Machinability improvement using high-pressure cooling in turning

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Abstract

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Process fluids are used primarily for their cooling and lubricating effect in machining. Many ways to improve their performance have been proposed; the analysis of some of them is provided in the paper. The effect of high pressure cooling has been investigated with regard to chip formation and tool life. Standard and for high pressure application particularly designed indexable cutting inserts were used with fluid pressure 1.5 and 7.5 MPa. The pressure effect on tool life at different feed rates was observed as well. Not each cooling pressure value or machined material showed favourable chip formation. Tool life though has improved significantly while machining with a lower feed rate.

Keywords: tool; indexable insert; high pressure cutting fluid application; cutting parameters; tool life

Management methods for managing the manufacturing processes and for quality improvement of product should be a part of every production organization (Korenko, Kaplík 2011). Not only in times of economic crisis but also in times of growth and prosperity of economy, manufacturing organizations must strive in order to the outputs of their production processes are most effective and achieve the best results. That way you can ensure the company's prosperity, growth and position in the market (Korenko et al. 2010).

The term machinability is understood as a complex of machined material properties, fulfilled by particular criteria such as cutting tool life, a simple achieving of shape and dimension accuracy, machining performance, low system load – low cutting resistance, and chip generation. Technological properties of cutting/cooling fluids used in machining influence the machining process quality (Kročko et al. 2012).

Chip generation is important for fully automated lines to prevent possible downtime occurrence due to cough and reeled up chips in the working space or chip conveyor. The chip reeled on the cutting edge can damage the finished surface on the machined part, cutting tool, or shorten the cutting tool life. Long bulky chips handling can introduce hazard/risk of operator's injury. This is why the shape and size of chip has to be under control.

The turning process is mainly a continuous cut with a high probability of long chip creation. The proper cutting parameters selection, such as cutting speed (v_c), the depth of cut (a_p) and feed per revolution (f_n) along with cutting tool micro- and macro-geometry and coating, can affect the chip shape and size (Žitňanský et al. 2012). On the contrary, the machined part material, specifically its chemical composition (effect of C, Cr, Ni, Mn and S content), thermal treatment and mechanical properties (tensile strength, yield strength, ductility) cannot be affected usually.

Cooling strategies could be divided as follows:
– high volume rate of cooling fluid,

– high pressure cooling,
– dry machining,
– cooling medium constitution change,
– minimum quantity lubrication (MQL),
– oil mist lubrication.

Machining with using no or min. amount of cutting fluid has become a global trend. This cannot be used for specific material groups and machining operations because of unfavourable chip formation, machined surface quality and allowances and machining performance. A standard cooling system is used in many machines, i.e. cooling fluid flow through a big diameter nozzle. This system function is more rinse, with a removal of chips, temperature decrease in machining workspace and cutting system elements preservation.

Standard cooling is not sufficient because of quite high temperature generation in the cutting zone in machining. Cutting fluid cannot reach the zone of the highest temperature in case of the standard cooling system because the fluid evaporates, and then vapours generated do not allow the cutting fluid to access the cutting edge, resulting usually in thermal cracks on it. That is why dry cutting was preferred using no cooling fluids.

Introducing a new approach to the cooling process – high-pressure cooling involves cooling fluid application using a high-pressure nozzle. A lamellar flow of the fluid is achieved, causing the contact area of the removing chip and cutting tool on the rake is reduced. The high cutting flow velocity is not so much influenced by water vapours. The cooling and lubricating effect is increased, and chip forming and breaking is improved. A jet of fluid pressure blast at the back of the chip and into the nip between the chip and the rake face provides cooling and an efficient and non-wearing chip-breaking action (Byers et al. 2006).

