The Multi-Layer Approach to Tool Life Improvement

Optimizing the Performance of Rotary Cutters for Handheld Tool Use

Even in this day and age of numerically controlled machining centers, the use of handheld power tools often remains the only practicable machining option. This is where rotary cutters excel, not only for fettling castings but also when it comes to precision work on high-tech components and safety critical workpieces. But highest standards can only be achieved with tools optimized for the specific purpose.

The Rüggeberg company headquartered in Marienheide/Germany was established in 1897 and is the world-renowned supplier of the PFERD brand of cutting, grinding, polishing, filing, and brushing tools. The company has a global workforce of about 1800, including 800 employees in Germany. Rotary cutters have been used, historically, for what are by today's standards fairly coarse machining or finishing tasks. The spectrum of materials worked with rotary cutters ranges from wood, plastics and fairly soft nonferrous metals to fiber-reinforced plastics and high-alloyed steels, and from there to corrosion-resistant grades and high temperature super alloys. This broad diversity of workpiece materials calls for the use of appropriate tool structures capable of performing at high output levels and with optimum durability. Accordingly, the materials employed in the manufacture of rotary cutters have gone from cold work steels to tool steels and from super-high speed steels to tungsten carbide. An end to the evolution of cutter materials is not in sight, with those currently in use being based primarily on TC-Co hard metals. This group of materials combines increased hardness with an edge strength and toughness commensurate with today's applications. It is thus highly qualified for use in manual machining operations, with the associated shock loads, at cutting speeds of several 100 m/min.

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Development of new cutting materials

The refinement of existing cutting materials and the development of new ones is closely related to the increasing demands imposed wherever products must be machined with 'defined cutting edge' type tools. The diversity of workpiece dimensions and geometries further extend the applications range. Metal castings may be miniature precision components weighing less than 1 g, but also occur in the form of large heavy-duty parts of more than 100 tons, e.g., in the steering gear of ocean-going ships. Castings often exhibit fins, for instance along the mould parting lines Removing these projections is a fairly straightfoward, coarse operation as long as the surfaces involved do not have to meet specific visual appeal standards or are intended to receive a subsequent ground finish. The same applies to the preparation of weld seams, e.g., in pipeline and curtain wall construction. But where surfaces must be milled to high functional or visual standards in a single operation, this coarse job turns into an art form. This is specifically true in sensitive applications such as the manufacture and repair of civilian and military aircraft engines (Fig. 1).

Fig. 1: Turbine IAE V 2500 (low pressure turbine supplied by MTU Aero Engines GmbH)

Changing geometries

The typical application consists in changing the geometry of a high-temperature alloy component subject to stringent safety specifications. On turbine blades, for instance, it is necessary to machine cracks and surface defects before filling the resulting groove by build-up welding and smoothing the surface afterwards. But the task underlying this simple-sounding description actually touches on a number of fundamental problems. The process of widening the original crack by milling is complicated by the fact that turbine blades are largely made of titanium and nickel-based alloys capable of resisting the high mechanical and temperature loads encountered in tubine operation. Nickel-based alloys are high temperature

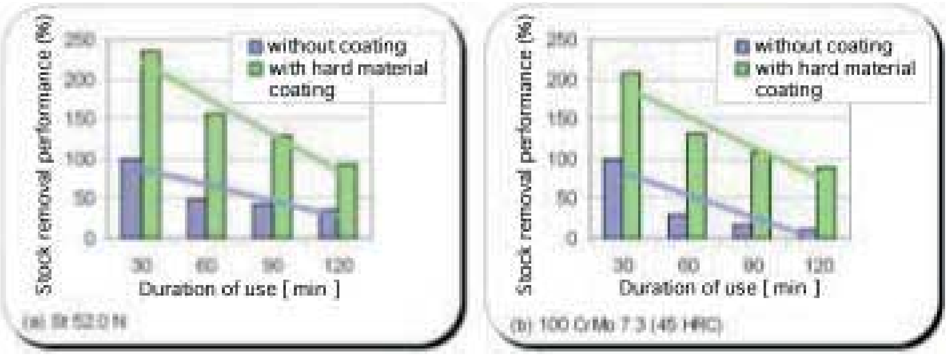

Fig. 2: Performance improvement achieved in machining low-alloy constructional steels (a) and quenched and tempered steels (b)

