the various required shapes and sizes. It is also an essential cutting tool for the engineering productions in the various aspects of engineering industries. For example, Automobile, Aerospace, Precision Engineering, Metal Stamping and Plastic Molding industries, therefore End mill is the most common and widely used type of milling cutters where the demand is very huge.

There are many different brands and types of End mill cutters available in the market, which manufacture from Japan, America, Europe, Korea, India, Taiwan and China, etc. The increasing competition in the market region spurs the various manufacturers to constantly develop many different kinds of high performances End mill cutters to cater the huge demand in the various aspect of engineering industries which can speed up the production time, processes and also reduce the production and labour cost.

My company OSG ASIA PTE LTD is the 100% subsidiary of OSG Corporation, which is one of the top manufacturers of cutting tools in Japan and has been manufacturing End mill cutters for the past 30 years. We have been constantly improving and developing innovative and high performances End mills cutters to constantly support the various aspect of engineering industries by providing them with the latest technologies, tooling solutions and high performances End mill cutters. On the other hand, it is also to compete with various End mill manufacturers globally in order not to face out in the metal cutting industry.

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ENG4111 & ENG4112 *Research Project*

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the works is original and has not been previously submitted for assessment in any other course or institution, expect where specifically stated.

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Student Number: D11379785

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Signature

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Date

Acknowledgements

I would like to express my deepest gratitude and most sincere appreciation to my supervisor for his insight and valuable guidance, supervision, suggestions and constant encouragement, also to my company for their approval and support throughout this research project.

I am equally grateful to University of Southern Queensland for making this project a success. Without their understandings and tolerances on my hectic schedule, this research project will not be able to complete within the specific time.

Thanks to all the teaching staffs for imparting valuable knowledge throughout this well organized degree course, which laid the foundations for this research project. Valuable technical knowledge gained during this course is applied into the research project.

Lastly, I would like to express my deepest love to my parents and family members. Without their continuous love and encouragement throughout this academic study, this research project would not be possible.

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1. Introduction

This project is to conduct a research and develop a Multi Purpose Carbide End mill to suit all kinds of cutting processes and engineering manufacturing works, which will uncover the background information on different kinds of End mill structures, tool materials and various surface treatments on the cutter. Research will also be conducted on the different types of cutting operations, cutting conditions, work materials and its characteristics used commonly in manufacturing processes.

Analysis and troubleshooting on the common problems faced by different types of End mill cutters during manufacturing processes will also be studied by conducting test cut on various work materials to justify its cutting performances and cutting conditions. Upon achieving all these technical information, I will start designing and constructing of the Multi Purpose Carbide End mill.

Once the Multi Purpose Carbide End mill prototype is produced, test cut on the End mill will be conducted to justify its cutting performances and condition on various work materials. Lastly, I will analysis and compare the Multi Purpose Carbide End mill test results against the conventional End mills to verify its cutting performances, cutting conditions and tool life.

1.1 Purpose

The purpose of this project is to help to solve the common problems faced in the manufacturing processes on the various aspects of the engineering industries. As these common problems will lead to more serious situations, like the increase in production time, production cost, machine cost, tooling cost and labour cost.

Some of the common problems faced in using End mill cutters are:

- Chipping and breakage of the End mill cutters due to wrong selection of cutters, inappropriate tool materials, milling speed or feed rate too high, excessive tool wear and not enough coolant.
- Unsatisfactory finishing of the work materials due to uneven hardness distribution on the work materials, End mill cutters not rigid enough and poor alignment accuracy of cutters against the work materials.
- Chattering marks on the work materials due to distortion and vibration of the End mill cutters, poor rigidity of the cutters and large spindle run out.

I strongly believe that, if the research and development of this Multi Purpose Carbide End mill is a success, it will greatly help the various aspects of the engineering industries in their manufacturing processes to solve their common problems in using End mill cutters. Generally, this Multi Purpose Carbide End mill will help in reducing production cost, production time, tooling cost, labour cost and speed up the manufacturing processes. On the other hand, it will also contribute a generous profit margin to my company.

1.2 Project Methodology

Before starting to do the project, definitely there must be some fundamental stages like; planning, discussions, research and development are the few important stages that must be conducted. As for this project, it is a company project and there are many people involved in it. They are the project manager, project engineers, project supervisors, and machinists. As for me, I’m playing the role as a project engineer and I will be the one dealing with research on required information and designing.

1.2.1 Fundamental steps of Project

- In the Planning stage, most of the ideas on how to start a project are theoretical basis through brainstorming method.
- After getting a rough idea on how to work about it, discussion stage comes in. This is a very important stage because a lot of matters have to be discussed and involved many people. As it is very important to voice out any matters and accept by all people involved in the meeting before can go further step.
- Upon finishing the discussion stage, a much clearer view about the project is out and the project manager will start to allocate different tasks to different people to start the project. Firstly, the project engineer will start the research stage and get all the required information ready for next stage.
- Once all the required information already available and project manager already given the green light to proceed, supervisor will get the machinists to start producing it.

The above few points are the very general guide to work on a project and on my next topic, I will briefly discuss on the general approach on how I work on my project with the helps of my fellow colleagues.

1.2.2 General Approach to Project

There are two general approaches to start this project. Planning & Discussion Stage is the first approach and follow by Research & Design Stage.

- **Planning & Discussion Stage**

  Brainstorming for various ideas to develop the Multi Purpose Carbide End mill and discuss with project manager for approval on my ideas. Upon reaching the approval stage, a formal meeting will be held which involves many people. Communication takes place in the meeting room where all the people will voice out suggestions and ideas for changes or modifications until everything is clear, project manager will make the final decision and release the project budget for approval.

- **Research & Design Stage**

  Research on different types of End mill cutters and their specifications will be conducted then study on the common problems faced while using those End mill cutters. Analysis those obtained information and come out with various solutions on developing the Multi Purpose Carbide End mill cutter. Start to design the Multi Purpose Carbide End mill and draw it in AutoCAD software and once everything is done, submit to project manager for review and approval.

2. What is an End mill?

Micro-grain end mills designed for cutting steel are Milling is a machining process in which metal is removed by a rotating multiple-tooth cutter. Each tooth removes a small amount of metal with each revolution of the spindle. An End mill is a milling cutter, which is shank-mounted to the machine tool. It has cutting edges on the face end as well as on the periphery, and may be single or double end construction. End mills are the most common and widely used type of milling cutters.

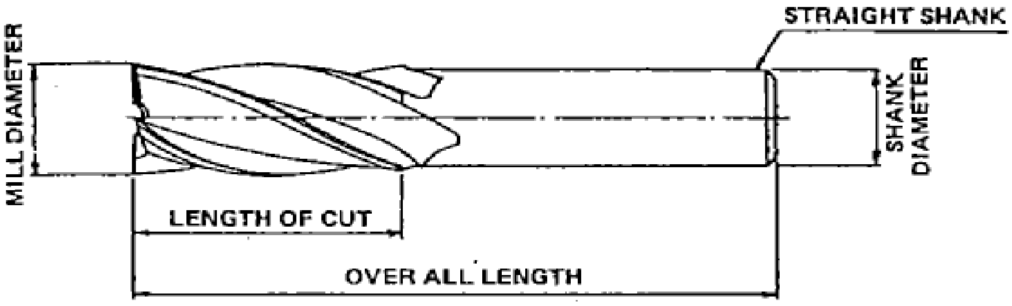


Fig.1. Straight Shank End mill

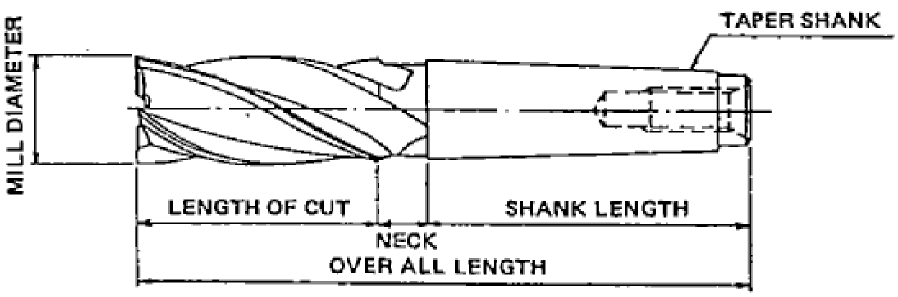


Fig.2. Taper Shank End mill

2.1 Terminology for End mill

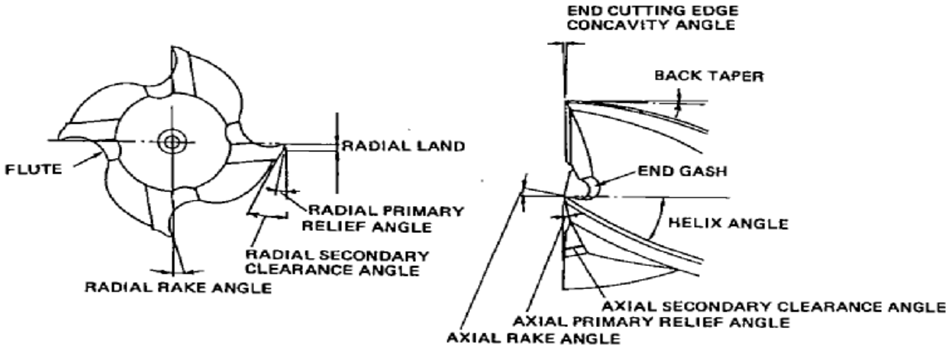
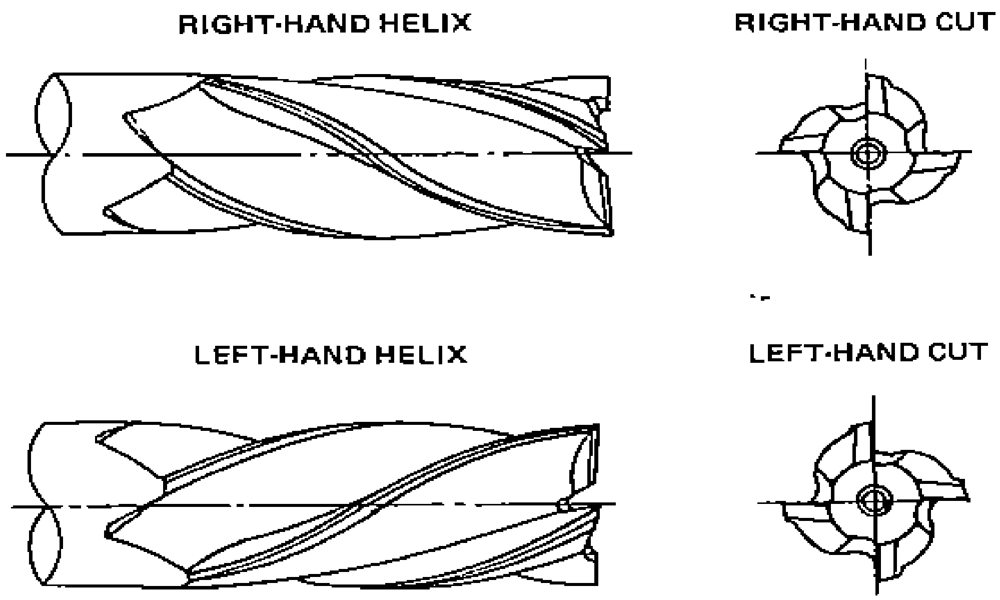


Fig.3. Detailed Flute Form

Clearance angle	The angle, which indicates the inclination of the flank relative to the finish surface.
Cutting edge	One of the elements of the cutting part. It is the intersecting line of the face and flank.
End cutting edge	The cutting edge at the end face opposite to the shank.
End gash	The flute of the end cutting edge.
Flute	The indented part between the neighbouring cutting edge and the heel. It becomes the chip space.
Helix angle	The angle made by the axial line and the helix cutting edge.
Length of cut	The length of the cutting part.
Neck	The necked part between the shank and the cutting part.
Overall length	The overall length (including length of cut and shank) measured parallel to the axis.
Primary relief	The part directly behind the cutting edge.
Radial Rake angle	The angle made by the inclination of the face relative to the reference plane.
Relief angle	The removal or absence of tool material behind the cutting edge.
Shank	The part of the tool held by the milling machine.
Shank diameter	The diameter of the straight shank.
Shank length	The length of the shank measured in parallel to axis.
Straight shank	The circular cylindrical shank.
Taper shank	The circular cone shank.

2.1.1 Direction of Helix & Hand

When an End mill is viewed from the shank side, the End mill having cutting edge face right is RIGHT HAND, and the End mill having cutting edge faced left is LEFT HAND. Both end mills have right helix type and left helix type, which makes 4 types in total.



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ig.4. Right-Hand Helix & Left-Hand Helix

(A) Right Hand Cut - Right Hand Helix

(B) Left Hand Cut - Left Hand Helix

(C) Right Hand Cut - Left Hand Helix

(D) Left Hand Cut - Right Hand Helix

The material and the shape of work piece should determine direction of hand and helix. Generally Type (A) is applied. In Case of Type (A) & (B), as cutting resistance force works to the teeth end direction, their shank used to have a thread, and in case of Type (C) & (D), as the cutting resistance force works to the shank end direction, their shanks used to be a taper with a tang. But currently, straight shank will do in any case due to the improvement of milling chucks.

The milling with Type (A) & (B) end mill is smooth as chips come up along the flutes. On the other hand, in milling with Type (C) & (D) surface finish of bottom face is rough and tool life is short, because chips go down toward work piece. Therefore these types are applicable only for special uses like drilling through holes or finishing cuts, in which chips do not cross over the marking-off line and burrs are not produced on the upper surface of work piece.

2.1.2 Number of Flutes

Number of flutes of end mills should be determined by milling materials, dimension of work piece and milling condition. Generally speaking, an end mill having small number of flutes and having big chip room is used for roughing cut and large number of flutes end mill is used for finishing cut.

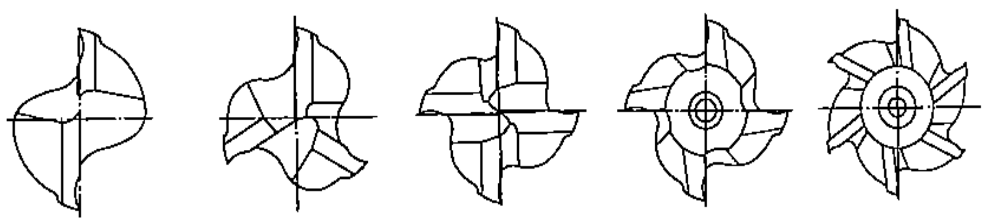


Fig.5. Different Flute Forms

The diagram below shows the differences of 2 flutes End mill to 6 flutes End mill, where the End mill is having less flute, the chip room is bigger and better chip ejection and End mill having more flutes, it is more rigid which will have lesser deflection and breakage.

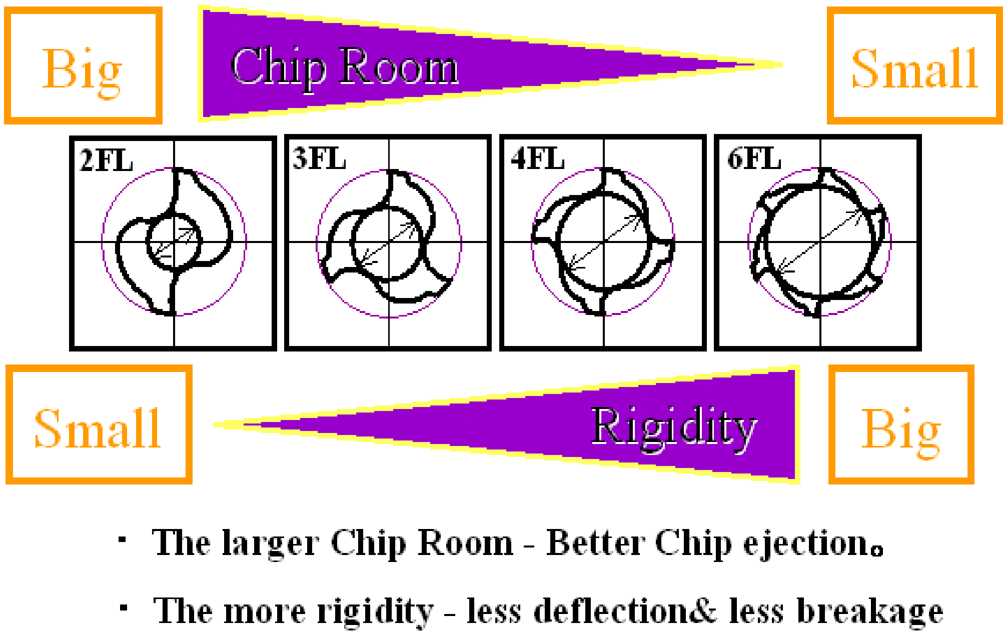


Fig.6. Chip Room & Rigidity

2.1.3 End Cutting Edge

There are Center Cut Type and Center Hole Type. The latter cannot be used for drilling, but is convenient for regrinding, while the former can be applied for any operation.

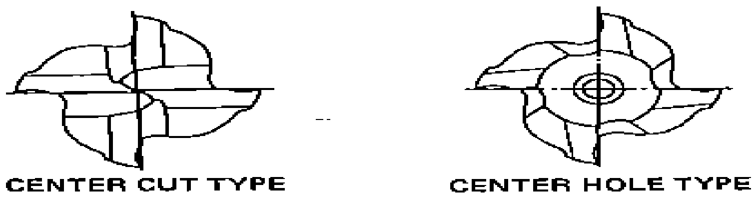


Fig.7. Different type of Cutting Edge

2.1.4 End Profile

End Style is divided into; Square End and Ball End. Corner radius, corner chamfer, corner round and drill nose can be gained by modification when regrinding, or by special order.

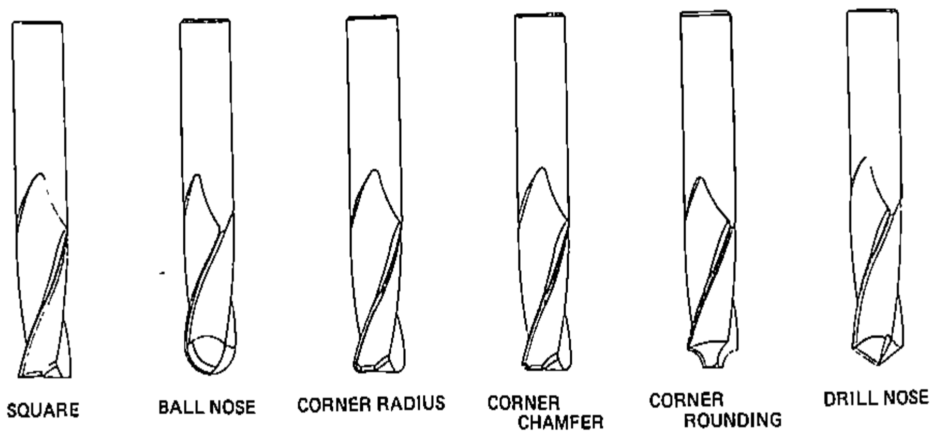


Fig.8. Various types of End Profile

2.2 Types of End mill

End mill cutters are probably the most commonly used of all the various types of cutters in the metal cutting industry. There are several different types of End mill available in the market and each individual type of End mill performs different functions and purposes.

Fig. 9. Two Flutes End mill

The feature of 2 flutes End mill is designed with wide chip space, which is good for chips ejection and high-speed milling. It is normally used on conventional application, such as slotting, drilling and roughing purposes and the number of flutes should also be determined by the work material, dimensions of the work piece and milling conditions.

Fig.10. Multiple Flutes End mill

Multiple flutes End mills have several different types of design and features. For example, 3 flutes, 4 flutes and 6 flutes End mill and different number of flutes on the End mill cutters are cater for different cutting operations. In general, multiple flutes End mill is more rigid than 2 flutes End mill therefore it is normally used for side milling and finishing cut operations.

Fig.11. Ball Nose End mill

Ball Nose End mill is used for profiling and finishing operation of corner radius. This End mill is especially effective when milling curved surfaces and the lesser of the Ball Run out tolerance, the better the surface finishing of the work materials.

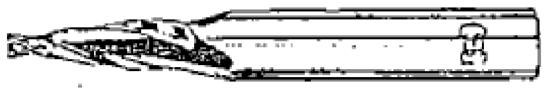


Fig.12. Tapered End mill

Tapered End mill has a constant helix flute on all the length of cut therefore the radial rake angle is constant on all the length of cut, which provides excellent sharpness. It is used for taper process for which the work material has a tapered shape. The constant helix flute and the sharpness of the cutting edge provide a smooth surface finish.

Fig. 13. Roughing End mill

This End mill is suitable for heavy duty milling of mild steels, hard steels, stainless steels and non-ferrous steels. The features are for heavy duty milling with deep cut, fast feed and high productivity is made possible by chip breakers in the cutting edge. Roughing End mill is divided into two groups.

- Fine pitch for steel milling, cutting speed can be increased by 30-50% and tool life is over twice as long as course pitch.
- Coarse pitch is used for cast iron and aluminum alloy.

Fig.14. Roughing & Finishing End mill

This End mill is designed for roughing and removing large amounts of metal as well as getting a medium surface finish. It is designed with nicks on the peripheral teeth. These nicks are shifted by pitch/number of flutes and the crest is flat. This shape tool creates a better surface finish. Chips are small and fine and there is a smooth chip ejection. However, the required cutting force is higher than roughing End mills but still lower than conventional End mills. There are two main kinds of roughing and finishing End mills.

