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Razvoj postopkov in naprav za uporabo pri suhem obdelovanju

Process and Apparatus Developments in Dry-Machining Applications

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V prispevku obravnavamo novejši razvoj v postopkih suhega obdelovanja. Pri suhem obdelovanju se izognemo problemom onesnaženja rezalne tekočine, njene odstranitve in nevarnosti za zdravje. Primernost obdelovanca za suho obdelovanje je odvisna od lastnosti materiala. Učinkovitost rezalnega orodja pri suhem obdelovanju je odvisna od lastnosti prevleke. Postopek ima tudi omejitve, ki jih moramo upoštevati: hitro in ponavljajoče se spreminjanje temperature povzroča raztezanje, krčenje ter povečano nevarnost nastanka toplotnih razpok na rezalnem robu. Prisotnost hladiva poveča problem toplotnega pokanja. Pri suhem obdelovanju ostaja orodje vroče in trdno. Med postopkom suhega obdelovanja prevleka prevzame vlogo hladiva pri varovanju rezalnih robov pred obrabo ter zagotavlja zanesljivo odstranjevanje odrezkov. Potrebne so nadaljnje raziskave suhega vrtanja ter pehanja materialov z dolgimi odrezki.

(Ključne besede: suhe obdelave, prevleke, rezilni vložki, življenjska doba orodij)

In this study a recent development in the dry-machining process is discussed. Dry machining eliminates the problems of cutting-fluid contamination, disposal, filtrations and the risk of health problems. The suitability of the workpiece for dry machining depends on the material's properties. The performance of the cutting tool for the dry-machining process depends on the properties of the coating. The process also has a restriction that must be taken into consideration: the rapid, repetitive fluctuations of the temperature lead to expansion, contraction and an increased risk of thermal cracking of the cutting edge. The presence of the coolant exacerbates the thermal cracking problem. Dry machining keeps the tool hot and tougher. During the dry-machining process the coating takes the place of the coolant in protecting the cutting edges from wear and ensures reliable chip evacuation. Additional studies are needed on the dry-drilling and taping process for long chipping materials.

(Keywords: dry machining, coatings, cutting inserts, tool life)

0 INTRODUCTION

Near-dry and dry machining are becoming increasingly popular as ways of reducing production costs, while at the same time protecting the environment [1]. Because of growing concern about pollution and the associated legislation, fluid disposal has become both costly and compulsory for environmental protection. Cutting fluids remove heat, reduce friction, wash away chips, reduce cutting forces and power requirements, improve the dimensional stability of the work part, improve the surface finish and prevent any built-up edge. Coolants are essential in the machining of materials such as aluminium and stainless steels, which tend to adhere to the tool and cause a built-up edge. Cutting fluids also cause some problems, such as odours, health hazards, and loss of their lubrication function with contamination ([2] to [4]). Some 16% of the costs of a machine part are directly attributable to the fluids that are used. Tooling accounts for 4% of the part's costs. Eliminating the coolant reduces the amount of waste dumped in land fills, the amount of airborne material in the factory atmosphere, and the risk of health problems for operators [5].

The transition from the use of coolants to near-dry and dry machining usually depends on the work material. Dry machining eliminates the problems of cutting-fluid contamination, disposal and filtrations. But the process also has a restriction that must be taken into consideration. During dry machining, the tool and the workpiece are subjected to higher temperatures. The friction between the chip, the tool and the workpiece increases during dry machining when processing with a conventional tool, and the adherence tendency of the chip to the tool is higher during dry machining. These negative effects of dry machining shorten the tool life and the stability of the workpiece ([4] and [6]). To overcome these restrictions new coats and coating processes are being developed and tested for dry-machining tools ([7] to [14]).

