Experimentation on High Feed Milling in Titanium Material-Ti6AL4V

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Abstract: High feed milling is one of the effective way to achieve high material removal rate in milling operation. With High feed application it is good to reduced the cycle time of particular set of operation. For the same kind of material removal as compared to the normal shoulder milling or face milling or pocket milling, high feed milling is very much effective and can reduced the cycle time by 40% to 60% and there by improvement in productivity and overall reduction in cost. For Titanium alloy machining High Feed is effective solution in improvement in MRR. Titanium has good amount of strength to weight ratio and tensile strength. Also because of its poor machinability and high hot hardness it is difficult to machine with higher parameter. Several studies have been made to find the best machining parameter and to achieve the greater MRR. There are very many chances of reduction in tool life and increase in tool wear while increasing the parameter. Simultaneously being the high feed application, it is essential to have robust machine and sufficient amount of spindle torque and power. The aim of this project is to define the parameter for high feed milling process in Titanium material and optimize the process in terms of MRR, Tool wear and Tool Life. Objective of the project is to maximize the productivity of the components by machining of titanium (Ti6Al4V) to match the customer demand.

Introduction: Ti- 6Al-4V alloy is considered as a difficult to machine material because of its low thermal conductivity and high chemical reactivity. Due to its low thermal conductivity, the heat generation during machining operation is very high which badly affects the machining performance and life of the tool[1][7]. In the present days titanium alloys are the most tempering metal alloys among all the other alloys because of its excellent corrosion resistance, fracture toughness, low density and superior strength to weight ratio[7]. Ti-6Al-4V alloy is one of the most popular titanium alloy which is widely used in aerospace industry, marine engineering, medical and chemical industries due to its excellent physical and chemical properties [1][8]. In the present days titanium alloys are the most tempering metal alloys among all the other alloys because of its excellent corrosion resistance, fracture toughness, low density and superior strength to weight ratio. Ti- 6Al-4V alloy is one of the most popular titanium alloy which is widely used in aerospace industry, marine engineering, medical and chemical industries due to its excellent physical and chemical properties [2]. Tool wear is a conspicuous problem for machining of Ti 6Al-4V, it has been also suggested that machining of Ti-6Al-4V is constant problem whatever the machining technique we are going to use[8]. So, it is essential to know proper optimization of machining parameter. As high temperature machining and tool wear involved, cooling and lubrication is dogmatic factor. It takes important part to discuss about cooling and lubrication of Ti-6Al-4V[3]. Milling is one of the most commonly used machining process in manufacturing industry. Now a days CNC Milling is mostly preferred to improve the quality of machining and to reduce the machining time[8]. As CNC milling is an expensive process it is necessary to select proper machining parameters to reduce the machining cost [4]. Rake Angle (α) the angle between the tool face and the plane normal to the surface of the cut and pressing through the tool cutting edge (Edwards, 1993).as shown in figure 1 Rake angle is a parameter used in various cutting and machining processes, describing the angle of the cutting face relative to the work. There are two rake angles, namely the back-rake angle and side rake angle, both of which help to guide chip flow. There are three types of rake angles: positive, negative, and zero [4].

Generally positive rake angles:

- Make the tool sharper and more pointed. This reduces the strength of the tool, as the small included angle in the tip may cause it to chip away.
- Reduce cutting forces and power requirements.
- Helps in the formation of continuous chips in ductile materials.
- Can help avoid the formation of a built-up edge.

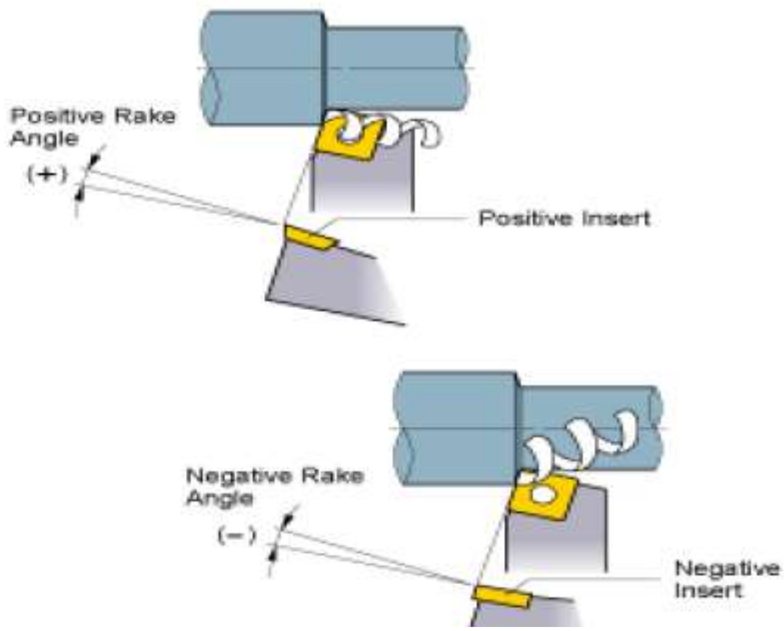

Fig. 1 Positive Rake Angle and Negative Rake Angle

Negative rake angles, by contrast:

- Make the tool more blunt, increasing the strength of the cutting edge.
- Increase the cutting forces.
- Can increase friction, resulting in higher temperatures.
- Can improve surface finish.

