INVESTIGATION ON TURNING OPERATION OF Al/SiC-MMC WITH VARIOUS TOOLING SYSTEMS

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Abstract Despite of superior mechanical and physical properties, Al/SiC-MMC,s are not widely used in industry due to their poor machinability. The presence of hard abrasive reinforced particles in the Al/SiC-MMC,s causes rapid tool wear during machining. A series of turning tests are conducted for selection of optimum tooling process for turning of Al/ 10 vol. % SiC-MMC. This paper presents experimental results from a series of turning test in which a number of different tooling systems are used to machine Al/ 10 vol. % SiC-MMC. The influence of the cutting speed, feed rate, depth of cut and inclination angle of tool holder on surface finish have been established for each of the tooling system. The influence of cutting time and length of continuous turning on the tool wear is also established for each of the tooling system. The results suggest that the fixed rhombic tooling (FRT) and fixed circular tooling (FCT) is most effective for proper machining of Al/ 10 vol. % SiC-MMC at high speed and low depth of cut. Neither flank built-up nor built-up edge are formed on the circular insert in rotary circular tooling (RCT) system during turning of Al/SiC-MMC. Self- propelled circular rotary tooling (RCT) system exhibits superior wear resistance and enhanced longer tool life compare to the other tooling systems.

Keywords : Tool wear , surface finish, RCT, Aluminium MMC

INTRODUCTION

About 30 years back, the metal matrix composites (MMC,s) were introduced in the aerospace and aeronautic industry and about 15 years since then, the MMC,s were reached into automotive and automobile industries. But still MMC,s are not wide spread used in these industries because of their poor machinability. Al/SiC-MMC is one of the important composite among the MMC,s, which have SiC-particles with Aluminium matrix composites are harder than tungsten carbide (WC). Al/SiC-MMC,s have very light weight, high temperature strength, high fatigue strength and wear resistance as compare to the conventional materials. The aluminium alloy reinforced with discontinuous ceramic reinforcements is rapidly replacing the conventional materials in various automotive, aerospace and automobile industries [1]. But Al/SiC-MMC,s machining is one of the major problems, which resist its wide spread engineering application [2]. The machining problem of Al/SiC-MMC,s is tool failure because of severally abrasive wear, formation of flank build-up and formation of broken fibre layer in the machine surface and in either side of the cutting edge. The main tool wear mechanism is abrasion, which is due to the relative motion between the reinforced fibres and tool cutting edge [3]. From some early conventional turning tests on Al/SiC-MMC,s [4,5] it is found that the tool wear is excessive and surface finish is very poor, while carbide tip tools are used for machining. The major factors affecting tool life are the SiC volume fraction [6]. During machining of metal matrix composite (A1/SiC-MMC,s) use of coolant increases tool wear. Use of coolant during machining of A1/SiC-MMC, the temperature at the chip formation zone will become low which increases the matrix strength, the reinforced fibre particles also adhere to the lower side of the chip and cutting edge of the tool which will resists together to cut the metal during machining [7]. The hard SiC particles of Al/SiC-MMC, which intermittently come into contact to the hard surface, are act as small cutting edges like those of a grinding wheels on the cutting tool edge, which in due course is worn out by abrasion [8]. In view of all these above mentioned machining problems, main objectives of the paper is to study different tooling systems during turning of A1/SiC-MMC and present the test results for optimal selection of the tooling which may overcome the machining barriers. An attempt has been made to introduce a effective machining method through development of a self propelled rotary circular tooling (RCT) system. In depth research investigations has also been made through selection of proper tooling for optimum machining at minimum cost.

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DESIGNING FOR EXPERIMENTATION

Discontinuous Aluminium metal matrix composite of LM25Mg10SiC$_P$ (Al/10vol.%SiC-MMC), 60 mm dia.

is used for experimentation. Table-1: shows the chemical composition of Al/10vol.%SiC-MMC used for experimentation. Table-2: shows the Physical and Mechanical properties of the Al/10vol.%SiC–MMC. The different sets of experiments were performed by turning operation on a Kirloskar Centre lathe using cutting speed range 40-225 m/min, feed range 0.16-1.25 mm / rev and range of depth of cut was 0.50-1.50 mm. Details of cutting tool used in experiments and condition of machining are listed in Table- 3 and Table- 4 respectively. Machined surface was measured using surface texture measuring instrument of TSK-surfcom 120 A type. After each turning test worn cutting edge was measured using toolmakers microscope for determination of maximum and minimum flank wear. The average values of flank wear (FV_{av}) were determined from maximum flank wear (FW_{max}) and minimum flank wear (FW_{min}) [9]. Apart from RCT system the influence of fixed circular Tooling (FCT) system, Fixed Square Tooling (FST) system and Fixed Rhombic Tooling (FRT) system were also consideration for the experimentation.

