

HSS Tools in Gear Manufacturing for Commercial Vehicle Applications

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The manufacturing of gearboxes for commercial vehicle applications is characterized by efforts to improve product quality and customer satisfaction. At the same time, a permanent downward pressure on prices has been and still is clearly noticeable. While the increase of customer benefit is mainly achieved through technical innovation – i.e. attractive products - realization of a consistently high product quality is a task requiring a holistic approach. This encompasses a robust design of components in line with requirements and includes, among others, the application of state-of-the-art manufacturing processes and methods.

Manufacturing processes play a major role not only in the attainment of high product quality, but also in the reduction of manufacturing and consequently also product costs. By using modern production technologies, significant potential for the reduction of costs can be exploited. The tools used are of major importance in this respect, as it is their job to convert the speeds and spindle outputs provided by the machine into metal cutting performance.

Contrary to the widely held view which automatically equates the fastest process with the greatest economy, a more differentiated analysis of the circumstances involved clearly shows that in large-scale industrial production it is, above all, process reliability and the resulting tool costs (which include much more than the tool acquisition costs) which need to be watched closely.

At its Gaggenau facility, DaimlerChrysler AG manufactures manual and automatic transmissions for the DaimlerChrysler Group. The product range reaches from gearboxes for passenger cars and vans through transmissions for light and medium-duty commercial vehicles to gearboxes for heavy trucks and buses.

This report will show to what extent and in which areas these outline conditions relating to the productivity of manufacturing processes have led to the use of HSS tools within our company and which technological advances have been achieved using this type of tool – and are set to be achieved in the future.

The selection of a cutting material always represents a trade-off between attaining maximum hardness, which determines the wear resistance of a tool, and the achievement of adequate tool toughness, which predominantly influences process reliability. The selection is always made based on the background of the component to be machined, the machining technology and the machinery available.

In the production of components for medium and heavy-duty commercial vehicle gearboxes in the transmission plant of DaimlerChrysler AG in Gaggenau, the outline conditions indicated above, result in the almost exclusive use of tools manufactured from cemented carbide or HSS substrates. Besides their higher toughness compared to carbide tools, HSS tools offer the additional benefit of lower purchasing and reconditioning costs as well the capacity to achieve higher process reliability. Due to their higher red hardness, carbide tools offer the advantage of a potentially higher metal removal rate. As economic aspects are of primary interest in the selection of tools, carbide tools will generally only be used in

machining processes which allow the higher purchasing and reconditioning costs of this type of tool to be compensated in controlled processes by correspondingly higher productivity.

An analysis of the tool substrates used across the process chains of the major transmission components shows that HSS tools are mostly used in gear-cutting processes while carbide tools are preferred for all turning and milling operations. Carbide is hardly used as a cutting material, on the other hand, in gear-cutting processes. The reasons for this relatively clear-cut separation of the fields of application for the two cutting materials become clearer when the requirements imposed on gear-cutting tools are analyzed.

Gear-cutting tools are characterized by a highly complex tool geometry. This is defined, on the one hand, by the need for a high number of cutting edges and, on the other hand, by the very close tolerances down to a few micrometers for the position and shape of the cutting edges. The high quality of the tools is ensured by the generating or profiling kinematics of the machining processes involved in gear cutting which result in a direct influence of the tool geometry on workpiece quality. Gear-cutting processes are also characterized by their interrupted cut, resulting in short contact times between tool and chip and therefore a lower thermal load on the tools compared to continuous cutting processes. In addition, all gear-cutting tools have a comparatively large volume in common. By using tools manufactured from HSS substrates, significant weight reductions can be achieved, greatly facilitating the handling of the tools. In some cases, however, the dimensions of the tools also exceed the sizes which can be realized in carbide in one piece. In such cases, multipart or “assembled” tools would have to be used whereby only the cutting edge parts would be manufactured from carbide. Due to the high input required for the assembly of these tools, their inadequate precision, and the problems associated with their reconditioning, such tools have not become established in the marketplace. The cutting edges of the tools normally account for only a small share of the volume of the complete tool, and the material costs for carbide cutting materials are many times higher than the costs for HSS. Beside the significantly higher input required for the production and grinding of blanks, this is a further reason for the lower purchasing costs of HSS tools. When analyzing the costs, the expense of reconditioning the tools must, however, also be taken into consideration in addition to the purchasing costs. Due to their high manufacturing costs, gear-cutting tools are not scrapped after their use in the machining process, as is normally the case for, for example, turning inserts, but are reconditioned. This reconditioning includes regrinding and, if applicable, recoating of the tools. As some gear-cutting tools are reconditioned significantly more often than twenty times, the expense involved amounts to a multiple of the purchasing costs and is significantly higher for carbide tools than for HSS tools.

