DESIGN OF INTERNALLY COOLED TOOLS FOR DRY CUTTING

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Abstract: In modern manufacturing more and more metal cutting is performed using so called dry cutting technique (no coolant). The process is used where cutting with coolant is not desired. Said dry cutting due to the non-use of coolants is also environmentally friendly, which is an important feature in today’s green manufacturing agenda. The paper gives an overview on the state-of-art internally cooled cutting tools. It also represents possible new designs of internally cooled tools for turning concentrating on today’s manufacturing needs. Novel solutions and concepts are introduced. Proposed concepts will give the guidelines for further research and development to be carried on. Key words: internal, cooling, tool, turning.

1. INTRODUCTION

During the cutting, due to the friction and chip deformation, high cutting temperatures occur and a tool and a workpiece are subjected to increased thermal load causing significant tool wear. It causes a wear and thermal damage of the cutting tool, shortening tool life and consequently, resulting in poor surface roughness and dimensional tolerance. To reduce the cutting temperature, cutting fluid is traditionally used to remove the heat generated, decrease cutting force, and improve tool life. Cutting fluid is also used to reduce a formation of a built-up edge and increase the removal of chips from a cutting area. However, the use of cutting fluid has its disadvantages. Depending on the workpiece, the production process, and the production location, the costs related to the use of cooling lubricants range from 7% to 17% of total costs of the manufactured workpiece [1]. Additionally, many cooling fluids contain harmful or damaging chemicals causing environment pollution and operator’s health hazards, so strict environmental policies and health regulations have been introduced in connection with the increasing awareness of the environment and human health [2, 3]. To cope with said hazards it is necessary to operate in dry cutting mode, where no cutting fluid is used. Therefore components and/or products can be manufactured both ecologically and economically. Dry cutting could be solution if other obstacles would not arise. In dry cutting in result of no cutting fluid more friction and adhesion between the tool and workpiece will occur. “Recently many research attempts has been initiated to investigate the possibility of avoiding the use of cutting fluid, such as, using new tool materials and geometries, adding a heat pipe to the cutting tool, coating with solid lubricant, and applying internal cooling, etc.” [1].

The most promising solution for dry cutting seems to be the use of internal cooling. Many researchers concentrate their research in this field, but still there is no concrete solution which could be brought into industry. This paper analyses internal cooling techniques and introduces novel solutions or concepts, on which research could be carried on.

2. PRIOR ART

In industry cooling of cutting tools as well as cutting area is provided still in a
conventional way - cutting fluid is fed into a cutting area directly. In said cutting area part of a cutting fluid evaporates and rest of cutting fluid mixes with chips. After certain time cutting fluid wears out and it cannot be used anymore.

First designs of internally cooled tools proposed the following solution: a cavity in tool holder was made; over said cavity a cutting insert was placed; cutting fluid was introduced through channel in tool holder; said cutting fluid flow to said cavity under the cutting insert; heat from cutting insert was transferred to said cutting fluid which in turn was pushed away from said cavity via outlet channel made into a holder. This is typical scheme of internally cooled tool in turning. Fig. 1 illustrates said typical scheme of internal cooling system [⁴].

Another approach introduces a cutting tool having a cutting element such as an insert is cooled indirectly by a micro-channel heat exchanger that is mounted against the rear face of the insert (see Fig. 2). The heat exchanger is formed with an internal cavity that receives a coolant such as a cryogen [⁵]. Said cavity may include fins to enhance the removal of heat by the cryogen from the insert. Coolant inlet and outlet tubes are coupled to the interior of the heat exchanger to supply cryogen to the cavity. The flow rate of cryogen required to cool the insert during a given machining operation is less than 1% of the amount of standard coolant required to cool the same insert during the same machining operation [⁶].