The main feature of the rotary circular tooling (RCT) system is to increase the tool life through reduction of tool wears. A self- propelled rotary tool holder has been designed and fabricated for the purpose. In this system of tooling a round insert is rotated due to the action of the rotational motion of the work-piece during turning operation. A circular insert is rotates counter clockwise motion due to the clockwise rotational motion of the work-piece. The cutting action is generated during turning operation by the obliquity of the cutting edge of the round insert. Fig.1 shows the mechanism of cutting action during turning by rotary circular tooling. This

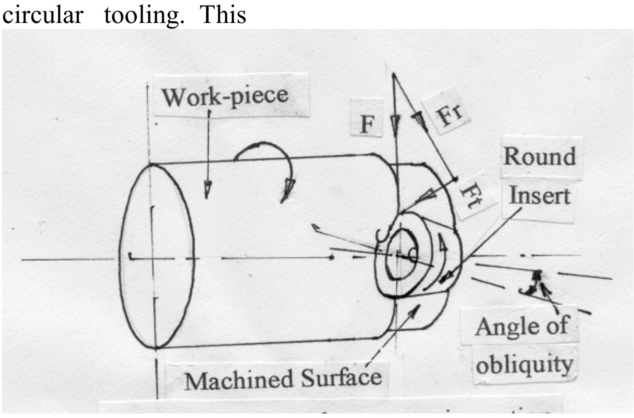

Fig. 1 Mechanism of rotary turning action

system of tooling is designated as Rotary Circular Tooling (RCT) system. Fig.2 shows an isometric view of the designed self-propelled rotary circular tooling (RCT) holder with round insert. The various components exhibits in Fig. 2: are (i) Indexing Holder (6 holes x 15^0 apart), (ii) Tool Holder, (iii) Round Insert of specification RCGX-10 T3-MO-AL-H10, (iv) Hollow-Stepped Rotary Shaft, (v) V-headed Screw and Nut, (vi) M-12 Bolt and Nut, (vii) M-6 Bolt and Nut, (viii) Needle Bearing of BNL HK- 1010 type.

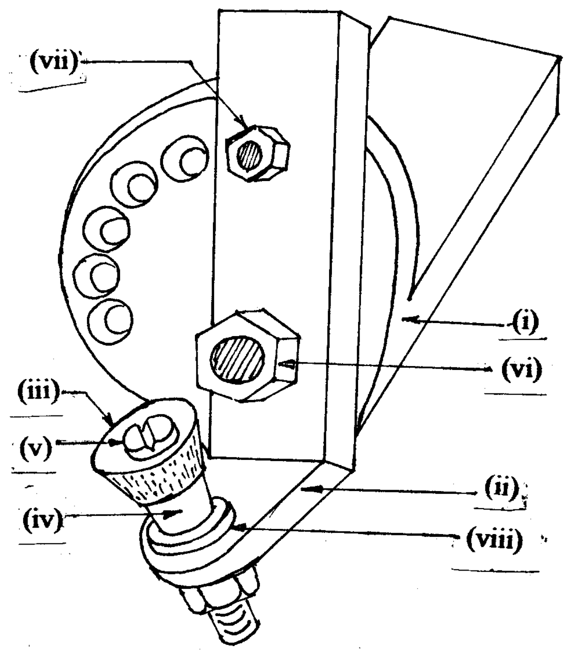

Fig.2 Assembled design rotary tool holder

TEST RESULTS AND DISCUSSION

The influence of cutting time on the average flank wear (FW_{av}) during turning of Al/10vol.%SiC-MMC without use of coolant are represented in Fig. 3. The turning operations were performed considering constant cutting speed (100m/min), feed (0.50mm/rev), depth of cut (0.50mm) using RCT, FCT, FRT and FST respectively. Experimental results represent that the tool wear is developed rapidly in fixed square tooling (FST), fixed rhombic tooling (FRT) and fixed circular tooling (FCT)