- **TUF-nick (TFS):** This roughing and finishing type End mill improves the surface finish and the tool life. During the finishing process the surface roughness is almost the same as the surface produced by a conventional End mill. When the surface finish tolerance is limited, TFS is the best.
- **Kraft mill (KFR):** There are only two kinds of Kraft mills: steam oxide and Tin coated. The Kraft mill is used when there is lack of rigidity in the machine. In fact, with this kind of End mill, chattering does not occur easily. The surface roughness is the same as TUF-nick End mills.

2.3 Tool Material

The recent advancements in work materials are very remarkable, being developed are hard Chromium-Molybdenum steels, tool steels and heat resisting alloys to be used for parts of aircraft, engines, etc. On the other hand, there have been big developments in the machine tools, making operations more productive and economical with the presence of high-speed full automatic profiling machines, Numerical Control milling machines and machining centers. In order to meet the requirement of milling such a difficult to machine material, the improvement of tool materials is indispensable.

Selecting the proper cutting tool material increases productivity, improves quality and ultimately reduces costs. Many factors affect the decision of which material to use:

- Hardness and condition of the work piece material
- Rigidity of the tool, the machine and the work piece
- Production requirements
- Operating conditions such as cutting force, temperature and lubrication
- Tool cost per part machined (including initial tool cost, grinding cost, tool life, labour cost)

There are three important properties that must be considered when manufacturing end mills:

1. Hardness
2. Wear Resistance
3. Toughness and Strength

- Hardness is the ability of a material to resist stresses and maintain hardness and cutting efficiency at elevated temperatures.
- Wear is the most common point of failure for cutting tools. Flank wear is directly related to speed and feed. As speed and feed are increased, rate of wear also increases.
- Toughness is the ability of the material to absorb energy and withstand plastic deformation without fracturing under a compressive load.

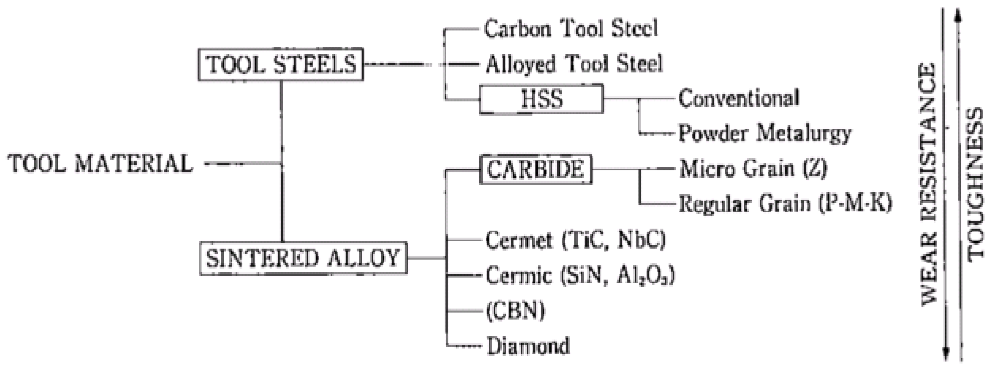


Fig.15. Various Tool Materials

2.3.1 High Speed Steel (HSS)

High Speed Steel has high toughness rating and is comparably cheap. HSS with cobalt is used for premium HSS and for higher cutting speed operations. High vanadium and high cobalt HSS cutters are used for difficult to machine materials.

Application	DIN	JIS	AISI	Nominal Composition (%)						
				OSG	C	W	Mo	Cr	V	Co
For conventional use	S 6-5-2	SKH 51	M 2	–	0.8	6	5	4	2	–
	S 6-5-3	SKH 53	M 3-2	HSSE	1.2	6	5	4	3	–
	S 6-5-2-5	SKH 55	M 35	HSS-Co	0.8	6	5	4	2	5
	–	SKH 56	M 36	HSS-Co	0.9	6	5	4	2	8
	–	SKH 58	M 7	HSS	1	1.8	8.8	4	2	–
For difficult-to-machine materials	–	SKH 57	–	–	1.2	10	3.5	4	3.4	10
	S 2-10-1-8	SKH 59	M 42	–	1.1	1.5	9.5	3.8	1.2	8
	–	–	M 43	–	1.25	1.8	9	3.8	2	8.3

Table 1. Application on High Speed Steel

2.3.2 Particle Metallurgy High Speed Steel

Beside, H.S.S. Co. materials, there are also higher grade of end mills made of Particle Metallurgy H.S.S. These types of tool material are with better quality and made possible on the presence of high vanadium super H.S.S. end mills.

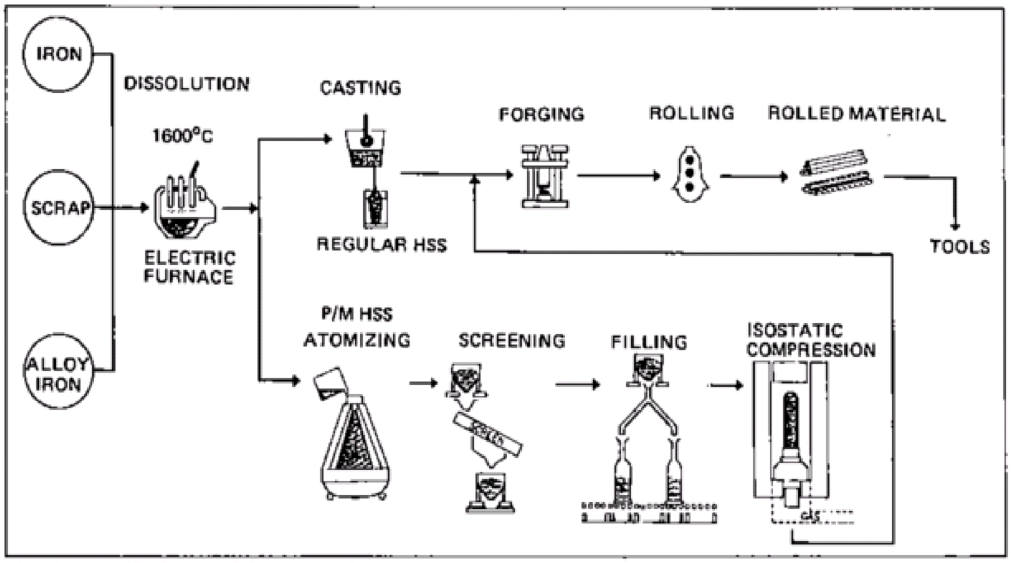


Fig.16. Manufacturing Process: Particle Metallurgy H.S.S. vs. Regular H.S.S.

Properties of Particle Metallurgy (HSS)

- Very fine and uniform size of carbides
- High toughness prevents tools from chipping in discontinuous milling

- To get high and uniform hardness
- Excellent grind-ability makes the manufacturing easy

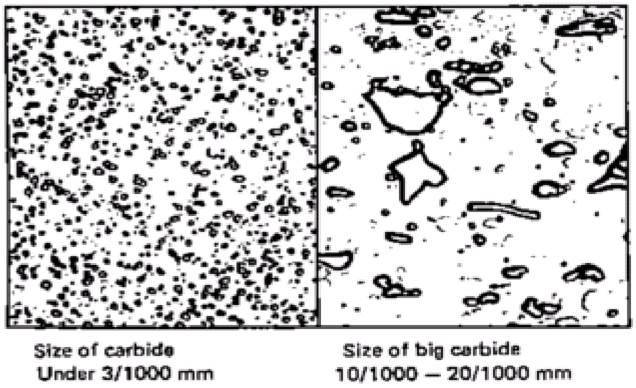


Fig.17. Microscope Photograph (Magnification: X400)

As the material is much more expensive, if it is used for milling mild materials, the user cannot enjoy the advantages of the Particle Metallurgy (HSS) end mills. In figure below, the ration of the performance of Particle Metallurgy (HSS) end mills to the same Conventional (HSS) end mills is indicated in the Y-axis left side, and the ratio of the machining cost of Particle Metallurgy end mills to the same of Conventional H.S.S. end mills is indicated in the Y-axis right side. Work material is shown in the X-axis.

The curve of the performance ration explains the harder or the more difficult to machine the work material is, the better the performance ratio of Particle Metallurgy (HSS) end mills is. The curve of machining cost also explains that Particle Metallurgy (HSS) demonstrates its advantage in machining cost in difficult to machine materials. When the two curves cross (the ratio of machining cost = 1) the ratio of performance marks 2. It means in those range in which the ratio of performance is more than 2, we can make good use of Particle Metallurgy (HSS) end mills.

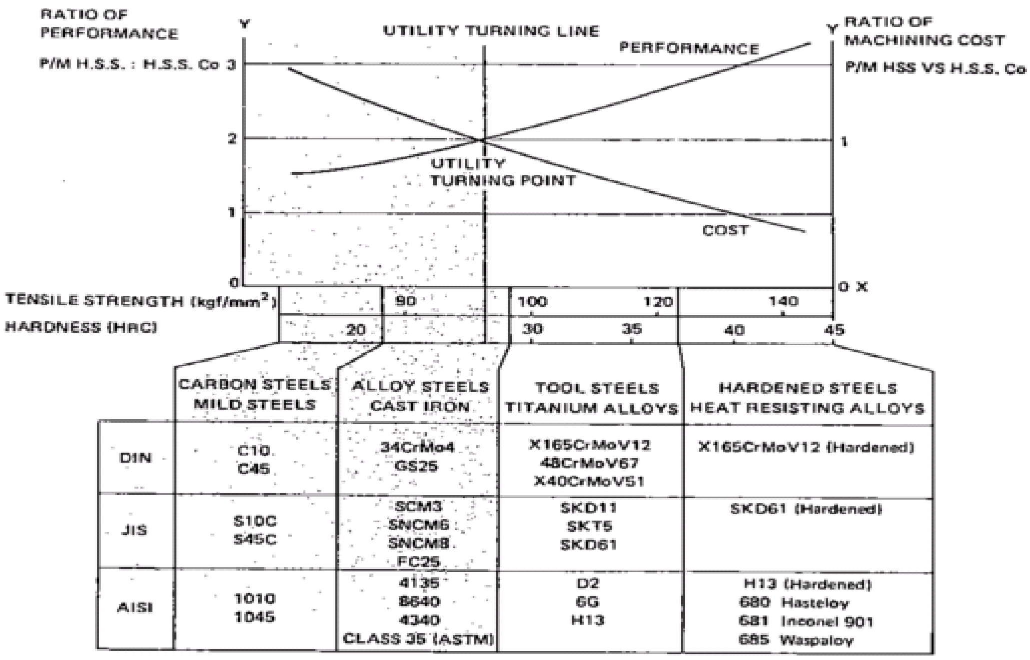


Fig.18. Performance vs. Machining Cost

Features of Particle Metallurgy H.S.S. End mills

- Rigid flute form to withstand heavy cutting torque
- High hardness for wear resistance
- High edge strength
- Shorter cutter sweep for higher rigidity (2 Flute)
- Toughness equal to conventional (HSS).

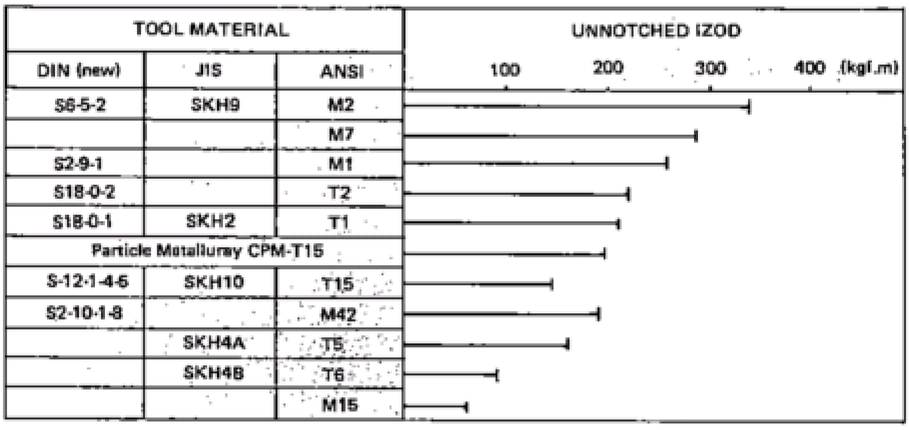


Fig.19. Relative Toughness at Typical Working Hardness

2.3.3 Carbide Material

There is various type of carbide materials exist in the market and I will explain on the two most common types, which are the Tungsten Carbide (TC) and Micro-grain Carbide (MG).

Tungsten Carbide (TC)

Tungsten Carbide included in the material composition provides higher wear resistance and is generally used for insert type end mills and turning tools.

There are four groups of carbide tools:

- Group P – for milling steels. If the work material produces longer chips, the tool must have high heat resistance. Tantal carbide (TaC) or Titanium carbide (TiC) is added in order to provide this heat resistance.
- Group M – this material performs in between P and K group
- Group K – for milling cast iron. Example, non-ferrous metal (Aluminium and copper). Chips come out like fine powder when milling cast iron.

- Group Z – for micro-grain tools. Recommended for small size milling in order to prevent chipping or breakage, and to provide higher toughness.

  All groups have cobalt content.

Symbol	Designation	Composition	Co content (%)	Hardness (HRA)	Transverse rupture strength (N/mm²)	Trend of performance
P	P10 P20 P30	WC+Co +TiC+TaC	4~9 5~10 6~12	up to 91 90 89	883 1079 1275	wear resistance ↑ / toughness ↓
M	M10 M20 M30	WC+Co +TiC+TaC (VaC)	4~9 5~11 6~13	91 90 89	981 1079 1275	
K	K10 K20 K30	WC+Co	4~7 5~ 8 6~11	90.5 89 88	1177 1375 1471	
Z	Z10 Z20 Z30	WC+Co +TaC	8 10~13	91 89.5 89.5	1275 1471 1668	

Table 2. Carbide Classification

Micro Grain Carbide (MG)

Milling with normal tungsten carbide end mills is limited to high speed milling over 50 m/min and to the use only for aluminium alloys, cast iron, etc., because of lack of toughness. It cannot mill steels satisfactory. This fact requires an ideal mill, which can machine steels at a low surface speed, getting toughness and greater coherence (binding power) among grains to avoid material pullouts.

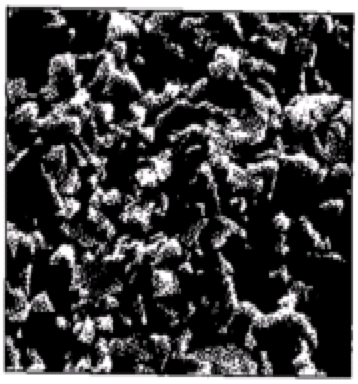
Micro-grain carbide is recommended for improving metal removal rates and tool life over those possible with high-speed steels for the condition where carbide with normal strength level would chip or break. The high edge strength of micro-grain carbide allows the use of high-speed steel tool geometry and when necessary, speed as low as those used with high speed steels.

Properties of Micro-grain Carbide

Micro-grain carbide has great toughness as well as wear-resistance and rigidity, which is as same as normal carbides. Its transverse rupture strength is 400 Kgf/mm2, which is almost the same as high-speed steel. Figure below shows the variation of feed when various end mills breaks. It certifies the toughness of MG end mills.

	HARDNESS HRA	TRANSVERSE RUPTURE STRENGTH kgf/mm^2	WC GRAIN SIZE (1/1000 min.)	
			BEFORE SINTERING	AFTER SINTERING
MICRO GRAIN CARBIDE	90.5	400	UNDER 0.5	UNDER 1.5
NORMAL CARBIDE	92.0	170	UNDER 2.0	UNDER 6.0

Fig.20. Properties of Carbide



x 10,000

Fig.21. Micro-grain Carbide

x 10,000

Fig.22. Normal Carbide

Features of Micro-grain Carbide End mills

- Provided with sharp cutting edge with a special flute form best suited to cut steel (hardened and high alloy steel)
- Tolerances of both two-flute and four-flute types of end mills are standardized to “minus range”. Thus, there is no necessity to make adjustment of dimensions after replacing the tools
- Furthermore, the total length and shank diameter are provided especially for numerical control machining, eliminating the necessity of measurement at each time of tool replacement.
- In addition to the features of excellent wear resistance and high rigidity, the Micro-grain with higher toughness is utilized.
- Also displays a full ability to cut cast iron and aluminium

3. Selection of Cutting Fluids

Milling process can be very complicated work and it significantly affect machined surface accuracy, tool life, cutting torque, etc. Different types of cutting fluids also affect it. Cutting fluids have basic three functions:

- Cooling
- Lubrication
- Anti-welding.

For the selection of cutting fluids, we must take the following three points into consideration:

- To make tool life longer
- To get better surface finish
- To get higher efficiency of operation

The table below shows the general properties of various cutting fluids.

	CUTTING OILS			WATER SOLUBLE FLUIDS	
TYPE / PROPERTY	STRAIGHT	COMPOUND INACTIVE	COMPOUND ACTIVE	EMULSIFIABLE FLUIDS	CHEMICAL FLUIDS
LUBRICITY	○	●	●	○	Δ
ANTI-WELDING	Δ	○	●	-	-
COOLING	○	○	○	●	●
INFILTRATION	●	●	●	Δ	○
RUST PREVENTION	●	○	○	Δ	Δ
FUMING & IGNITABILITY	Δ	Δ	Δ	●	●

● Very Good ○ Good Δ Insufficient

Table 3. Properties of Cutting Fluids

MILLED MATERIAL	GENERAL RECOMMENDATION	TO IMPROVE SURFACE FINISH	TO IMPROVE PRODUCTIVITY	TO IMPROVE TOOL LIFE	POSSIBILITY OF USE OF WATER SOLUBLE FLUIDS
CARBON STEELS ALLOY STEELS	Sulfur base-inactive (Sulfur 1-3%)	Sulfur-chlorine base-active (active sulfur under 2%)	Sulfur base-inactive (Chlorine 5-10%)		Emulsifiable (Dilution 1:10)
STAINLESS STEELS HEAT RESISTING STEELS	Sulfur-chlorine base-active (active sulfur under 2%) (Chlorine-under 5%)	Sulfur-chlorine base-active (active 2-5%) (Chlorine 1-5%)	Sulfur-chlorine base-active (active sulfur under 2%) (Chlorine 5-10%)		Impossible
CAST IRON	DRY	Sulfur-chlorine base-active (active sulfur under 2%) (Chlorine under 5%)			Emulsifiable (Dilution 1:10)
ALUMINIUM ALLOYS	Straight cutting oil (fat 5-10%)				
COPPER ALLOYS	Straight cutting oil (fat 5-10%)	Chlorine base-inactive (chlorine 1-3%)			
THERMO SETTING PLASTICS (Bakelite, Epoxy)	Dry	————			Impossible
THERMO PLASTICS (Poly carbonite, Vinyl chloride)	Straight cutting oil (fat 5-10%)				Water

Table 4. Recommendation Chart for Cutting Fluids

The influence of Cutting Fluids on Micro-grain Carbide End mills

Micro-grain carbide contains more cobalt than normal carbides to get higher toughness, but when cutting steels, cooling by cutting fluids is required, in order to avoid material pull outs. Below chart is the milling test result on 2 flutes micro-grain carbide end mill with cutting fluids and without cutting fluids performances.

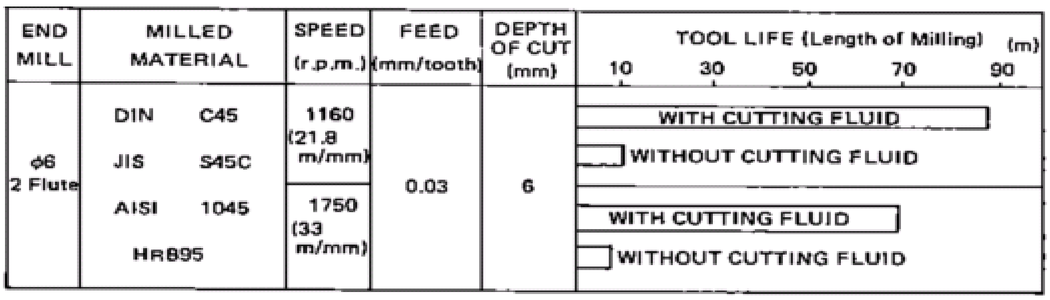


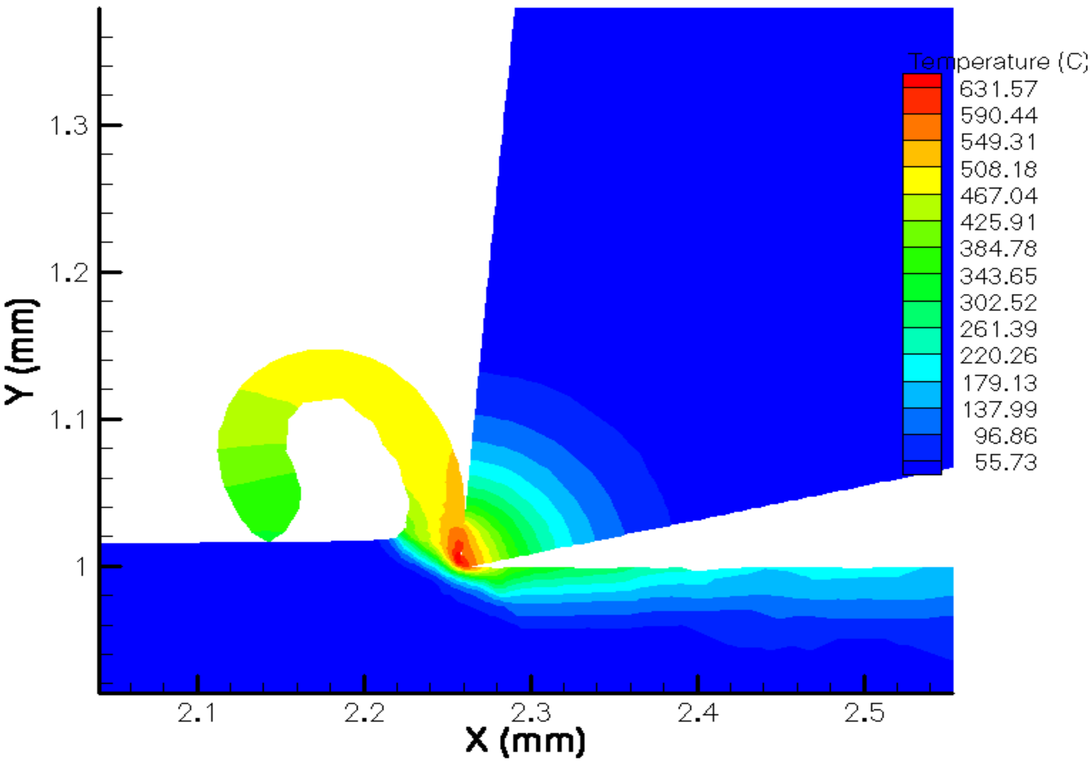
Fig. 23. Limit of Wear Land: 0.4 mm & Cutting Fluid: Sulfo-Chlorinated Mineral Oil

4. Surface Treatment

Metal cutting tools are often given surface treatments to improve tool performance and longevity. As cutting tools cut on material, it will generate heat, welding of material chips onto cutting tools, friction and wear off of cutting tools etc. Therefore appropriate types of coating are required to prevent all these problems.

