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ISSN 0543-5846
METABK 51(2) 253-256 (2012)
UDC – UDK 621.773:621.833:669.781/661.55=111

FINISH MACHINING OF HARDENED GEARS WHEELS USING CUBIC BORON NITRIDE (CBN) INSERTS

Received – Prispjelo: 2011-05-19
Accepted – Prihvaćeno: 2011-09-29
Preliminary Note – Prethodno priopćenje

The paper presents some results of investigation of finish machining of hardened bearing surfaces of cylindrical gear wheels. Finish machining has been performed with wedges of defined geometry made of CBN. The presented investigation results are related mainly to the wear processes of the cutting wedges. Additional results of quality examination of finish machined gear wheels have been presented, too.

Key words: finish machining, hardened gears, CBN

Završna obrada zakaljenih zupčanika pomoću kubično borovih nitridnih (KBN) oštrica. Rad prikazuje rezultate istraživanja završne obrade zakaljenih površina cilindričnih zupčanika. Završna obrada se ostvaruje oštricama definirane geometrije izrađene iz KBN. Prikazani rezultati istraživanja odnose se uglavnom na process trošenja reznih oštrica. Dodatno su prikazani rezultati ispitivanja kvalitete obrađene površine zupčanika.

Ključne riječi: završna obrada, zakaljeni zupčanici, KBN

INTRODUCTION

Majority of gear wheels with hardened bearing surfaces are finish machined by grinding with tools of undefined cutting geometry. The heat released during grinding can have disadvantageous influence on the surface layer of the machined teeth. Investigations of finish machining of hardened gear wheels with tool edges made of sintered carbides have been performed since many years [1-3]. In recent years, the availability of very hard tool materials, including CBN (Cubic Boron Nitride), has increased significantly. Therefore, investigation of finish machining of cylindrical gear wheels has been performed [4]. The machining process has been examined with the use of a head with CBN inserts additionally coated with a layer of TiN. The tool head has been specially designed and made for generating of gear wheels.

The construction of the tool head allows ground inserts, VBGW1609408 to be fixed on it. The geometry of the head, combined with the kinematics specially elaborated for the investigation, makes it possible generation of gear wheels with geometrical parameters within broad limits [5]. Limitations of the machining arise mostly from the necessity to avoid collision of the tool with unmachined surfaces of the wheel being processed. For example, when machining gears with modules less than 2 mm, the VBGW160408 insert cannot be positioned in the space betwen teeth.

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INVESTIGATION CONDITIONS

The inserts have been examined during machining without cutting fluid. Gear wheels with 16 teeth and module of 4,5 mm were made of 16MnCr5 steel, carbonized and hardened. The carbonized layer, with thickness 1,1 mm, has reached the hardness of 60 to 61 HRC after hardening. The machining has been performed on the DMU60 MonoBlock machining centre (Figure 1).

The finish machining has formed the bearing surfaces of the teeth in thirty enveloping passes. The following variable parameters have been adopted during machining with the multiedge head. The thickness of the allowance q removed in one operation. The range of variation of parameter q has been adopted within the

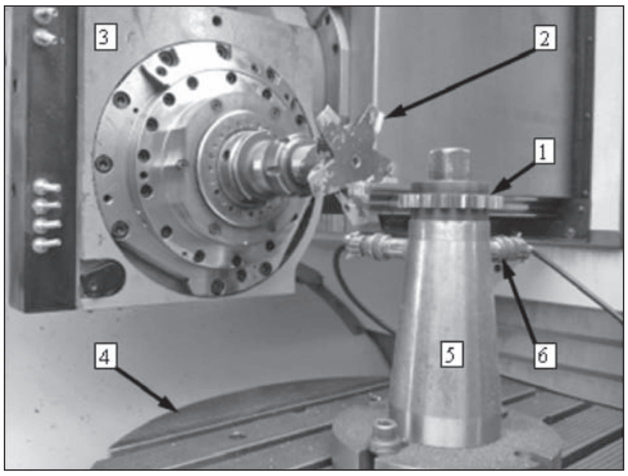

Figure 1 Investigation scheme: 1 - gear wheel, 2 - the head, 3 - the machine tool spindle, 4 - rotatable table, 5 - fixture of the gear wheel