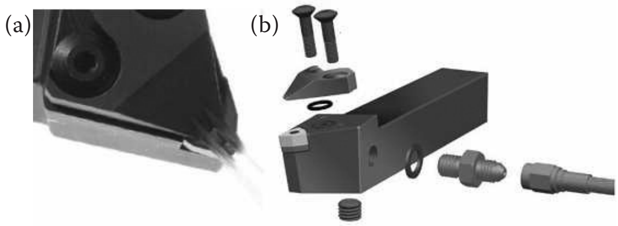

Fig. 1. Jet Stream system, Seco (a) type of cooling, (b) assembly of Jet Stream

High pressure cooling results in few advantages, including higher cutting parameters use, cutting edge life extension (from 20% up to 70%), and a better chip control and removal. Some disadvantages include higher initial costs, higher power consumption, higher system maintenance costs, higher demands on cooling emulsion, and working space exhausting.

MATERIAL AND METHODS

Analysis of selected tool manufacturer's solutions. Standard tools cannot be used, although they are equipped with cooling fluid channels through the tool. The cooling channel is of a too large diameter, and it is not directed to the cutting zone properly. Several manufacturers offer own tooling systems for high-pressure cooling in various concepts.

The company Seco (Fagersta Stainless AB, Fagersta, Sweden) offers a Jet Stream system (Fig. 1). The advantage of this system is a rigid clamping of the indexable cutting insert (ICI), but two channels for cooling fluid application are not pointed to the ICI tip when machining with a small depth of cut. Moreover, cooling channels finish is not ideal, so swirl flow instead of lamellar one can occur at lower pressures.

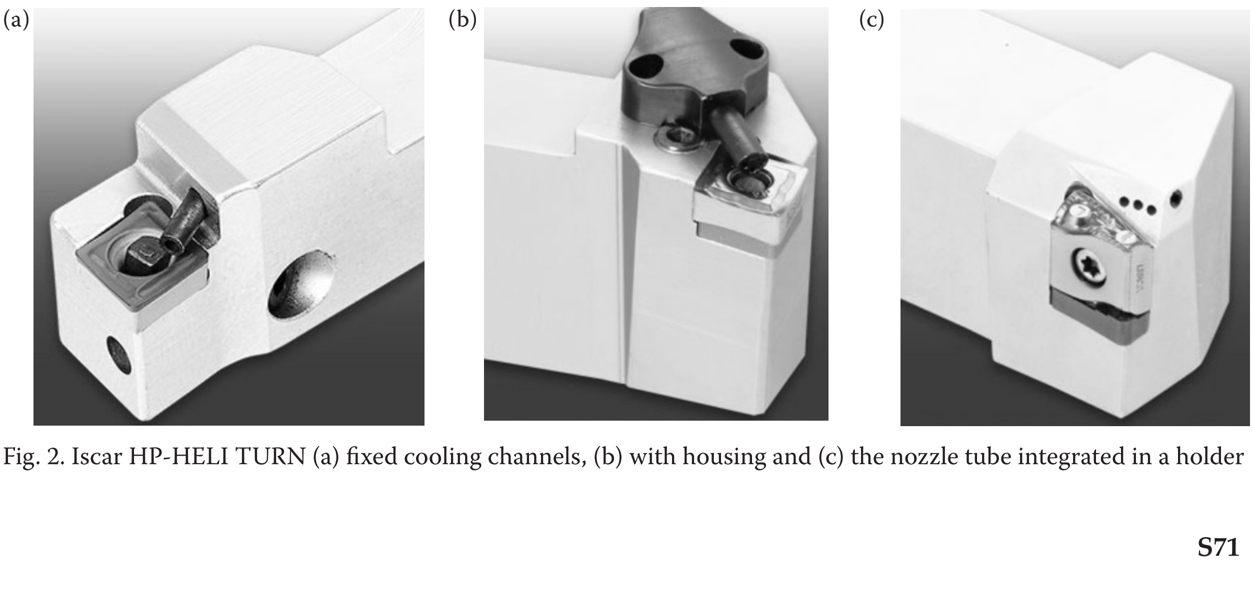

Fig. 2. Iscar HP-HELI TURN (a) fixed cooling channels, (b) with housing and (c) the nozzle tube integrated in a holder