The below diagram is the FEM analysis of heat generated when cutting tools cut on material.

Fig.24. FEM Analysis



The table below shows the purpose and applications on various surface treatments:

TYPE	CHARACTERISTICS	PURPOSE	APPLICATION
STEAM OXIDE	* Fe3O4 film * Retain coolant with porous surface * Reduce friction * Prevent welding	Anti-welding	Stainless steel Soft and ductile steel not suitable for aluminium
NITRIDE	* Treated thickness 30 ~ 50 μm * Surface hardness 1000 ~ 1300 Hv	Increase Wear resistance	High tensile steel Cast Iron Aluminium die casting
TiN Coating	* Treated thickness 2 ~ 3 μm * Surface hardness 2000 Hv	Anti-welding Reduce of friction Wear resistance	High tensile steel Stainless steel Heat resistance steel Titanium alloy
TiCN Coating	* Treated thickness 3 ~ 6 μm * Surface hardness 2700 Hv * Wear resistance * Friction coefficients 30% less than TiN	Anti-welding Thermal resistance Wear resistance	Dry high speed cutting Long tool life High speed cutting Suitable for HSS tools
TiALN Coating	* Treated thickness 2 ~ 6 μm * Surface hardness 2800 Hv	Thermal resistance High wear resistance	Hard materials Abrasive materials High speed cutting Suitable for carbide tools

Table 5. Surface Treatment Purpose and Applications

The table below shows the various coating features and applications

Coating	Colour	Hardness (HV)	Friction Coefficient	Oxidation Point	Adhesion	Features	Applications
TiN	Gold	2,000	0.4	500°C (932°F)	●	High adhesion with HSS	Available for cutting conventional steels. For aluminium alloy, effective under high speed chatting
TiC	Red-Purple	3,000	0.2	300°C (572°F)	Δ	High hardness but low heat resistance. High adhesion with carbide	For tungsten carbide tools
TiCN	Gray-Purple	2,700	0.3	400°C (752°F)	○	Better adhesion resistance due to higher hardness & lower friction coefficient than TiN	Effective for cutting steels & superior to TiN on high speed cutting
TiALN	Gray-Purple	2,800	0.3	700°C (1292°F)	○	High hardness than TiCN & high heat resistance	For cutting cast iron & high silicon aluminium alloy. Suitable for carbide tools. Effective for hard steels (over 45HRC) & for high cutting speed.

● Very Good ○ Good Δ Insufficient

Table 6. Coating Features and Applications

- **Steam Oxidizing:**

This process produces a film on the surface of the drill, as the tools are heated in a steam furnace for 30 to 60 minutes at 500 to 550 º C (932 – 1040 º F). The benefits of this treatment include reduced heat from friction and improved welding and build up prevention.

Steam oxidizing is therefore most effective for milling low carbon steel or stainless steel (known for often causing welded).

- **Nitride:**

The nitride process produces a surface that is harder than regularly heat-treated (HSS) End mills are submerged in a cyanide salt bath of 500 to 560 º C (932 – 1040 º F) for a specific period of time (30 ~ 90 min). Nitride End mills exhibit improved lubricant retention properties, which ultimately reduce galling and metal pickup. The benefits of using a nitride-coated tool are:

- High surface hardness
- High wear resistance
- High heat resistance
- High corrosion resistance

Coating Operations

CVD:

Tools are placed in a vacuum reactor chamber. Carrier gas is then introduced into the chamber at precise quantities. The driving force of the process is the high temperature (950 ~ 1065 º C, 1742 ~ 1949 º F), which dissociates the reactive gases, causing the desired coating compound to form on the tool surface. CVD exceeds the tempering temperature of (HSS).

The high temperature of the CVD process makes it somewhat less popular than the PVD method. CVD coating also tends to be somewhat thicker (0.008mm) than PVD produced coating (0.003mm).

PVD:

The PVD process relies on ion bombardment instead of high temperatures (260 ~ 485 º C, 500 ~ 905 º F). The reactive ion plating involves the ionization of vaporized "target material", such as titanium, in the presence of the reactive gas (N2 for TiN coating) again with electrical potential applied to accelerate the TiN ions towards the tool.

The initial investment in equipment for PVD coating machines is three to four times greater than for CVD machines, but the PVD process cycle time can be 10 times faster than CVD. The diagram below shows on the PVD process.

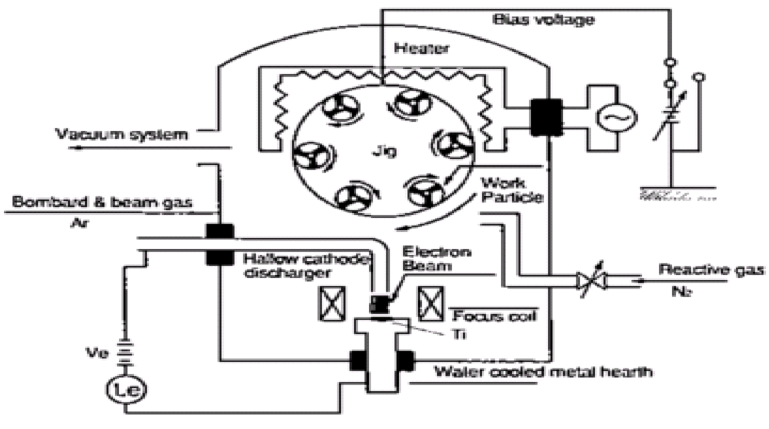


Fig.25. Physical Vapor Deposition Process

- **Titanium Nitride (TiN):**

Rapid developments in machine technology increase the demand for faster and more efficient operations. The popularity of unmanned and automated operations is increasing around the world. Surface coating, first introduced in 1980, greatly improved the capabilities of machinery tools. Coated products quickly dominated the market, and today, TiN coating is the most popular treatment for precision tools.

TiN coated tools reduce the contact length at the chip-tool interface thereby reducing tool temperatures and adhesions wear near the cutting edge. Today cutting tools are coated with titanium nitride and titanium carbide by the two previously mentioned methods:

- Chemical Vapor Deposition (CVD)
- Physical Vapor Deposition (PVD)

Tools coated with TiN have surface hardness that is about three times harder than un-coated HSS tools. TiCN is fast becoming one of the most advantages coatings for H.S.S. cutting tools, but TiN coated tools are still applicable to a broader range of operations.

The benefits of TiN Coating on HSS:

Coated tools produce better chips because temperature increase caused by friction is significantly reduced. The shape of these chips is more manageable than chips produces with conventional End mills.

Properties of TiN:

Hardness considerable exceeds that of high-speed steel.

- TiN offers a low coefficient of friction.
- TiN possesses high chemical stability and is extremely resistant to corrosion.
- TiN resists adhesion, welding and galling, even at elevated temperatures.
- TiN allows for increases in speeds and feeds.

- **Titanium Carbide Nitride (TiCN):**

TiCN is the most recent development in coating innovation, and will most likely become the dominant coating used in the industry.

It is now believed that increased hardness is achieved when nitrogen is partially substituted for carbon in titanium carbide. The titanium carbon nitride offers a compromise between the high hardness of the carbide (2700 HV versus 2000 HV for nitride) and the superior thermo chemical stability and anti-seizure properties of nitride.

The TiCN coating process is nearly the same as the PVD method mentioned before, but in this case we use a compound of titanium nitride (TiN) and titanium carbide nitride (TiCN). The characteristics are also similar to TiN coating, but the surface hardness is improved and the welding tendency is significantly reduced (75% that of TiN coated tools).

- **Titanium Aluminum Nitride (TiALN):**

It is clear that no universal coating exists for all kinds of cutting processes. For example, TiCN was designed to reduce abrasive wear, while TiALN lowers the oxidation wear. TiALN is harder than TiCN or TiN, and also has superior heat resistance. The temperature of oxidation is high, which is good for milling high-hardened steel and for high cutting speeds. The adhesion of the coating on the HSS tool is, however, significantly weaker.

The diagram below shows the performances of various coating. It stated clearly that TiALN is the most suitable coating for End mills to operate at high-speed milling.

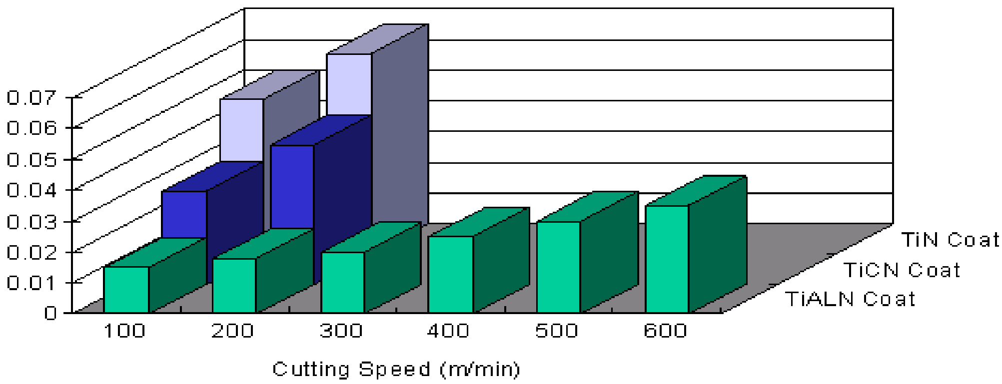


Fig.26. Various coating against High Speed Milling

5. Selection of work materials

In metal cutting industries today, innumerable kinds of material are handled and their characteristics are various. In addition, a same material may have difference properties through different heat treatment and so on.

There is not a generally acknowledged or expression of “MACHINABILITY”, the degree of ease with which a particular material can be machined. But, Machinability Rating is known as a mean of quantitative expression of machinability.

MR (Machinability Rating) is the value of cutting speed (V60) of a material (AISI 1112 steel = 100), which is measured when the tool life become 60 minutes. A large figure of MR means to be milled at higher speed in a same tool life or to get longer tool life at a same cutting speed.

	MATERIAL			MR
	DIN	JIS	AISI	
CARBON STEELS	C10	S10C	1010	55
		S25C	1025	75
	C45	S45C	1045	60
LOW TENSILE ALLOY STEELS	34Cr4	SCr3	5130	65
	34CrM04	SCM3	4135	60
		SNCM2		45
		SNCM6	8640	55
		SNCM8	4340	50
CAST STEELS		SC		70
CAST IRON	GS25	FC25	ASTM CLASS 35	70
	GGG	FCD		75
	GTS	FCMB		90
STAINLESS STEELS	X10Cr13	SUS410	SUS410	50
	X20Cr13	SUS420	SUS420	40
	X22CrNi17	SUS431	SUS431	50
	X5CrNi189	SUS304	SUS304	30
	X12CrNi25 21	SUS310	SUS310	25
TOOL STEELS	X165CrMoV12	SKD11	D2	25
	48CrMoV67	SKT5	6G	55
	48CrMoV67	SKT5(HRC43)	6G	18
TITANIUM ALLOYS				20 ~ 35
TITANIUM ALLOYS(AGING)				10 ~ 15

	MATERIAL			MR
	DIN	JIS	AISI	
HEAT RESISTING ALLOYS (Ni base)			680 Hastelloy	12
			681 Inconel 901	20
			685 Waspaloy	12
			687 U700	8
			688 Incorel	15
HEAT RESISTING ALLOYS (Fe base)			661 N155	15
			662 Discaloy	25
FREE CUTTING BRASS (Pb3)				200
BRASS				70
ALUMINIUM BRONZE				40
COPPER				40
BERYLLIUM COPPER				40
ALUMINIUM ALLOY			2011	~230
			7075	~120
MAGNESIUM ALLOYS				500~

Table 7. Machinability Rating

This machinability rating of a given work material changes with the type of operation involved and with the tool material selected. In addition, for the same MR value materials, if their properties not the same, different type of tool and different cutting conditions are recommended. The application of the machining rate should be restricted to very special situations where the ratings have meaningful and consistent value.

- **Structural Steels**

Structural steels are divided into two types, Carbon Steels and Alloy Steels. When annealed, 0.25% carbon containing steel has best machinability, when they contain effective alloying elements, among which Nickel affects the machinability most. In case of low-alloy steels, machinability is worse, when the Nickel percentage is 2%, while phosphorus, sulfur and lead improve machinability. Vanadium affects nothing within the usual percentage. Machinability of structural steels has strong relationship with the hardness given by heat treatment.

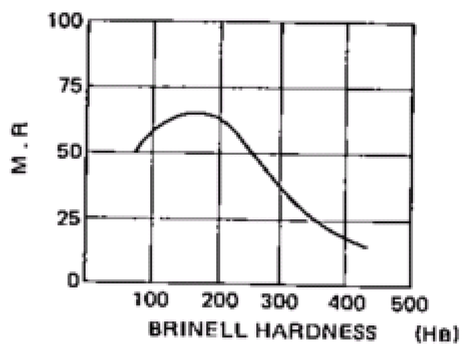


Fig.27. Relation between M.R and hardness of Steel

- **Stainless Steels**

Stainless steels are most difficult to cut than structural steels due to the following reasons.

- Tensile strength is higher
- Easy to weld
- It is more work hardening

Austenite stainless steels (18-8, 25-20) have the above-mentioned properties much and low machinability. Martensite stainless steels (13Cr) have similar properties to low carbon alloy steels, but they need higher driving power for milling. Ferrite stainless steels are a little brittle and the styles of chips are produced in pieces. But when they contain high chromium, the chips are produced in coil shape as austenite stainless steels.

Precipitation hardening stainless steel (17-4PH) are difficult to cut same as austenite stainless steels, Particularly refined one has extremely low machinability like heat resisting alloys.

- **Alloy Tool Steels**

Alloy tool steel contain high carbon and more alloying elements than structural steels, resulting in poor machinability. Chromium, Tungsten, Molybdenum and Vanadium, in some parts, are combined with carbon and form hard carbides. Others are melted into ferrite, making matrix hard and tough. Nickel and cobalt are also melted into ferrite and make matrix very hard. Alloy tool steels are similar to high carbon structural alloy steels and making cutting tools wear easily with their double carbides.

Among alloy tool steels, one for impact working, containing low carbon (DIN 35WcrV17, JIS SKS41, AISI S1, etc.) and for cutting, containing few alloying elements (DIN 142WV13, JIS SKS11, AISI F2 etc.) is comparatively easy to be cut. On the other hand, cold forming die steels (DIN X165CrMoV12, JIS SKD11, AISI D2) have large carbide and are difficult to be machined. Hot forming die steels (DIN X40CrMoV51, JIS SKD61, AISI H13) are used after refining, and are difficult to be cut.

- **Cast Iron**

As cast iron is produced in various complicated forms by casting process without any mechanical operation, its tensile strength and toughness are very low. Ductile cast iron, malleable cast iron and nodular cast iron have improved mechanical properties.

Cast iron has a wide variety, ranging from the hardest but the most brittle pig iron to the most machinable ferrite cast iron. The machinability of gray cast iron is practically determined by its hardness, although it is affected considerably by state of matrix. The higher the hardness is, the shorter tool life becomes as Figure below shows. But, generally speaking, they are easier to cut than steels, since the contained graphite flake works as lubricant and breaks chips into fragments. And even if the hardness is low, it is not viscous.

The machinability of malleable cast iron is good. For hard materials, use low milling speed and Nodular cast iron is easier to cut than gray cast iron.

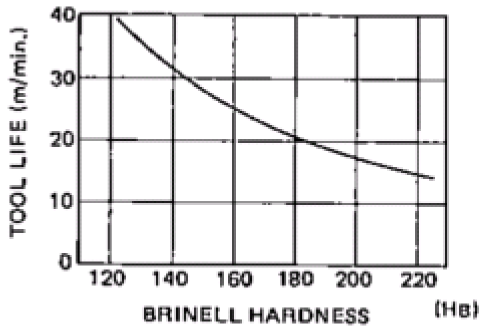


Fig.28. Relation between Tool life and Work hardness

- **Copper & Copper Alloys**

Lead containing free cutting brass, free cutting bronze and free cutting phosphorus bronze are able to cut at high speed and fast feed. On the other hand, copper, plain bronze, phosphorus bronze, aluminum bronze and Beryllium copper are mild, and make the tool wear easily.

- **Aluminium Alloys**

Aluminium alloys do not have high strength a cast or annealed, but they have high strength through working. For example, cold working for precipitation hardening type and heat treatment for aging hardening type.

Since aluminium alloys are cut with low cutting torque and thermal conductivity is good, most if them are milled economically without any trouble. On the other hand, as they are viscous and apt to produce built-up edge, attention must be paid not deform the work piece by cutting force and thermal expansion.

Precipitation hardening aluminium alloys are mild and easily affected by work hardening. Cold wrought ones are a little machinable, aging hardening aluminium alloys are cut to be good surface finish with or without cutting fluids. Refined one is easier to be cut than annealed one.

High-speed milling is possible and the limit of speed is determined by the work piece caused by the lack of rigidity of tools. Length of cut can be increased to the limit of the strength of work piece, holding strength of tools, machine tools power and chip ejection. Feed can be also increased to the limit of surface roughness and rigidity.

- **Magnesium Alloys**

Machinability of magnesium alloys is good and chips are produced in the form of fragments, which results in high efficiency milling. Surface finish is also good without any relation to presence of cutting fluids or milling speed.

- **Titanium Alloys**

Titanium alloys have following characteristics during milling.

- It acts upon the components like oxygen and nitrogen in tool material at high temperature. It may cause wear and galling during cutting.
- Since the shearing deformation is small, thin chips have small area of contact to the tool. This property and high tensile strength (annealed: 80

Kgf/mm, refined: 100 Kgf/mm) make the contact press high, resulting in high temperature at cutting edge.

- Thermal conductivity is comparatively low, which makes the temperature at cutting edge high.
- As modulus of elasticity is comparatively low. Clamping press and cutting force easily deform it.

Surface finish is comparatively good. Work hardening is little therefore much cutting force is not necessary. But high-grade tool material (Particle Metallurgy H.S.S.) should be used and the cutting fluids containing halogen elements like chlorine must not be applied, because they may corrode work piece.

- **Heat Resisting Alloys**

Heat resisting alloys are one of the most difficult to machine materials. Their characteristics are as follows.

- High shearing strength causes high cutting resistance.
- Work hardening
- Contains hard chemical compound, which makes the tool wear easily
- As thermal conductivity is low, heat is apt to concentrate at the cutting edge.

By the milling test stated below, we find out that for milling Inconel, slow milling speed (around 5 m/min) is recommended in order to avoid over heating, but excessive slow feed is not recommended in order to prevent the work piece from work hardening.

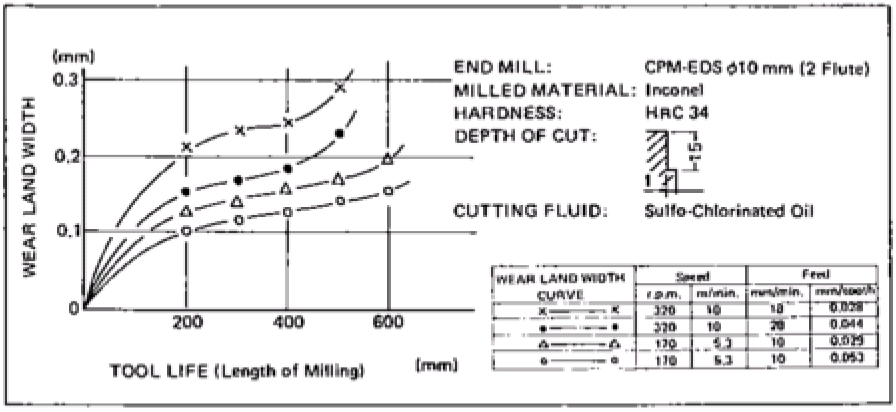


Fig.29. Milling test on Inconel material

5.1 Guide for milling difficult to machine materials

➢ **Ductile and High Tensile Materials**

Austenite stainless steels, Titanium alloys and heat resisting alloys

- In case of short length of cut or slow feed, the surface hardened by pervious tooth cut (work hardening) is milled once again by next tooth. If a tooth cannot bite easily and slides out the surface, which will result in short tool life. For milling heat-resisting alloys, as short length of cut is not permitted, even if they are difficult to machine, extremely low milling speed must be applied.
- The properties of high tensile strength and toughness produce strong chips. In addition, due to high viscosity it is apt to produce a built-up edge.