A zero-rake angle is the easiest to manufacture, but has a larger crater wear when compared to positive rake angle as the chip slides over the rake face. Recommended rake angles can vary depending on the material being cut, tool material, depth of cut, cutting speed, machine, and setup [4]. The high-feed milling technology used provides high material removal with high tool feed. This type of machining is used in large-scale and mass production, where the advantages of this technology will be most apparent. It is important to choose a suitable tool and machine with appropriate cutting parameters. The current trend is to increase the efficiency and productivity using new machines, tools and technologies [5]. The HFM mechanism is based on the “chip thinning” effect. Chip thinning

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depends on the lead angle of a milling cutter. A cutter with a 90° lead angle has no benefit of chip thinning as 0.2 mm of feed per tooth only delivers the same 0.2 mm of chip thickness (Fig. 2). In the case of a cutter with a 45° lead angle, a 0.25 mm of feed per tooth creates a 0.178 mm of chip thickness (Fig. 3) which allows the feed to be increased, resulting in reduced cycle time. Fig. 3 shows the chip thinning effect of DoFeed, Tungaloy's best selling HFM line, where a 1.27 mm of feed per tooth provides chip thickness of only0.178 mm, and cycle time is typically decreased by 50% or more.Low cutting force is also an advantage of HFM. The lead angle on a cutter decides the direction of the cutting force. A 90° cutter (Fig. 2) will produce cutting force that acts perpendicular to the spindle, putting incredible pressure on the tool. As for a 45° cutter (Fig. 3), cutting force acts against the spindle at a 45° angle. With DoFeed, cutting force is almost parallel, and directed back to the spindle due to its acute lead angle (Fig. 4), which means less pressure on the spindle[6].

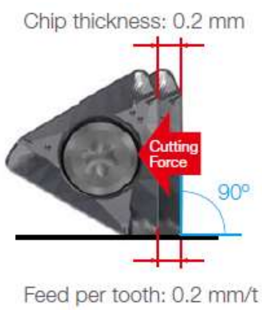

Fig. 2

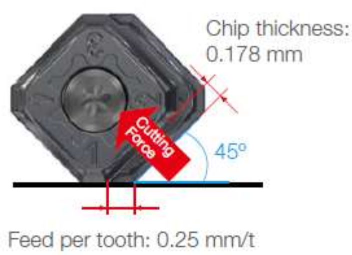

Fig. 3

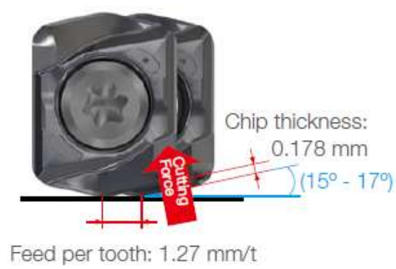

Fig. 4

Key Definition: I) Material Removal Rate (MRR), II) Tool wear, III) Tool Life

I) Material Removal Rate: Material removal rate (MRR) is the amount of material removed per time unit[9]

$$Q = \frac{Vol_{Chip}}{T_{total}} = a_p a_e v_f$$

II) Tool wear: Tool wear is the gradual failure of cutting tools due to regular operation.[5]

III) Tool Life: Tool life is defined as the time period between two successive grinding of tool and two successive replacement of tool[5][8]

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Selection of material: The raw material Titanium -Ti6Al4Vwith dimensions LxWxH= 190x180x38 is selected for the machining.

