Comparison of PM-HSS and Cemented Carbide Tools in High-Speed Gear Hobbing

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Management Summary

This article examines the dry hobbing capabilities of two cutting tool materials—powder metallurgical high-speed steel (PM-HSS) and cemented carbide. Cutting trials were carried out to analyze applicable cutting parameters and possible tool lives as well as the process reliability. To consider the influences of the machinability of different workpiece materials, a case hardening steel and a tempered steel were examined. The results of the cutting trials show that carbide tools are superior to PM-HSS tools. When machining case hardening steel, the advantage is the high productivity. When machining tempered steel, a longer tool life can be reached. This shows that carbide offers higher potentials for gear hobbing.

Introduction

For green machining of external gears, dry hobbing with PM-HSS and cemented carbide are established processes in the industry. Although some have investigated the use of cermets for gear hobbing, these materials are not an alternative to PM-HSS or cemented carbide. Cermets do not provide any advantage compared to carbides regarding productivity, tool life or process reliability. Because of the high expected tool cost, they can not be used economically for gear hobbing.

Focusing again on the common cutting materials PM-HSS and cemented carbide, the question came up: Which are the most effective cutting conditions for which cutting material? Today's hobs combined with modern, hard material coatings are able to reach high productivity and tool life. Typically, carbide tools can be used at high cutting speeds, while the advantages of PM-HSS are relatively low tool costs and high chip thicknesses.

The goal of this study is to evaluate the potentials of the cutting materials PM-HSS and cemented carbide for gear hobbing. For this, applicable cutting parameters, resulting tool lives and estimated manufacturing costs will be considered.

For the trials, the case hardening steel 16MnCr5 and the tempered steel 42CrMo4V are compared. The case hardening steel has a strength of R_m = 570 N/mm², and the tempered steel has a strength of R_m = 1,090 N/mm². The real trials were made in an analogy process for gear hobbing. In these trials, a single fly-cutter was used, and through the kinematics of the machine tool, the full hob was simulated. The tool simulated a hob with a module of 2.5 mm, 15 gashes and 2 starts. The examined gear is typical of the automotive sector. All tools were coated with an aluminum chrome nitride coating (Al,Cr)N.

Wear Development and Performance of the Applied Cutting Materials

Generally, for the case hardening steel, higher cutting parameters can be chosen due to the lower strength of the workpiece material. With carbide tools, higher cutting speeds

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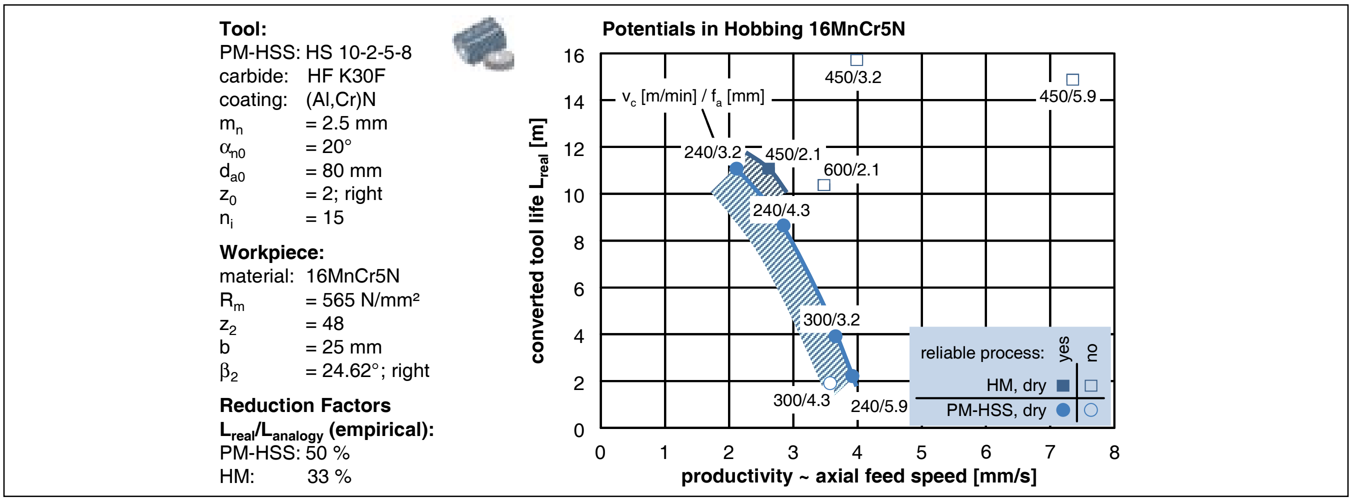

Figure 1—Potentials in machining case hardening steel 16MnCr5N.

can be reached because of their high warm strength. In contrast PM-HSS has a higher toughness, and so higher axial feed usually can be chosen.

For the rating of a cutting tool, two different properties are required. One is the tool life, and the other is the reliability. The process must be reliable against sudden chipping at the cutting edge. Carbide tools are especially at risk of getting damaged—not only during the cutting operation, but also by mishandling—due to their high brittleness.