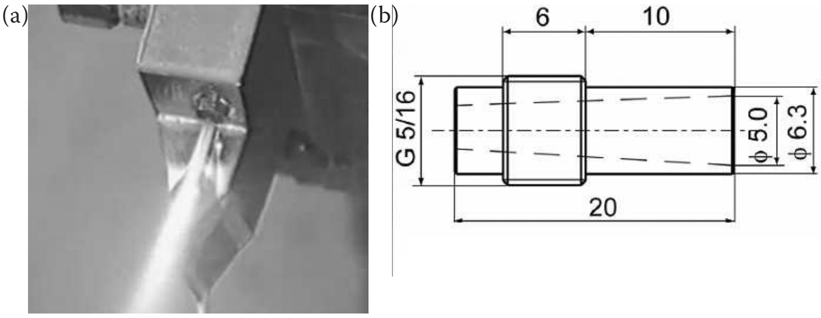

Fig. 3. Nozzle and cooling of ChipBlaster company (a) example of cooling and (b) shape of nozzle tube

The Iscar company (Tefen, Beit-Dagan, Israel) offers two systems: JET HP – HELI TURN (Fig. 2), with ICI clamped tangentially (designed for conceptual ICI) and then standard ISO ICI.

Holders HELI TURN for ISO ICI do not have designed the cooling pipe reliably. The pipe is inserted into the holder body and is pulled out by the pressure of cooling fluid running into. The pipe itself is not designed to concentrate the pressure to one spot and became a barrier for long chip running out of the cutting zone.

As the first company on the market, ChipBlaster offers a comprehensive solution of high-pressure cooling (Fig. 3). It was the first applying for the patent of the cooling pipe as a nozzle for laminar flow. Tool holders are designed for standard ICI, and it allows selecting the proper nozzle diameter with regard to the pump performance. The only disadvantage of this system is that it only contains one nozzle, limiting the disposable depth of cut.

Another company selected, offering tools for high-pressure cooling, is Sandvik Coromant AB (Sandviken, Sweden). It offers tool holders for ISO ICI with three cooling nozzles used (Fig. 4), exchangeable, similarly to the ChipBlaster solution, in accordance with flow rate generated by the pump type. ICI clamping is in some respect an obsolete solution, using a clamp, but no barrier is created for cutting fluid application to the cutting zone with an appropriate angle, forming an angle of 10° with rake.

The advantage of this system is the possibility of cutting fluid direction, according to the machined surface type, i.e. a cylinder or face surface. The cutting fluid stream can be pointed to the ICI tip in case of finishing operation (Fig. 5).

Used indexable cutting inserts. Standard ISO indexable cutting inserts can be used for high-pressure cutting tools, but they have to be equipped with a wider groove so that no mechanical barrier is present in front of the cutting edge to disturb the cooling fluid flow. To fulfil this requirement, a specific ICI with a special shape for high-pressure cooling is recommended by manufacturers (Fig. 6).

Seco has a specific ICI geometry, adjusted to SECO tool holders. These holders use two cooling channels completely modified to their ICI, with a wide opened groove (Fig. 7).

RESULTS AND DISCUSSION

The aim of laboratory sets was to compare chip generation and type in particular machining conditions. A standard geometry MM2025 was compared to an optimised geometry for high-pressure cooling MMC2025 (Fig. 8) in laboratory tests. Particular ICIs in a standard tool holder rigid clamp (RC)