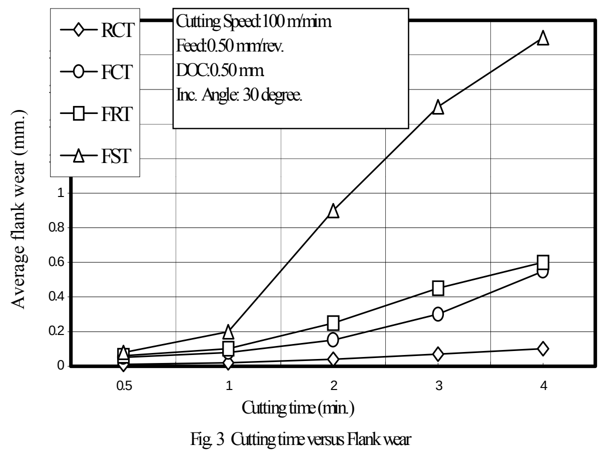

Fig 3 Cutting time versus Flank wear

system. From the cutting time versus average flank wear (FW_{av}) graph, it can be observed that in self-propelled rotary circular tooling (RCT) system with use of same graded round insert exhibits superior wear resistance compare to FCT system during turning of Al/10 vol % SiC–MMC. Tool life has been estimated through measurement of maximum tool wear (FW_{max}) with respect to the continuous length of machining. Tool life has also been estimated through measurement of maximum tool wear (FW_{max}) with respect to the cutting time during continuous turning of Al/10 vol. % SiC MMC. Tool life is assumed to have ended before the maximum flank wear width (FW_{max}) reaches its limit of 0.3 mm.

Fig. 4 shows the influence of continuous length of turning on maximum flank wear. Tool wear versus

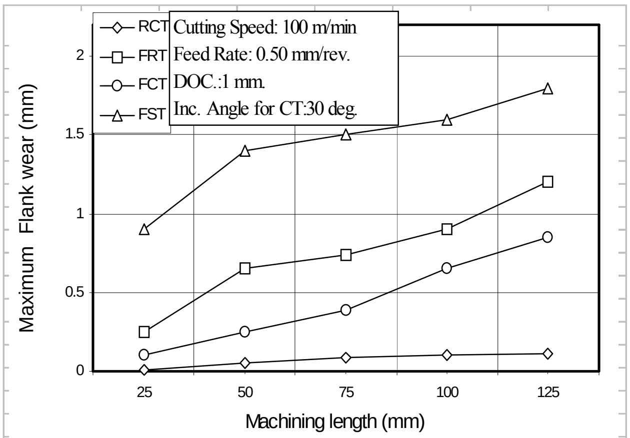

Fig. 4 Machining length versus Maximum Flank wear

continuous length of turning curves show that in self propelled rotary circular tooling (RCT), the flank wear is only 0.15 mm for 125 mm length of continuous tuning where as for same length of turning the flank wear is 1.20

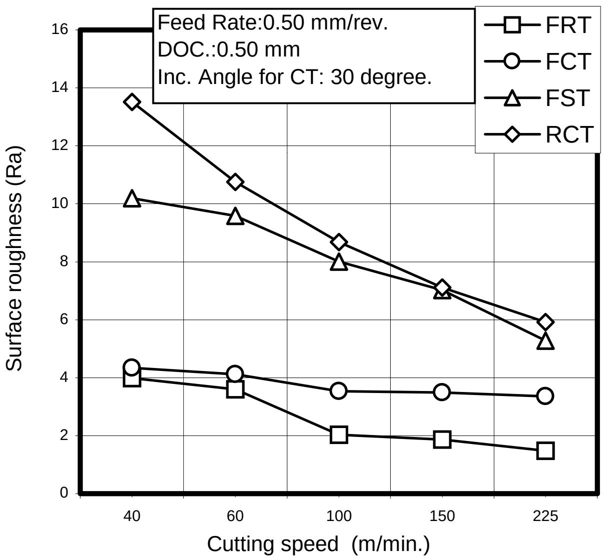

Fig. 5 Cutting speed versus Surface roughness

mm in FRT, 0.85 mm in FCT and 1.80 mm in FST respectively. From the graph as shown in Fig. 3, it can be

concluded that the approximate tool life is only 3 min for fixed circular tooling (FCT), approximate tool life is 2.15 min for fixed rhombic tooling (FRT), approximate tool life is only 1.15 min for fixed square tooling (FST) where as it is approximately about 10 min for self propelled rotary circular tooling (RCT) considering maximum 0.3 mm of width wear as a life span of tool.

