CVD diamond tools machining aluminium in the new 5-Series BMWs

While thin-film CVD diamond tools are already being used widely for example in the machining of graphite, their use in the machining of aluminium is rather the exception. With the new 5-series BMWs, due to BMW's extensive know-how in aluminium, working together with toolmakers and coaters one of the first series uses for these tools in the machining of aluminium has been put into practice in the manufacture of rear-axle supports. This report by **J. Halwax** and **R. Pfaffenberger**.

Fig 2 Rear axle for the 5-Series BMW made of solid aluminium

The new 5-Series BMW was introduced to the German market on 5 July, 2003. For this Series in 1995, BMW had produced the first welded aluminium chassis manufactured in series in the automotive industry and with it set new standards in terms of weight saving, improved driving dynamics, traction characteristics and fuel consumption. With the new 5-Series BMW (Fig 1), along with an aluminium/steel body a solid aluminium chassis is again being used (Fig 2). In order to achieve as much efficiency and quality as possible in production, the manufacture of the cars involves further developments in existing technologies and also new technologies.

Thin-film CVD diamond tools far superior to pure carbide tools

The aluminium chassis components are produced at the BMW Group's largest plant, in Dingolfing, on a surface area of some 80,000 m^2. In the engine and chassis division the main components produced are front and rear axles and also front-axle and rear-axle transmissions for all the BMW series as well as wheel sets for motorcycles. The BMW specialists at the Dingolfing plant have the corresponding know-how in everything to do with aluminium, whether it be pressing (since autumn 1999 one of the world's largest suction transfer presses), forming (since spring 2000 the shaping even of complex components with internal high-pressure forming) or in the area of machining. Here, no coolant is used in the manufacture of the new rear axles, on the one hand due to environmental considerations and on the other due to cost considerations (disposal, cleaning of components, etc).

The dry machining of the rear-axle support that consists of a total of four aluminium cast alloys threw up the question of a tool material that would be suitable for the machining operation. As the aluminium alloys used can be machined relatively easily, the challenge lay in the removal of the long chips to prevent them sticking to the tool's cutting edge. Since machining without using a coolant can largely only be achieved by using an optimised tool geometry with steps ground into the tool face, polycrystalline diamond (PCD) cannot be used as the tool material because, unlike with carbide tools, the geometry of the chips cannot be produced, or only by involving a very great deal of time and therefore cost-intensively. On the other hand, the tool life achieved with uncoated carbide with an optimised tool geometry was not satisfactory, so for various machining operations tests were carried out with diamond-coated carbide inserts.

Even the very first tests showed a considerable improvement, with tool life increasing by up to a factor of 10. After optimising the tools in a number of ways in terms of the thickness of the diamond layer, the carbide substrate, the roughness of the layer, etc, the results achieved were so good that now the series machining of the left and right cast joints of the rear-axle supports for the new 5-Series BMW is carried out with diamond-coated tools.

Fig 1 The new 5-Series BMW with an aluminium/steel body and solid aluminium chassis

Reliable machining with a tool life of 1,500 joints

As referred to above, the cast joints to be machined are made of the aluminium alloy $AlSi_7Mg$ which is relatively easy to machine. As well as the boring of the supporting bearing bush, the machining operation includes producing the weld connection for the tubular cross member and also the milling of various chamfers and plane faces. The following machining parameters are used for boring the bearing bush, the chamfering operations and the face milling:

- Rotational speed U = 5,500 min^{-1}
- Feed f = 1,650 mm/min
- Depth of cut a_p = 6 mm

The main machining criterion here is adherence to dimensional tolerance, while with surface quality a R_z value of > 40 μm is required in order to ensure that the rubber bearing is securely fixed.

The boring bar that is used here (Fig 4), supplied by Komet Präzisionswerkzeuge Robert Breuning GmbH, Besigheim, is fitted with eight indexable carbide inserts (K10 carbide, less than 6% cobalt) of specification CPGT090304, coated with a 4 μm thick CVD diamond layer. This is a nanocrystalline diamond layer with a grain size of between 20 and 200 nm. Due to the small grain size an extremely smooth tool face is obtained, which contributes to the ready removal of chips from the machining zone. Also, a ground-in step with a positive rake angle of 20° and a clearance angle of 11° ensures the removal of chips. These measures minimise the forming of a built-up edge.

The weld connection for the tubular cross member is machined with the bell-shaped tool also shown in Fig 4. In this operation the component is machined at a speed of 7,500 min^{-1} with a feed of 4,125 mm/min and a depth of cut of 10 mm. Here too the main machining criterion is adherence to dimensional tolerance. The bell-shaped tool, also from Komet, has two R9 radius inserts with a positive rake angle. As with the boring bars, the tool inserts are coated with a 4 μm thick nanocrystalline CVD diamond layer in order to minimise the forming of a built-up edge.

Fig 3 Faces to be machined on the right and left aluminium cast joints

Fig 4 Boring bar and bell-shaped tool with CVD diamond-coated carbide indexable inserts

The machining of the right and left cast joints described above takes place simultaneously on a Becker 400-2H hybrid machining centre. With cycle times of 15 seconds, tool lives of 1,500 sets of cast joints (right and left) are achieved in a reliable process. This corresponds to about a day's production, so the tools are changed every day. The end of the tool's life is when the cutting edge breaks, caused by deposits forming on the tool edge. Although these results are satisfactory compared with uncoated carbide tools, work is being carried out together with toolmakers and coaters to achieve optimised solutions. The aim is to achieve tool lives of up to 10,000 sets of cast joints. Tests are also being carried out with diamond-coated tools for various boring and milling operations on other components of the rear-axle support so that in the medium term here too a dry machining process can be developed. ◆

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