- For good chip ejection, sharp cutting edge and large clearance angle is indispensable. On the other hand, this weak cutting edge is recovered by the rigidity of machine tools. Re-sharpening in early stage is recommended, because dull teeth increases cutting torque, hardening work piece surface and produce built-up edge, resulting in damage to tools.
- Feeding must be automatic and must not stop during operation. If it does, it may cause work hardening of work piece.
- Cutting fluids should flow strongly to the cutting portion, in order to push out chips and help cooling.

➢ **Hard Steels**

Hot forming die steels (over HRC 35)

- Select as large size mill as possible to get high rigidity
- Use strong and rigid machine tools and tooling in order to avoid vibration
- Use high-grade tool materials like Particle Metallurgy H.S.S.
- Cutting speed and feed should be slow in inverse proportion to the hardness of work piece
- In side milling, climb milling will get longer tool life, if machining condition (back lash, rigidity and tolerance) permits it.

6. Cutting Conditions

The factors to determine the cutting condition are:

- Material to be milled
- Surface finish required
- Depth of Cut
- Tool life

The combination of these factors determines the revolution and the feed. As the revolution and the depth of cut are in mutual relationship, which is the change of one makes the other change.

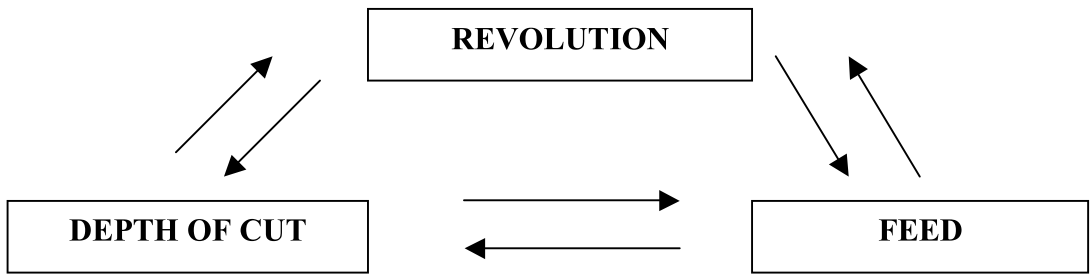


Fig.30. Inter-Relationship of three factors

- **Revolution**

Revolution is the most important factor to determine the tool life. Generally, it depends on the material to be milled. The below are the various cutting condition formulas to calculate cutting speed and spindle speed.

Formulas for Square End mill:

$$Vc = \Pi \times Dc \times N / 1000$$

$$N = Vc \times 1000 / \Pi \times Dc$$

Vc: Cutting Speed (m/min)
Dc: Diameter of Tool (mm)
N: Spindle Speed (rpm)
Π: 3.142

For milling with long length of cut, lower milling speed is recommended, as it is apt to deflect and chatter. Refer to Table.

Material / Type	Mild Steels (~50 kgf/mm2) Brass, Copper	Medium Tensile Steels (50~80 kgf/mm2) Mild Steel Forgings Cast Iron, Hard Brass Bronze, Copper	High Tensile Steels (80~100 kgf/mm2) Unalloyed Titanium Heat Resistant Ferritic Low Alloys	High Tensile Steels (100~180kgf /mm2) Tool Steels Medium Strength Stainless Steels	Heat Resistant High Alloys High Strength Titanium Alloys High Strength Stainless Steels	Aluminium Alloyed Aluminium Plastics Woods
Short	35 ~ 45	28 ~ 33	15 ~ 20	10 ~ 15	5 ~ 10	80 ~ 120
Long	20 ~ 30	15 ~ 25	10 ~ 15	8 ~ 12	3 ~ 8	50 ~ 80

Table 8. General Recommendation for Cutting Speed (HSS-Co)

The revolution should vary with the difference of the tool materials. Especially in the operation with carbide end mills, the recommended speeds are much variable according to the materials of work piece. So, it must be carefully selected. For detail information, please refer to the recommended milling conditions data attached.

Formulas for Ball Nose End mill:

$$Ve = \Pi \times De \times N / 1000$$

$$De = 2\ Sqt\ [Ap\ (Dc - Ap)]$$

$$Vf = N \times Fz \times Zn$$

$$N = Ve \times 1000 / \Pi \times Dc$$

Ve:	Effective Cutting Speed (m/min)
Vf:	Table Feed (mm/min)
N:	Spindle Speed (rpm)
De:	Effective Cutting Diameter (mm)
Dc:	Diameter of Tool (mm)
Zn:	Number of Teeth
Π:	3.142

- **Feed**

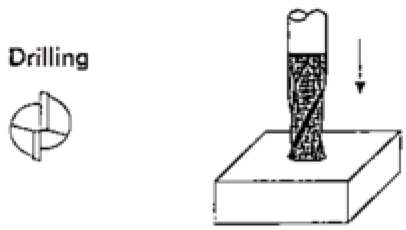
Feed is the most important factor for the productivity. The recommendation of feed is affected by the material to be milled, tool material and depth of cut, while the tool life is respected.

The formulas below are to calculate table feed and various effective feed per tooth.

$$Vf = N \times Fz(eff) \times Zn$$

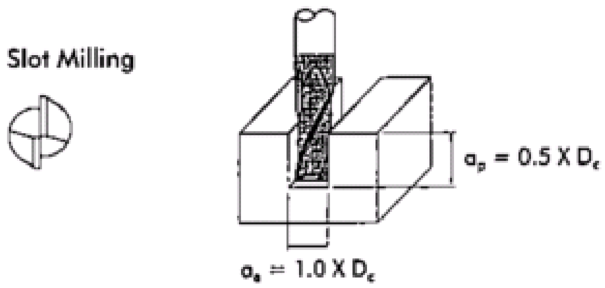
Vf:	Table Feed (mm/min)
N:	Spindle Speed (rpm)
Fz(eff):	Effective Feed per Tooth (mm/teeth)
Zn:	Number of Teeth

Effective Feed per Tooth Fz(eff) for Roughing / Semi Finishing



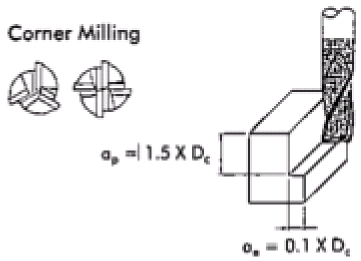
Fz(eff) = 0.5 x Fz

Fz: Feed per Tooth (mm/teeth)



Fz(eff) = 1.0 x Fz

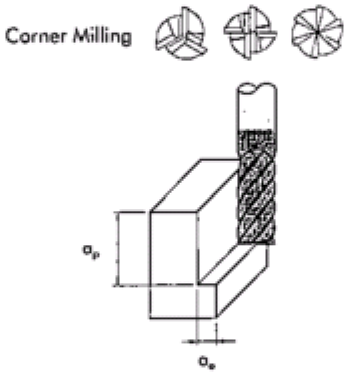
For Harden Steel (Above HRC 40)
Ap = 0.05 x Dc
Ae = 1.00 x Dc



Fz(eff) = 2.0 x Fz

For Harden Steel (Above HRC 40)
Ap = 1.00 x Dc
Ae = 0.02 x Dc

Effective Feed per Tooth Fz(eff) for Finishing



Fz(eff) = 2.0 x Fz

Ap = 1.50 x Dc
Ae = 0.10 x Dc

For Harden Steel (Above HRC 40)
Ap = 1.00 x Dc
Ae = 0.02 x Dc

Fz(eff) = 1.0 x Fz

Ap = 1.00 x Dc
Ae = 0.20 x Dc

For Harden Steel (Above HRC 40)
Ap = 0.70 x Dc
Ae = 0.04 x Dc

Feed per tooth, Fz (mm/teeth)							
Material	Cutting Speed	∅ 3	∅ 4	∅ 5	∅ 6	∅ 8	∅ 10
General Steels (< HRC 20)	70 - 85	0.010-0.030	0.015-0.030	0.020-0.045	0.025-0.050	0.030-0.070	0.040-0.090
Alloy Steels (HRC 20 - 30)	45 - 60	0.010-0.030	0.015-0.035	0.020-0.045	0.025-0.050	0.030-0.070	0.040-0.090
Alloy Steels (HRC 30 - 40)	30 - 45	0.010-0.020	0.015-0.035	0.015-0.045	0.025-0.050	0.025-0.070	0.035-0.080
High Alloy Steels (< HRC 40)	20 - 35	0.005-0.015	0.008-0.020	0.010-0.020	0.012-0.030	0.015-0.035	0.020-0.045
Cast Iron	60 - 75	0.010-0.035	0.020-0.050	0.030-0.065	0.030-0.080	0.060-0.100	0.070-0.160
Stainless Steels / Titanium Alloys	45 - 60	0.005-0.010	0.008-0.018	0.010-0.023	0.012-0.030	0.015-0.035	0.020-0.045
Aluminium alloys	180 - 220	0.010-0.030	0.015-0.035	0.020-0.045	0.025-0.050	0.030-0.070	0.040-0.090

Table 9. Feed per tooth on Square End mill

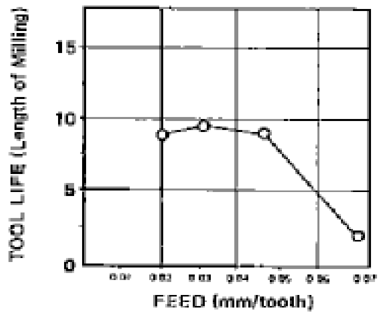
Feed per tooth, Fz (mm/teeth)							
Material	Cutting Speed	∅ 3	∅ 4	∅ 5	∅ 6	∅ 8	∅ 10
General Steels (< HRC 20)	35-50	0.010-0.020	0.015-0.025	0.025-0.035	0.030-0.040	0.040-0.050	0.045-0.055
Alloy Steels (HRC 20 - 30)	25-40	0.010-0.020	0.015-0.025	0.025-0.035	0.030-0.040	0.040-0.050	0.045-0.055
Alloy Steels (HRC 30 - 40)	15-30	0.050-0.015	0.010-0.020	0.012-0.030	0.015-0.030	0.020-0.035	0.025-0.040
Cast Iron	40-60	0.010-0.020	0.015-0.030	0.020-0.040	0.025-0.045	0.035-0.055	0.045-0.070
Stainless Steels / Titanium Alloys	35-50	0.005-0.015	0.010-0.020	0.012-0.030	0.015-0.030	0.020-0.035	0.025-0.040
Aluminium alloys	160-200	0.015-0.025	0.020-0.035	0.025-0.050	0.030-0.065	0.040-0.080	0.055-0.100

Table 10. Feed per tooth on Ball Nose End mill

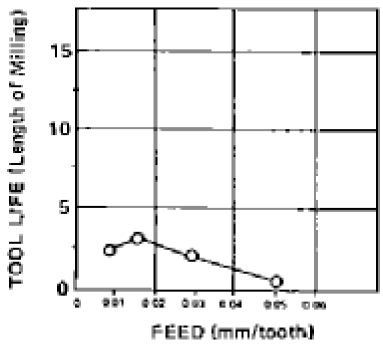
a) Relation of Feed per tooth to milled material

Figures below show the best feed per tooth varies with the change of milled materials.

FEED PER TOOTH & MILLED MATERIALS



END MILL:	EDS-DIN327 ϕ 6mm (2 Flutes)
MILLED MATERIAL:	DIN C45
	JIS S45C
	AISI 1045
HARDNESS:	HRB 94-96
SPEED:	33 m/min (1,750 rpm)
DEPTH OF CUT:	3 mm (Slotting)
CUTTING FLUID:	Sulfo-Chlorinated Oil
LIMIT OF WEAR LAND:	0.4mm



END MILL:	EDS-DIN327 ϕ 6mm (2 Flutes)
MILLED MATERIAL:	DIN X40CrMoV51
	JIS SKD61
	AISI H13
HARDNESS:	HRC 40
SPEED:	8.5m/min (450 rpm)
DEPTH OF CUT:	3 mm (Slotting)
CUTTING FLUID:	Sulfo-Chlorinated Oil
LIMIT OF WEAR LAND:	0.4mm

MILL DIA.	MILD STEEL	HARD STEEL
mm	mm/teeth	m/tooth
3	0.011	0.005
4	0.018	0.009
5	0.025	0.012
6	0.03	0.015
8	0.05	0.025
10	0.071	0.036
12	0.08	0.045
14	0.09	0.05
16	0.095	0.056
18	0.1	0.063
20	0.1	0.071
25	0.1	0.09
30	0.1	0.1
40	0.1	0.1

Table 11. Feed per tooth for Mild Steel & Hard Steel

Table above shows adequate feed per tooth for mild steel and hard steel.

MILLED MATERIALS

Mild Steel:	DIN	C45
	JIS	S45C
	AISI	1045
Hard Steel:	DIN	X40CrMoV51
	JIS	SKD61
	AISI	H13

MILLED CONDITIONS

Slotting Depth of Cut: ½ Diameter deep

b) Relation of Tool material to Feed per tooth

Feed per tooth should alter according to tool materials, namely, High Speed Steel and Tungsten Carbide.

It is very important to select the feed not to cause chipping, particularly in milling of hard materials (over HRC 40). Milling data below indicates the tool life varies very markedly when the feed is changes in both of Carbide end mills and particle metallurgy H.S.S. end mills.

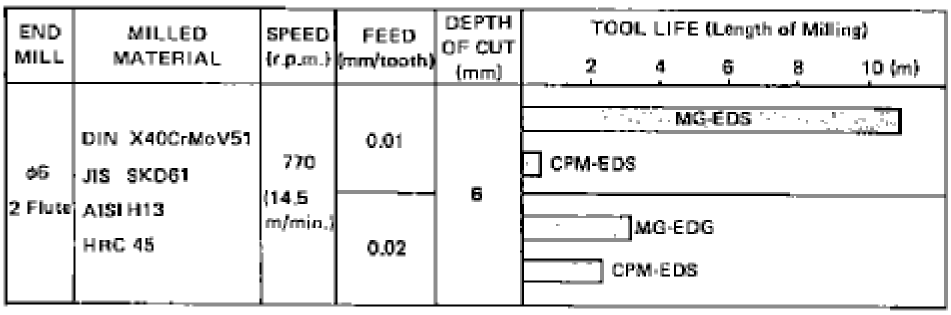


Fig.31. Milling Data

MILLING CONDITION

End Mill:	MG-EDS ϕ 6mm (2 Flutes)
	CPM-EDS ϕ 6mm (2 Flutes)
HARDNESS OF MILLED	
Material:	HRC 44-45
Speed:	14.5m/min (770 rpm)
Depth of Cut:	6mm (Slotting)
Cutting Fluid:	Sulfo-Chlorinated Oil
Limit of Wear Land:	0.4mm

c) Relation of Depth of cut to Feed per tooth

Feed per tooth should vary with the change of depth of cut, too.

In slotting operation, our recommendation chart picks up 1/2D (a half mill diameter) for depth of cut. If it is increased to 1D, feed is decreased to 50%, but even if it is decreased to 1/4D, feed must not be increased to double. 30% increase will be the maximum because there is limit to the strength of cutting edge and it may cause chipping. To get higher productivity selecting larger number of flute end mills is recommended, in case of small depth of cut.

In side cutting, our recommendation chart picks up 1.5D x 0.1 D (axial depth and radial depth) for depth of cut. If the radial depth is changed to 0.3D, feed should be decreased 50% and in case of under 0.05D radial depth of cut like finishing operation. For example, it produces better surface finish to increase revolution 20 – 30% than to increase feed same percentage. In general, decreasing feed produces better surface finish.

7. Re-Sharpening and Inspection

7.1 Case of Re-Sharpening

When the product finish becomes worse, the cutting edge must get dulled, chips become smaller and the cutting sound gets louder. In such cases, an End mill must be re-sharpened. The following are the damages of End mills when the re-sharpening is required.

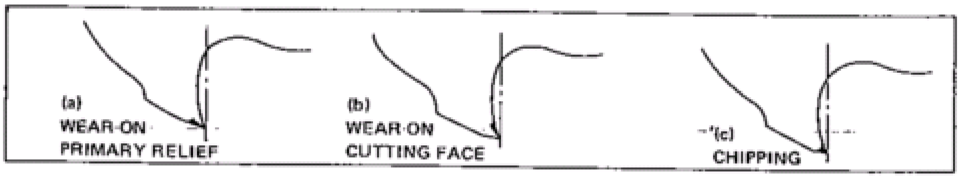


Fig .32. Damages of Cutting Edge

The wear on primary land is seen often and re-sharpening the primary land makes the End mill perform almost the same as new one. The width of the wear land develops very fast after a time period of use, resulting in rough surface finish and chipping. Re-sharpening must be done before it occurs. In general, when the width of wear land become 0.2 ~ 0.4 mm (in case of roughing End mill: 0.5 mm) re-sharpening is required.

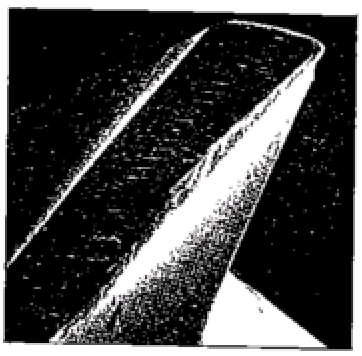


Photo.1. Damaged Cutting Edge

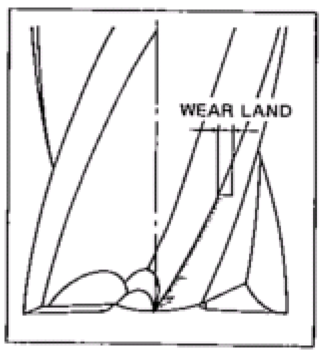


Fig.33. Wear land and Primary Relief

7.2 How to Re-Sharpen Primary Land

There are three types of re-sharpening according to three types of primary relief. Hereafter, we show to re-sharpen eccentric relief, which is superior both in cutting edge strength, surface finish and tool life.

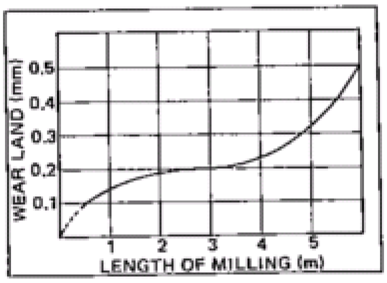


Fig.34. Relation between Wear Land & Length of Milling

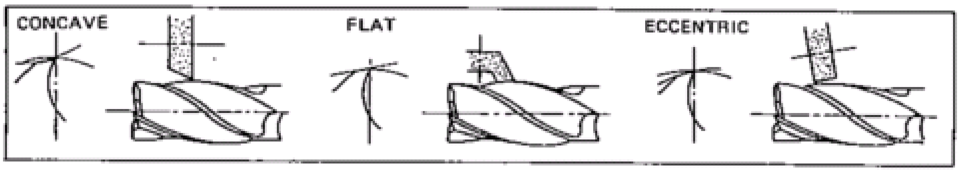


Fig.35. Three types of Primary Relief

7.2.1 The Principle of Eccentric Relief

When an End mill and a wheel are set up as per Figure 36 and the wheel is advanced to the radial direction, in the section X-X, the top of the End mill's cutting edge (a) is on the high side of the wheel. A tooth rest supports the End mill. At the same time, in another section Y-Y, the top of the cutting edge is shifted out of the centerline of the wheel by the helix of the End mill flute and the wheel has contact with the point (a').

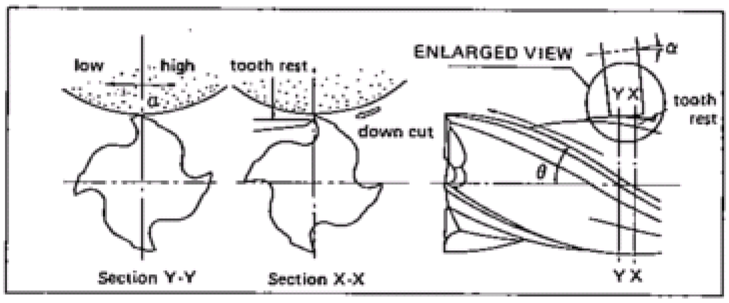


Fig.36. Eccentric Relieving

At this section, the top of the cutting edge is positioned lower than the tangent line of the wheel. Therefore, point (a') is ground in lower position than point (a) by aa' tan α.

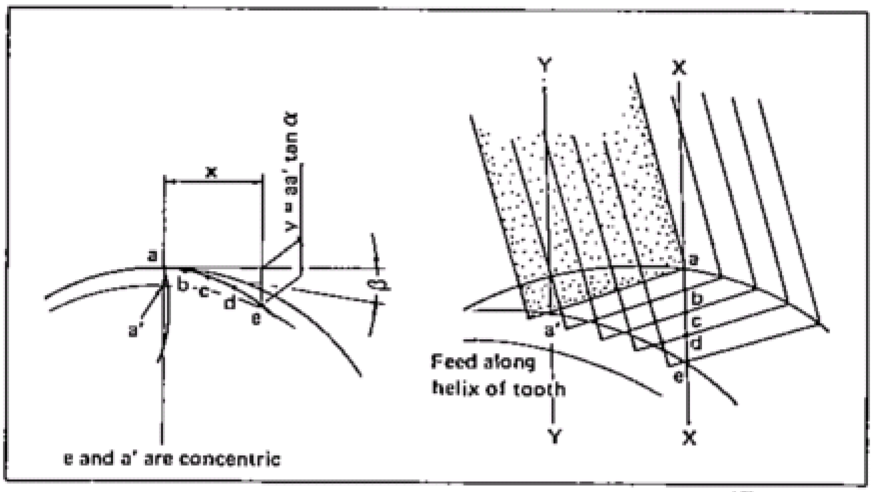


Fig.37. Enlarged View

If the cutting edge of the End mill is advanced, in the helix axial direction, being supported by the tooth rest in the section X-X, the wheel transverses the point (a), (b), (c), (d), (e). The curved line connecting the point (a), (b), (C), (d), (e) is the tangent line of eccentric relief. As Figure 37 the point (e) is ground to be lower than the point (a), and the point (e) and the point (a') are positioned concentric.