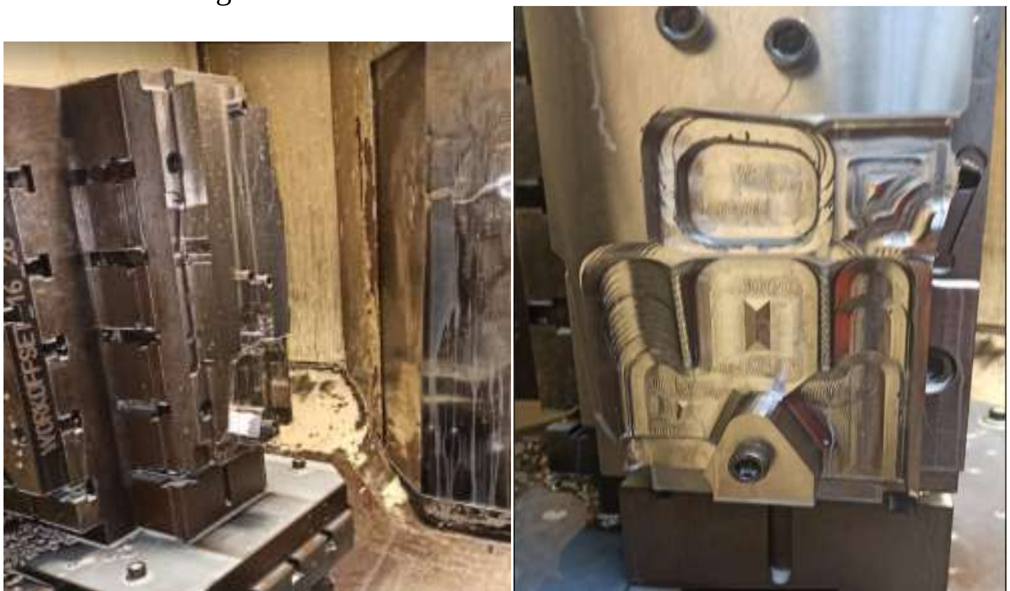

Fig. 5 Machining Setup of Material

Selection of High Feed Cutter and insert: Three types of cutter were selected from Different supplier to perform the experimental analysis and optimize the parameter. Below table listed the condition of rake angel, insert type, insert designation and High feed cutter[5].

Table 1: Selection of Insert and Cutter from Suppliler

Sr. No.	Rake Angle	Insert Type	Insert Designation	High Feed Cutter	Supplier
1	Negative Rake Angle	Negative Insert	WOEJ090512SRHD	KF2X125W0903C125L600	Kennametal [10]
2	Positive Rake Angle	Positive Insert	SOMT100420ERGM	MFH- 32-S32-10-3T	Kyocera [11]
3	Positive Rake Angel	Positive Insert	XDPT120512ERD411	7792VXD12CA032Z3R70	Kennametal [12]

Experimentation on material Ti6Al4V: - 1) 1st experiment conducted on the material with the Tool from Kennametal having Negative rake angle with the Negative Insert **WOEJ090512SRHD**.

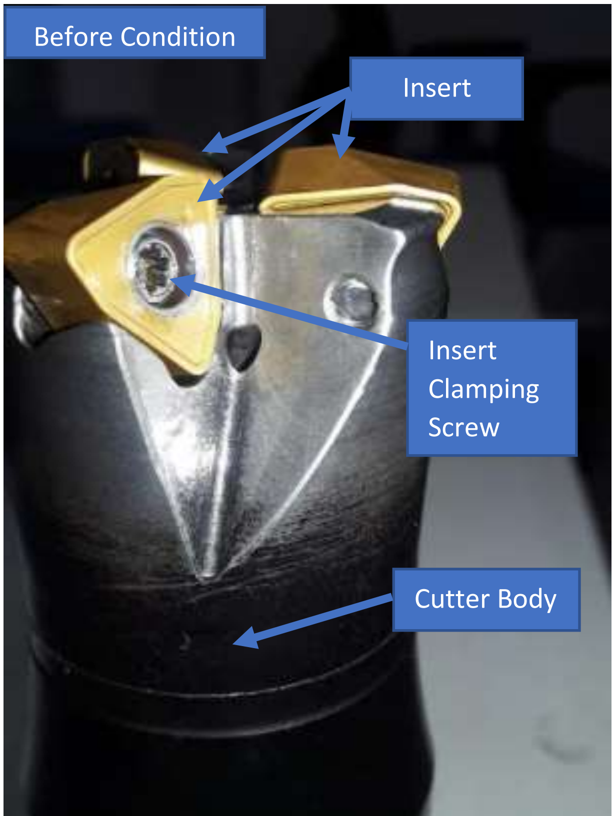

Fig. 6 Kennametal Insert and Cutter

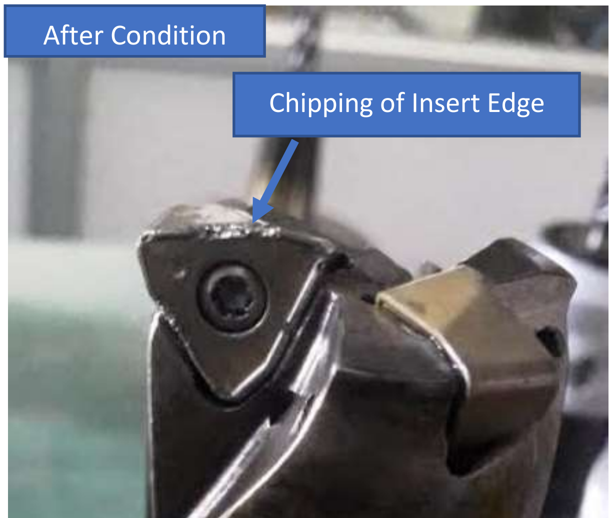

Fig. 7 Insert Chipping after two parts

Fig. 8 Cutter Damage

Table 2: Cutting parameter and Analysis in 1st Experiment.

