Dynamic Chip Breaker Design for Nickel-Base, Inconel 718, Alloy with Coated Carbide Tools Using Negative Angle Tool Holder

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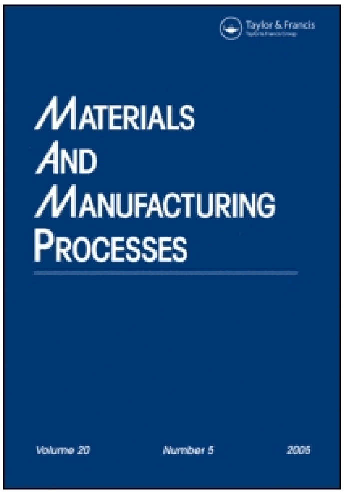

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Dynamic Chip Breaker Design for Inconel 718 Using Positive Angle Tool Holder

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This study has focused on the chip-breaker design and experimental cutting of Inconel 718 with the designed chip breaker. The process of chip breakage for Inconel 718 with respect to cutting speed, depth of cut, and feed rate then chips and machined surfaces were analyzed from the experimental results. For this purpose, the nickel-based super alloy, Inconel 718, was machined with two layers PVD coated (TiAlN–TiN) carbide insert at feed rates of 0.10, 0.15, 0.20, 0.30 mm/rev, 0.5, 1, 1.5, 2 mm with depth of cuts, and 30, 45, 60, 75 m/min cutting speeds using developed dynamic chip breaker with positive tool holders in dry cutting conditions. Chip pictures and surface roughness (Ra) were recorded. Chip breakability during machining of the Inconel 718 depends on DC motor speed and chip breaker position on the cutting tool. The experimental results show that the designed chip breaker can break long chips at any cutting condition and acceptable surface finish can be achieved. In addition to this, according to cutting conditions, the usages of dynamic chip breaker on the surface of cutting insert are measured between 1% and 44% cooling effects.

Keywords Chip breakability; Chip breaker; Chip curl; Chip flow; Chip parting; Cutting insert temperature; Dynamic chip breaker; Inconel 718; Machining; Mild steel; Oscillatory feed cutting; Super alloy; Surface roughness; Temperature distribution; Turning.

Introduction

In machining chips that vary in shape and length, short broken chips are desired. The study of chip-breaking is very important for optimizing the machining processes. This is more significant in mild steels and nickel-based Inconel 718 super alloys light cuts with positive rake angle tools. The reliability of machining operations is an essential requirement of modern automatic manufacturing systems. Since long chips cause decrease in productivity, unbroken chips are the major obstacles for automation and for turning processes. Several chip control methods and techniques have been developed and applied into practice: (a) inserts or cutting edges with chip breakers are widely used, but the selection and the design of the perfect geometry are still a problem; (b) predictive models developed through experimental database help in the selection of cutting tools and cutting conditions; (c) special means to produce broken chips (use of vibrating tools, high pressure coolant, hardened work piece material, etc.) are successfully applied for some operations [1]. Through the development of high-speed machines and strong inserts, engineering productivity has increased, but many problems originating from the continuous chip have come to light; these problems pose a danger to the operator and have adverse effects on machines, tools, work pieces, and factory automation. Steel is the main material in industry, particularly mild steel, which is an important material, used more than 40% as mechanical parts in factories. In the continuous cutting operation, the disposal of chips is an important factor of factory automation, which increases productivity and improves the safety of operators and also cost savings [2]. Advanced materials, such as nickel-based and titanium alloys as well as composites are widely used in the aerospace and power industries. These materials are designed for high temperature applications and at the same time maintain very high strength-to-weight ratios. Nickel-based alloys have high creep and corrosion resistance as well as the ability of maintaining high strength-to-weight ratio, essential for the economic exploitation of aerospace engines [3]. They are used in the areas of industrial gas turbines, space vehicles, rocket engines, nuclear reactors, submarines, stream production places, petrochemical devices, hot tools, and glass industries. Cutting forces decreased with increasing coolant supply pressure due to improved cooling and lubrication at the cutting interface as well as effective chip segmentation ensured by the momentum of the coolant jet [4]. Excellent chip breakability has been reported when machining difficult-to-cut materials with high-pressure coolant supply. Machining Inconel 718 with lower coolant pressures, up to 150 bars, produced long continuous spiral chips, while smaller segmented chips were produced when machining with higher coolant pressure of 203 bars. Chip breakability during machining is dependent on the depth of cut, feed rate, and cutting speed employed as well as on the coolant pressure employed. Machining Inconel 718 with lower coolant pressures did not produce chip segmentation [5] Over 50 mm of length of chip has a bad influence on productivity. Over 0.3 mm/rev of feed rate and over 1.5 mm of depth of cut, chips are able to be parted under 50 mm length by the chip breaker. In other areas, chips are unable to be parted. Conventionally, the chip parting process has been carried out by changing cutting conditions or using chip breakers. However, these methods are uncertain and