In relation to the eccentric relief, the following formula is made up.

$$\tan\alpha = \tan\beta \times \tan\theta$$

θ: Helix angle of End mill
β: Primary relief angle

And when the checking distance is x and the relief amount (drop) is y, the following formula are made up.

$$\beta = \tan^{-1}\frac{360^\circ\left\{\frac{D}{2} - \sqrt{\left(\frac{D}{2} - y\right)^2 + x^2}\right\}}{\pi D \tan^{-1}\left(\frac{x}{\frac{D}{2} - y}\right)}$$

α: Angle of wheel inclination
D: Mill diameter

A helical tooth is required to generate eccentric relief, theoretically any helix angle, but actually the helix must be more than 15 degree to be successful.

7.2.2 How to Re-Sharpen (re-sharpening order)

To produce an eccentric relief, the position of an End mill, a wheel and a tooth rest is constant.

1) Setting

Hold an End mill between the centers freely enough to rotate, parallel to the axis of a grinding wheel. If the End mill does not have a center hole, hold it by its shank.

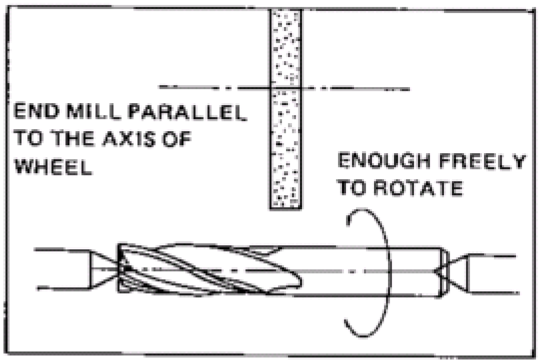


Fig.38. Holding End mill

2) Selection of a Wheel & Dressing

Recommended wheel is alundum type and about 120 mm diameter cup type. The wheel is 2 or 3 times as wide as axially measured primary land width. The wheel is dressed parallel to the axis or wheel by a diamond dresser.

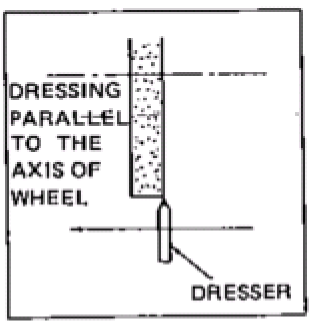


Fig.39. Dressing

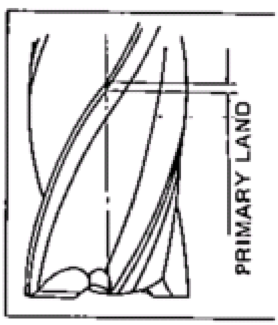


Fig.40. Axial Length of Primary Land

3) Angle of Wheel inclination

The wheel is positioned with its axis at a slight angle to the cutter axis and changing the angle of wheel inclination varies the degree of relief.

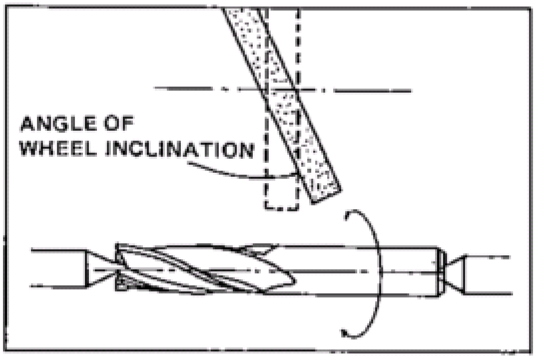


Fig.41. Wheel Inclination

MILL DIAMETER		PRIMARY RELIEF ANGLE	ANGLE OF WHEEL INCLINATION
OVER	UNDER		
4.75	6	11.8 ~ 19	8.5
6	7.5	11.2 ~ 18	8
7.5	9.5	10.6 ~ 17	7.5
9.5	11.8	10 ~ 16	7.1
11.8	15	9.5 ~ 15	6.7
15	19	9 ~ 14	6.3
19	23.6	8.5 ~ 13.2	6
23.6	30	8 ~ 12.5	5.6
30	37.5	7.5 ~ 11.8	5.3
37.5	47.5	7.1 ~ 11.2	5
47.5	60	6.7 ~ 10.6	4.75
60	75	6.3 ~ 10	4.5

Table 12. Primary Relief Angle & Angle of Wheel Inclination

4) To set tooth rest

The high point of the tooth rest must contact the tooth face at the high side of the wheel and be the same height as the wheel and work centers, but as usual End mills have a positive rake angle, the high point of the tooth rest is positioned a little higher than the height of the wheel and work centre.

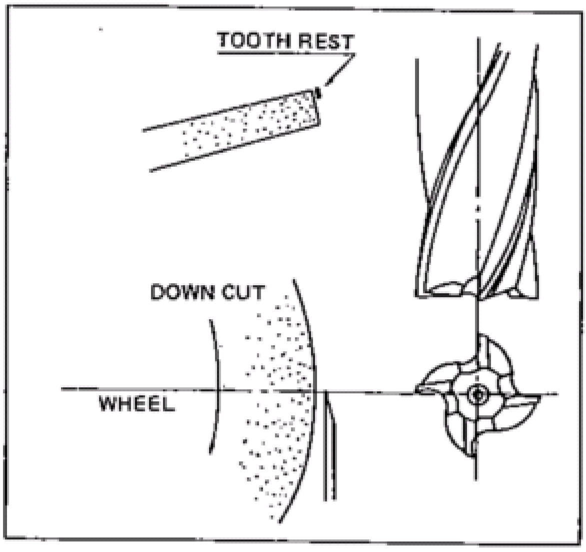


Fig.42. Position of wheel, End mill and tooth rest

5) Trial Grinding

The grinding should be done from End mill's shank side to end teeth. Do down grinding not to make the tooth drop from the tooth rest which makes the cutting edge dull. The work is rotated against the tooth rest as the cutter grinder table is transverse and it is done at constant speed.

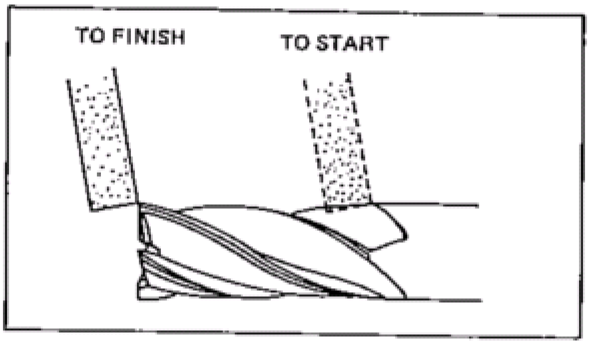


Fig.43. Trial Grinding

6) Checking Eccentric relief & adjustment of height of tooth rest

Watch the primary relief after trial grinding, to check that the reflection light or primary relief surface is parallel to axis of the End mill. If the reflection is not correct, adjust the height of tooth rest. (See Figure 44)

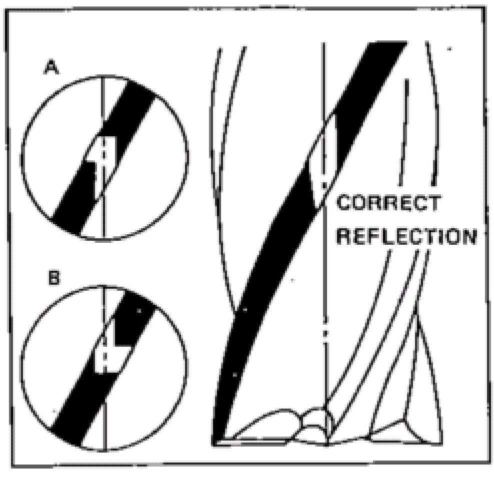


Fig.44. Check of Eccentric Relief

In case of 'A', make the tooth rest in lower position.

In case of 'B', make the tooth rest in higher position.

7) **Grinding**

Grind the primary relief until all of the wear has been removed, taking care to avoid excessive diameter loss and burring. The amount of stock removed is 0.01mm per pass. (Roughing: 0.2mm) Light finishing cuts are required to produce smooth cutting face.

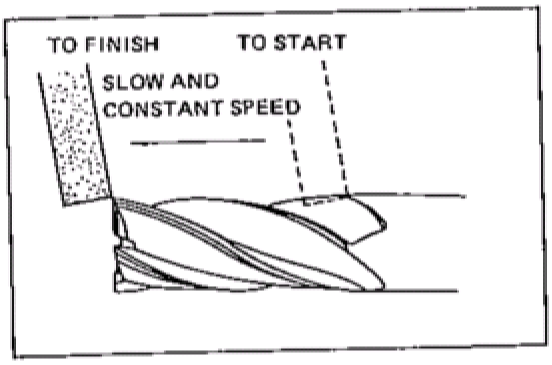


Fig.45. Grinding Primary Relief

8) **Removing Burrs**

The grinding will produce burrs on the cutting edge. The burrs are removed, soon after milling is started. But, if good surface finish is required, they must be removed, an acrylic or aluminium plate is softly touched along the helical teeth.

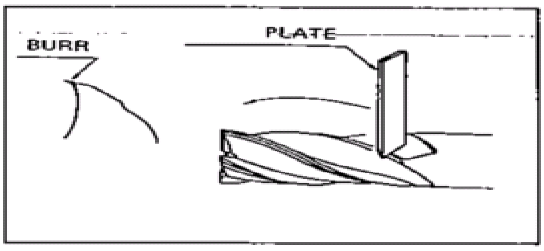


Fig.46. Removing Burrs

Note: When a primary land is wide, regrinding of secondary clearance face should be done first to avoid grinding burn. Get the tooth rest down without any other set-up change, and grind the secondary clearance face to concave form. In grinding should be done before primary relief grinding.

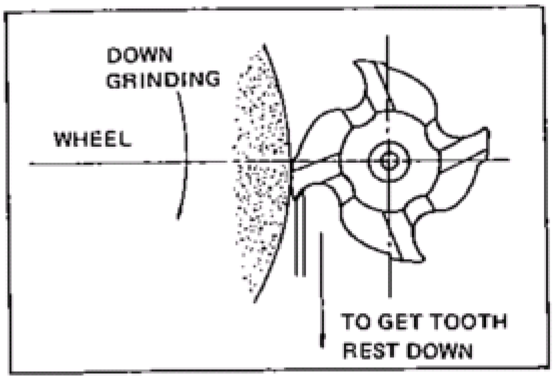


Fig.47. Grinding Secondary Clearance

7.2.3 Regrinding Cutting Face

Slight grinding will do, removing welded materials in case of regrinding cutting face of finishing End mills. But, in roughing End mills, as it is not re-sharpened on primary relief, cutting face must be reground until wear land on primary relief is completely removed. Generally recommended cutting angle is 12 degree – 18 degree.

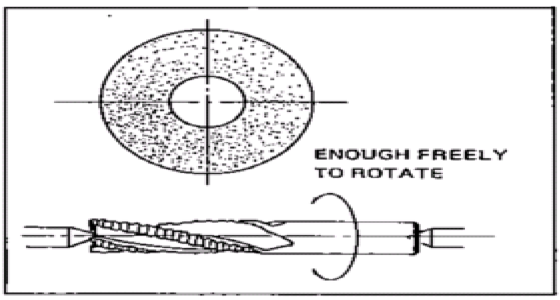


Fig.48. Holding End mill

- **To hold End mill**

  The End mill mounts on the table perpendicular to axis wheel and hold it between centers concentric but loosely enough to rotate, as primary relief grinding holding between centers is better.

- **Selection of wheel and dressing**

  Use alundum type, 100 – 130 diameter and saucer type wheel. Dress the wheel with diamond dresser carefully not to make radial run-out.

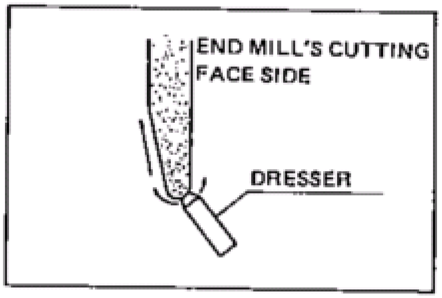


Fig.49. Dressing

- **Angle of Wheel Inclination**

  The angle of wheel inclination should be 1 degree – 3 degree larger than the helix angle of the End mill to make a slight clearance between the End mill's cutting face and the wheel.

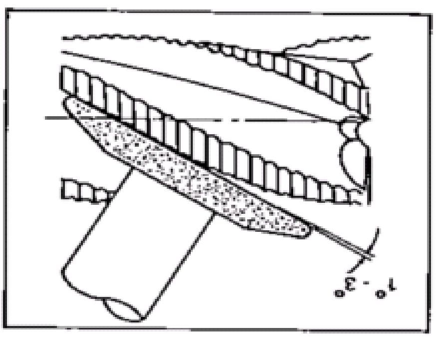


Fig.50. Angle of Wheel Inclination

- **Adjustment of Offset**

  Adjust offset amount to make wheel face have contact with whole cutting face of the End mills (from cutting edge to bottom of flute). Increase offset, when the wheel contacts cutting edge side only (cutting angle gets smaller), and reduce offset, when the wheel contacts bottom of flute only (cutting angle gets longer).

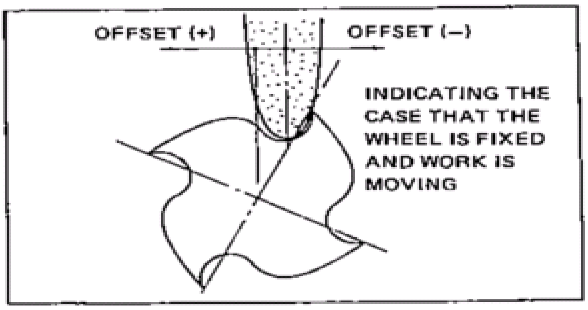


Fig.51. Adjustment of Offset

- **Grinding**

  Grind the cutting face from shank side forward cutting end, having a soft contact to cutting face. The feed of the wheel must be as slow and constant as possible, because it affects the surface roughness of cutting face. Particularly when the wheel passes through the end of mill, help the rotation of End mill by hand, carefully not to make the cutting edge dull.

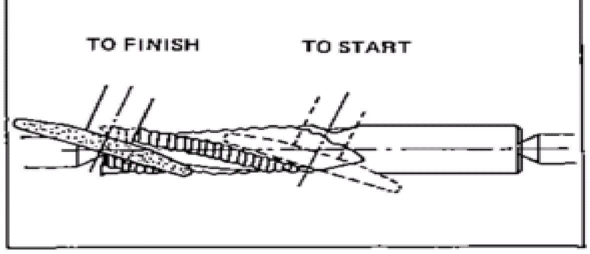


Fig.52. Grinding

7.2.4 Re-Sharpening End mill

Primary land is first to be re-sharpened and the necessity of re-sharpened secondary clearance face and end gash depends on seriousness of damages. In any cases, indexing equipment is required.

- **Sharpening Primary Land**

Set up an End mill and a cup wheel as per Figure 53. The End mill is set inclined at the angle of axial primary relief and end cutting edge concavity. Table 13 indicates usual degree of the mentioned two angles. For the End mill only for drilling, the angle should be 8 degree – 12 degree.

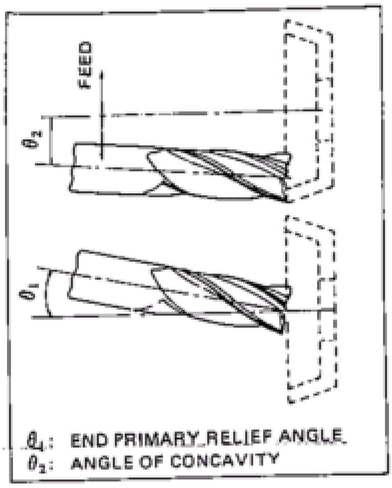


Fig.53. Grinding of End Primary Relief

MILLED MATERIAL	θ_1	θ_2
STEELS	3 – 7°	1 – 3°
NON-FERROUS METALS	8 – 12°	3 – 5°

Table 13. Angle of Primary Relief and End tooth concave

- **Re-Sharpening End Gas**

When the removed amount of regrinding on end primary land is big, it becomes wide and chip room becomes smaller. In such case, the end gash should be re-sharpened by cup type wheel, setting the End mill inclined at gash angle.

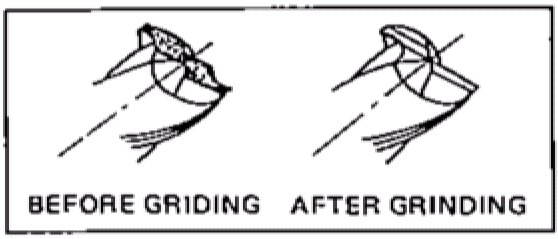


Fig.54. Comparison of before & after Gash grinding

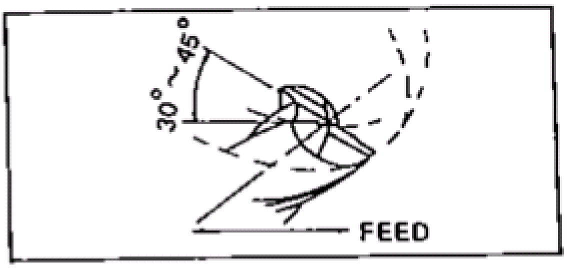


Fig.55. Re-Sharpening Gash

7.2.5 Inspection

Although the regrinding is done, if the specifications are changed, the milling performance as a new End mill cannot be regrind and the regrinding work is evaluated as wasted.

Followings are necessary checking points.

1) Primary relief angle
2) Cutting angle

3) Radial run-out of peripheral teeth and axial run-out of end teeth
4) Surface roughness

- **Inspection of Primary Relief Angle**

After confirming the primary relief is eccentric, the primary relief angle must be checked. The angle is calculated by using the formula given above. But as it is too much work, it is better to apply the procedure to check with indicators.

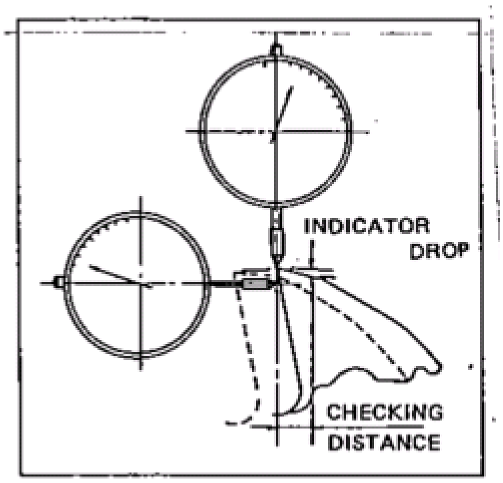


Fig.56. Indicator Set-Up for checking Radial Relief

Procedure to Check Radial Relief Angles with Indicators.

1) Mount the cutter to rotate freely with no end movement.
2) Adjust the sharp pointed indicator to bear at the very tip of the cutting edge, pointing in a radial line, shown in Fig 56.
3) Roll the cutter on the tabulated amount given under "checking distance" using the second indicator as a control.

4) Consult for amount of drop for the particular diameter and relief angle.

- **Inspection of Cutting Angle**

To measure the cutting angle, the procedure using indicators as Figure 57 shows is easy. Measuring the indicator drop (y) within the checking distance (x), consult table 14.

Since the cutting face is hook form, it is better to measure twice at different checking distance and to get the average. Generally the checking distance is MILL DIAMETER x 0.025.

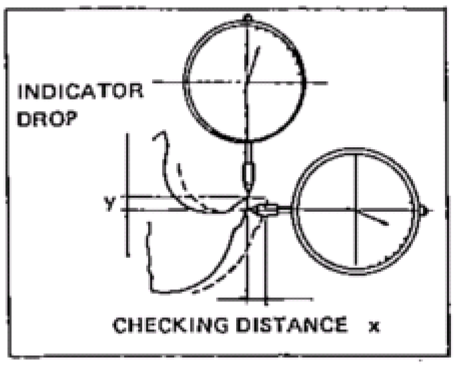


Fig.57. Checking Cutting Angle

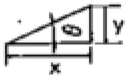


Table 13. CUTTING ANGLE AND INDICATOR DROP (mm)

θ° \ x (mm)	0.15	0.20	0.30	0.40	0.50	0.60	0.70	1.00
4	0.010	0.014	0.021	0.028	0.035	0.042	0.049	0.070
5	0.013	0.017	0.026	0.035	0.044	0.052	0.061	0.087
6	0.016	0.021	0.032	0.042	0.053	0.063	0.074	0.105
7	0.018	0.025	0.037	0.049	0.061	0.074	0.086	0.123
8	0.021	0.028	0.042	0.056	0.070	0.084	0.098	0.141
9	0.024	0.032	0.047	0.063	0.079	0.095	0.111	0.158
10	0.026	0.035	0.053	0.071	0.088	0.106	0.123	0.176
11	0.029	0.039	0.058	0.078	0.097	0.117	0.136	0.194
12	0.032	0.043	0.064	0.085	0.106	0.128	0.149	0.213
13	0.035	0.046	0.069	0.093	0.115	0.138	0.162	0.231
14	0.037	0.050	0.075	0.100	0.125	0.150	0.175	0.249
15	0.040	0.051	0.080	0.107	0.134	0.161	0.188	0.268
16	0.043	0.057	0.086	0.115	0.143	0.172	0.201	0.287
17	0.046	0.061	0.092	0.122	0.153	0.183	0.214	0.306
18	0.049	0.065	0.097	0.130	0.162	0.195	0.227	0.325
19	0.052	0.069	0.103	0.138	0.172	0.207	0.241	0.344
20	0.055	0.073	0.109	0.146	0.182	0.218	0.255	0.364

Table 14. Cutting Angle and Indicator Drop (mm)

- **Inspection of Cutter Run-outs**

A cutter performs best when the cutting edge of all teeth runs true with the axis. Then each tooth does its share of work. Radial and axial run-outs should be checked with an indicator after each sharpening. Put an End mill on a Vee block and measure run-outs of peripheral teeth and end teeth with indicators, rotating the End mill.