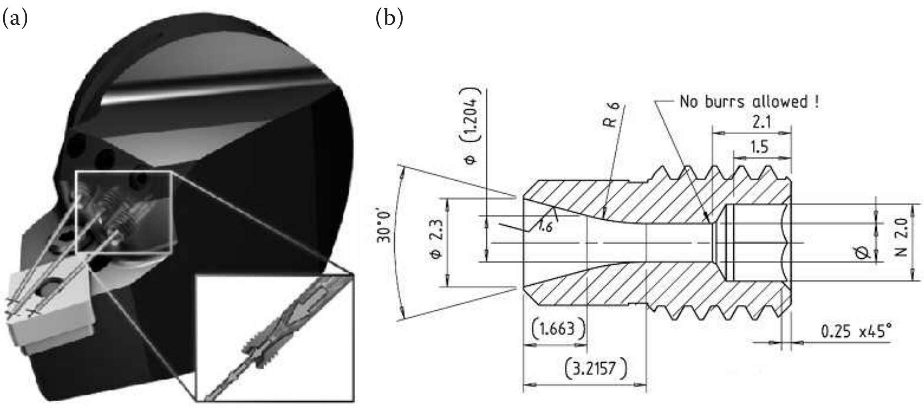

Fig. 4. Cooling system Sandvik Coromant (a) and a detail of cooling nozzle design (b)

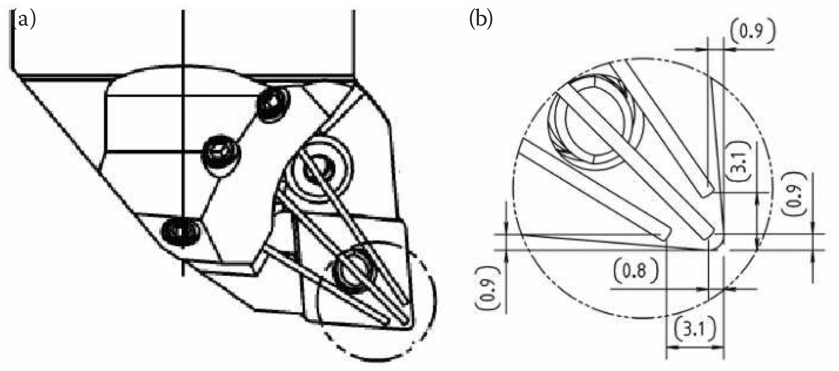

Fig. 5. Cooling fluid lines of flow distribution to the cutting zone (a) concentrated flow cooling in one place and (b) destination of the flow cooling on the inserts

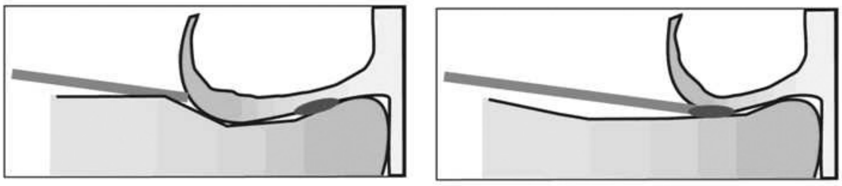

Fig. 6. Difference between geometry standard (a) and specific shape optimized for high pressure (b) of ICI and its application in high-pressure cooling tool holders

and special tool holder for high-pressure cooling at the cooling fluid pressures of 1.5 and 7.5 MPa on the Okuma machine (Okuma, Oguchi-cho, Japan) were compared. Workpiece material was austenitic stainless steel 1.4404 (ThyssenKrupp, Essen, Germany). Facing was used as a machining operation. Cutting parameters were used as follows:

cutting speed v_c = 200 m/min; depth of cut a_p = 1.0 mm; feed per revolution f_n = 0.12 mm and 0.2 mm. Used ICI type – CNMG120408.

Resulting chips are presented in Fig. 9:

(a) Tool holder effect: the use of RC clamp and standard cooling system does not improve chip generation either at higher cooling fluid pressure. In spite of that, the use of tool holder for high-pressure cooling improved chip generation even at lower pressure of cooling fluid (1.5 MPa), with a spiral chip going away easily. The chip generated at pressure 7.5 MPa was naturally broken, elemental.

(b) Feed effect: the common theory was confirmed that higher feed values improve chip generation with machined surface finish deteriorating (not measured in our tests).

(c) Indexable cutting inserts geometries did not influence chip generation so much, mainly thanks to the fact that both geometries were equipped with a wide groove, forming no barrier to cooling fluid.