1 EFFECTS OF DRY MACHINING ON THE CUTTING TOOLS

The important coating properties of the cutting tool are a low coefficient of friction, oxidation resistance, chemical stability against the workpiece material, hot hardness, hardness, ductility, resistance to abrasive wear, crack retardation, and thermo-physical properties. The hardness of the tool material during machining is related to the hot hardness characteristics of the tool material. The hot hardness property usually requires a trade-off in toughness, as hardness and toughness are opposing properties [4]. The hardness characteristics of various tool materials at elevated temperatures are illustrated in Figure 1. In the dry-machining process the coolant is eliminated and the tool reliability is increased. However, the recently developed coated cemented carbide ceramics, cermets, CBN and diamond tools are brittle. These tools chip, fracture and crack during facing and milling operations. Rapid, repetitive fluctuations of the temperature lead to expansion, contraction and increase the risk of the thermal creaking risk of the cutting edge ([16] and [17]). The presence of the coolant exacerbates the thermal cracking problem. Dry machining keeps the tool hot and tougher. The distribution of heat generated during dry machining according to cutting speed is illustrated in Figure 2. In the machining process the high-efficiency machining range is identified according to the time and the cost per piece, as illustrated in Figure 3. Figure 1, 2, and 3 show that there is an optimum temperature limit for economic machining.

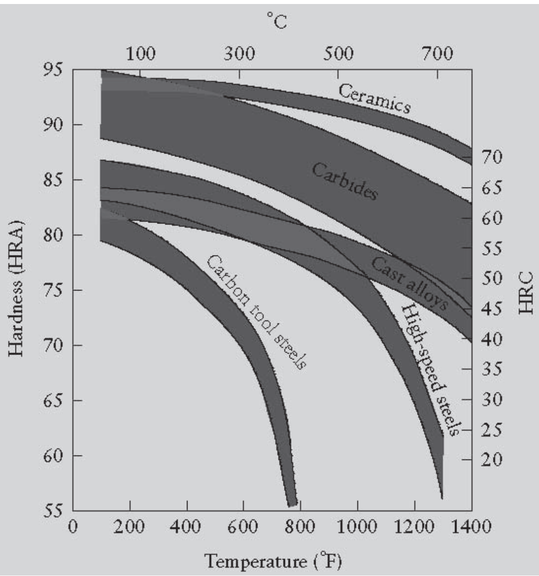

Fig. 1. *Hardness characteristics of cutting tool materials, at elevated temperature [15]*

2 DEVELOPMENTS IN TOOLS FOR DRY MACHINING

In the dry-machining procedure the unwanted effects of temperature on the tool can be compensated by selecting a harder grade insert. Selecting an insert with a larger nose radius can be used to improve the feed-dependent surface finish. An increase in temperature lowers the hardness, while at the same time increasing the toughness of the cutting edge, as seen in Figure 1. During a facing operation of a cylindrical workpiece, the tool cuts with a constant rpm and a variable surface speed. Using coolant as the cutting tool moves from the outer side to the centre of the face of the part causes the temperature of the cutting edge to decrease. Fluctuations in temperature change the stress state of the tool, which is effective during the thermal cracking of the tool [17]. Dry machining in similar conditions will give better results in terms of tool life. The cutting speed, feed and depth of the cut are the factors that control the metal removal rate during turning. These parameters determine the tool life. An increase of 50% in the cutting-speed feed and the depth of the cut results in a decrease of the tool life by 90%, 50% and 10% respectively [19]. On the other hand, increasing the depth of the cut is not an option for near-net-shape part production. Consequently, increasing the feed rate and decreasing the cutting speed have a positive impact on tool life. The disadvantage of this approach is a deterioration of the surface finish. The selection of

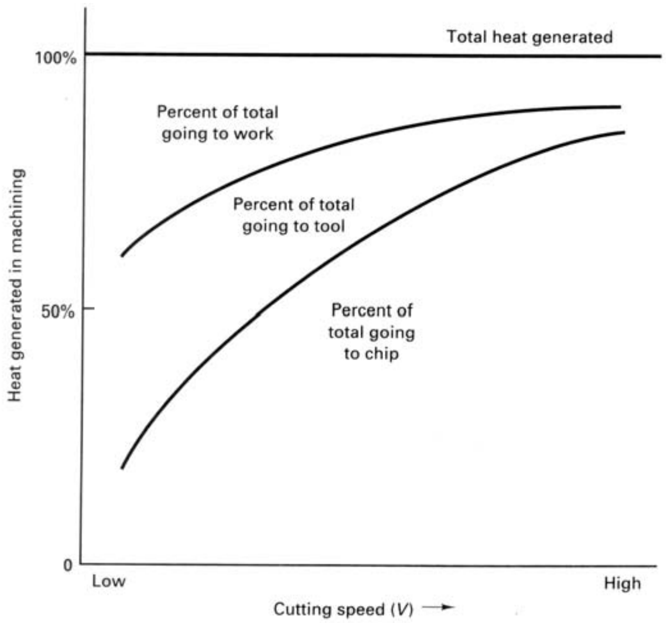

Fig. 2. *Distribution of heat generated in dry machining according to cutting speed [18]*