The investigations in wear development showed that for machining the case hardening steel with the carbide tools, a cutting speed of v_c = 450 m/min and an axial feed of 2.1 mm can be reached reliably, as seen in Figure 1.

The converted tool life shown on the vertical axis is reduced by an empiric factor for the conversion of results from the analogy trials to real hobbing operations. This factor was already determined in former trials. The main wear characteristic is flank wear. With higher cutting parameters, even higher tool life can be realized, but the process is not reliable.

For a reliable machining operation with PM-HSS as cutting material, lower cutting speeds have to be chosen, but higher axial feeds are possible. A view on the wear behavior of PM-HSS shows that the defined wear criterion of VB_{max} = 0.15 mm is reached by the flank and the root almost at the same time. In general, PM-HSS allows for a wider range of parameters to be used, whereas for carbide, only a very small range of cutting parameters leads to reliable processes. However, when considering the productivity in combination with the tool life, PM-HSS offers only a small range as well. Overall, the carbide has a slight advantage against the PM-HSS because of carbide's high productivity and tool life.

For machining tempered steel, similar effects can be seen. But the reachable cutting parameters for both the carbide and PM-HSS tools are lower due to the higher strength of the 42CrMo4V (Figure 2). With the PM-HSS tools, gears can only be machined reliably with cutting speeds of v_c < 120 m/min. With carbide tools, higher axial feeds result in huge cracks that make the process unreliable. The reliable and therefore usable area of cutting parameters is marked shaded. Concerning the productivity, tempered steel should be machined with carbide because of the much higher reachable tool life and an equal productivity, as measured by the axial feed speed.

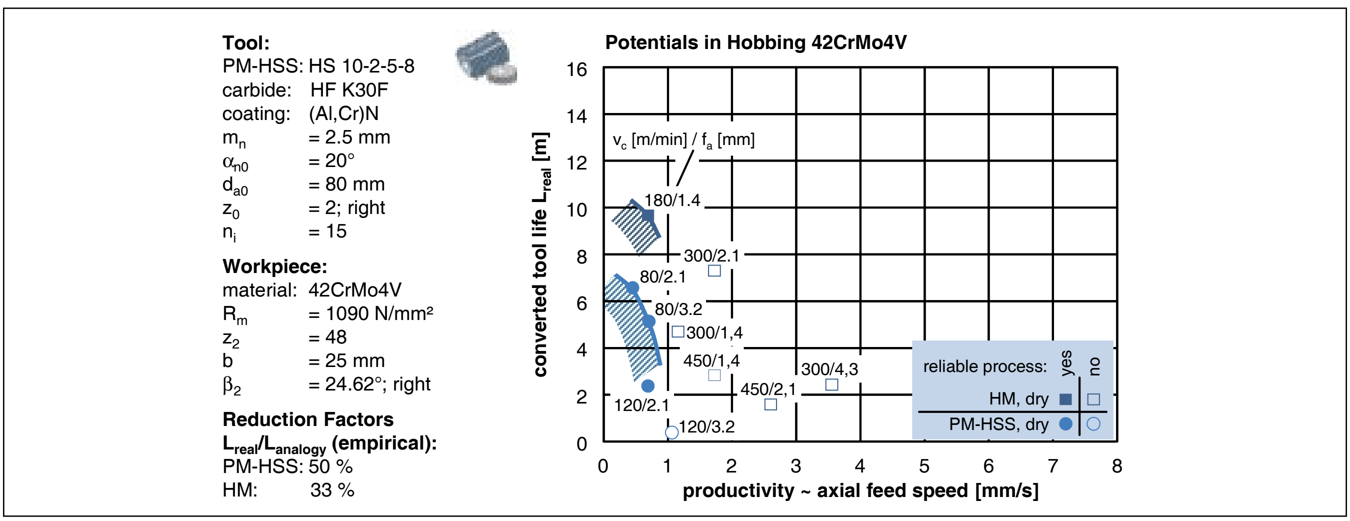

Figure 2—Potentials in machining tempered steel 42CrMo4V.

