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INVESTIGATION OF MACHINABILITY OF SELF PROPELED ROTARY CUTTING TOOL

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Abstract

The hard and heterogeneous nature of the metamorphic rocks, offer a significant challenge for the machining of the same. However, these types of materials are finding more and more applications in areas ranging from construction materials to home appliances. Very often these require machining operation to have finished products. At present single point based cutting tools are used for machining. This has the disadvantage of high wear rate and high temperature at the tip of the cutting tool leading to the premature failure of the same. Previous studies have revealed that, in spite of the hard varieties of cutting tool used, the tool life has little improvement in machining of rocks. Thus single point cutting tools have got little importance in this scenario. This research project mainly focuses on the turning aspects of metamorphic rocks using multi point cutting tool such as self-propelled rotary cutting tools.

***Keywords**:* Metamorphic rock; Rotary cutting tool; Surface finish; Tool wear.

1. INTRODUCTION

Presently rocks are used for many industrial applications. Very often these materials require machining operation to have finished product. But machining of rock is not an easy task. Metamorphic rock is a difficult-to-cut material because of its physical properties and non-homogenous nature. Generally single point cutting tools are used for machining the same. It leads to high wear rate and high temperature at the tool tip, which causes premature failure of the tool. Literature has shown that, in spite of the hard varieties of cutting tool used, the tool life has little improvement when it comes to the machining of rocks. Thus single point cutting tools has got little importance in this scenario. Thus the study focuses on the machining of rocks with multi point cutting tool such as self-propelled rotary cutting tool (SPRT).

The enhancement of tool life using rotary cutting tool which is capable of removing considerable quantity of heat between the tool and work piece interface is introduced in the 19th century [1]. The scope of SPRT has been investigated in face milling operation and reported that rotary tool inserts could be machined at lower temperatures than the stationary inserts [2]. A scientific study has been conducted to find the influence of static inclination angles with tool life. It was reported that the tool life is 20 times greater than the result obtained with stationary tools [3]. A comprehensive study of chip morphology was carried out in rotary cutting tool and was claimed that the chip cross-sections were triangular although the interference areas of cut were approximately rectangular. It indicates the decline in cutting force due to the reduction of frictional component in the rotary action of the cutting edge [4]. The high speed machining of SiC whisker-reinforced aluminium composites using SPRT were conducted and the results were found to be challenging in the manufacturing industry [5]. Research was carried out using multitasking lathe on Inconel 718 at 500 m/min to realize the advantages of rotary cutting tool for high-speed dry cutting conditions. It was verified that it is necessary to select an optimum inclination angle, tool rotation speed and tool diameter so as to enable the main cutting force direction to align with the highest rigidity direction of an applied rotary tool [6-7].

Based on the literature survey in this paper the following aims and objectives were fixed.

- Development of a self-propelled rotary cutting tool for the machining of rock.
- Analysis of the effect of inclination angle of rotary cutting tool on surface finish.
- Analysis of the effect of cutting parameters on surface finish.

2. Mechanism of oblique rotary tool cutting

The SPRT rotates about its axis by the interaction between the tool and work piece during chip formation. During cutting operation static inclination angle α produce a force component along the cutting edge which propels and accelerates the tool to an equilibrium tangent velocity (V_r) along each point of the cutting edge. The cutting edge is continuously fed into the cutting region and cyclically exposes a portion of the cutting edge and rake face to the chip formation process, as occurs in most traditional processes, so that the tool temperature and tool wear can be reduced and tool-life increased without affecting the metal removal rate.

The force component along the cutting edge is,

$V_r = V_w \sin \alpha$, where

V_r = rotary tool tangent Velocity

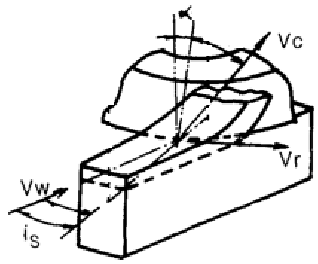

Figure 1: Rotary oblique cutting

V_w = work piece velocity

α = inclination angle of the rotary tool.

The axis of self propelled rotary tool turning the tools should be inclined with respect to the work piece axis so that the work piece velocity V_w, propels the tool in the appropriate direction during the chip formation process.

3. Characteristics of rotary tool

The figure shown below is a typical rotary cutting tool in the form of a disk that rotates about its own axis. As a result of the tool spinning, each section of the tool is only engaged in cutting for a short period of time, followed by a much longer period of time for the cutting edge to cool. This leads to inherently high cooling capability.

In SPRT cutting process, the spinning action is achieved by the interaction between the tool and the chip, which requires the cutting edge to be oblique with the cutting velocity (V). The tool rotational velocity (V_t) is a function of the cutting velocity and the inclination angle (β) between the axis of the work piece and axis of tool inserts. Obviously, the inclination angle β is very important since it determines the SPRT cutting performance.