Fig. 5 shows the influence of cutting speed on surface roughness (R_a, μm) during turning of Al/10 vol.%SiC-MMC using fixed rhombic tool (FRT), fixed circular tool (FCT), fixed square tool (FST) and self propelled rotary circular tool (RCT) without use of coolant. The test results show that value of surface roughness (R_a, μm) is low at high cutting speed and comparatively high at low cutting speed. Fixed rhombic tooling (FRT) and fixed circular tooling (FCT) provides better surface finish compare to that of fixed square tooling (FST) and self propelled rotary circular tooling (RCT). From Fig. 5 it is observed that

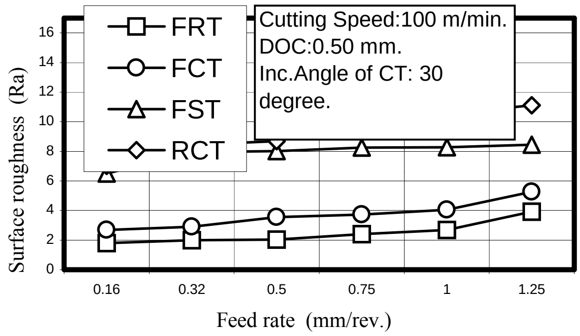

Fig. 6 Feed rate versus Surface roughness

RCT tooling provides very low surface finish even at high cutting speed.

Fig. 6 shows the influence of feed rate on surface roughness (R_a, μm) during machining of Al/10vol%SiC-MMC using RCT, FST, FRT and FCT tooling systems. Experimental results show that for all the tooling system, the surface roughness value (R_a, μm) is increased by increasing feed rate. Fixed rhombic tooling (FRT) and fixed circular tooling (FCT) provides better surface finish compare to self propelled rotary tooling (RCT) and fixed square tooling (FST). RCT system provides very poor surface finish compare to the other tooling systems. Fixed square tooling (FST) produced poor surface finish because are of (i) rapid flank wear, (ii) formation of build-up edge and (iii) cutting edge frittering when built-up edge is torn away during machining of Al/ 10 vol.% SiC-MMC. Its negative rake angle also leads to increase the surface roughness value.

Fig. 7 shows the influence of depth of cut on surface roughness (R_a, μm) during machining of Al/10 vol% SiC-MMC using self propelled rotary circular tooling (RCT), fixed circular tooling (FCT), fixed rhombic tooling (FRT) and fixed square tooling (FST) without use of coolant. From the depth of cut versus surface finish graphs it is observed that the increase of depth of cut decrease the quality of surface finish i.e. increases Ra Value. The self-propelled rotary circular tooling provides poor surface finish compare to FRT, FST and FCT tooling.

Fig. 8 shows the influence of the obliquity of cutting edge angle i.e. inclination angle of tool holder on surface roughness (R_a, μm) during turning of Al/10 vol%SiC- MMC using RCT, and FCT tooling without use of coolant. Inclination angle (degree) versus surface roughness (R_a, μm) graph shows that the best surface finish is produce at 30 degree of inclination angle for both the tooling system, i.e. FCT and RCT.

From the above explanation on the experimental results, it is clear that the self propelled circular tooling (RCT) system increases tool life by decreasing tool wear compare to fixed circular tooling (FCT), fixed square tooling (FST) and fixed rhombic tooling (FRT) system. The main advantages of the self-propelled rotary circular tooling (RCT) system over any other existing conventional system are (i) distribution of heat generation over the entire cutting edge during turning, (ii) intermittent cooling of the cutting edge, (iii) distribution of tool wear over the entire cutting edge (iv)