Lagerberg [⁶] proposes a cutting insert having a cutting edge for chip removing machining (see Fig. 3). The cutting insert comprises a supporting body comprising a porous material forming a micro-porous structure throughout the supporting body to conduct a flow of cooling medium. The supporting body having an outer periphery including an upper surface and a side face, the supporting body being enveloped by a shell substantially impermeable to cooling medium. The shell includes a wear body disposed on the upper surface of the supporting body and forming the cutting edge. The shell has at least two openings exposing the supporting body, a first of the openings disposed remotely from the cutting edge and serving as an entrance for cooling medium, and a second of the openings disposed at an upper end of the side face beneath the cutting edge and serving as an exit for cooling medium to cool the cutting edge. The outer periphery of the supporting body defining an inner volume, wherein the micro-porous structure occupying the entire inner volume [⁷]. Said solution partly represents a concept of internal cooling, because cutting fluid escapes through porous structure of cutting insert into environment. Said solution does not provide complete internal
cooling and cannot be considered to comply with environmental policies and health regulations. It can be considered that such tools cannot be classified as internally cooled tools.

Fig. 3. Cutting holder with cutting insert having internal cooling [6].

Internally cooling tools also gives such an option as monitoring a temperature in cutting area. Bahram Keramati [7] proposes a cutting tool having on-line monitoring system measuring the heat generation rate at the cutting edge and relating this to the condition of the cutting edge. A flow of fluid coolant contacts the back surface of the cutting tool and the coolant temperature rise is measured during the machining process. The temperature difference and its rate of rise or fall is a direct indication of the heat generation rate and is related to tool conditions such as excessive and rapid wear and breakage (see Fig. 4).

Fig. 4. a) a side view of a tool holder; b) a plan view of the coolant channel machined into the cutting tool seat; c) a partial side view of the tool holder and insert [7]

Enders [8] suggests a design of cutting tool insert that includes: a body defining a rake face, a flank face, and a cutting edge at an intersection of the rake and flank faces; and a cooling micro duct within the body (see Fig. 5). A portion of the micro duct extends along the cutting edge not more than 0.5 millimeter from the rake face, and not more than 0.5 millimeter from the flank face. The micro duct has a cross-sectional area of not more than 1.0 square millimeter. The micro duct is adapted to permit the flow of a coolant there through to transfer heat away from the cutting edge and extend the useful life of the insert. Secondary conduits having cross-sectional area no larger than 0.004 square millimeter may communicate between the micro duct and the rake and/or flank face to exhaust coolant behind the cutting edge and further enhance cooling.

Fig. 5. Cutting tool insert having internal microduct for coolant being assembled [8].

Samir [9] describes an arrangement whereby fluid dynamics is used to provide a cooling effect to a cutting tool while in use. A cooling element comprising a long, restricted channel arranged on a support plate in a tightly spaced continuous pattern and having an inlet for any desired cooling fluid and an outlet (see Fig. 6). Cooling fluids can be contained within the system for indefinite reuse or can be cycled through (i.e. air or water). Samir [9]
suggests that preferred cooling fluids could be tap water or ambient air.

Fig. 6. Cutting tool comprising long, restricted channel [1].

Another solution proposes internally cooled cutting tool which has a “bottle-cup” insert and chamfered adaptor plate as shown in Fig. 7. “When the insert and adaptor come together, a cooling tube with triangular section will be formed for the cooling liquid to flow through. Their research concluded that under the same thermal boundary conditions, the simulated cutting tip temperatures of internally cooled tools are much lower that non-cooled cutting tool. It was also concluded that the diameter of the cooling tube has the most significant impact on the tool cooling efficiency” [1].

Fig. 7. Structure of insert with internal cooling [1].

In every research of internally cooled tools it was concluded that in real cutting internally cooled tools will considerably decrease the cutting temperature and thus improve the cutting process as well as tool life.