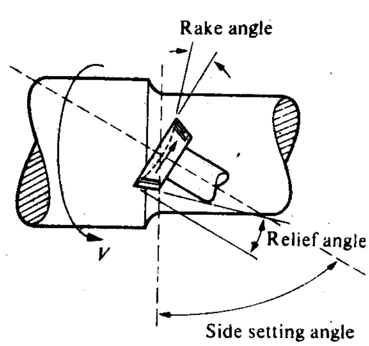

Figure 2: Schematic diagram of self-driven rotary tool during machining.

3.1 Tool geometry

The edge inclination angle (α) determines the relative cutting speed (V_r), relative chip flow velocity (V_{cr}), power consumption, cutting temperature, the degree of chip formation and the unit cutting forces etc. So it has got a significant effect on the life of rotary tools, and only a little effect on the fixed circular inserts. The increase in inclination angle (α) cause variation of the effective working angles along the curved cutting edge causes exacerbate fatigue problems. Hence optimising the edge inclination angle (α) is a challenging task in SPRT machining process.
The influences of the effect of tool insert diameter on tool life are:

- A larger insert will have longer cutting edge and less intensive tool wear.
- Radius of the tool inversely proportional to tool contact angle which eliminates the variation of the working angles along the arc. This slows down the rotational speed, lowers the fluctuation of strain and stress and reduces the tendency for fatigue wear.
- The rake and clearance angles of the insert influence the working rake angle, heat capacity of the cutting edge and friction between the flank face and the machined surface.

3.2 Structure and design of SPRT

In structural design, the rotary tool must be simple and have a compact structure because of the space limitation of the machine tool. Sufficient stiffness must also be provided to prevent the tool from undergoing deflection and vibration.
In manufacturing, the rotary tool must be precisely fabricated and easy to assemble. Dynamic runout of the rotary insert must be minimized.
A wide range of rotary speeds of the insert and enough driven torque must be assured, so that the rotary speed can be adjusted to achieve optimum operating conditions.
The tool geometry should be selected in order to achieve the largest possible depths of cut, feed rate, stable cutting, superior surface finish, low relative cutting speed (V_r) and low cutting temperature. Use of excessive nose radius, excessive running clearance of the bearing and eccentricity of the circular cutting edge could cause chatter during machining. This can be eliminated using the smallest possible insert, increase in edge inclination and reduction of the eccentricity of the round insert.

4. Experimental setup

4.1 Centre lathe

The experimental setup includes an Indian made centre lathe LB-25 (HMT). Various machining conditions can be set by changing the inclination angle of the rotary cutting tool and also by changing the various cutting parameters on the lathe.

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Figure 3: Experimental set-up

4.2. Tool holder

A rotary tool holder as shown in Figure.4 was designed and fabricated for these experiments. MS- flat having a thickness of 6.35mm and width of 75mm is used to make the tool holder. The tool holder contains 2 parts connected each other using a nut and bolt. The first part of the tool holder can firmly fixed on the tool post of the lathe, for that a through hole having diameter 24 mm is provided on the top and bottom face of the MS flat.

Another through hole having diameter 15 mm is provided on the vertical sides of the two pieces, a bolt can be inserted on these holes and using a nut we can firmly tight these two parts.

A small hole having diameter 6 mm is made on the just above the large hole for inserting the indexing pin. The second part contains the indexing holes and it holds the rotary insert. Indexing bracket helps changing inclination angle from 0 to 42^0 in a step of 14^0.

Figure 4: Rotary tool holder

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After setting a specific inclination angle, the indexing bracket can be located by the locating pin and clamped using the clamping screw during experiments.

4.2. Rotary carbide insert

A carbide insert d having a thickness of 6 mm, outer diameter 16 mm, and inner diameter 6.5 mm is taken for conducting the experiments. Clearance angle of 10^0 is given over the circumference of the rotary insert. There is no rake angle is provided at the surface of the rotary insert.

Figure 5: Rotary carbide insert

4.3. Properties of metamorphic rock

Rocks are generally characterized by properties such as porosity, specific gravity, thermal conductivity etc. But uni-axial compressive strength is considered as the basic property denoting the strength of a rock.

Table 1: Properties of metamorphic rock

Property	Value
Compressive strength	120 MPa.
Abrasivity	Class 3(highly Abrasive)
Hardness	65(HRF) ~ 6 (Mohs' scale)

Figure 6: Metamorphic rock –Specimen

SPRT with an inclination angle from 0 to 42^0 in a step of 14^0 was used to carry the machining tests on metamorphic rock work piece. The work piece was in the form of 50 mm diameter and 170 mm length. Table.1 shows the properties of metamorphic rock.

Mineralogy : the rock is composed of quartz, felpspar, mica (biotite) and hornblende.

Texture : the characteristic gneissocity is due to the alternative layers of quartzo feldspathic minerals and mafic minerals.

Circular insert of 16 mm outer diameter was used in this investigation. The spindle speeds were in the rage of 50 to 250 rpm. The depth of cut of .25 mm and feed rate (0.069 mm/ rev) was kept constant. The inclinations angle 0^0,14^0,28^0 and 42^0 are chosen. Following each cut, the surface finish obtained was measured using a TR 200 hand held roughness tester. The display (Ra) range of this tester varies from 0.005 μ m ~ 16 μ m.