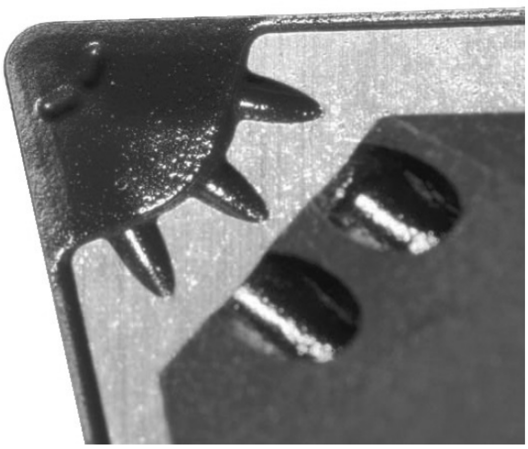

Fig. 7. Detail of SECO ICI for high-pressure cooling with position of cooling channels

To prove the fact that high-pressure cooling can be used at pressure 0.7 MPa, roughing operation was used with a demand of as most as possible material removal rate achievement. The following materials were used in machining:

- austenitic steel 1.4301, hardness 180 HB (ThyssenKrupp, Essen, Germany),
- deep-drawing sheet – low carbon steel C15, hardness 125 HB (ThyssenKrupp, Essen, Germany).

A long chip is generated when machining these materials at standard conditions, causing significant problems mentioned above.

Test No. 1

- machine tool Mori Seiki NL2500,
- material 1.4301, austenitic stainless steel,
- tool holder used: C5-PDJNL-35060-15HP (Sandvik Coromant AB, Sandviken, Sweden),
- indexable cutting insert used: DNMG150608-MMC 2025 (Sandvik Coromant AB, Sandviken, Sweden).

Cutting parameters:

- cutting speed v_c = 150 m/min,
- feed per revolution f_n = 0.25 mm,

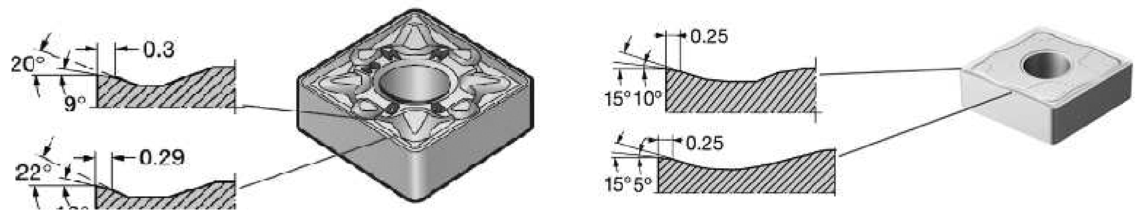

Fig. 8. Geometry of (a) MM – standard geometry (medium feed for stainless steel) and (b) MMC – optimized medium geometry for stainless steel for high pressure coolant

– depth of cut a_p = 2.0 mm,
– cooling fluid pressure p = 0.7 MPa.

Tool life was 8 machined pieces (cutting time 36 min). The original solution tool life was 6 machined pieces (cutting time 27 min) with the same parameters.