Experimental Parameter on Kennametal WOEJ090512SRHD and Cutter KF2X125W0903C125L600										
Tool Dia	Cutting Depth	Cutting Width	Cutting speed	Teeth	Feed/Teeth	Table Feed/min	RPM	Material removal Rate	Tool Wear	Tool Life
D	a (ap)	b (ae)	Vc = D x 3.141x N / 1000	Z	fz	F (Vf)	N	Q = (ap x ae x Vf) / 1000		
mm	mm	mm	m / min	tooth	mm/tooth	mm/min		cm3/min		
32	1	16	52	3	1.38	2130	515	34.08	Chipping of the Cutting edge	2

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Analysis after 1st Experiment:

1) Life Obtained is two parts per edge.
2) After the two part of life the insert has wear out with chipping at its cutting edge (Fig 7).
3) Insert life is good at high parameter at the start.
4) With continuous use the body get deteriorated (Fig. 8) very early.
5) Inserts tends to brake (Fig. 9) and cost benefit tends to reduced
6) On an average less life of insert as well as cutter body is less
7) Vibration are huge because of negative geometry.
8) Because of vibration the screw breaks in between cycle.
9) Pocket itself get deformed because of simultaneous vibration and axial force (Fig. 10).
10) Because of pocket deformation insert back side impact on the sitting face cause the insert to chipped off during operation (Fig. 9)
11) Screw used for insert clamping is M3.5 which is not sufficient to with stand the load.