If the End mill has centre holes on both ends, it can be held by centre. Table 15 indicates the tolerance of run-outs.

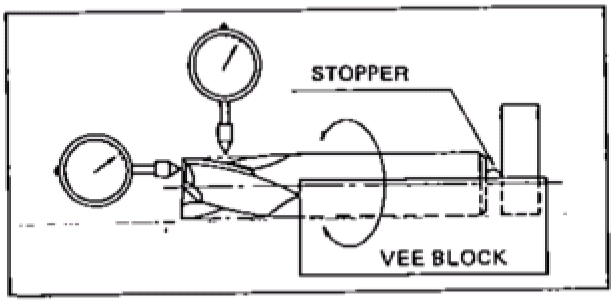


Fig.58. Measuring Cutter Run-outs

END MILL \ RUN-OUT	PERIPHERAL TEETH (mm)	END TEETH (mm)
FINISHING MILL	UNDER 0.03	UNDER 0.05
ROUGHING MILL	UNDER 0.05	UNDER 0.05

Table 15. Tolerance of Cutting Run-outs

- **Surface Roughness**

Use Profile meter equipment to test on the surface roughness. The surface roughness must be under than 6s. Rough surface finish may cause bad surface finish of work piece and chipping of cutting edge.

8. Machining problems in Conventional End mills

Normally when production workers using conventional End mills to perform on certain machining jobs, they will face with some common milling problems.

Some of the problems:

- Different End mills use for different applications
  - Result in higher tooling cost
  - Longer machining time and cost
- Improper selection of End mills
  - Result in poor quality milling and damage work material
  - Cause tool breakage which will also affect milling machine capacity
- Unable to achieve high speed milling and cutting process
  - Not using high speed CNC machining centre
  - Using conventional End mills

The below table is the standard troubleshooting guides on the principal problems and solutions of End mill

8.1 Troubleshooting Guides

SPECIFIC PROBLEM	CAUSE	SOLUTION
Chipping	Feed too fast	Slow down to proper feed
	Feed too fast on first cut	Slow down on first bite
	Not enough rigidity of Machine tool & Holder	Change rigid machine tool or holder
	Loose hold (tool)	Correct to tight holding
	Teeth too sharp	Change weaker cutting angle, primary relief
Wear	Speed too fast	Slow down, use enough coolant
	Hard material	Use higher grade tool material, add surface treatment
	Biting chips	Change feed & speed to change chip size or clear chips with coolant or air blow
	Improper feed & speed (too slow)	Increase feed & speed and try down cut
	Improper cutting angle	Change to correct cutting angle
	Too small primary relief angle	Change to larger relief angle
Breakage	Feed too fast	Slow down feed
	Too large cutting amount	Make smaller cutting amount per teeth
	Too long flute length or long overall length	Hold shank deeper, use shorter end mill
Chattering	Feed & speed too fast	Correct feed & speed
	Not enough rigidity (Machine & Holder)	Use better machine tool or holder or change condition
	Too much relief angle	Change to smaller relief angle, put margin (touch primary with oil stone)
	Cutting too deep	Correct to smaller cutting
	Too long flute or long overall length	Hold shank deeper, use shorter end mill or try down cut
Short tool life (dull teeth)	Too much cutting friction	Regrind at earlier stage
	Tough work material	Apply premium tool
	Improper cutting angle	Change cutting angle & primary relief
Chip packing	Too much cutting amount	Adjust feed or speed
	Not enough chip room	Use less number of flute end mill
	Not enough coolant	Apply more coolant or use air blow
Rough surface finish	Feed too fast	Slow down to correct feed
	Too much wear	Regrind at earlier stage
	Chip biting	Cut less amount
	No end teeth concavity	Put concave on bottom teeth
Burr	Too much wear on primary relief	Regrind at earlier stage
	Incorrect condition	Correct milling condition
	Improper cutting angle	Change to correct cutting angle
No dimensional accuracy	Too tough condition	Change to easier condition
	Lack of accuracy (Machine & Holder)	Repair machine or holder
No-perpendicular side	Feed too fast	Slow down to correct feed
	Too much cutting amount	Make less cutting amount
	Too long flute length or long overall length	Use correct length tool & hold shank deeper
	Less number of flutes	Use Large number of flute end mill

9. Safety Procedures

Designing features on Multi Purpose Carbide End mill for user friendly

During my designing stage, I have to take note on certain areas that will not cause any injuries to the operators while using my multi purpose Carbide End mill.

- **Handling of the End mill cutter**

  Problem: - As the cutting edge of the End mill cutter is very sharp and if the operators did not handle it with care or without safety protection (safety gloves), they will cut their hand very easily.

  Solution: - Add in a corner protection chamfering at the tip of the cutting edge will minimize the operators to cut their hands accidentally and the End mill cutter will still be sharp enough to perform an excellent surface finishing quality. On top of that, operators must also always remember to put on safety gloves.

- **Work material chips produced by End mill cutter**

  Problem: - Normal work material chips produced by conventional End mill cutters are long and curly, which can get tangled in the spindle or the work material. Operators will have to manually remove it by hands.

  Solution: - The unique design of the multi purpose Carbide End mill is able to produce short and broken chips. This feature improves automated milling operation, as operators do not need to be beside the machine to manage chip ejection and the risk of getting their hands cut are reduced.

- **Distortion and Vibration of the End mill cutter.**

  Problem: - While using multi purpose Carbide End mill cutter, it causes vibration and distortion of the milling machine, which will spoil the work material and also cause injuries to the operators.

  Solution: - Operators using the multi purpose Carbide End mill need to have proper technical guidance on how to use it by informing them the accurate cutting speed and feed rate. Suitable tool chuck holder should also be introduced to hold the End mill cutter tightly and rigidly, in order to prevent distortion or vibration and unnecessary injuries to the operators.

Safety issue to take note while using cutting tools

1. **Don't use tools in the inappropriate cutting condition**
   - Utilize the recommended cutting conditions just as general guide, when starting operation. It is necessary to adjust cutting condition when an unusual vibration, different sound occur by cutting.

2. **Don't use tools with considerable wear or cracks**
   - Wear or cracks in the tools cause breakage. Be sure that there is no wear, no cracks before using tools.

3. **Don't use tools by the reverse rotation**
   - Tool is usually used by the right rotation. Confirm attached indication package in the cause of the left rotation.

4. **Attach tools firmly to the holders to prevent shaking**
    - Insufficient retention of tools causes breakage. Confirm that tools are attached firmly to the holder.

5. **Fix work materials firmly to the machine**
    - Insufficient retention of the work materials causes breakage of tools. Confirm that work material is fixed firmly.

6. **Don't touch cutting edges with your bare hand**
    - Touching sharp cutting edge with bare hands caused injury. Handle tools by wearing protective gloves or hold a part except the cutting edge.

7. **Don't touch chips with your bare hand**
    - Chips are very hot immediately after processing and very sharp. Never touch them with your bare hand.

8. **Prevent body and clothes from touching scattered and coiled tips**
    - Chips sometimes scatter, or coil round with stretching long. Use a cover and protection glasses.

9. **Don't wear the gloves during the rotation**
    - Don't wear gloves during rotation because it is involved in the tool.

10. Prevent a body and clothes from touching tools during the rotation

- Touching tools causes caught in the machine. Ensure that you wear fitting clothes.

11. Handle heavy tools by using transport equipment or chain block

- It is likely to become lumbago when heavy tools are lifted alone. There is an attached warning sheet on the package of the heavy tools beyond 20kg.

12. Wear safety shoes to avoid foot injury in case of tools falls

- Be sure of laceration or bruise by dropping tools and wear safety shoes.

13. Cover machine and exclude a combustible in the case of dry cutting

- By sparks during cutting or heat by breakage, or hot chips, there is danger of fire. Take fire prevention measures.

14. Don’t use oil base coolant in the place where there is danger of the ignition and the explosion

- Using non-water cutting oil cause fire due to sparks, heat by breakage. Install CO_2 fire extinguishing system.

General Guidelines

The tooling supervisor or the operators using this multi purpose Carbide End mill must have a thorough knowledge on how to use this End mill cutter and also follow to the recommended general guidelines closely, in order to prevent accidents from happening. Some of the recommended general guidelines are:

- Ensure that all safety equipments are put on.
- Ensure that all safety measures are properly followed.
- Before starting the milling operation, check that the End mill are properly fit into the machine tightly.
- Before starting the milling operations, secure all doors on the panel or operating panel.
- Ensure that the correct cutting speed and feed rate are correctly keyed into the CNC Machine.
- Inspect the work area surrounding and ensure that extra safety measures are taken off on those unsafe points.
- Always be alert of any abnormal vibration, distortion or noise created during the milling operations. Stop the operation immediately if it happens.

10. Concept of developing Multi Purpose Carbide End mill

The concept of developing this Multi Purpose Carbide End mill is to provide a possible solution to solve the milling problems face in machining jobs, which will in terms, improve on the machining time and cost.

The Multi Purpose Carbide End mill can also be able to perform complex multi-task applications, which will help to save in tooling costs. One of the features of this Multi Purpose Carbide End mill is that it is very effective for side milling on deep wall cavity due to the unique design of this End mill.

On the making of this Multi Purpose Carbide End mill, the carbide material is selected to be group Z micro grain carbide, which has great toughness as well as wear resistance and rigidity. With the TiALN coating on the End mill flute surface, the surface roughness and productivity of this Multi Purpose Carbide End mill is much better than general types of End mills. Lastly, due to the mentioned factors on the carbide material and TiALN coating, therefore it is able to perform high-speed milling and cutting process and at the same time maintaining the excellent surface finish of the work material.

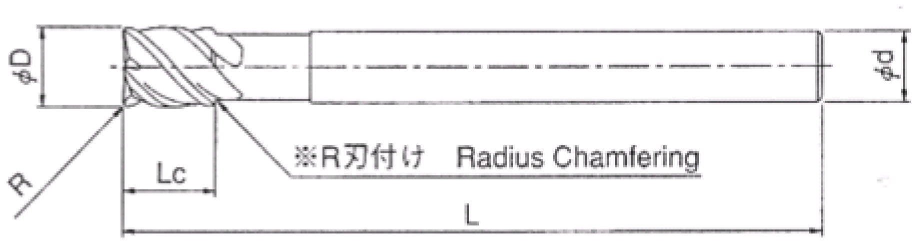
10.1 Developing of Multi Purpose Carbide End mill

The whole processes of producing Multi Purpose Carbide End mill are as follow:

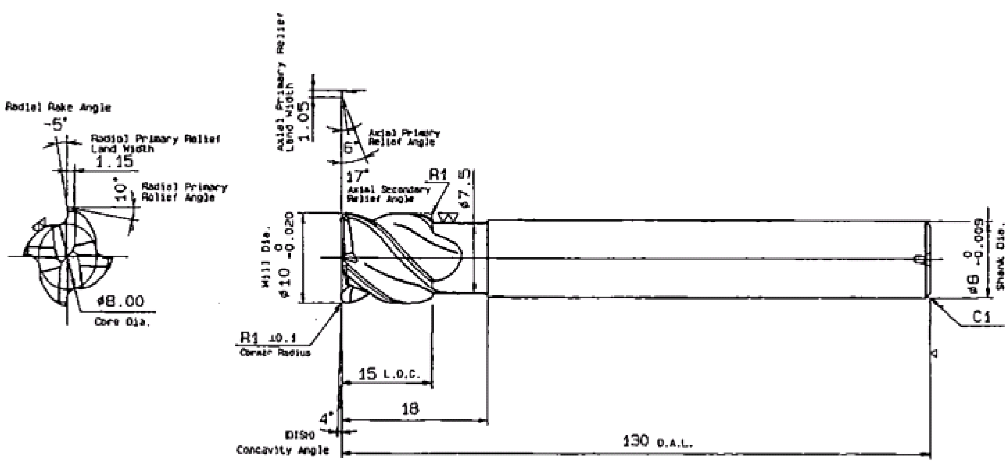
- Design the specification of the Multi Purpose Carbide End mill
- Calculate the cutting condition of the End mill for high speed milling
- Gathering all raw materials that are needed for production. (Micro Grain Carbide blank rod materials)
- Using the Lathe machine to part off the required size of the blank rod.
- Put the blank rod into the center-grinding machine for center grinding the surface of the blank rod to the required specification.
- Using Grinding machine with Diamond grinding wheels to grind the grooves and angles of the blank rod to form the required cutting flute form of the Multi Purpose Carbide End mill.
- Send for heat treatment process for hardening the Multi Purpose Carbide End mill to reach the optimum toughness and hardness.
- Send it to CNC Grinding machine for finishing process grinding to obtain the precise tolerance
- Send for surface treatment process by applying TiALN coating layer on the End mill flute surface to make it more durable and tough.
- Send for Quality Control process for quality inspections of the dimensions and specifications
- Test cut the Multi Purpose Carbide End mill on the calculated cutting condition for high speed milling on various work material to verify the cutting performances, cutting conditions and tool life

10.2 Technical Drawing of Multi Purpose Carbide End mill

Below is the design of the Multi Purpose Carbide End mill.



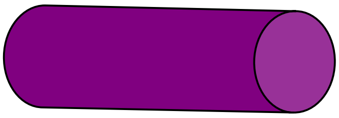
Draft Drawing



Detailed Technical Drawing

10.3 Making of Multi Purpose Carbide End mill

Below is the simple illustration of the making of the Multi Purpose Carbide End mill.



Blank Carbide Rod

Grinding Machine

Heat Treatment

CNC Grinding Machine (Finishing process)

Surface Treatment

QC Check & Test Cut

10.4 Picture of Multi-Purpose Carbide End mill

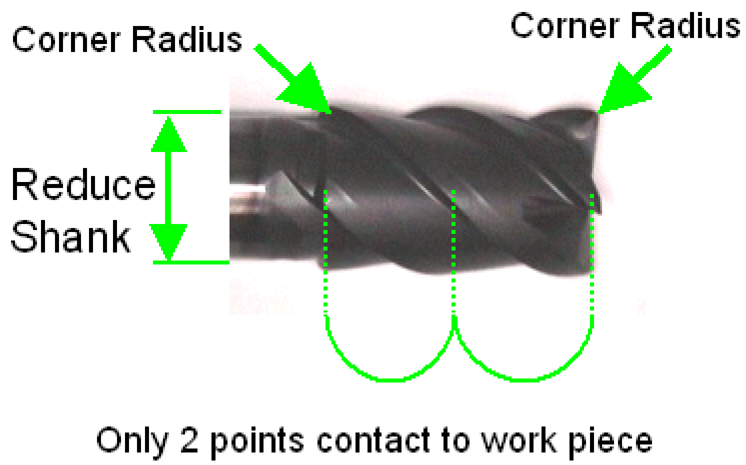
Below is the photograph of the Multi Purpose Carbide End mill.

Photo 2.

Photo 3.

10.5 Features of Multi Purpose Carbide End mill

The features of this Multi Purpose Carbide End mill is the unique design of the flute form and the reduce shank.



- Micro Grain Carbide (Group Z) as the End mill material
- Coated with TiALN coating
- High Helix angle of 40 degree
- Corner radius on four cutting edges
- Reduce shank design

The unique design of this Multi Purpose Carbide End mill allows it to perform complex multi-task applications and also able to perform highly precise and efficient side milling of deep wall area, as most of the general End mills are unable to perform side milling on deep wall cavity effectively due to the conventional design of the End mills, which will cause the End mill to deflect against the deep wall, that results in damaging the End mill and also unable to obtain satisfactory finishing on the work piece.

The picture below shows the difference on the Multi Purpose Carbide End mill against the general End mill on performing the side milling operation on the deep wall cavity.

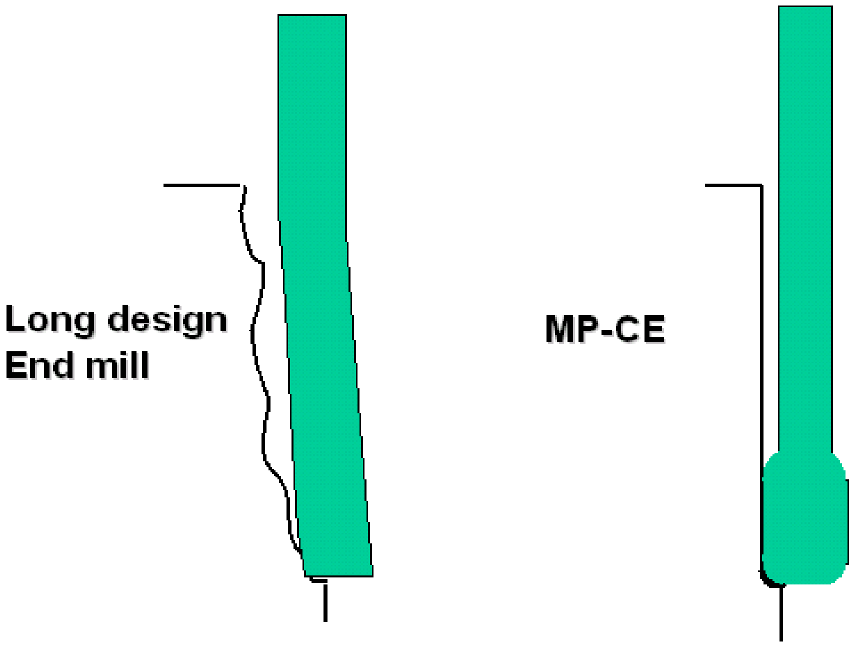


Fig.59. Comparison of MP-CE against Long design End mill

It shows that the long design End mill performs on the side milling operation on deep wall cavity will deflect as it has to mill the side wall with the whole flute length, while the Multi Purpose Carbide End mill does not deflect as much as the long design End mill because of the reduce shank design which requires to perform step milling operation.

The design of the long slim shank also has other advantages comparing to the conventional types of End mill, which the over-hang length can be adjusted therefore it is able to perform various types of milling applications.

For example,

- Step finishing for deep wall side milling
- Deep pocket milling
- Helical Drilling
- Ramping process
- Deep portion milling with corner radius
- Contour process

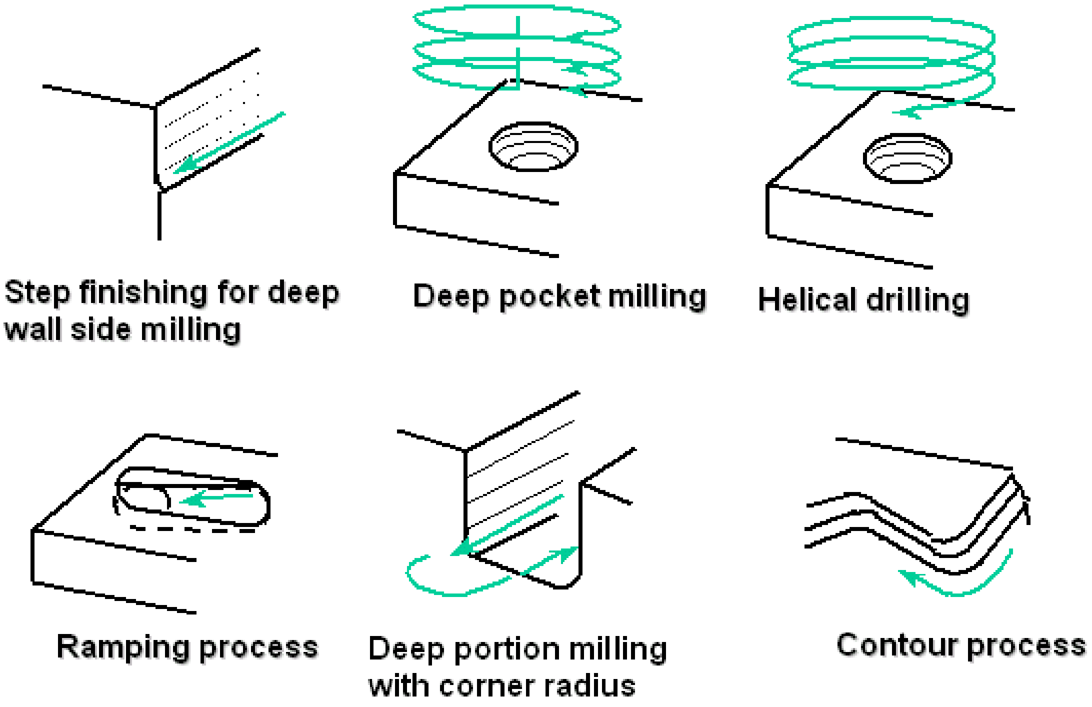


Fig.60. Various applications of MP-CE

In the past, it is a need to use different types of End mills to perform these various applications but now it is not necessary, as the Multi Purpose Carbide End mill is able to perform these various applications and also at high speed milling.