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time-consuming. Therefore, the oscillatory feed cutting that can break long chips in any cutting condition was developed. An increase in steel pressed parts and a reduction in the depth of cut from net-shaping will make chip processing more and more difficult in the future [6]. Long chips curl around the tool and can pose serious hazards to the work piece surface, the operator, and the machine-tool parts. The situation becomes more critical under the environment of automated machine loading and unloading and in-process inspection of the machined parameters of the work piece. To overcome this difficulty, a number of researchers have investigated effective control of chip flow and chip-breaking [7]. This study has focused on the chip-breaker design and experimental cutting of Inconel 718 with the developed chip breaker. The process of chip breakage for Inconel 718 with respected to cutting speed, depth of cut, and feed rate then was analyzed from the experimental results.

Experimental procedures

Generally, using the large feed rate or depth of cut can cause shorter chips. But in all cutting conditions used in the experiments without developed chip breaker, chips are continuously discharged especially in lower feed rate or depth of cut. Figure 1 shows the developed chip breaker for fine and rough cutting conditions of Inconel 718.

The function of the developed chip breaker is as follows. DC motor revolves the milling cutter three different speeds (3500 rpm, 8500 rpm, 20.000 rpm) according to feed rate and cutting speed, using a low voltage power supply. DC motor is rotating unmachined surface direction for a good surface roughness. If DC motor rotates in the machined surface direction, chips scratch the machined surface of the work piece. The work principle of developed chip breaker is that fracture is generated by the force and shock acting on the chip surface with the rotary milling cutter. It is difficult to achieve a good chip-breaking condition for a conventional chip breaker in a condition where the depth of cut is smaller than 1 mm. So, chip breaker was developed and experimented with these cutting conditions. The major factor of efficient chip breaks with this system all cutting conditions must be set carefully, namely, the horizontal distance between the work piece and dynamic chip breaker and vertical distance between the cutting insert and dynamic chip breaker. According to the depth of cut and feed rate, the distance between the cutting edge and chip breaker can be changed. In the depth of cut 0.5 mm and feed rate 0.10 mm/rev cutting condition, the vertical distance between dynamic chip breaker and cutting insert must be maximum 0.25 mm, which is half of the minimum depth of cut. If the vertical distance is bigger than 1 mm between dynamic chip breaker and cutting insert, the chip will continuously be discharged under the dynamic chip breaker. After setting up the distance between dynamic chip breaker and cutting insert, chip segmentation is considerably enhanced, and the chip curl radius and also the chip length are reduced significantly, all cutting conditions according to DC motor speed. The chip curl radius and chip length also depend on the feed rate and cutting speed. Chip breaker design experiments were carried out on a conventional turning machine. Then experimental machining trials and chip breaking processes were carried out CNC lathe in dry conditions. Specimens of Inconel 718 are prepared 50 mm diameter ×400 mm long and then used for the chip breaking experiments. The chemical composition and physical properties of the work piece are given in Tables 1 and 2, respectively.