a tool that has a larger nose radius will compensate for this deterioration. Increasing the cutting edge, the rake angle and adjusting the lead angles decreases the friction and the temperature. Under certain conditions where lubrication is needed, such as drilling, grooving, parting off, the machining of stainless steels and high-temperature alloys, minimum-quantity lubrication (MQL), which consists of a drop or droplets of oil suspended in compressed air, must be used. During the dry drilling and taping of long chipping materials, premature tool replacement or expensive waste because of tool failure are common problems. The extreme temperatures that develop at the cutting edges are the main source for such problems because the tool becomes more susceptible to wear and fracture. The deformed hot chips, which may weld to the tool and form built-up edges, also greatly impair the reliability ([5] and [20]). Recently produced tools with new coatings combine a harder and soft coating and provide effective chip evacuation without any conventional lubrication. The hard layer is a titanium aluminium nitride (TiAlN) coating, while the soft lubricant layer is tungsten carbide/carbon (WC/C), a coating of medium hardness and a low coefficient of friction, as seen in Figure 4.c. The combination of these coating layers results in an improved chip flow, while generating a lower coefficient of friction ([5], [8] and [14]). This coating combines the advantages

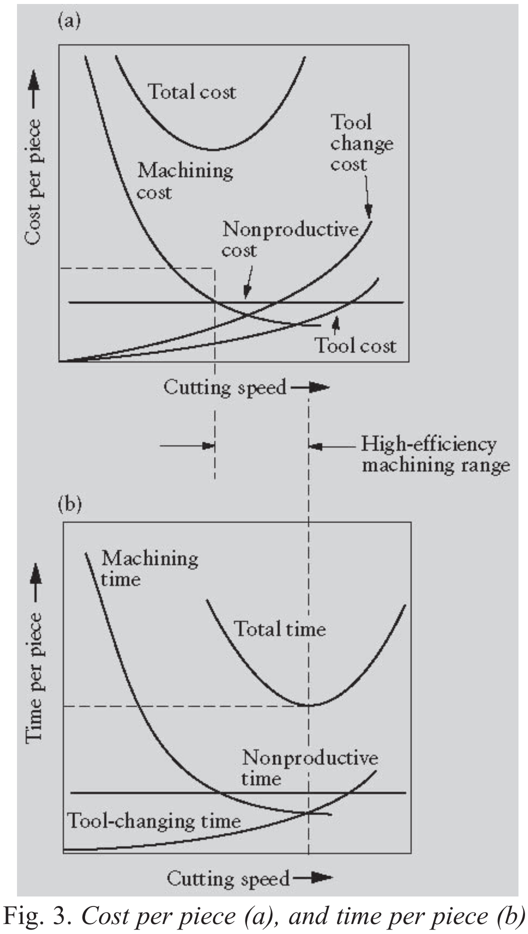

Fig. 3. *Cost per piece (a), and time per piece (b) in high efficiency machining [15]*

