Cutting tools in CNC machining

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CUTTING TOOLS IN CNC MACHINING

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Summary :
This paper reviews the current situation and trends with regard to tools used in CNC machines and attempts to clarify the thinking of the user in his quest for alternative tool materials. It intends to create a general awareness of the real requirements of a cutting tool in the overall production environment. Specific cutting tool material types are discussed and the thinking behind new tool design and construction concepts for optimum tool performance and utilisation is presented.

Introduction

With the high degree of automation in present day machining processes, reliability in the performance of cutting tools has become a very important consideration. If the tools fail frequently or prematurely, or if the performance is not consistent, the capabilities of machine tools cannot be fully exploited. CNC machining centres and CNC lathes today are capable of cutting metals and non-metallics at high material removal rates. Another important feature of these machines is the high degree of rigidity and vibration free operation even under extreme rotational speeds. It is in this non-traditional operating environment that the function of the cutting tool must be examined.

The Machining 'System'

Although this paper concentrates primarily on the cutting tool, the tool and the workpiece must be considered as a system together with the machine tool. The latter provides the interaction between the tool and the workpiece. The ultimate aim is to provide the most efficient and cost-effective method of such interaction. In this context, the term *machinability* may be taken to imply the number of components produced per hour, the cost of machining the component and the quality of surface finish achieved together with dimensional accuracy rather than simply the rate at or ease with which material is removed.

It is relevant to note here the diversity of conditions experienced by the tool in the machining processes of today. Apart from machining traditional materials, viz. steels, cast-irons and non-ferrous metals such as aluminium and copper alloys, CNC machines are called upon to machine a variety of difficult-to-machine materials. These are primarily the space-age-metals such as different grades of tough and abrasive stainless steels, titanium alloys, high strength thermal resistant super alloys (Nimonics, Inconel series, Hasteloys etc.) and refractory metals (tungsten, tantalum, molybdenum etc.). Numerous problems are encountered when machining such metals which tend not only to wear out the tool but gall and weld on to the cutting edge. Rigidity of the entire machining system is essential to minimize these effects and the CNC machines offer the correct base, provided tool materials and tool design can take up the challenge.

Tool Materials

Requirements

As the cutting edge wears out, control over the part size, ie. meeting the specified tolerances, becomes difficult and the surface finish deteriorates. There are courses of action to be taken in this situation. One obvious solution is simply to change or regrind the tool. Here, down time for tool change decreases machine output. A second solution is to reduce machining speeds and thereby control the rate of tool wear. This too is unattractive as it lowers machine output. A third solution that improves machine prodcutivity is to use a more wear resistant, better performance cutting tool. This is where the search for new materials has paid dividends. Attention is drawn here to the fact that harder the tool material becomes (hence more wear resistant it is) the lower will be its toughness. This is the compromise one has to make. It is therefore not surprising that the modern tool materials with superior wear resistance have found applications exclusively in the CNC machine tools sphere. These advanced materials cannot be used with conventional machines.

The property requirements of an 'ideal' cutting tool material can be listed as:

- Adequate strength
- Strength retention at cutting edge at machining temperature
- Reasonable toughness
- Thermal shock resistance
- Superior wear resistance
- Oxidation resistance and chemical stability.

Obviously, no one tool material can meet the diversity of industrial conditions. The popular grades in use today are those which combine a satisfactory balance of the above mentioned properties.

The primary concerns of industry, particularly in the context of CNC machining are:

- Adequate tool life coupled with reliability
- Reproducibility of performance between workpieces, and
- Adaptability to a variety of machining situations.

Increased productivity is sought by industrial user through higher cutting speeds, which means that tool material development has been aimed at realising much enhanced temperature capability.

Types and Selection

The tool materials used in CNC machining fall basically into the following broad categories:

1. High Speed Steels
2. Carbides
3. Coated Carbides
4. Cermets
5. Ceramics
6. Ultra-hard materials

Within each of these specialised groups, many grades are commercially available posing problems of selection on the shop floor. There is also considerable area of overlap where different tool materials are in competition, particularly in the speed range 100 - 400 m/min. Thus there is no unique choice as such available to the user. HSSs, Carbides, and cermets cater for the bulk of the machining jobs, the ceramics and ultra-hard materials being reserved for special applications. Maximum cutting speeds possible with these tool materials could be as high as 1200 m/min. when machining grey cast irons and certain non-ferrous alloys.

Although HSSs are indispensable as a tool material and HSSs (both plain and coated) are used in CNC machining on a large scale, HSS applications are not over emphasised in this paper since the focus is more on the tool materials which are specifically meant to be used in the CNC machine tool environment.

Carbides (Cemented Carbides)

Cemented Carbides are primarily the tools for mass production. They are prefered to HSSs where very rapid metal removal is to be carried out on rigid machine tools.

Produced through the sintering process, WC/Co unalloyed grades ('straight grades') and WC/TaC/TiC/Co alloyed grades ('steel cutting grades') form the bulk of the cemented carbide tools. These are very hard and moderately tough materials. Fine-grained cemented carbides have much improved toughness and are used in applications such as solid carbide drills and end mills, traditionally the domain of HSSs only.

(Carbides may be damaged by thermal shock. The intermittent nature of the cutting process makes it extremely difficult to apply a cooling medium without causing thermal shock to the carbide. Therefore if coolant is used, the cutter should be flooded or subjected to a high-volume coolant stream. A dry operation is much better than a poorly cooled one.)