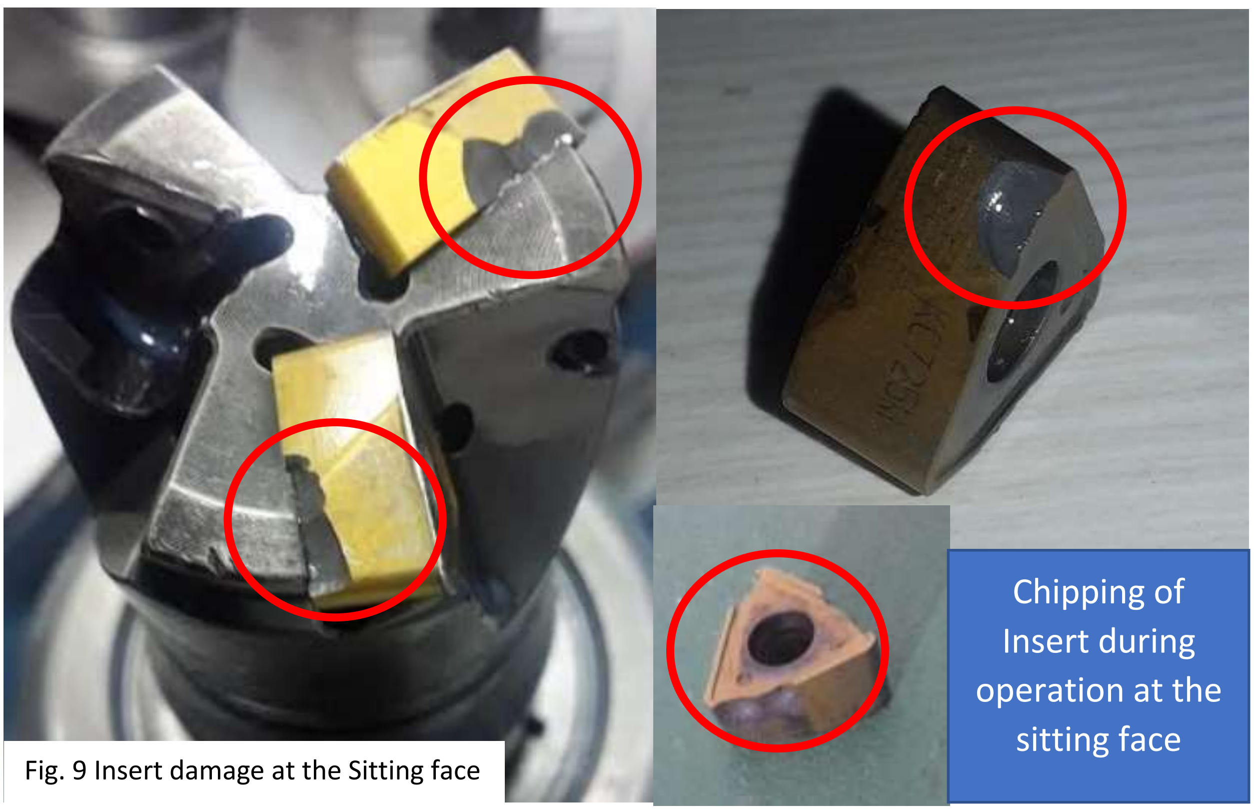

Fig. 9 Insert damage at the Sitting face

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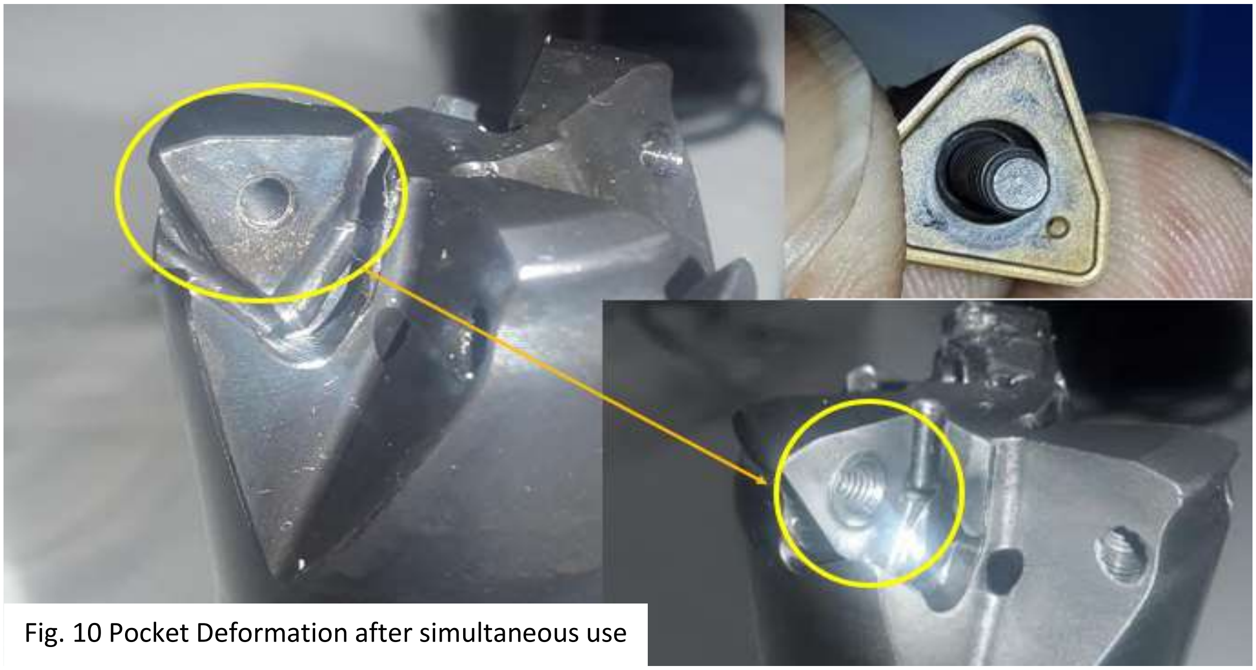

Fig. 10 Pocket Deformation after simultaneous use

2) 2nd Experiment conducted on Ti6Al6V material from Kyocera having positive rake angle with positive insert **SOMT100420ERGM**.