Table 1.—Chemical composition of Inconel 718 (wt%).

C	Mn	Si	Cr	Ni	Co	Mo	Nb+Ta	Ti	Al	Fe
0.040	0.08	0.08	18.37	53.37	0.23	3.04	5.34	0.98	0.50	17.80

PVD-coated carbide insert with ISO tool designation SCMT120408 was used for machining tests with positive angle tool holder. Technical specifications of cutting tool and insert are given Table 3.

The following cutting conditions were employed in this investigation according to ISO 3685 [8]:

1. Cutting speed (m min − 1): 30, 45, 60, 75;
2. Feed rate (mm rev − 1): 0.10, 0.15, 0.20, 0.3;
3. Depth of cut (mm): 0.5, 1, 1.5, 2.

Surface roughness was measured with Mahr perthometer M1 digital type instrument. Surface temperature on the cutting insert was measured with Professional High Temperature Infrared Thermometer 8858. Three times repeated 128 different experiments have been done for surface roughness and surface temperatures. After every experiment has been repeated three times, their averages were counted. Surface roughness values were measured three times and their averages counted in all the cutting conditions after achieving chip break Inconel 718 alloy.

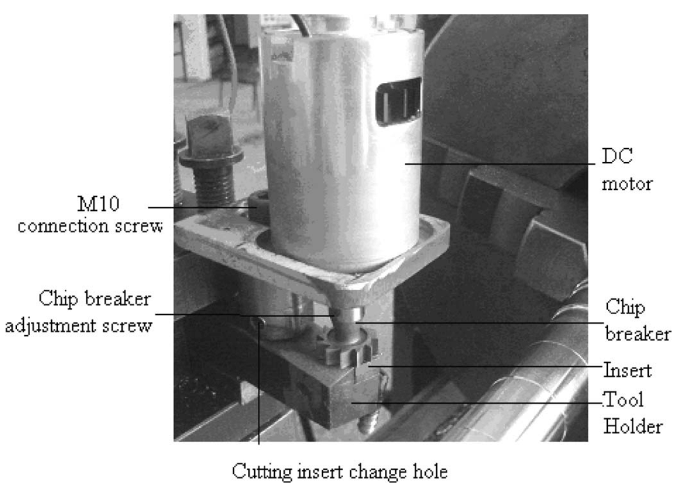

Figure 1.—Dynamic chip breaker [9].

Table 2.—Physical properties of Inconel 718.

Tool holder-name of the manufacturer	Cutting insert geometrical form	Material quality of ISO	Explanations
SSBC R 2525 M12 T MAX U-Sandvik	SCMT 120408	MM 1025	4 μm PVD TiAlN-TiN coated

TABLE 3.—Technical specifications of cutting tool and insert.

Hardness (HB)	Yield strength (MPa)	Tensile strength (MPa)	Elongation % (5 do)
388	1375	1170	23.3

EXPERIMENTAL RESULTS AND DISCUSSION

Machining of Inconel 718 with $d = 0.5\,\text{mm}$ depth of cut, $f = 0.1\,\text{mm/rev}$ feed rate, $V = 30\,\text{m/min}$ cutting speed with cutting insert having positive tool holder without chip breaker produced long continuous snarled and untidy chips [Fig. 2(a)], while smaller segmented chips (elemental chips according to ISO 3685) were produced using the same cutting conditions with developed chip breaker [Fig. 2(b)].

According to the distance between the cutting edge and the chip breaker, chip length and chip curl radius can be changed. As the distance between the cutting edge and chip breaker increases, chip length also increases [Fig. 2(c)]. If the distance between the cutting edge and chip breaker decreases, the length of chip becomes shorter and shorter because of the force and shock acting on the chip surfaces with dynamic chip breaker, as shown in Fig. 2(d).