Test Data 1

Company:	**OSG**	Company B
End Mill:	**MP-CE**	HSS-CPM + TiCN
Size:	**Ø 6**	Ø 6
Speed:	**150m/min (8,000/rpm)**	40m/min (2,100/rpm)
Feed:	**800mm/min (0.05mm/t)**	210mm/min (0.1mm/t)
Machining Time:	**60mins.**	126mins.

Work Material:	Alloy Steel (35HRC)
Coolant:	Water Soluble
Machine:	Makino V750 (V)
Depth of Cut:	0.5mm
Others:	2D milling

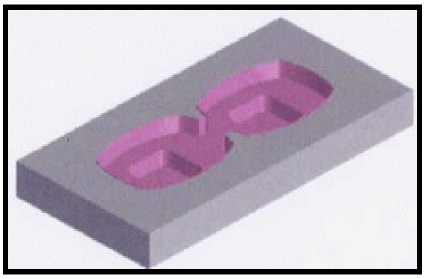


Fig.61. Test Data 1

This test data is the comparison of the Multi Purpose Carbide End mill against general Powder Metallurgy End mill with TiCN coating on the cutting speed, feed and machining time. As per indicated the work material is Alloy Steel (35HRC), coolant is water soluble, depth of cut is 0.5mm and using Makino V750 CNC machine. The cutting speed and feed applied on the Multi Purpose Carbide End mill is 8000rpm and 0.05 mm/t respectively, while the cutting speed and feed applied on the general End mill is at 2100rpm and 0.1mm/t.

As the result obtained, the machining time of the Multi Purpose Carbide End mill is almost 2 times faster than the general End mill. This data proves that Multi Purpose Carbide End mill is able to perform at high speed milling than general End mill.

Test Data 2

Company:	**OSG**	Company C
End Mill:	**MP-CE**	Micro-Grain + TiALN
Size:	**Ø 6**	Ø 6
Speed:	**470m/min (15,000/rpm)**	470m/min (15,000/rpm)
Feed:	**6,000mm/min (0.2mm/t)**	5,500mm/min (0.18mm/t)
Tool life:	**14hrs.**	8hrs.

Work Material:	Stainless Steel (SUS 304)
Coolant:	Water Soluble
Machine:	Makino V750 (V)
Depth of Cut:	0.3mm
Others:	3D milling

Fig.62. Test Data 2

This second test data is the comparison of the Multi Purpose Carbide End mill against general Micro Grain Carbide End mill with TiALN coating on the tool life. The cutting conditions applied on both cutters are the same and the work material is Stainless Steel (SUS 304), coolant is water soluble, depth of cut is 0.3mm and using Makino V750 CNC machine. The result stated on the tool life of Multi Purpose Carbide End mill is 14 hours and general Micro Grain Carbide End mill is 8 hours.

As the result obtained, the Multi Purpose Carbide End mill is having much longer tool life than general Micro Grain Carbide End mill, because the unique design of the Multi Purpose Carbide End mill on the flute form is much better than the general Micro Grain Carbide End mill.

Test Data 3

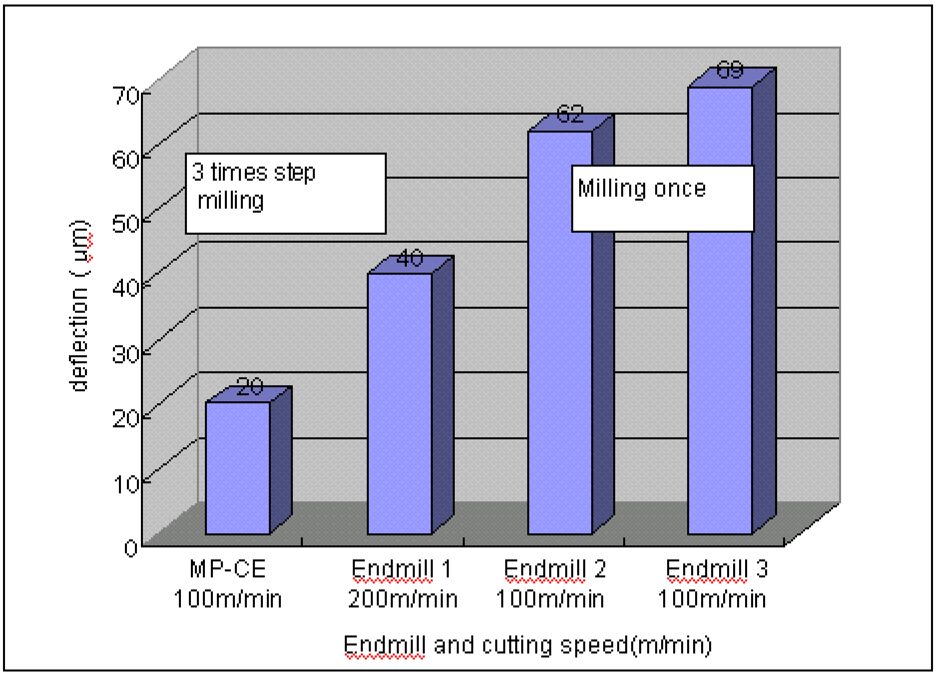


Fig.63. Comparison of the deflection

The third test data explains on the comparison of the Multi Purpose Carbide End mill against various general End mill on the deflection rate. From the figure above, it shows that Multi Purpose Carbide End mill is performing three times step-milling operation, while the other general End mills are performing one time milling operation.

The results obtained from the figure shows that the Multi Purpose Carbide End mill has the lowest deflection rates compare to the other three general End mills, while they are having the similar cutting speed.

Test data 4

The table below shows on the detailed information of the Multi Purpose Carbide End mill against the general long series End mill while putting on test.

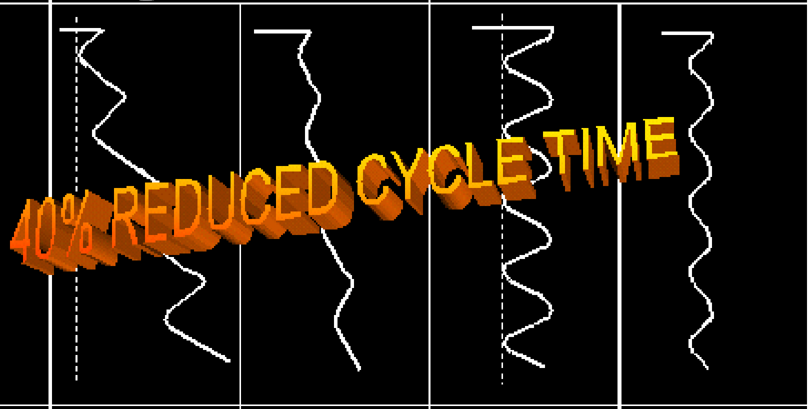
Endmil	Long Series End mill		MP-CE	
deflection				
deflection(μ m)	49	17	18	10
Axial roughness(μ mRy)	6.72	4.1	3.56	3.68
Milling speed (m/min)	20	←	200	←
Feed (mm/min)	127	←	1061	←
Radial depth (mm)	0.05	←	0.05	←
Zero cutting (times)	0	3	0	1
Time proportion	1	4	0.6	1.2

Table 16. Cycle Time reduction

The results obtained show that the Multi Purpose Carbide End mill is much better quality than general long series End mill in various aspect. While having the same radial depth of cutting, it shows that the Multi Purpose Carbide End mill is operating at high feed and speed milling.

The deflection rate and axial roughness is tremendously better than the general long series End mill, which in terms, of having 40% reduced in cycle time.

11. Conclusion

After the various tests on the Multi Purpose Carbide End mill against the general conventional End mills. It is able to justify that this newly developed Multi Purpose Carbide End mill is also able to operate at high-speed milling. At the same time, the tool life is also much better than general conventional End mill.

On top of comparing high-speed milling and tool life, the deflection rate is also tremendously reduced, while operating on the application of side milling on deep wall cavity. It is also proven that this Multi Purpose Carbide End mill is able to perform multi complex applications, which previously using general conventional End mill is unable to achieve.

With the success of developing this Multi Purpose Carbide End mill, it will definitely help the metal cutting industry to solve the common machining problems in using different types of general conventional End mills. Generally, it will help in reducing production cost, cycle time, tooling cost, labour cost and speed up the milling operations.

Appendix A

Project Specification

1. Research background information on different types of End mill.
2. Study on the End mill materials and surface treatment.
3. Study on various cutting performances and conditions
4. Research on various types of work materials
5. Analysis & Troubleshooting on milling problems
6. Research and Develop on Multi Purpose Carbide End mill.
7. Design and Construct on Multi Purpose Carbide End mill.
8. Liaise on the production of the Multi Purpose Carbide End mill Prototype.
9. Testing on the milling performance of Multi Purpose Carbide End mill.
10. Comparison of MPC End mill against general End mills.
11. Evaluation on MPC End mill cutting performances & conditions.
12. Discussion for the Thesis Outline with supervisor.
13. Thesis initial drafting - each chapter in draft form is shown to supervisor so that the thesis can be finished reading by 7 September 2004.
14. Final draft of thesis, to incorporate modifications suggested by supervisor
15. Complete the thesis in requested format.

Appendix B

List of References

1. Cutting Characteristics of Carbide End mills; Kitaura, Seiichiro (Akashi Plant); Source: KOBELCO Technology Review, n 17, Apr, 1994, p 16-19

2. TIPS ON CHOOSING/USING END MILLS; Rakowski, Leo R.; Source: Machine and Tool Blue Book, v75, n 1, Jan, 1980, p 60-72

3. OSG END MILLS TECHNICAL GUIDE; Source: OSG MFG. Company & OSG Corporation, Toyokawa, Japan, 1982.

4. Milling Cutters and End Mills; Source: The American Society of Mechanical Engineers, United Engineering Center, ANSI /ASME B94.19, 1985

5. Mechanical Behavior of Materials; Michael, B. Bever; Source: McGraw Hill International Editions, USA, 1990.

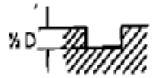
6. Machinery's Handbook; E.Oberg, F.D.Jones, H.L.Horton, and H.H.Ryffel; Source: Industrial Press, UK, 1992.

Appendix C

Recommended Milling Condition 1

H.S.S. Co. END MILLS

SLOTTING 2 FLUTE



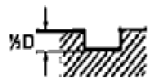
MILL DIA. (mm)	MATERIAL / CUTTING CONDITION / NUMBER OF FLUTE	MILD STEELS (~50 kgf/mm²) BRASS BRONZE			MEDIUM TENSILE STEELS (60~100 kgf/mm²) MILD STEEL FORGINGS CAST IRON HARD BRASS AND BRONZE COPPER			HIGH TENSILE STEELS (80~100 kgf/mm²) UNALLOYED TITANIUM HEAT RESISTANT FERRITIC LOW ALLOYS			HIGH TENSILE STEELS (100~150 kgf/mm²) TOOL STEELS MEDIUM STRENGTH STAINLESS STEELS			HEAT RESISTANT HIGH ALLOYS HIGH STRENGTH TITANIUM ALLOYS HIGH STRENGTH STAINLESS STEELS			ALUMINIUM ALLOYED ALUMINIUM PLASTICS WOODS		
		SPEED 35~45 m/min.	FEED		SPEED 28~33 m/min.	FEED		SPEED 15~20 m/min.	FEED		SPEED 10~15 m/min.	FEES		SPEED 5~10 m/min.	FEED		SPEED 80~120 m/min.	FEED	
		r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.
3	2	4500	0.012	106	3350	0.011	75	2000	0.009	36	1400	0.007	20	900	0.005	9	11200	0.011	250
4	2	3160	0.02	125	2360	0.018	85	1400	0.014	40	1000	0.012	25	630	0.009	11	8000	0.018	290
5	2	2500	0.028	140	1900	0.025	95	1120	0.02	45	800	0.017	28	500	0.012	12	6300	0.025	315
6	2	2240	0.034	150	1700	0.03	100	1000	0.024	48	710	0.02	28	450	0.015	14	5600	0.028	315
8	2	1600	0.056	180	1180	0.05	118	710	0.04	56	500	0.034	34	315	0.025	16	4000	0.048	387
10	2	1250	0.08	200	950	0.071	132	560	0.056	63	400	0.048	38	250	0.036	18	3150	0.063	400
12	2	1000	0.095	190	750	0.08	118	450	0.067	60	315	0.06	38	200	0.045	18	2500	0.075	375
14	2	900	0.1	180	670	0.09	118	400	0.075	60	280	0.071	40	180	0.05	18	2240	0.08	355
16	2	800	0.106	170	600	0.095	112	355	0.085	60	250	0.08	40	160	0.056	18	2000	0.085	345
18	2	710	0.118	165	530	0.1	106	315	0.09	56	224	0.09	40	140	0.063	18	1800	0.095	345
20	2	630	0.125	160	475	0.1	85	280	0.1	56	200	0.1	40	125	0.071	18	1600	0.1	315
22	2	560	0.132	150	425	0.1	85	250	0.1	50	180	0.1	36	112	0.08	18	1400	0.106	300
24	2	500	0.14	140	375	0.1	75	224	0.1	45	160	0.1	32	100	0.09	18	1250	0.112	280
25	2	500	0.14	140	375	0.1	75	224	0.1	45	160	0.1	32	100	0.09	18	1250	0.112	280
26	2	500	0.14	140	375	0.1	75	224	0.1	45	160	0.1	32	100	0.09	18	1250	0.112	280
28	2	450	0.14	125	335	0.1	65	200	0.1	40	140	0.1	28	90	0.1	18	1120	0.118	265
30	2	450	0.14	125	335	0.1	65	200	0.1	40	140	0.1	28	90	0.1	18	1120	0.118	165
32	2	400	0.15	120	300	0.1	60	180	0.1	36	125	0.1	25	80	0.1	16	1000	0.118	236
35	2	355	0.15	105	265	0.1	53	160	0.1	32	112	0.1	22	71	0.1	14	900	0.125	224
36	2	355	0.15	105	265	0.1	53	160	0.1	32	112	0.1	22	71	0.1	14	900	0.125	224
40	2	315	0.16	100	236	0.1	48	140	0.1	28	100	0.1	20	63	0.1	12	800	0.125	200
45	2	280	0.16	90	212	0.1	42	125	0.1	25	90	0.1	18	56	0.1	11	710	0.125	180
50	2	250	0.16	80	190	0.1	38	112	0.1	22	80	0.1	16	50	0.1	10	630	0.125	160
56	2	224	0.16	71	170	0.1	34	160	0.1	20	71	0.1	14	45	0.1	9	560	0.125	140
63	2	200	0.16	65	150	0.1	30	90	0.1	18	63	0.1	12	40	0.1	8	500	0.125	125

Appendix D

Recommended Milling Condition 2

H.S.S. Co. END MILLS

SLOTTING 3 FLUTE



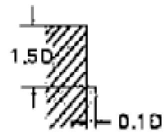
MILL DIA. (mm)	MATERIAL / CUTTING CONDITION / NUMBER OF FLUTE	MILD STEELS (~50 kgf/mm²) BRASS BRONZE — SPEED 35 ~ 45 m/min. r.p.m.	FEED mm/teeth	FEED mm/min.	MEDIUM TENSILE STEELS (50 ~ 100 kgf/mm²) MILD STEEL FORGINGS CAST IRON HARD BRASS AND BRONZE COPPER — SPEED 29 ~ 33 m/min. r.p.m.	FEED mm/teeth	FEED mm/min.	HIGH TENSILE STEELS (80 ~ 100 kgf/mm²) UNALLOYED TITANIUM HEAT RESISTANT FERRITIC LOW ALLOYS — SPEED 15 ~ 20 m/min. r.p.m.	FEED mm/teeth	FEED mm/min.	HIGH TENSILE STEELS (100 ~ 150 kgf/mm²) TOOL STEELS MEDIUM STRENGTH STAINLESS STEELS — SPEED 10 ~ 16 m/min. r.p.m.	FEED mm/teeth	FEED m/min. mm/min.	HEAT RESISTANT HIGH ALLOYS HIGH STRENGTH TITANIUM ALLOYS HIGH STRENGTH STAINLESS STEELS — SPEED 5 ~ 10 m/min. r.p.m.	FEED mm/teeth	FEED mm/min.	ALUMINIUM ALLOYED ALUMINUM PLASTICS WOODS — SPEED 80 ~ 120 m/min. r.p.m.	FEED mm/teeth	FEED mm/min.
3	3	4500	0,010	140	3350	0,010	100	2000	0,008	48	1400	0,008	26	900	0,004	12	11200	0,009	315
4	3	3150	0,017	160	2360	0,016	112	1400	0,012	53	1000	0,011	32	630	0,007	14	8000	0,016	375
5	3	2500	0,024	180	1900	0,022	125	1120	0,018	60	800	0,016	36	500	0,011	16	6300	0,021	400
6	3	2240	0,030	200	1700	0,026	132	1000	0,021	63	710	0,017	36	450	0,013	18	5600	0,024	400
8	3	1600	0,050	236	1180	0,042	150	710	0,036	75	500	0,030	45	315	0,022	21	4000	0,042	500
10	3	1250	0,067	260	950	0,060	170	560	0,048	80	400	0,042	50	250	0,032	24	3150	0,056	530
12	3	1000	0,085	260	750	0,067	150	450	0,060	80	315	0,053	60	200	0,040	24	2500	0,067	500
14	3	900	0,085	236	670	0,075	150	400	0,067	80	280	0,063	53	180	0,045	24	2240	0,071	475
16	3	800	0,095	224	600	0,085	150	355	0,075	80	250	0,071	63	160	0,050	24	2000	0,075	450
18	3	710	0,100	212	530	0,090	140	315	0,075	71	224	0,080	53	140	0,056	24	1800	0,085	450
20	3	630	0,112	212	475	0,090	125	280	0,085	71	200	0,090	53	125	0,063	24	1600	0,085	400
22	3	560	0,118	200	425	0,090	112	250	0,085	65	180	0,090	48	112	0,071	24	1400	0,095	400
24	3	500	0,118	180	375	0,080	100	224	0,090	60	160	0,080	42	100	0,080	24	1250	0,100	375
25	3	500	0,118	180	376	0,090	100	224	0,090	60	160	0,090	42	100	0,090	24	1250	0,100	375
26	3	500	0,118	180	375	0,090	100	224	0,090	60	160	0,090	42	100	0,090	24	1250	0,100	375
28	3	450	0,118	160	335	0,090	90	200	0,090	53	140	0,090	38	90	0,090	24	1120	0,106	355
30	3	450	0,118	160	335	0,090	90	200	0,090	53	140	0,090	38	90	0,090	24	1120	0,108	355
32	3	400	0,132	160	300	0,090	80	180	0,090	48	125	0,090	34	80	0,090	21	1000	0,108	315
35	3	355	0,132	140	265	0,090	70	160	0,090	42	112	0,090	30	71	0,090	19	900	0,110	300
36	3	355	0,132	140	265	0,090	70	160	0,090	42	112	0,090	30	71	0,090	19	900	0,110	300
40	3	315	0,140	132	236	0,090	63	140	0,090	38	100	0,090	28	63	0,090	17	800	0,110	265
45	3	280	0,140	118	212	0,090	56	125	0,090	34	90	0,090	24	56	0,090	15	710	0,110	236
50	3	250	0,140	106	190	0,090	50	112	0,090	30	80	0,090	21	50	0,090	14	630	0,110	212
56	3	224	0,140	95	170	0,090	45	100	0,090	28	71	0,090	19	45	0,090	12	560	0,110	190
63	3	200	0,140	85	150	0,090	40	90	0,090	24	63	0,090	17	40	0,090	11	500	0,110	170