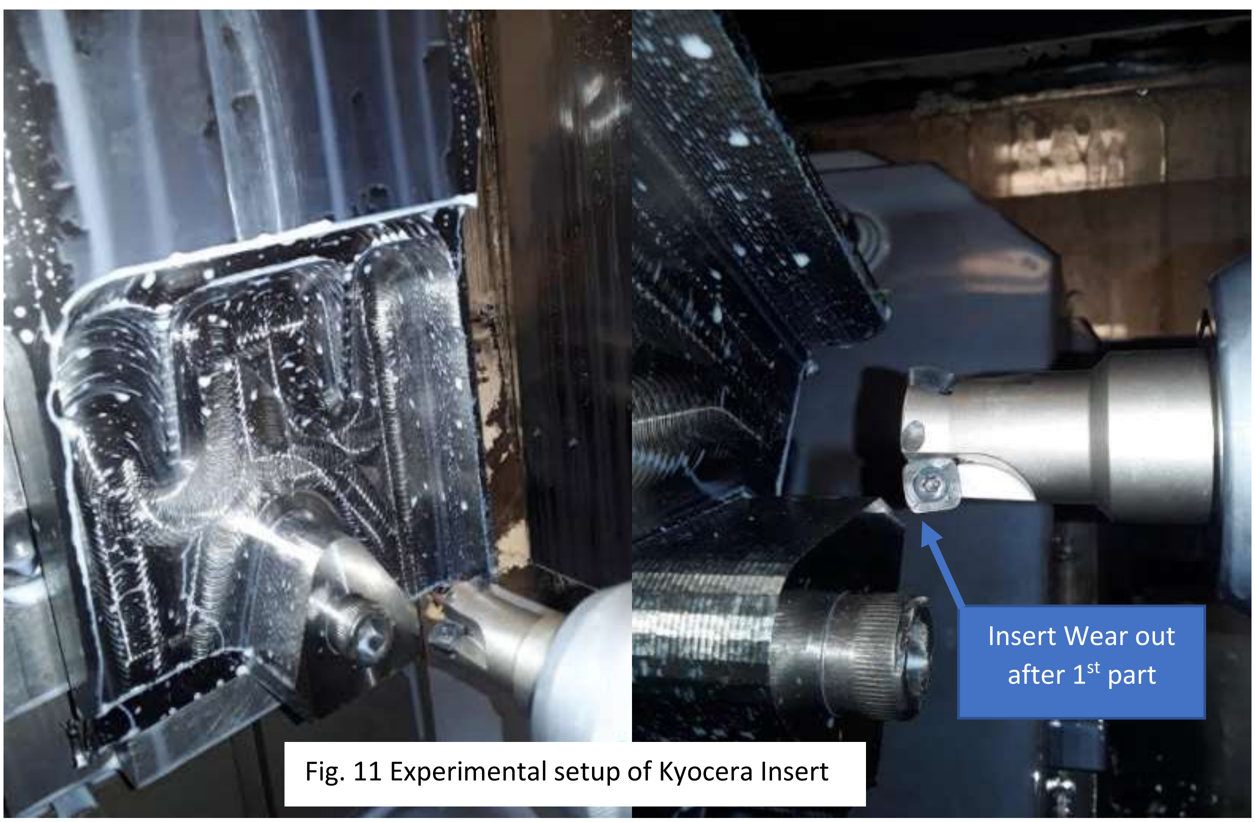

Fig. 11 Experimental setup of Kyocera Insert

Table 3: Cutting parameter and Analysis in 2nd Experiment

Experimental Parameter on Kyocera SOMT100420ERGM and Cutter MFH- 32-S32-10-3T										
Tool Dia	**Cutting Depth**	**Cutting Width**	**Cutting speed**	**Teeth**	**Feed/Teeth**	**Table Feed/min**	**RPM**	**Material removal Rate**	**Tool Wear**	**Tool Life**
D	a (ap)	b (ae)	Vc = D x 3.141x N / 1000	Z	fz	F (Vf)	N	Q = (ap x ae x Vf) / 1000		
mm	mm	mm	m / min	tooth	mm/tooth	mm/min		cm3/min		
32	1	16	52	3	1.38	2130	515	34.08	Edge chipped off	1


Fig. 12 Normal Wear out Insert

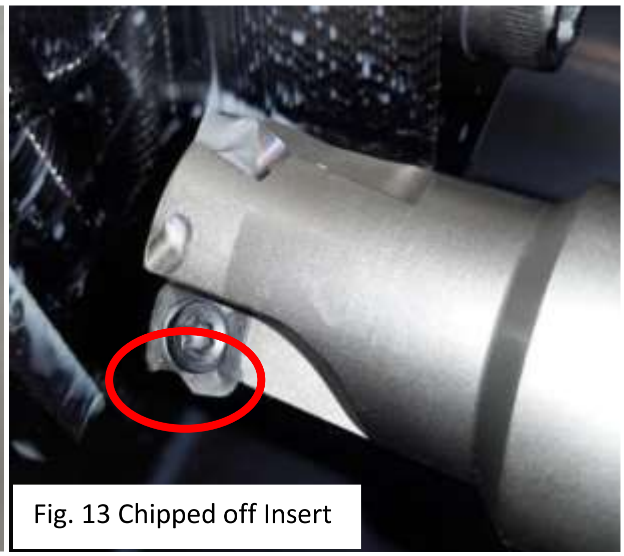
Fig. 13 Chipped off Insert

Analysis after 2nd Experiment:

1) Life of the Insert is 1 part only
2) If run for 2nd part insert tends to chipped off.
3) Vibration was reduced and cutting was smooth.
4) Insert grade is not sufficient hard to withstand the load of feed 2130mm/min
5) Insert chipped off at regular interval.
6) Screw used for holding is M4.5 which is sufficient to withstand the load unlike in 1st experiment.