$d = 1.5\,\text{mm}$ depth of cut, $f = 0.1\,\text{mm/rev}$ feed rate, $V = 60\,\text{m/min}$ cutting speed with cutting insert using positive tool holder without chip breaker produced long continuous helical and snarled chips [Fig. 3(a)], while smaller segmented chips were produced through machining same cutting conditions with developed chip breaker [Fig. 3(b)]. $d = 2\,\text{mm}$ depth of cut, $f = 0.1\,\text{mm/rev.}$ feed rate, $V = 45\,\text{m/min}$ cutting speed with cutting insert having positive tool holder without chip breaker produced long continuous helical chips [Fig. 3(c)]; smaller segmented chips were produced when machining in the same cutting conditions with developed chip breaker [Fig. 3(d)]. The ISO 3685-1977 (E) is containing the standard chip forms. ISO standard gives the possibility to formulate five classification tasks. The chip form classes to be identified in these assignments are listed as follows: 1. ribbon, tubular, spiral, washer-type, conical helical, arc; 2. long, short, snarled; 3. ribbon long, ribbon snarled, tubular long, tubular short, tubular snarled, spiral flat, spiral conical, washer-type long, washer type short, washer type snarled, conical long, conical short, arc connected, arc loose; 4. flat, short, snarled, long, conical, connected, loose; 5. good, acceptable, dangerous—describing the stability of chip removal. For each of the experiments, the machined chips were collected and classified according to type as specified in ISO 3685. For the cutting tests, the lengths of the chips were measured after machining. If the vertical distance between dynamic chip breaker and cutting insert equal to 0.25 mm, then all of the cutting test machined chip lengths were measured 0.4 mm–16 mm, and chip types were 5.2 short and 6.2 loose according to ISO 3685.

Figure 4 shows the surface roughness values measured when machining at a different cutting speed. The curves show that lower surface roughness values were generated when machining at lower feed rate of 0.10 mm/rev, while higher values were generated at a higher feed rate of 0.30 mm/rev. In this research, three times repeated 128 different experiments have been done. After every experiment has been repeated three times, their averages were counted. Surface roughness values were measured three times, and their averages counted in all the cutting conditions after achieving chip break Inconel 718 alloy. It compared dynamic chip breaker cutting with normal cutting; acceptable surface finish was achieved when

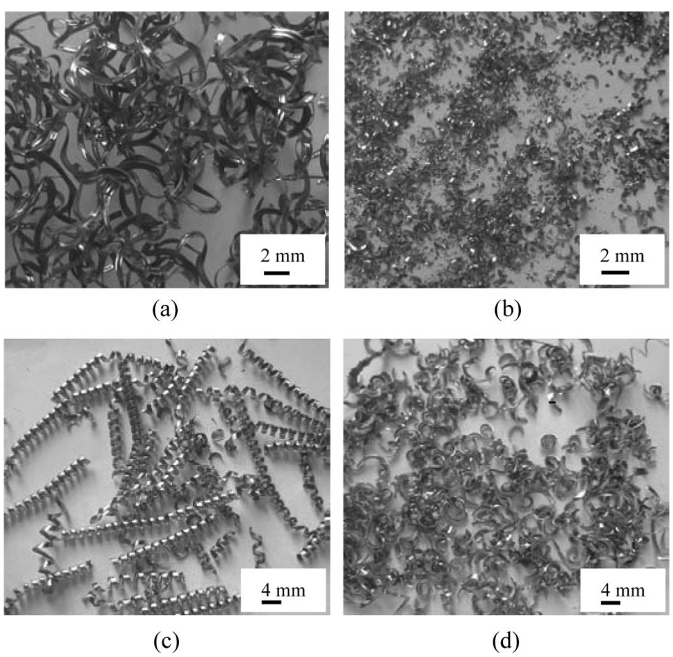

FIGURE 2.—(a) Without using the developed chip breaker; (b) with the developed chip breaker.