Appendix E

Recommended Milling Condition 3

H.S.S. Co END MILLS

SIDE CUTTING MULTIPLE FLUTE



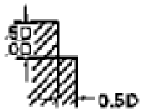
MILL DIA. (mm)	MATERIAL / CUTTING CONDITION / NUMBER OF FLUTE	MILD STEELS (~50 kgf/mm²) BRASS BRONZE			MEDIUM TENSILE STEELS (50~80 kgf/mm²) MILD STEEL FORGINGS CAST IRON HARD BRASS AND BRONZE COPPER			HIGH TENSILE STEELS (80~100 kgf/mm²) UNALLOYED TITANIUM HEAT RESISTANT FERRITIC LOW ALLOYS			HIGH TENSILE STEELS (100~150 kgf/mm²) TOOL STEELS MEDIUM STRENGTH STAINLESS STEELS			HEAT RESISTANT HIGH ALLOYS HIGH STRENGTH TITANIUM ALLOYS HIGH STRENGTH STAINLESS STEELS			ALUMINIUM ALLOYED ALUMINIUM PLASTICS WOODS		
		SPEED 40~50 m/min.	FEED		SPEED 32~38 m/min.	FEED		SPEED 20~25 m/min.	FEED		SPEED 10~15 m/min.	FEED		SPEED 5~10 m/min.	FEED		SPEED 140~180 m/min.	FEED	
		r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.
3	4	5300	0.012	250	4000	0.012	190	2650	0.009	95	1600	0.007	45	900	0.005	18	18000	0.011	800
4	4	3750	0.02	300	2800	0.02	224	1900	0.014	106	1120	0.012	53	630	0.009	22	12500	0.018	900
5	4	3000	0.028	335	2240	0.028	260	1500	0.02	118	900	0.017	60	500	0.012	24	10000	0.025	1000
6	4	2650	0.034	355	2000	0.034	266	1320	0.024	125	800	0.02	63	450	0.015	28	9000	0.028	1000
8	4	1900	0.058	425	1400	0.056	315	950	0.04	150	560	0.034	75	315	0.025	32	6300	0.048	1180
10	4	1600	0.08	475	1120	0.08	355	750	0.056	170	460	0.048	85	250	0.036	36	6000	0.063	1250
12	4	1180	0.095	450	900	0.095	335	600	0.067	160	365	0.06	85	200	0.046	36	4000	0.075	1180
14	4	1060	0.1	425	800	0.1	315	530	0.075	160	315	0.071	90	180	0.05	36	3550	0.08	1120
16	4	950	0.106	400	710	0.106	300	475	0.085	160	280	0.08	90	160	0.056	36	3150	0.085	1060
18	4	850	0.118	400	630	0.112	280	425	0.09	160	250	0.09	90	140	0.063	36	2800	0.095	1060
20	4	750	0.125	375	560	0.112	250	375	0.1	160	200	0.1	80	125	0.071	36	2500	0.1	1000
22	6	670	0.106	425	600	0.09	265	335	0.08	160	180	0.08	85	112	0.08	36	2000	0.09	1060
24	6	600	0.112	400	450	0.09	236	300	0.08	140	160	0.08	75	100	0.08	53	1800	0.095	1000
25	6	600	0.112	400	450	0.09	236	300	0.08	140	160	0.08	75	100	0.08	48	1800	0.095	1000
26	6	600	0.112	400	460	0.08	236	300	0.08	140	160	0.08	75	100	0.08	48	1800	0.095	1000
28	6	530	0.112	355	400	0.09	212	265	0.08	125	140	0.08	67	90	0.08	43	1600	0.1	950
30	6	530	0.112	355	400	0.09	212	265	0.08	125	140	0.08	67	90	0.08	43	1600	0.1	950
32	6	475	0.118	335	355	0.09	190	236	0.08	112	125	0.08	60	80	0.08	38	1400	0.1	850
35	6	425	0.118	300	315	0.09	170	212	0.08	100	112	0.08	53	71	0.08	34	1250	0.106	800
36	6	425	0.118	300	315	0.09	170	212	0.08	100	112	0.08	53	71	0.08	34	1250	0.106	800
40	6	375	0.125	280	250	0.09	150	190	0.08	90	100	0.08	48	63	0.08	30	1120	0.106	710
45	8	335	0.1	266	250	0.085	170	170	0.08	106	90	0.08	56	56	0.08	36	1000	0.095	750
50	8	300	0.1	236	224	0.085	160	150	0.08	95	80	0.08	50	50	0.08	32	900	0.095	670
56	8	265	0.1	212	200	0.085	140	132	0.08	85	71	0.08	45	45	0.08	28	800	0.095	600
63	8	236	0.1	190	180	0.085	125	118	0.08	75	67	0.08	40	40	0.08	25	700	0.095	530

Appendix F

Recommended Milling Condition 4

H.S.S. Co. END MILLS

ROUGHING CUT



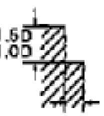
MATERIALS	MEDIUM TENSILE STEELS (~80 kgf/mm²) MILD STEEL FORGINGS CAST IRON BRASS AND BRONZE COPPER		HIGH TENSILE STEELS (80 ~ 100 kgf/mm²) UNALLOYED TITANIUM HEAT RESISTANT FERRITIC LOW ALLOYS		HIGH TENSILE STEELS (100 ~ 140 kgf/mm²) TOOL STEELS MEDIUM STRENGTH STAINLESS STEELS		HEAT RESISTANT HIGH ALLOYS HIGH STRENGTH TITANIUM ALLOYS HIGH STRENGTH STAINLESS STEELS MEDIUM STRENGTH TITANIUM ALLOYS		ALUMINIUM ALLOYED ALUMINIUM PLASTICS WOODS	
MILL DIA. (mm)	SPEED	FEED	SPEED	FEED	SPEED	FEED	SPEED	FEED	SPEED	FEED
	r.p.m.	mm/min.	r.p.m.	mm/min.	r.p.m.	mm/min.	r.p.m.	mm/min.	r.p.m.	mm/min.
6	1500	63	1120	40	850	25	560	15	4500	265
8	1060	75	800	48	600	30	400	18	3150	315
10	850	85	630	53	475	34	315	20	2500	350
12	670	95	500	60	375	38	250	22	2000	400
14	600	100	450	63	335	40	224	24	1800	425
16	530	106	400	67	300	42	200	25	1600	450
18	475	112	355	71	265	45	180	25	1400	475
20	425	128	315	75	236	48	160	28	1250	500
22	375	112	280	70	212	45	140	25	1120	475
24	335	106	250	67	190	42	125	25	1000	450
25	335	106	250	67	190	42	125	25	1000	450
26	335	106	250	67	190	42	125	25	1000	450
28	300	100	224	63	170	40	112	24	900	425
30	300	125	224	80	170	50	112	32	900	530
32	265	118	200	75	150	48	100	30	800	500
35	236	112	180	71	132	45	90	28	710	475
36	236	112	180	71	132	45	90	28	710	475
40	212	106	160	67	118	42	80	26	630	450
45	190	100	140	63	106	40	71	25	560	425
50	170	90	125	56	95	38	63	22	500	375
56	150	80	112	50	85	32	56	20	450	335
63	132	70	100	45	75	28	50	18	400	300

Appendix G

Recommended Milling Condition 5

H.S.S. Co. END MILLS

ROUGHING AND FINISHING CUT



MATERIALS	MEDIUM TENSILE STEELS (~80 kgf/mm²) MILD STEEL FORGINGS CAST IRON BRASS AND BRONZE COPPER		HIGH TENSILE STEELS (80~100 kgf/mm²) UNALLOYED TITANIUM HEAT RESISTANT FERRITIC LOW ALLOYS		HIGH TENSILE STEELS (100~140 kgf/mm²) TOOL STEELS MEDIUM STRENGTH STAINLESS STEELS		HEAT RESISTANT HIGH ALLOYS HIGH STRENGTH TITANIUM ALLOYS HIGH STRENGTH STAINLESS MEDIUM STRENGTH TITANIUM ALLOYS		ALUMINIUM ALLOYED ALUMINIUM PLASTICS WOODS	
MILL DIA. (mm)	SPEED	FEED	SPEED	FEED	SPEED	FEED	SPEED	FEED	SPEED	FEED
	r.p.m.	mm/min.	r.p.m.	mm/min.	r.p.m.	mm/min.	r.p.m.	mm/min.	r.p.m.	mm/min.
6	1600	50	1120	32	850	20	560	12	4500	212
8	1060	60	800	38	600	24	400	14	3150	250
10	850	67	630	42	475	26	315	16	2500	280
12	670	75	500	48	375	30	250	18	2000	315
14	600	80	450	50	335	32	224	19	1800	335
16	530	85	400	53	300	34	200	20	1600	355
18	475	90	355	56	265	35	180	21	1400	375
20	425	100	315	63	236	40	160	24	1250	400
22	375	90	280	56	212	36	140	21	1120	375
24	335	85	250	53	190	34	125	20	1000	355
25	335	85	260	63	190	34	125	20	1000	355
26	335	85	250	63	190	34	125	20	1000	355
28	300	80	224	60	170	32	112	19	900	335
30	300	100	224	63	170	40	112	24	900	425
32	265	95	200	60	160	38	100	22	800	400
35	236	90	180	66	132	36	90	21	710	375
36	236	90	180	66	132	35	90	21	710	375
40	212	85	160	53	118	34	80	20	630	355
45	190	80	140	50	106	32	71	19	560	335
50	170	72	125	45	95	28	63	17	500	300
56	150	63	112	40	85	28	56	15	450	270
63	132	56	100	36	75	22	50	13	400	240

Appendix H

Recommended Milling Condition 6

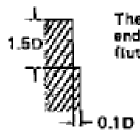
CARBIDE END MILLS

The indicated speeds and feeds are applicable for slotting cuts, a diameter deep. For deeper slotting cuts or cavity applications, feed should be decreased.

SLOTTING

MILL DIA. (mm)	MATERIAL / MILLING CONDITION / NUMBER OF FLUTE	CAST IRON			MEDIUM TENSILE STEELS (50 ~ 80 kgf/mm²) MILD STEEL FORGINGS			HIGH TENSILE STEELS (80 ~ 100 kgf/mm²) TOOL STEELS MEDIUM STRENGTH STAINLESS STEELS			HEAT RESISTANT HIGH ALLOYS HIGH STRENGTH TITANIUM ALLOYS HIGH STRENGTH STAINLESS STEELS			ALUMINIUM ALLOYED ALUMINIUM PLASTICS WOODS		
		SPEED 32 ~ 38 m/min.	FEED		SPEED 32 ~ 38 m/min.	FEED		SPEED 23 ~ 27 m/min.	FEED		SPEED 18 ~ 22 m/min.	FEED		SPEED 100 ~ 140 m/min.	FEED	
		r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.
2	2	5600	0.0095	106	5600	0.007	80	4000	0.006	45	3150	0.003	20	19000	0.003	112
3	2	3750	0.014	106	3750	0.011	85	2650	0.009	45	2120	0.005	20	12500	0.0045	112
4	2	2800	0.022	125	2800	0.016	90	2000	0.0125	50	1600	0.006	20	9500	0.006	112
5	2	2240	0.031	140	2240	0.020	90	1600	0.0175	56	1250	0.008	20	7500	0.0075	112
6	2	1900	0.040	150	1900	0.024	90	1320	0.021	56	1060	0.009	20	6300	0.009	112
8	2	1400	0.064	180	1400	0.032	80	1000	0.028	56	800	0.012	20	4750	0.012	112
10	2	1120	0.085	190	1120	0.036	67	800	0.035	56	630	0.013	16	4000	0.014	112
12	2	950	0.105	200	950	0.042	56	670	0.042	56	530	0.015	16	3150	0.018	112

CARBIDE END MILLS



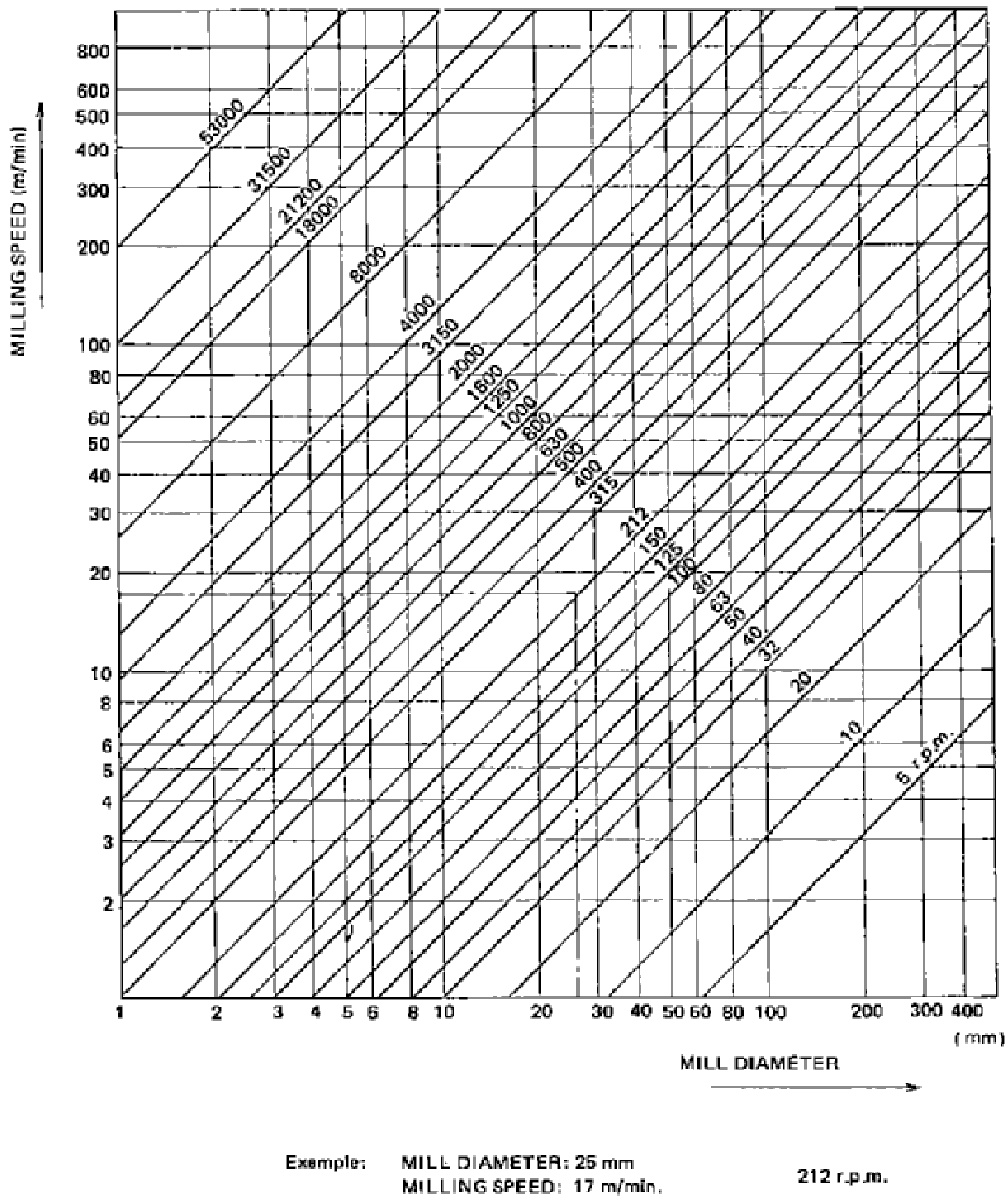
The indicated speeds and feeds are applicable for side milling, with 4 flute end mills, 1/10 diameter deep x 1.1/2 diameter wide. For milling with 2 flute end mills, the feed should be half of the above figures.

SIDE CUTTING

MILL DIA. (mm)	MATERIAL / MILLING CONDITION / NUMBER OF FLUTE	CAST IRON			MEDIUM TENSILE STEELS (50 ~ 80 kgf/mm²) MILD STEEL FORGINGS			HIGH TENSILE STEELS (80 ~ 100 kgf/mm²) TOOL STEELS MEDIUM STRENGTH STAINLESS STEELS			HEAT RESISTANT HIGH ALLOYS HIGH STRENGTH TITANIUM ALLOYS HIGH STRENGTH STAINLESS STEELS			ALUMINIUM ALLOYED ALUMINIUM PLASTICS WOODS		
		SPEED 37 ~ 43 m/min.	FEED		SPEED 32 ~ 38 m/min.	FEED		SPEED 23 ~ 27 m/min.	FEED		SPEED 18 ~ 22 m/min.	FEED		SPEED 100 ~ 140 m/min.	FEED	
		r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.	r.p.m.	mm/teeth	mm/min.
3	4	4250	0.018	315	3750	0.016	240	2650	0.013	140	2120	0.007	60	12500	0.011	560
4	4	3150	0.030	375	2800	0.022	250	2000	0.019	150	1600	0.009	60	9500	0.015	560
5	4	2500	0.042	425	2240	0.030	265	1600	0.025	160	1250	0.012	60	7500	0.020	600
6	4	2120	0.056	475	1900	0.037	280	1320	0.030	160	1060	0.014	60	6300	0.025	630
8	4	1600	0.112	710	1400	0.038	212	1000	0.040	160	800	0.015	48	4750	0.035	670
10	4	1320	0.120	630	1120	0.042	190	800	0.050	160	630	0.013	32	4000	0.042	670
12	4	1120	0.132	600	950	0.050	190	670	0.060	160	530	0.015	32	3150	0.053	670

Appendix I

Relation among Mill Diameter, Revolution & Milling Speed



Appendix J

Approximate Relation among Various Hardness Scale

Diamond Pyramid hardness number, Vickers	Brinell hardness 3,000 kg: Standard 10 mm ball	Brinell hardness 3,000 kg: Hultgren 10 mm ball	Brinell hardness 3,000 kg: Tungsten carbide 10 mm	Rockwell hardness: A scale 60 kg Brale	Rockwell hardness: B scale 100 kg 1/16-in.	Rockwell hardness: C scale 150 kg Brale	Rockwell hardness: D scale 100 kg Brale	Rockwell hardness: Superficial 15N	Rockwell hardness: Superficial 30N	Rockwell hardness: Superficial 45N	Shore scleroscope hardness number	Approx tensile strength 1,000 psi
Hv	HB			HRA	HRB	HRC	HRD				HS	
940	–	–	–	85.6	–	68	76.9	93.2	84.4	75.4	97	–
900	–	–	–	85.0	–	67	76.1	92.9	83.6	74.2	95	–
865	–	–	–	84.5	–	66	75.4	92.5	82.8	73.3	92	–
832	–	–	739	83.9	–	65	74.5	92.2	81.9	72.0	91	–
800	–	–	722	83.4	–	64	73.8	91.8	81.1	71.0	88	–
772	–	–	705	82.8	–	63	73.0	91.4	80.1	69.9	87	–
746	–	–	688	82.3	–	62	72.2	91.1	79.3	68.8	85	–
720	–	–	670	81.8	–	61	71.5	90.7	78.4	67.7	83	–
697	–	613	654	81.2	–	60	70.7	90.2	77.5	66.6	81	–
674	–	599	634	80.7	–	59	69.9	89.8	76.6	65.5	80	326
653	–	587	615	80.1	–	58	69.2	89.3	75.7	64.3	78	315
633	–	575	595	79.6	–	57	68.5	88.9	74.8	63.2	76	305
613	–	561	577	79.0	–	56	67.7	88.3	73.9	62.0	75	295
595	–	546	560	78.5	–	55	66.9	87.9	73.0	60.9	74	287
577	–	534	543	78.0	–	54	66.1	87.4	72.0	59.8	72	278
560	–	519	525	77.4	–	53	65.4	86.9	71.2	58.6	71	269
544	500	508	512	76.8	–	52	64.6	86.4	70.2	57.3	69	262
528	487	494	496	76.3	–	51	63.8	85.9	69.4	56.1	68	253
513	475	481	481	75.9	–	50	63.1	85.5	68.5	55.0	67	245
498	464	469	469	75.2	–	49	62.1	85.0	67.6	53.8	66	239
484	451	455	455	74.7	–	48	61.4	84.5	66.7	52.5	64	232
471	442	443	443	74.1	–	47	60.8	83.9	65.8	51.4	63	225
458	432	432	432	73.6	–	46	60.0	83.5	64.8	50.3	62	219
446	421	421	421	73.1	–	45	59.2	83.0	64.0	49.0	60	212
434	409	409	409	72.5	–	44	58.5	82.5	63.1	47.8	58	206
423	400	400	400	72.0	–	43	57.7	82.0	62.2	46.7	57	201
412	390	390	390	71.5	–	42	56.9	81.5	61.3	45.5	56	196
402	381	381	381	70.9	–	41	56.2	80.9	60.4	44.3	55	191
392	371	371	371	70.4	–	40	55.4	80.4	59.5	43.1	54	186
382	362	362	362	69.9	–	39	54.6	79.9	58.6	41.9	52	181
372	353	353	353	69.4	–	38	53.8	79.4	57.7	40.8	51	176
363	344	344	344	68.9	–	37	53.1	78.8	56.8	39.6	50	172
354	336	336	336	68.4	(109.0)	36	52.3	78.3	55.9	38.4	49	168
345	327	327	327	67.9	(108.5)	35	51.5	77.7	55.0	37.2	48	163
336	319	319	319	67.4	(108.0)	34	50.8	77.2	54.2	36.1	47	159
327	311	311	311	66.8	(107.5)	33	50.0	76.6	53.3	34.9	46	154
318	301	301	301	66.3	(107.0)	32	49.2	76.1	52.1	33.7	44	150
310	294	294	294	65.8	(106.0)	31	48.4	75.6	51.3	32.5	43	146
302	286	286	286	65.3	(105.5)	30	47.7	75.0	50.4	31.3	42	142
294	279	279	279	64.7	(104.5)	29	47.0	74.5	49.5	30.1	41	138
286	271	271	271	64.3	(104.0)	28	46.1	73.9	48.6	28.9	41	134
279	264	264	264	63.8	(103.0)	27	45.2	73.3	47.7	27.8	40	131
272	258	258	258	63.3	(102.5)	26	44.6	72.8	46.8	26.7	38	127
266	253	253	253	62.8	(101.5)	25	43.8	72.2	45.9	25.5	38	124
260	247	247	247	62.4	(101.0)	24	43.1	71.6	45.0	24.3	37	121
254	243	243	243	62.0	100.0	23	42.1	71.0	44.0	23.1	36	118
248	237	237	237	61.5	99.0	22	41.6	70.5	43.2	22.0	35	115
243	231	231	231	61.0	98.5	21	40.9	69.9	42.3	20.7	35	113
238	226	226	226	60.5	97.8	20	40.1	69.4	41.5	19.6	34	110
230	219	219	219	–	96.7	(18)	–	–	–	–	33	106
222	212	212	212	–	95.5	(16)	–	–	–	–	32	102
213	203	203	203	–	93.9	(14)	–	–	–	–	31	98
204	194	194	194	–	92.3	(12)	–	–	–	–	29	94
196	187	187	187	–	90.7	(10)	–	–	–	–	28	90
188	179	179	179	–	89.5	(8)	–	–	–	–	27	87
180	171	171	171	–	87.1	(6)	–	–	–	–	26	84
173	165	165	165	–	85.5	(4)	–	–	–	–	25	80
166	158	158	158	–	83.5	(2)	–	–	–	–	24	77
160	152	152	152	–	81.7	(0)	–	–	–	–	24	75