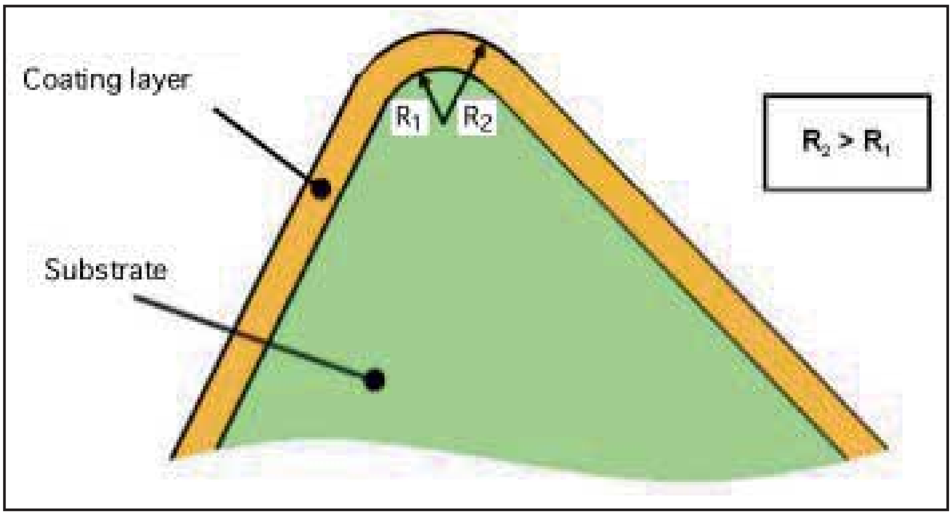

Fig. 3: Effects of the hard metal coating on the cutting edge radius

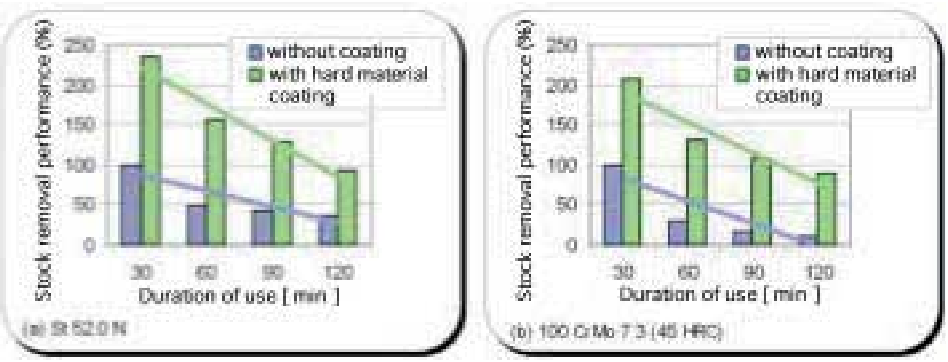

Fig. 4: Optimizing stock-removal rates on aluminium (example given for an AlMgSi… alloy)

resistant (at low thermal conductivity), resistant to corrosion, and very tough. Their chemical, mechanical and thermal properties make them difficult to machine. The small spherical rotary cutters (3 – 6 mm dia.) used in widening cracks will often reach the end of their service life after a milling path of as little as 30 – 50 mm. High thermal and mechanical loading of the cutting edges, swarf build-up, and the work-hardening tendency of some alloys will soon render the tool useless. Particularly in such applications, it is therefore necessary to adapt the tool material and geometry to the task at hand. Inmachining conventional materials the situation is much the same.

Hard material coating

Apart from ongoing efforts to refine tool geometries and materials, hard material coatings have been investigated since the mid-60s as a potential route to performance improvement. Eliminating tool edge to material contact, the coating reduces wear resulting from abrasion, adhesion, oxidation, and diffusion effects. Depending on the application, specific characteristics of the multi-layer system need to be addressed,
e.g.

- for hard or abrasive materials:
  - – coating hardness
  - – coating adhesion to the substrate (main tool body)

- for materials promoting wear by diffusion or oxidation:
  - – the thermodynamic stability of the coating

By adapting the coating system, the stock removal performance of rotary cutters can be increased significantly. Although in handheld applications these improvements are not as spectacular as in stationary machining, tool performance can be doubled in the majority of cases (Fig. 2). However, it is necessary to observe a number of boundary conditions. First, the coating-to-substrate adhesion and the toughness and edge strength of the substrate material are of decisive importance. Manual work is associated with higher levels of shock and chatter. This may cause the coating to flake off, specifically along the cutting edge, ultimately causing breakouts of the edge itself. For very rough operating conditions (large angle of wrap, castings with high sand inclusion levels) such coatings are therefore less suitable. Another factor requiring attention in rotary cutter design is the radius of the cutting edge. The chip thickness will usually be minimal, given the fine tooth pattern and high cutting speeds acting in combination with the low process forces generated in manual use.

Low cutting edge radius

Care must therefore be taken to minimize the cutting edge radius of rotary cutters. Even a slight increase in radius may cause the tool to appear dull or even useless in the operator's view. A coating-related dilemma is encountered here, since the benefits of the coating are obtained at the cost of covering the tool edge, i.e., the radius of the cutting edge is increased by the coating thickness (Fig. 3). This may offset, or even reverse, the advantages offered by the coating system. For tough materials tending to cause tool-loading problems, such as aluminium alloys (which contain no, or only slightly, abrasive intermediate phases), a sharp cutting edge is indispensable. Increasing the hardness of the cutting portion beyond that of hard metal does not make much sense if this yields a cutting edge having the stock removal properties of a worn tool. The thickness of the coating must therefore be minimized. Furthermore, it has been found useful in such applications to adopt a coating which, apart from being as thin as possible, minimizes tool-to-workpiece friction and adhesion. A coating of this type will improve the chip flow while counteracting tool loading problems due to chip adhesion. One implication of this design is that the tool's performance will not be radically enhanced at the outset; rather, its chip-removal properties will be uniformly preserved over an extended service life (Fig. 4).

Outlook

The use of rotary cutters in handheld machining has remained a state-of-the-art technology and indeed represents the only practicable or cost-effective approach in many cases. Such tools are used in both classic applications (e.g., fettling of castings) and high-tech domains (e.g, aerospace). However, ever increasing demands on performance call for a continuous revision of cutting materials, geometries, and process parameters. Another strategy for improving the performance of chip-cutting tools lies in the use of coatings adapted to the specific application and tool characteristics. In recent years we have seen the emergence of such improved coatings for rotary cutters, so that coating systems are now available for the further enhancement of tools for virtually all metals.