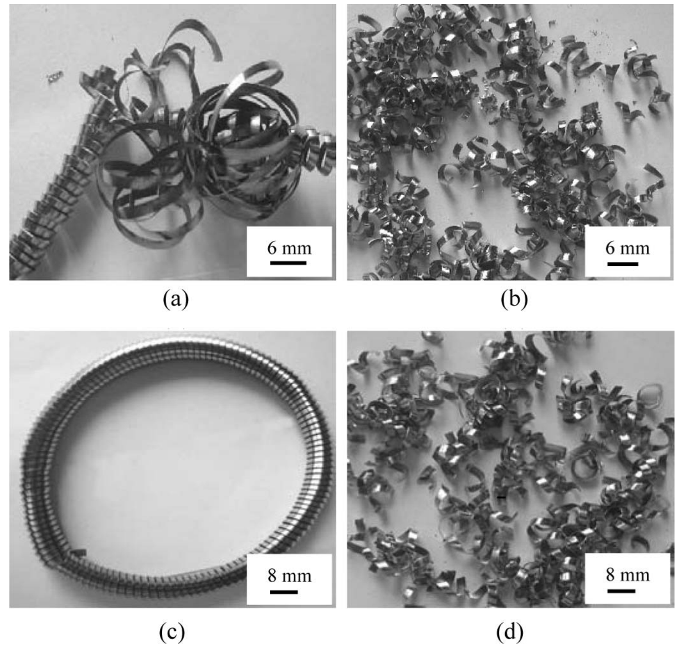

FIGURE 3.—(a) Without using the developed chip breaker; (b) with the developed chip breaker.