Coated Carbides

Undoubtedly the greatest improvements in the performance of carbide tools have come from the introdution of vapour deposited coatings, initially of TiN or TiN/TiC, but now covering a variety of compositions including ceramics such as Al_2O_3. These coatings are applied by the CVD (*Chemical Vapour Deposition*) or the PVD (*Physical Vapour Depostion*) processes. These give very substantial increases in tool life over the uncoated carbides, and benefitting from the 'throw-away tip' concept, have made significant in-roads into the carbide market. This, on the other hand, has resulted in a problamatic situation confronting the user as far as selection is concerned, since a wide variety of coating types have proliferated the market.

Cermets (**CER**amic with **MET**allic binders)

Similar to the cemented carbides, Cermets consists of a hard phase bonded together by the sintering process. A popular grade is TiC/TiN bonded with Ni. These carbides and nitrides excel in strength and oxidation resistance at high temperature in comparison with WC which is the principal element in cemented carbides. Cermets hardly react with work metals and enjoy a status in between cemented carbides and ceramic tools.

Ceramics

The development of Alumina (Al_2O_3) tool materials was at one time considered a major break-through in the the tool material field, but the original expectations were not quite realised. The ceramics require very rigid machine tools operating at high speeds and the observance of good machining practice. Perhaps the user application of ceramics to unsuitable operations has been responsible for some of the mistrust placed on ceramics at one time.

Alumina-base ceramics (including pure Alumina) and Silicon Nitride - base ceramics (SIALONS) are established tool grades in this sector. Alumina reinforced with silicon carbide whiskers is another potential addition among other developments. A noteworthy application of ceramic tools is in continuous cutting of grey cast iron at extremely high speeds (up to 1200 m/min.). Ceramic tools excel in wear resistance, adhesion resistance, oxidation resistance and heat resistance and are used for machining a variety of metals including superalloys. Ceramics are expensive tool materials.

Ultra-Hard Materials (Polycrystalline Grades)

These are tool materials for dealing with hard and abrasive workpiece materials.

For example, compact polycrystalline diamond (PCD),generally on a cemented carbide substrate, is successfully applied for machining high silicon containing aluminium alloys used as piston metals and also for machining glass-fibre-reinforced plastics. Inspite of being 20 - 30 times as expensive as its carbide equivalent, coated diamond tools still have the potential for claiming overall economic superiority. *Diamond tools are however not suitable at all for machining steels.* Polycrystalline cubic boron nitride (CBN), which is even more expensive, is the other established material in this group. CBN is used as tips on standard carbide substrate or as solid inserts and is suitable for machining aerospace metals, hardened steels and cast irons which would otherwise need grinding.

Tool Design Concepts

The emphasis in tool material development as evident from the preceding paragraphs has been towards improving the high temperature capabilities. However, one cannot be ignorant of the importance of tool reliability. As already pointed out, harder the tool material becomes more brittle, and hence liable to fracture, it will be. The really significant (hidden) costs are the losses due to lost production time. On the otherhand, direct costs of frequent tool replacement it self will be prohibitive when dealing with the super hard tool materials - Sialons, PCD, CBN etc.

Reliability in performance (ie. avoidance of premature fracture) and cost-effectiveness of the CNC age tool materials has been achieved primarily through revolutionary changes in tool design concepts as will be examined in this section.

The idea of **THROW-AWAY-TIPS** became a reality when tool regrinding costs were found to be prohibitive for certain classes of newer tool materials. Long before that, it was common practice to use the more expensive tool materials as small tips mounted on a tool shank rather than as entire tools. These tips were permenently brazed on to a steel shank. The shank also compensated for the lack of toughness in the harder tool materials and allowed their superior wear resistant characteristics to be exploited in full.

While diamond wheels could be used to regrind cemented carbide tools, this was often a costly solution. For coated carbides, regrinding was not a solution as it would, only result in the few micron thick hard surface layer being removed exposing the less wear resistant substrate. Such tools had to be obviously discarded once worn out. The idea of using multiple cutting edges in a tip instead of a single cutting edge was thus conceived. This provided economic justification for use of coated carbide grades. It also meant that instead of permanently fixing the tip on to the shank, some form of rigid mechanical clamping was neccessary. Today **INDEXABLE-INSERTS** are widely used in tools for CNC machining centres and lathes, and have eliminated the need for regrinding. Furthermore it has enabled a significant reduction of machine down time. Inserts with 3 or 4 cutting edges are commonly used.

Machining with a positive rake angle is common practice with HSSs. The power consumption is low and the product surface finish is good. For exmple, with a rake angle of +30° and a clearance angle of 5° the included angle (wedge angle) of the tool would be 55°. If a brittle tool material is used, it is very likely that the bending moments resulting from forces on the rake face could cause fracture of the tool edge. In such circumstances one has to resort to negative rake cutting. With a rake angle of -10° and a clearance angle of 5°, the included angle of the tool would be 95°. Although negative rake cutting consumes more power and affects product surface finish, it is the only viable solution for the more brittle types of tool materials. The rake angle for cemented carbide tools never exceeds +10°, but usually negative. Some tool holder designs provide the option of using positive rake inserts in the same tool holder that accepts negative rake inserts.

A wedge angle of 90° is an interesting situation. Such a geometry would permit doubling the number of cutting edges available per insert. A 90° wedge makes it possible for the insert to be turned over so that the back edges also can be used. The advantages of a 90° wedge does not end with this. The manufacturing process for carbides and ceramics is powder pressing followed by sintering. A 90° wedge would enable the inserts to be pressed as one long cylinder from which they are sliced off prior to final sintering, thereby significantly reducing the manufacturing costs.