3) 3rd Experiment conducted on Ti6Al4V material from Kennametal having positive rake angle and positive insert **XDPT120512ERD411.** The insert selected is quite larger than that of previous experiment. In 3rd experiment insert is of the size of 12mm which is useful to sustain the load. Also, the cutter body material change. Here in 3rd experiment material used is H11.

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Table 4: Cutting parameter and Analysis in 3rd Experiment

Experimental Parameter on Kennametal XDPT120512ERD411 and Cutter 7792VXD12CA032Z3R70										
Tool Dia	**Cutting Depth**	**Cutting Width**	**Cutting speed**	**Teeth**	**Feed/ Tooth**	**Table Feed/ min**	**RPM**	**Material removal Rate**	**Tool Wear**	**Tool Life**
D	a (ap)	b (ae)	Vc = D x 3.141x N / 1000	Z	fz	F (Vf)	N	Q = (ap x ae x Vf) / 1000		
mm	mm	mm	m / min	tooth	mm/tooth	mm/min		cm3/min		
32	1	16	52	3	1.38	2130	515	34.08	Crater Wear [8]	2

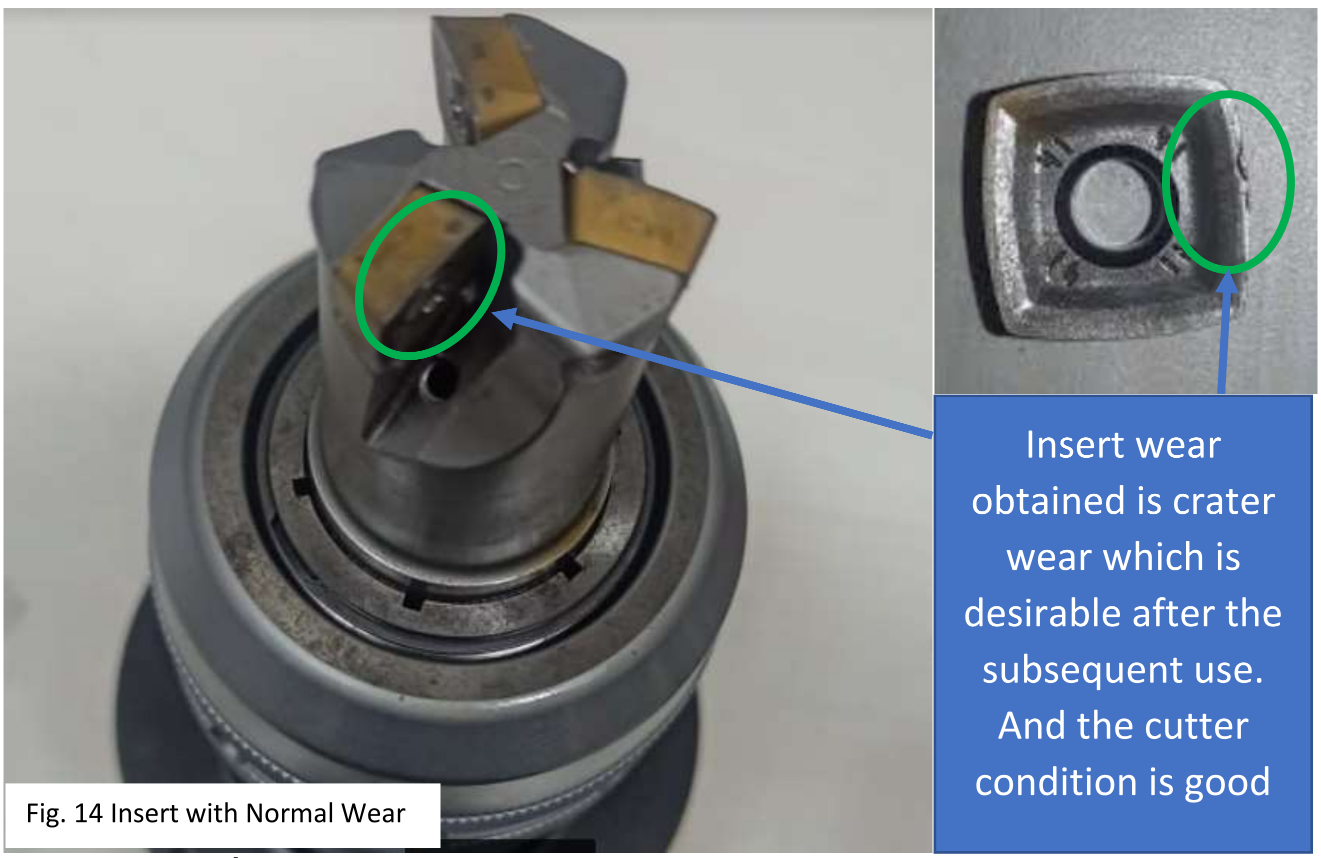


Fig. 14 Insert with Normal Wear

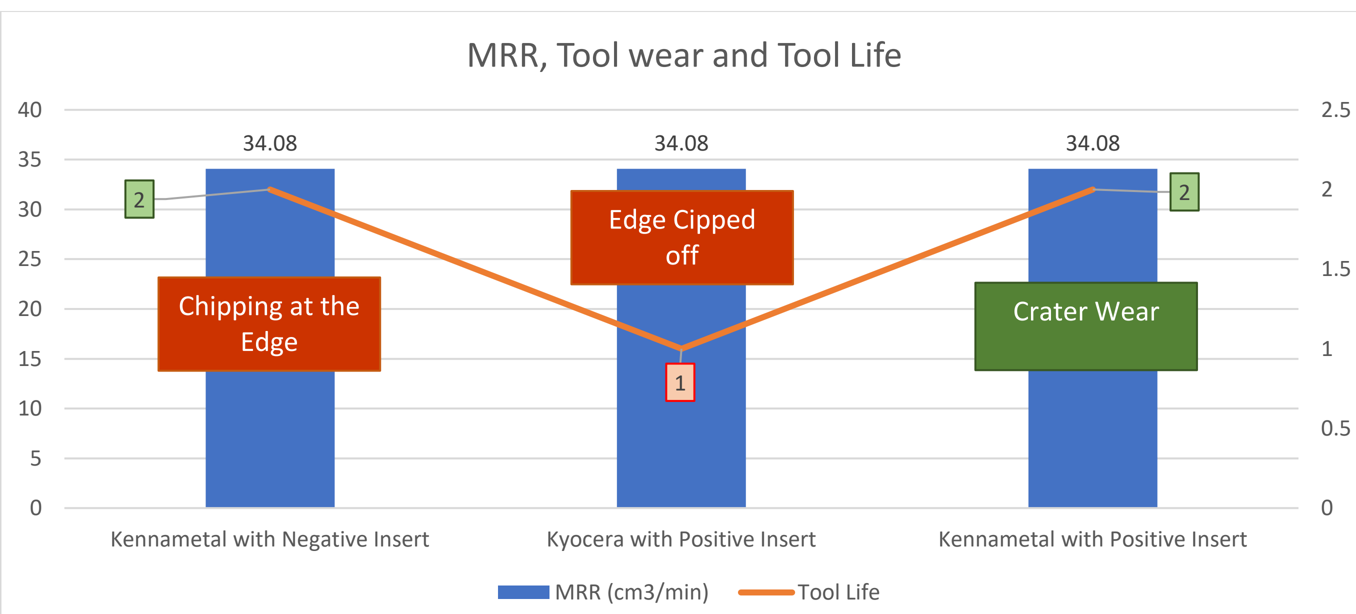
Analysis after 3rd Experiment:

1) Insert wear is normal even after the 2nd Parts
2) Cutter body withstand the load developed during machining
3) Cutter is steel running and cross 500 parts.
4) The cutting is smooth and the vibration are quite less.