Due to the limited red hardness of HSS substrates, which may result in a thermal breakdown of the tools when cutting parameters are increased, HSS tools are often considered unproductive or obsolete. Contrary to this assumption, cycle times for the hobbing of a gearwheel in the Gaggenau plant show that productivity was almost doubled between 1999 and 2004 using HSS hobs. This was made possible by the development of HSS substrates manufactured using powder-metallurgical processes yielding a higher red hardness than substrates previously manufactured using melt-metallurgical substrates, and by advances in the field of coating technology. However, future-orientated solutions are not assessed on the basis of their current productivity, but on performance potential they promise for the future. Against this background, discussions with machine and tool manufacturers as well as with coating specialists conducted at our location indicated that over the next 5 years a reduction of

cycle times by a further 50% is anything but unrealistic, not least due to the introduction of dry machining.

This analysis shows that the selection of the correct tool substrate in line with requirements necessitates precise characterization of the specific tool loads during the machining process, and that the selection of the tool substrate should not be carried out until these loads have been balanced against tool properties. Practical experience indicates clearly that a tool substrate selection according to the principle “the harder and the greater the wear resistance the more efficient” does not yield the desired results in most cases. In contrast, in the field of gear rough machining, the use of commercially available HSS cutting materials with the highest hardness values – which are still significantly lower than comparatively soft carbide substances – is frequently rejected. Instead, more ductile HSS substrates are used for reasons of process reliability.

Where HSS tools are operated near the performance limits, for example in hobbing processes, their wear behaviour changes. While the tool life is determined by the abrasive wear of the cutting edges at moderate cutting speeds, the wear behaviour at high cutting rates is determined mainly by crater wear on the rake face of the tool. Studies have shown that before the onset of crater wear, thermal damage of the tool substrate occurs, finally resulting in a breaking up of the coating and direct cratering. With regard to the expansion of the application range of HSS hobs, scientific research has revealed – and practical industrial experiences bear this out - that innovative coatings lead not only to a reduction of the peak temperature due to a lowering of the friction between the tool and chip, but also to a thermal insulation of the tool as a result of the hard material layer. This new possibility of using the coating as thermal barrier leads to a significant shift of the window of realizable cutting values.

To estimate the future significance of HSS substrates, the most important gear-cutting processes will be discussed below from the point of view of their potential for further increasing cutting values and the possibility for the introduction of dry machining methods.

The properties of coatings of the latest generation described above will allow further cutting value increases to be achieved during hobbing. In the area of rough machining of gearwheels and transmission shafts for heavy-duty commercial vehicle gearboxes, the indications are that – as is already common practice for passenger car transmissions – in future HSS hobs will also be used for dry-cutting. Across the whole product portfolio of the Gaggenau transmission plant, the share of HSS hobs is at present significantly higher than 85%.

During gear shaping, the possibilities for increasing the cutting parameters are limited. The reason is not so much the performance of the HSS cutting wheels used, but the limits imposed by the machinery due to the specific process kinematics (crank mechanism). At present, in all areas both fully coated and reground HSS cutting wheels are used in combination with cooling lubricants. Most recently, however, there has been an increasing trend towards the use of fully coated tools. On gear-cutting machines of the latest generation, these can also be used for dry cutting. Innovative coatings and further improvements in the area of powder-metallurgical HSS substrates will ensure further increases in tool performance with regard to the number of parts per regrinding cycle. Due to the machine-related limitations regarding potential cutting values, carbide tools will not find acceptance in the foreseeable future in the field of gear shaping.

The selection of the cutting material for the broaching of components for commercial vehicle gearboxes is often already restricted to HSS substrates due to the dimensions of the components. Given the low thermal load of the tools resulting from the low cutting speeds (< 10 m/min), changing to tools using other cutting materials than HSS does not make much sense from a technological point of view either. At present, uncoated tools and tools coated and reground on the tool face are used for wet cutting. In future, in case of a reduction of the coating costs for broaches and associated tool life quantity advantages, the use of fully coated tools may become a sensible option. Further tool life advantages could be gained from the use of powder-metallurgical HSS substrates. Only insufficient experience is available from this field at present, however. Due to the very low cutting speeds which can be realized, it is unlikely that dry processing will be a viable alternative.

The only soft finishing process used extensively for gears, soft shaving, is a combination of a cutting and a forming process. This special process features makes the use of cooling lubricant mandatory. The high mechanical loads imposed on the tool and the low machining temperatures in conjunction with the low metal-removal volume make HSS cutting materials the ideal materials for shaving cutters. Due to the complex geometry of these tools, production from carbides would not be economically feasible. At present, the tools are almost exclusively used uncoated. Tests using coated tools have not resulted in tool life benefits. The same applies to the used of powder-metallurgical HSS substrates.

Against this background, the conclusion may be drawn that, almost exclusively, HSS tools are used today for the soft machining of gears. From today's point of view, there are neither technological nor economic reasons pointing towards a future change of cutting material.