of an extremely hard and thermally stable TiAlN coating with the sliding and lubricating properties of the outer WC/C coating. During the dry-machining process the coating takes the place of the coolant to protect the cutting edges from wear, while simultaneously ensuring reliable chip evacuation. These lubricious coatings reduce the generation of heat by decreasing the amount of friction. Coatings such as molybdenum disulfide and tungsten carbide-carbon have low coefficients of friction and can lubricate the cutting action. These coatings are soft and have a relatively poor tool life. To compensate for this limitation, these coatings are often used with hard under-layers such as titanium carbide, titanium aluminium nitride, aluminium oxide or some combination of these. Diamond-like carbon (DLC) coatings are the first kind of coating for the dry machining of aluminium alloys [22]. The surface of a DLC coating is exceptionally smooth and has an extremely low friction coefficient, 0.05 to 0.2 μ, for aluminium alloys. DLC coatings are based on the same carbon chemistry as diamond and graphite and feature an amorphous structure that provides a high hardness and good lubrication ([10] and [21]). The lubrication properties of DLC coatings improve the chip versus uncoated inserts. The DLC coating reduces the cutting temperature and the cutting force by 25% and 50%, respectively [22]. DLC coatings give reasonable results in low-silicon aluminium and in finishing/semi-finishing milling applications. Keiichi et al. compared a DLC-coated insert with an uncoated tool in the machining process for aluminium materials. They report that as a result of a lower heat generation the chips from the DLC-coated insert were about 1.5 times the length of those from the uncoated insert [10] and [21]. Hanyu H. et al. produced a 1-μm surface roughness of the diamond coating on cutting edges and flutes of drills using a chemical vapour deposition (CVD) technique. In the study using dry cutting conditions an aluminium alloy including 12% silicon was drilled with different tools. The numbers of holes were 94, 731 and 3080 for the non-coated, conventionally diamond coated and fine-crystallized smooth diamond-coated drills, respectively. The increase in the number of holes for the fine-crystallized smooth diamond-coated tool is explained by the difference in the friction and the anti-sticking properties [2].

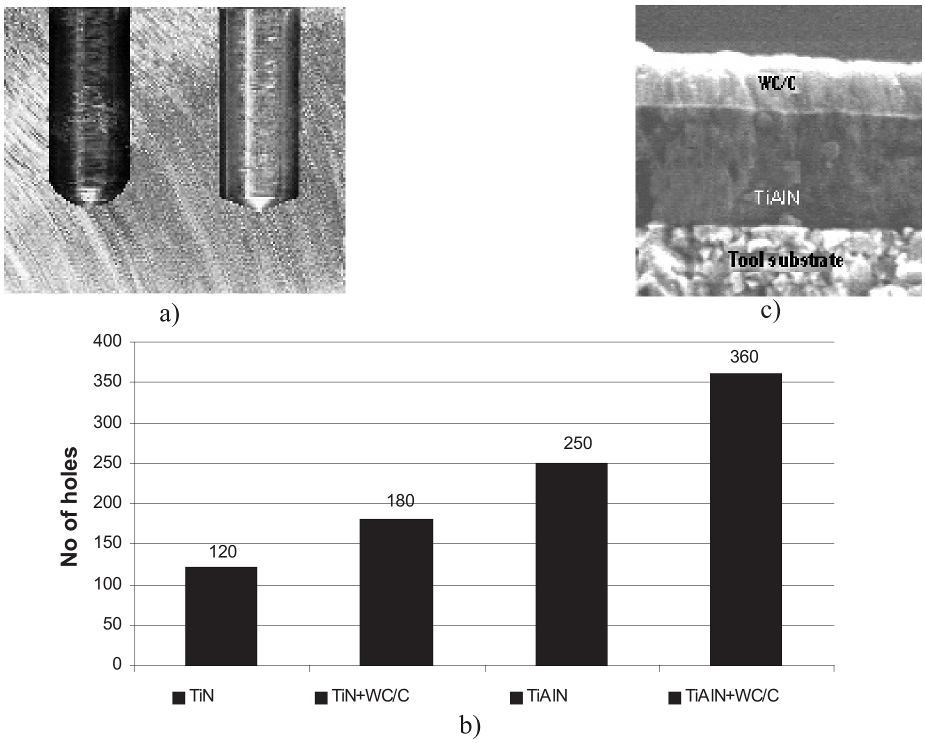

Fig. 4. a) *Surface quality after the same number of drilled holes: TiAlN (left), and TiAlN+WC/C (right), b) Coating performance in dry machining, c) SEM cross-section of the TiAlN+WC/C [5]*

3 DRY MACHINING OF COMMON METALLIC MATERIALS

The suitability of the workpiece for dry machining depends on the material properties, and in some cases the fluids may be undesirable, for example, where there is a risk of contamination. The cutting fluids stain the part or contaminate it.

Cast iron and alloyed steel. Cast iron and alloyed steel materials are relatively easy to dry machine and conduct heat well, allowing the chips to carry away most of the generated heat.

Low-carbon steel. Low-carbon steel becomes more adhesive as the carbon content falls. Newly developed tools may be used to prevent welding. The key variables for the dry machining of nonferrous materials are achieving a higher spindle speed, improving the chip-ejection geometry and the design.