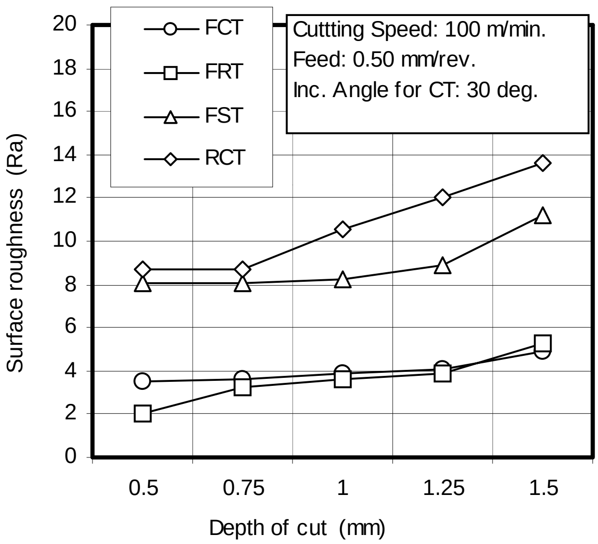

Fig. 7 Depth of cut versus Surface roughness

No built-up edge or flank build-up are formed even at low cutting speed; (v) relive abrasive tool wear due to the relative rotational motion between tool and work, ultimately increase the tool life. The rough surface are produce in self propelled circular tooling (RCT) system during turning of Al/10 vol %SiC-MMC may be due to the following reasons: (i) large nose radius of the rotary circular insert, (ii) greater Py (Pxy Cosθ) component, where θ is entering angle, (iii) vibration produced due to clearance and tolerance of the rotary parts of the RCT tooling system. The geometry of the machined surface is affected due to inclination of the rotary tool, which also influences the surface finish.

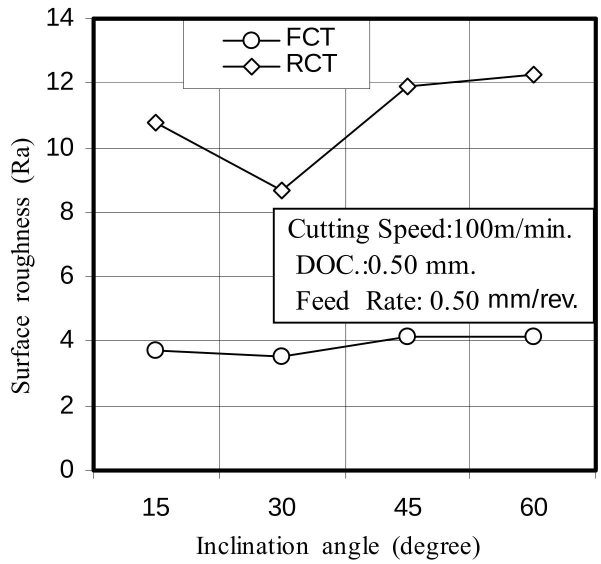

Fig . 8 Inclination angle versus Surface roughness

On effect of increase in the cutting speed, tool will be subjected to the condition of thermal softening and consequently work-piece material, Al/SiC-MMC will harden thermally and it will lead to increase the abrasive wear. The softer work-piece material sliding over the surface of the harder tool material may contain appreciable concentration of hard particles. The hard particulate reinforced fibres of Al/SiC-MMC, which intermittently come into contact to the cutting edge, are dragged along or rolled over the cutting zone during turning. These particles may plough grooves into the contact surface of the cutting tool. This is another cause of abrasive wear of the cutting tool and in turn formation of poor surface finish. Not only that, when softer metal slides over a harder metal such that it always presents a newly formed (nascent) surface to the same portion of the hard metal and consequently due to friction, high temperature and pressure the particles of the Al/SiC-MMC adhere to the cutting material. In this way more particles will join up with those already adhering and so-called built up edge is formed during turning of Al/SiC-MMC using FST, FCT and FRT tooling system. When this process continue for some time, it appears as like as nibbled away and some uneven surface formed on the tool during turning of Al/SiC-MMC, it may also be the cause of formation of adhesion wear which results in the flank wear. It has also been observed that the rate of flank wear width is slow at the beginning of the metal cutting with respect to the time, then it will increased in the steady rate and finally width of the flank wear increased in rapid rate during turning of Al/SiC-MMC. The rate of flank wear is approximately 1.5 times more in final stage compare to that of the initial stage of experiment.