Comparative Analysis of the Experiment Conducted:

Table 5: Comparative Analysis of the Experiment

	Comparative Analysis of the Experiment		
	Supplier		
Parameter	*Kennametal with Negative Insert*	*Kyocera with Positive Insert*	*Kennametal with Positive Insert*
Insert	WOEJ090512SRHD	SOMT100420ERGM	XDPT120512ERD411
Cutter Body	KF2X125W0903C125L600	MFH- 32-S32-10-3T	7792VXD12CA032Z3R70
Insert Cutting Edge (mm)	9	10	12
Insert Thickness	5	4	5
Cutter Body material	en24	en24	h11
Hardness of Cutter Body (HB)[13]	248	248	599
Feed (mm/min)	2130	2130	2130
RPM	515	515	515
ap (mm)	1	1	1
MRR (cm3/min)	34.08	34.08	34.08
Tool Life	2	1	2
Tool wear	Chipping	Chipped off	Crater Wear
Cutter Body Life	23-25	56-58	more than 500
Vibration	Vibration occur	Less vibration	Less vibration



Result and Conclusion:

1) Negative insert with Negative rake Angle: Though the tool life is good at the start, with subsequent use cutter body deteriorate result in breakage of insert.
2) Positive insert with Positive rake angle: Vibration is less in Positive insert. Insert grade should be sufficient enough to withstand the feed force
3) Positive insert with Positive rake angle and cutter body with high hardness and toughness: Because of the higher cutting-edge length cutting forces distributed and less wear happened.

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