Aluminium alloys. Aluminium alloys can be dry machined because of the relatively low cutting temperatures. Sharp edges and highly positive rake angles make it possible to solve the welding problem of the chips. When dry machining aluminium alloys at high speeds, recently developed TiAlN+WC/C, DLC or diamond-like-film-coated PCD tools can be used.

Stainless steels. At the machining temperature stainless steels are sticky and have a propensity to cause build-up along the cutting edge, leading to a poor surface finish.

Nickel and chromium based alloys. During the machining of nickel- and chromium-based alloys a higher temperature is generated, which must be taken into consideration in the dry-machining process. These materials require tools that have better lubrication and hot hardness properties.

Titanium. The properties of titanium prevent it from being dry machined. Titanium is also sticky at higher temperatures, has a low thermal conductivity and a low flash point. Consequently, the chips do not carry the heat away and the workpiece can get hot enough to ignite and burn [23].

Magnesium. Magnesium can be dry machined, but there is a risk of burning of the workpiece because of the lower flash point. Magnesium use in industrial application is expanding and it may be "the metal of the future"; this is because it has high strength, light weight, a good damping capacity and can be formed to a near-net shape fairly easily. The dry-machining process might be an important technique for solving technological problems in the use of magnesium. Magnesium chips are a fire hazard and they react with water in the coolant and form magnesium hydroxide. This reaction releases hydrogen, which is dangerous and makes the water in the coolant harder. The quality of the wetted magnesium chips (magnesium hydroxide) deteriorates, so the recycling of the chips can be a problem.

4 PROBLEMS IN DRY MACHINING

The main problems associated with dry machining are related to heat. Deformation occurs earlier, thereby reducing the tool life. Another problem associated with dry machining is the instability in the workpiece size, caused by the increasing temperature. Without coolant the temperature of the tool, the tool holder, the machine components and the workpiece increases and the size of the workpiece changes [4]. To eliminate these effects the contact time between the tool and the workpiece must be reduced. For applications that require several operations, planning the order of the operations reduces the temperature. Using an insert, which has the appropriate chip groove, makes it possible to remove the chip with the minimum deflection or deformation. Minimising the deformation during the machining reduces the generated temperature [14]. By minimizing the depth of the cutting in the finishing process it is possible to lower the temperature of the cut. During dry machining precautions must also be taken to prevent chip breakage and evacuations. The chips at a high temperature are more ductile than their cooler counterparts, so chip breaking becomes more difficult in higher-temperature regimes. The tools that are designed with a versatile chip groove control the stringy chips and eliminate this problem. However, in dry machining the hot chips can remain in the cutting region, heating up the workpiece, the tool and the machine. Overheating results in work hardening and serious geometrical and dimensional flaws in the finished part. Gravity may be used to remove the chip from the cutting region. The chips can fall on a conveyor if the tools are used vertically or diagonally upward [22]. Increasing the cutting speed in the drilling operations forces the chips to leave the hole more quickly and reduce the heat in the cutting region and so increase the tool's life.

5 RESULTS

During the dry-machining process optimisation of the tool and the workpiece is needed to identify the parameters of the cutting speed, the depth of cut and the feed rate. The performance of the cutting tool for the dry-machining process depends on the properties of the coating. The feed rate can be increased, while the cutting speed is decreased during dry machining for a defined material-removal rate. Success during dry machining requires a methodical approach to control the heat produced in the process.

Any advances in dry machining will enhance the industrial applications of magnesium and magnesium alloys, which have a good strength/density ratio. The presence of the coolant exacerbates the thermal cracking problem of the cutting tool. Dry machining keeps the tool hot and tougher. During the dry drilling and taping of long chipping materials, premature tool replacement or expensive waste because of tool failure are common problems. Additional studies are needed on drilling and taping. The combination of TiAlN+WC/C coating layers results in an improved chip flow and a low coefficient of friction during dry machining. In the dry machining process the coating takes the place of the coolant to protect the cutting edges from wear and ensure reliable chip evacuation. Molybdenum disulfide, diamond-like carbon (DLC) and tungsten carbide-carbon (WC/C) coatings are lubricious coatings and have low coefficients of friction. In the dry-machining processes special precautions must be taken to remove the chips from the cutting zone.

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