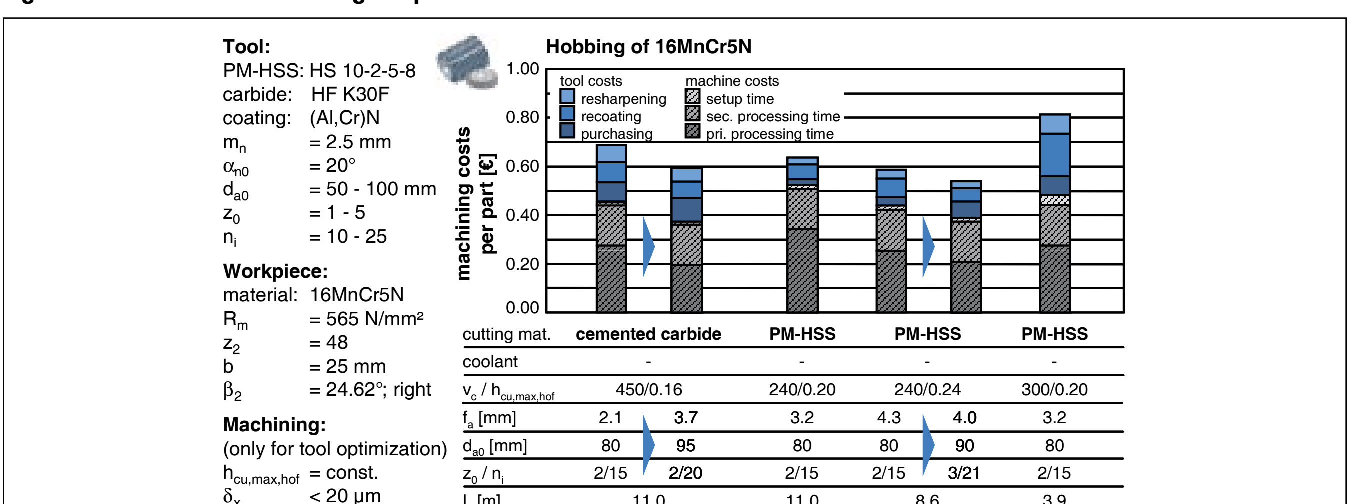

Figure 3—Profitability analysis of machining case hardening steel 16MnCr5N.

Economic Analysis

For deciding which cutting material is preferable, not only the productivity and the tool life are important, but also the tool costs. Generally the tool costs for a PM-HSS hob are lower. The tool costs consist of three parts: the purchase cost, the recoating cost and the resharpening cost. The recoating and resharpening costs are especially important in the economic analysis of hobbing tools.

The costs for recoating are similar for both cutting materials. But the purchase costs and the resharpening costs, due to the strength, are higher for carbide tools. For a closing analysis regarding which is the best tool, the total costs of ownership are interesting.

For the material 16MnCr5, an analysis on the profitability is shown in Figure 3. Starting with the investigated parameters in the analogy process trials, the process is successively optimized with gear hobbing calculation software. The first, third, fourth and sixth column each show the machining cost per part for cutting parameters used in the trials. The cost per part for PM-HSS at medium cutting speed (third and fourth columns) is already without any optimization lower than for machining with carbide.

Only the PM-HSS trial with very high cutting speeds (sixth column) is not competitive. With the results of the trials, an optimization is made with the target of an axial feed rate with feed marks of $d_X < 20$ µm and a constant maximum chip thickness for each cutting parameter. The tool outside diameter and number of starts and gashes is varied. With these default values, the software calculates every tool design which achieves these requirements. The result is again lower costs per part and still the lowest overall cost for a PM-HSS variant.

For tempered steel (not displayed here), the situation is just the other way around. For tempered steel, machining with carbide leads to lower costs per part.

Conclusion

Based on the current state of the art regarding tool development, the capabilities of PM-HSS and cemented carbide have been examined as materials for gear hobbing. Cutting trials were carried out in fly-cutter gear hobbing to analyze applicable cutting parameters and possible tool lives as well as the process reliability. To consider the influences of the machining properties of cutting different workpiece materials, a case hardening steel with a tensile strength of $R_m = 570$ N/mm² and a tempered steel with $R_m = 1{,}090$ N/mm² have been examined.

Machining case hardening steel has shown that a cutting speed of $v_c = 450$ m/min can be reached employing carbide tools at relatively low axial feeds. A high tool life can be reached reliably using these parameters. Enhanced machining parameters may lead to an increased tool life, but the fly-cutters fail because of breakouts of the cutting edge.

By the application of PM-HSS at a cutting speed of $v_C = 240$ m/min and medium axial feeds, an appropriate tool life can be reached. By raising the cutting speed or the axial feed beyond these values, heavy crater wear causes reductions in tool life.

To reach acceptable tool lives reliably in machining tempered steel, the cutting parameters must be reduced significantly for both cutting materials because of the high mechanical and thermal load.

With the carbide cutting material, tool lives that are similar to those achieved when machining case hardening steel can be achieved.

The results of the cutting trials show that carbide tools are superior to PM-HSS tools. When machining case hardening steel, the advantage is the high productivity. When hobbing tempered steel, a longer tool life can be reached. This shows that carbide basically offers higher potentials for gear hobbing.

However, the economic analysis shows that both cutting materials can be employed at similar machining costs. A trend can be identified that the application of high speed steel is slightly cheaper for machining case hardening steel while carbide tools offer advantages in cutting tempered steel.

The study shows that PM-HSS and carbide tools are capable of hobbing in a similar way. Carbide tools offer high productivity and good tool life while PM-HSS shows very low tool costs. Basically, PM-HSS hobs can be used beneficially to cut materials with lower hardness and tensile strengths, while tougher materials should be machined with carbide tools. However, the machinability of actual gears in an industrial environment is also affected by the specific tooth profile and the workpiece material.

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