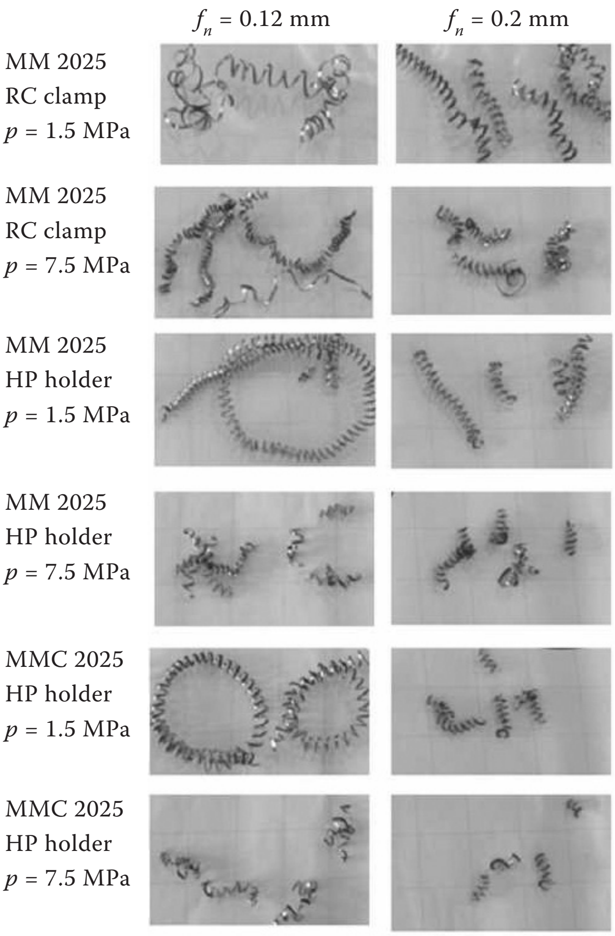

Fig. 9. Chip generated in machining using different geometries, clamping systems and cooling emulsions pressures at two different feeds

MM – standard geometry (medium feed for machining stainless steel); p – cooling pressure; f_n – feed rate; MMC – optimized medium geometry for stainless steel for high pressure coolant; HP – high pressure holder

Test No. 2

– machine tool Famar (Famar S.r.l., Avigliana, Italy),
– material C15 (ThyssenKrupp, Essen, Germany),
– ICI type used: CNMG120408-MMC 2025 (Sandvik Coromant AB, Sandviken, Sweden).

Cutting parameters:
– cutting speed v_c = 250 m/min,
– feed per revolution f_n = 0.4 mm,
– depth of cut a_p = 1.5 mm,
– cooling fluid pressure p = 0.7 MPa.

The tool life was 54 machined pieces (cutting time 77.4 min). The original solution tool life was 20 machined pieces (cutting time 28.6 minutes).

An example of resulting chips from this test is provided in Fig. 10.

High-pressure cooling success conditions:
– emulsion cleanness – filter devices cannot remove contamination with a size higher than 5 μm,
– emulsion concentration – 8–10%,
– proper nozzle diameter for an appropriate emulsion flow rate (pressure, volume) with pressure applicable area 0.7–7.0 MPa,

Fig. 10. Chips shape when machining using high-pressure cooling, f_n = 0.25 mm, a_p = 2 mm

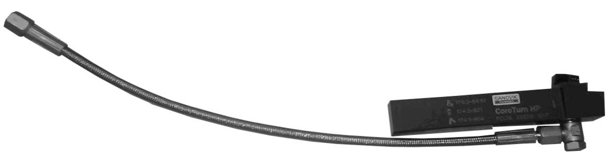

Fig. 11. Cutting tool set used in machining tests

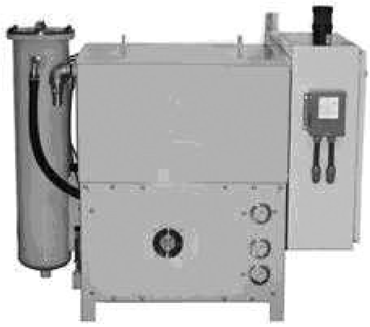

Fig. 12. High-pressure cooling device with filtration (Swiss Blaster SD30)

- multistep cutting tools use with an adjustable base unit only; otherwise, the risk of flow rate loss occurs.

The use of ICI geometry other than that designed for high-pressure cooling (Fig. 11) can result in a lower cutting edge life or proper function loss. Other ICI geometry can be used only in case of proper nozzle diameter combination.