3. NEW DESIGN OF INTERNALLY COOLED TOOL

Given publications define prior art or known technical level and give a proof that tools with internal cooling can provide advantages over conventional tools, allowing to operate new tools in dry cutting without decreasing its performance. After extensive research of known internal cooling techniques or concepts, we concluded that the field is still in conceptual level. One of the main drawbacks of internally cooled tools with closed circuit flow is its complicated manufacturing. Present designs of internally cooled tools have complicated channel systems as well as complicated insert shapes. Another reason for slow acceptance of internally cooled tools is non-existence of strict rules according to use of cutting fluids or coolants. It all can change if governments will impose stronger restrictions on use of cutting fluids. Such restrictions can come into the force if governments will tend to support green manufacturing incentives.

After research of prior art we propose our conceptual design our internally cooled tool for turning in dry cutting. In Fig. 8 is shown one of the conceptual designs of the internally cooled tool. The tool has a two part tool holder. The tool holder itself has many possibilities for improvement. Some research could be done in developing a tool holder made of different grades of material. Such a combination of materials could serve as a heat-sink. The tool holder itself can comprise different sensing devices such as thermo-couple, force sensors etc. to control the cutting process. Implementing said sensing devices into the internally cooled tool upgrades the tool to the level of smart tool. A smart tool can be used for developing adaptive control of machining process improving its productivity.

It was concluded that basically there can be indicated two possible design solutions for internal cooling of a tool. The first approach includes cooling fluid channels
that are built into the insert itself. In given solution the insert comprises multiple channels or passages forming a heat sink. The channels should be configured to provide effective transportation of heat away from cutting area. In given approach a compromise should be achieved between two important factors: structural integrity of the insert (tool) vs. cooling performance of the insert (tool).

The second solution includes cooling fluid channels that are built in a tool holder (see Fig 8 and 9). Only tool holder is modified leaving standard insert. Said tool has a good integrity but in some conditions could not be able to provide enough cooling performance, because cooling channels are further away from cutting area than cooling channels formed into the insert. The cooling performance can be improved by developing the channel of cooling fluid as well as increasing flow parameters of the cooling fluid (mainly pressure).

When two parts are put together they form solid tool holder. The tool holder is formed as standard tool holder allowing to use it in lathes without modification or minor modification of tool holding system (see Fig. 10).

As mentioned above, one of the main problems for internally cooled tools are their restriction by technology or manufacturing capabilities. Usually internally cooled tools include relatively small fluid passages or channels which are complicated to manufacture, especially is standard manufacturing methods are used. One of the solutions to ease a manufacturing of the tool is to produce a holder of the cutting tool basically in two pieces (see Fig. 9). Each piece or part comprises half of the cooling channel.

We predict that in the future one of the most promising solution for manufacturing of internally cooled tools, especially inserts, with any possible design will be a 3D printing technology, for example a selective laser sintering (SLS). 3D printing is new and fast growing additive manufacturing technique. This technique gives a possibility to produce a tool in any possible form and configuration without any design restrictions. Tool and insert can be made in any form intended by designer. Additionally, 3D printing can be successfully used to bring newly designed tools to market in significantly faster pace. It means that further search should be done
in close cooperation with 3D printing industry. It should be kept in mind that the new designs of cutting tool inserts and holders will need to have its own standard. The new standard will provide easier introduction of internally cooled tools in industry.

4. CONCLUSIONS AND FURTHER RESEARCH

Prior art illustrates certain trends in design of internally cooled tools. Majority of designs are still in conceptual level. Authors do not give certain reasons why internally cooled tools are not so widely used in industry. After extensive analysis we can conclude that probable reason of tools not being popular in industry is its complicated manufacturing. Use of 3D printing techniques can significantly improve a product life cycle - from research to application in manufacturing. 3D printing could be one of the solutions to manufacture of tools in economically feasible manner.

Idea of using internally cooled tools is relatively new and said tools are not used in everyday life of manufacturing. We can predict that after implementation of tighter rules on the use of cutting fluids, researches of internally cooled tools could find its way into industry.

5. REFERENCES


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