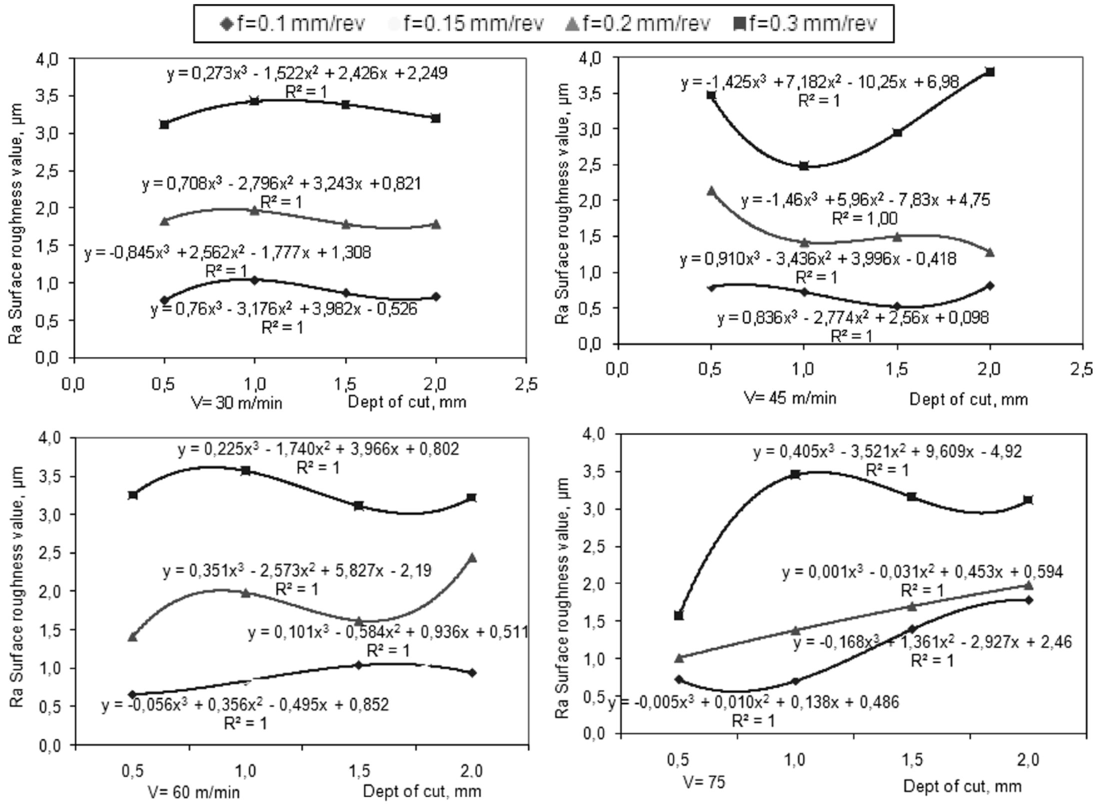

FIGURE 4.—Surface roughness values.

machining Inconel 718 with developed chip breaker. It was aimed to incorporate the equipment into the production line of Inconel 718 and mild steel which have difficulty in processing the chips. Machining precision was satisfactory and chips were reliably parted.

CUTTING TOOL TEMPERATURE

In the experiment, the cooling effect of dynamic chip breaker on the cutting insert surface has been researched. During machining, the surface temperature of cutting insert has been measured by digital infrared thermometer. $V = 45 - 60 - 75$ m/min cutting speed, $a = 0.5$, 1, 1.5 mm depth of cut, $f = 0.1$ mm/rev constant feed rate has been used to measure cutting insert surface temperature.

In Fig. 5(a), the cutting insert surface temperature values are indicated. In Fig. 5(b), under the same machining conditions, by using dynamic chip breaker, the cutting insert surface temperature values are indicated. As shown in Fig. 6, during machining, 80% of the temperature is thrown away

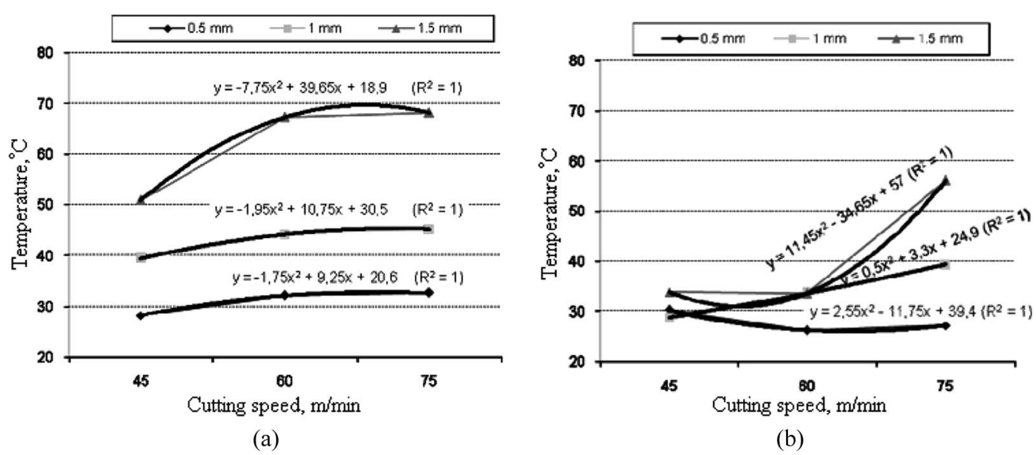

FIGURE 5.—(a) The temperature values in machining of without chip breaker, (b) with dynamic chip breaker depend on cutting speed and dept of cut.