The above-mentioned test was carried out at the CNC lathe (Famar S.r.l., Avigliana, Italy) with standard filtration up to 50 µm; approximately five min after test start, the nozzles got choked up with small chip particles. The machine tool has to be fitted with a filtering system for high-pressure cooling (Fig. 12). Filtering using paper filters or a hydrostatic filter system with high filter capacity should be used to prevent blockage of the holes, along with constant surface finish and longer tool and coolant life ensuring (Stephenson, Agapiou 2006).

The effect of feed rate on tool life with high-pressure cooling is depicted in Fig. 13. The material used in this test was steel grade 11523 of hardness 180HB, ICI CNMG120408-PMC 4224, cutting speed v_c = 335 m/min, and depth of cut a_p = 2.0 mm. Three different feed per revolution values were used: 0.2, 0.3 and 0.4 mm.

Sensibility of standard and special ICI geometry tool life on cooling fluid pressure

Another test was carried out to find out an influence of cooling fluid pressure on the tool life of standard ICI geometry and special high-pressure ICI geometry. The material used was steel grade 11523 of hardness 180HB (ThyssenKrupp, Essen, Germany).

The geometry of the cutting insert was CNMG120408-PMC and PM 4225. Cutting parameters: cutting speed v_c = 300 m/min, depth of cut a_p = 2.0 mm and feed per revolution f_n = 0.2 mm. The tool life criterion was the wear area size of flank VB 0.2 mm. The result is shown in Fig. 14.

CONCLUSION

The first conclusion is that high-pressure cooling is not working properly with pressure value 0.7 MPa when machining the material with a continuous chip (deep-drawing sheet metal). It is no problem to obtain an elemental chip when machining materials giving natural broken chip (Test No. 1). Although the elemental chip (or favourably formed) was not obtained in both tests, high-pressure cooling proved a positive effect on cutting edge life.

When observing chip generation with different feed rates, we found useful using a lower feed rate in case of HPC geometry of indexable cutting insert. Machining with feed per revolution 0.2 mm produced a well-formed chip in the whole range of

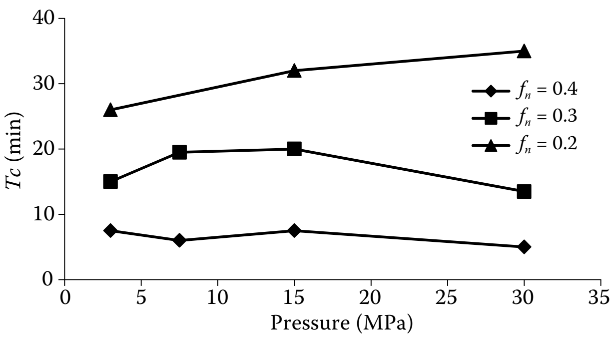

Fig. 13. Effect of feed rate at various cooling fluid pressures on tool life

Tc – tool life, *fn* – feed rate per revolution

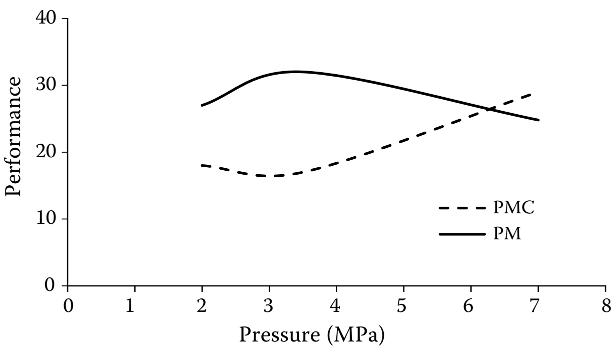

Fig. 14. Effect of cooling fluid pressure on standard (PM) and special high-pressure (PMC) ICI geometry tool life

cooling pressure used and tool wear occurred on the flank only.

At higher feed rates per revolution 0.3 and 0.4 mm, the chip was elemental, but the feed stressed (loaded) the cutting edge much more, resulting in groove wear on the rake.

After that, we can say it is better to use standard geometry in case of low cooling pressures device available, while optimised geometry is suitable only at high cooling pressure values (from 7.0 MPa).

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