5. Results and discussions

5.1. Surface finish

The experimental result using a SPRT and single point carbide tool is shown in the tables given below. It is observed that better surface finish is obtained at increased cutting speed and 14^0 is the better inclination angle of the cutting tool compared to the other inclinations. For all the experimental trials better surface finish is obtained at 14^0 inclination angle. Compared to the single point cutting tool the surface finish is slightly less for rotary cutting tools, but when tool life is considered rotary cutting tools will give more benefits over single point cutting tools. And also better surface finish is obtained at maximum cutting speed.

Table 2: Roughness values of Metamorphic rock using SPRT

SL NO.	Cutting speed (cm/sec)	Depth of cut (mm)	Inclination Angle(α) (degrees)	Surface finish (µm)
1	10.467	0.20	0^0	8.345
2	10.467	0.20	14^0	9.035
3	10.467	0.20	28^0	9.754
4	10.467	0.20	42^0	10.230
5	41.867	0.20	0^0	6.384

Table 3: Roughness values of Metamorphic rock using single point cutting tool

SL NO.	Cutting speed (cm/sec)	Depth of cut (mm)	Surface finish (µm)
1	10.467	0.20	8.369
2	41.867	0.20	7.974

6	41.867	0.20	14^0	6.799
7	41.867	0.20	28^0	7.324
8	41.867	0.20	42^0	7.951

The influence of inclination angle on surface finish is represented in Fig. 7. The trails were conducted at constant feed and depth of cut whereas cutting speed was selected in four levels.

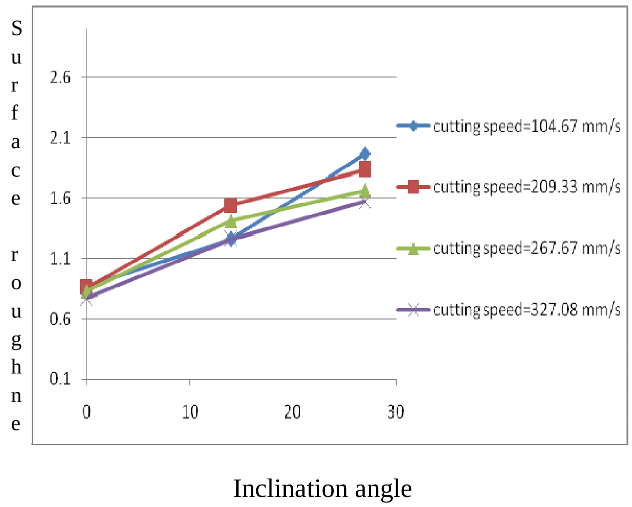

Figure 7: Surface roughness (µm) Vs tool inclination angle (Degrees)

5.2. Tool wear

The tool flank wear predominantly occurs in multi-point cutting tools. The surface finish of the work piece to be machined mostly depends upon the amount of flank wear. So the tool wear has significant influence on tool life and the surface finish in the rotary tool cutting process. The tool wear can thus be selected as one of the main parameters to analyse surface roughness. Also the direct effect or combination and interaction effect of the input parameters, namely speed, feed and depth of cut on the output response is studies.

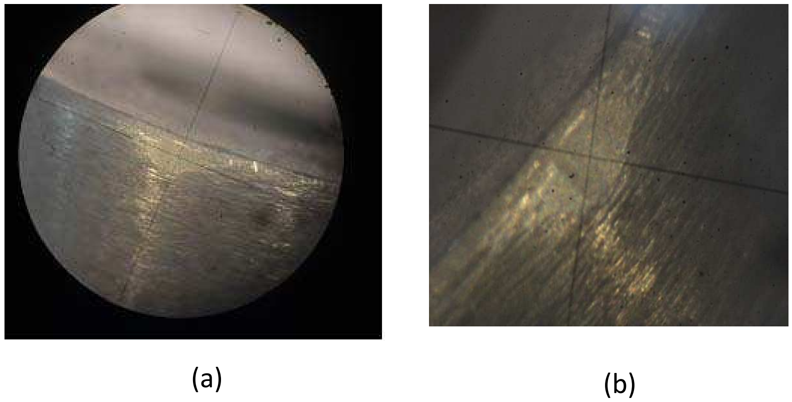

Figure 7: Flank wear of rotary cutting tool
(a) Microscopic view (b) Magnified view

5. Conclusion

An experimental investigation of hard turning of metamorphic rock using SPRT is presented. The tool performance is analyzed and longer tool life was obtained during machining with SPRT compared with fixed tools under the same cutting conditions. The self-propelled motion of the insert was critically monitored. It is identified that velocity of the insert is linearly proportional to the cutting speed. Exhaustive studies have not been reported in the machining of rock using rotary cutting tool. Experiments were conducted to optimize the inclination angle of the rotary cutting tool. Adopting surface finish as a criterion, it is found that 14^0 inclination angle is found to be optimum for a rotary cutting tool. The microscopic analysis of machined surfaces obtained in the experimental trials indicates 'Flank wear' as the predominant mode of tool wear in the SPRT machining operation of metamorphic rock.

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