CONCLUSIONS

Based on the performance and test results of the self propelled rotary circular tooling (RCT), fixed rhombic tooling (FRT), fixed circular tooling (FCT), and fixed square tooling (FST) system during machining of Al/10%vol.SiC-MMC without use of coolant, the following points can be concluded as listed below:

1. Rotary circular tooling (RCT) of RCGX-10-T3-MO-Al-H10 type round insert exhibits superior wear resistance compare to that of the other tooling systems. Rotary circular tooling enhanced longer tool life compared to FRT, FCT and FST tooling due to the (i) distribution of tool wear over the entire cutting edge, (ii) intermittent cooling of the cutting edge and (iii) relive abrasive tool wear due to the rotational motion between the tool and work.

2. Fixed rhombic tooling (FRT) of CCGX-09-T3-04 Al-H10 type insert is most effective for proper machining of Al/SiC-MMC at high speed and low depth of cut. FRT provides better surface finish at all cutting speed , feed rate and up to 1.25 mm depth of cut compare to the FST, RCT and FCT systems.

3. Fixed circular tooling (FCT) of RCGX-10-T3-MO-Al-H-10 type round insert provides effective machining of Al/SiC-MMC at low speed and at high depth of cut. Above 1.25 mm depth of cut FCT system produces better surface finish compare to the FRT, RCT and FST systems. 30 degree inclination angle is recommended for fixed circular tooling for effective machining of Al/SiC-MMC, which provides better surface finish.

4. Fixed square tooling (FST) of SNMG-12-04-04-QR type insert is not recommended for proper machining of Al/SiC-MMC.

5. Rotary circular tooling (RCT) produced very low surface finish because are of (i) large nose radius of the rotary circular insert and (ii) vibration due to the different rotary parts.

However, self-propelled rotary circular tool have more life compare to that of fixed circular tool during turning of Al/SiC-MMC. It is recommended as best tooling system for rough and high speed machining of Al/SiC-MMC, where large amount of material is required to remove at least time and optimum cost. Hence, the above mentioned research finding utilizing different types of tooling systems will provide useful economical solutions to the machining problems faced by the modern manufacturing engineers during processing of Al/SiC-MMC which is otherwise usually machined by costly PCD and CBN tools.

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Table 1: Composition of Al / SiC – MMC used for experiment

Types of MMC	Types of reinforced particle	% SiC	% Si	% Mg	% Fe	% Cu	% Mn	% Zn	% Ti	Al
Disconti-nuous MMC	SiC APS:45μm	10.00	7.01	0.60	0.12	0.18	0.10	0.10	0.10	Rema-ining

Table 2: Physical and Mechanical Properties of Al / SiC – MMC

Material	Density (gm/ cm^3)	Tensile Strength (Mpa)	Yield Strength .(Mpa)	% 0f Elongation	Hardness (BHN)	Modulus of Elasticity (Gpa)
LM25Mg-10SiC$_P$	2.69	295	260	1.5 - 2	105	95

Table 3: Details of cutting tools used in experiment

Tooling system	Types of Tool used	Tool Specificat-ion	Tool Material	Rake Angle	Clearance Angle	Cutting edge Angle	Obliq-uity
RCT	T-Max-U Positive Circular Type Insert (Rotary)	RCGX 10 T3 MO-Al-H 10	Uncoated Tungsten Carbide(WC) (H10-HW-K10)	0^0	7^0	Round	Inclin-ation
FCT	T-Max-U Positive Round Insert (Fixed)	RCGX 10 T3 MO-Al-H 10	Uncoated Tungsten Carbide (WC) (H10-HW-K10)	0^0	7^0	Round	Inclin-ation
FST	T-Max-P Negative Square Insert (Fixed)	SNMG 12 04 04-QF	Coated Tungsten Carbide(WC) (HC-P01)	- 6^0	0^0 Nose Radius; 0.4 mm	90^0	Nil
FRT	T-Max-U Positive Rhombic Insert (Fixed)	CCGX 09 T3 04-Al H 10	Uncoated Tungsten Carbide(WC) (HW-K10)	5^0	7^0 Nose Radius;0.4 mm	80^0	Nil

Table 4: Machining condition for different tooling system

Condition of Machining	Condition of Work	Condition of Tooling	Cutting Speed Range	Feed Rate Range	Depth of cut Range	Inclination angle Range	Cutting fluid
Turning	Rotate clockwise	Rotate counterclo ckwise and fixed	40 - 225 m/min	0.16 – 1.25 mm/rev.	0.5 – 1.5 mm.	15^0 - 60^0 for RCT and FCT.	Not used