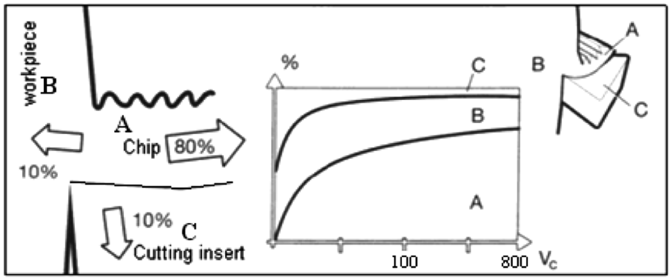

FIGURE 6.—Temperature distribution of metal machining [10].

by chip, 10% of the temperature is transferred to cutting insert, and 10% the temperature is transferred to work piece [10]. As indicated in Figs. 5(a) and (b), increasing cutting speed, depth of cut, and feed rate increases cutting insert surface temperature. High temperature values were measured on the cutting insert surface at higher depth of cut and feed rate. Because chip friction to cutting insert surface increased, at the same time cutting insert friction to work piece with and without dynamic chip breaker increased. As shown in Fig. 5(b), lower temperature values were measured in the same machining condition with dynamic chip breaker. Measuring lower temperature stemmed from chip split, cooling effect of dynamic chip breaker and reduction of the contact between chip and cutting insert interface.

The chip broken out of work piece during machining has flow on the cutting insert without being broken, and it transfers the temperature to cutting insert, causing a temperature increase of the cutting insert. In machining with dynamic chip breaker, throwing chip away from the cutting surface and air flow caused by high speed helps the cooling effect of cutting insert. Observing all the experiments, the dynamic chip breaker has an effect on cutting surface temperature ranging between 1–44% depending on machining conditions.

CONCLUSIONS

The results of this experimental study can be summarized as follows:

1. Using dynamic chip breaker, long chips can be broken, regardless of cutting condition when machining Inconel 718. With a lower or higher depth of cut, chip-breaking conditions are good. These experimental results prove the superiority of the developed chip breaker.
2. The horizontal distance between the cutting edge and chip breaker increases when chip length increases. If the vertical distance between the cutting edge and chip breaker decreases, the length of chip becomes shorter and shorter due to the force and shock acting on the chip surface with designed chip breaker.
3. Chip split is considerably enhanced; the chip curl radius and chip length is reduced significantly; all cutting conditions according to DC motor speed.
4. Dynamic chip breaker is suitable for conventional turning machine and CNC turning machine.
5. Acceptable surface finish can be achieved when machining Inconel 718 with designed chip breaker. The surface roughness values were generated when machining at lower feed rate of 0.10 mm/rev, while higher values were generated at a higher feed rate of 0.30 mm/rev.
6. Small, broken chips are not disturbing the machine and the environment. They have no negative effect on the cutting process and are far easier to handle, store, transport, and recycle.
7. Small, broken chips are desirable since they are easy to handle, store, transport, and recycle. They do not have negative effect on cutting tools and machine tools.
8. Chip breaker throwing chips away from the cutting surface and air flow caused by high speed helps the cooling effect of cutting insert. When V is 75 m/min cutting speed and in 0.5 mm depth of cut, without chip breaker, the measured temperature was 32.6. In the same cutting conditions with dynamic chip breaker, temperature was obtained as 30.2. This was a 3.55% improvement. When V is 60 m/min cutting speed and in 0.5 mm depth of cut, without chip breaker, the measured temperature was 32.1. In the same cutting conditions with dynamic chip breaker, temperature was obtained as 26.1. This was a 3.55% improvement. When V is 45 m/min cutting speed and in 1.5 mm depth of cut, without chip breaker, the measured temperature was 50.8. In the same cutting conditions with dynamic chip breaker, temperature was obtained as 33.8. This was a 33.46% improvement. When V is 60 m/min cutting speed and in 1.5 mm depth of cut, without chip breaker, the measured temperature was 67.2. In the same cutting conditions with dynamic chip breaker, temperature was obtained as 37.1. This was a 44.79% improvement. Observing all the experiments, dynamic chip breaker has an effect on cutting surface temperature ranging between 1–44% depending on machining conditions.
9. $R^2 = 1$ value was obtained for the regression models depending on experimental results. This value is proving extremely reliable of the experimental results.

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