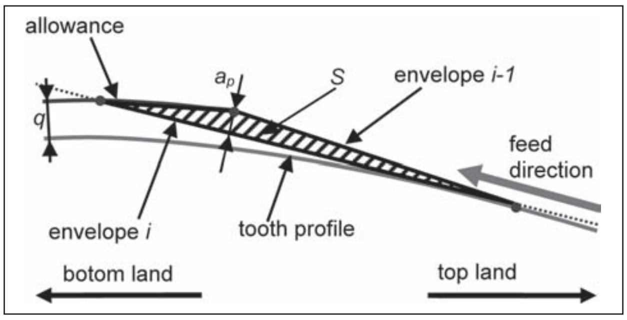

Figure 2 Geometry of the removed layer

limits from 0,04 mm to 0,3 mm. The thickness of the layer removed in the subsequent enveloping passes a_p, is much less than the q allowance (Figure 2). Feed per tooth f_z within the range of 0,09 mm to 0,4 mm. The value of cutting speed has been assumed constant at 300 m / min.

The life period of the edges has been examined as a function of the variable parameters. The value of the parameter of abrasion wear (spalling of the TiN coating) on the flank face VB_b, qualifying a inserts to be discarded, has been determined at the level of 0,25 mm. Another criterion limiting the life period of a wedge is chipping.

Machining with the multiedge head has been carried on without cooling fluid. In the course of the investigation, it turned out to be difficult to present a reliable value of the inserts life period. Life period in a time unit would not be reliable due to the differences in the geometry of the layers removed in the phase of cutting in with radial feed and in the phase of machining along the tooth line. It has been decided to convert the edge working time to the length of the path the inserts covers while cutting the material. For one enveloping pass, that length depends mainly on the width of the gear wheel rim and the thickness of the removed allowance q. Machining of the side surfaces of a gear wheel teeth with allowance q = 0,1 mm requires path L equal to 12,737 m.

Maximum thicknesses of the removed layer occur in machining of the tooth vertices. In the course of material removing, the thickness of the removed layer grows in a linear way from the value of zero to the maximum one (Figure 2). During the removal of the allowance of q = 0,1 mm, the maximum thickness a_p of the removed layer reaches values close to 0,04 mm.

WEAR OF THE INSERTS

The results of tool wear investigation in the conditions corresponding to those of finish machining have been shown in Figure 3.

Each point of the curve represents the arithmetic average of fifteen measurements except machining with the allowance of 0,3 mm, where the values have been calculated from four measurements due to premature chipping of cutting edges (Figure 4.).

During machining with the multiedge head with five inserts, the most loaded insert has reached the wear criterion after 24 wheels had been made. An increase of the number of edges results in a linear increase of machining productivity. When the number of inserts was increased from one to five, the productivity increased by 3,76 times.In Figure 5, one can see a worn insert where VB_b has reached the value of 0,19 mm. The clearest traces of wear, particularly on the rake face are visible at the place of the corner radius transition into the rectilinear edge. This is the area which removes the largest material volumes.

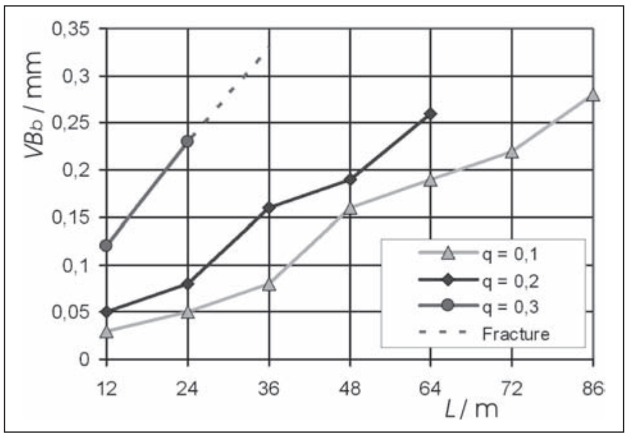

Figure 3 Tool wear for feed f_z = 0,09 mm

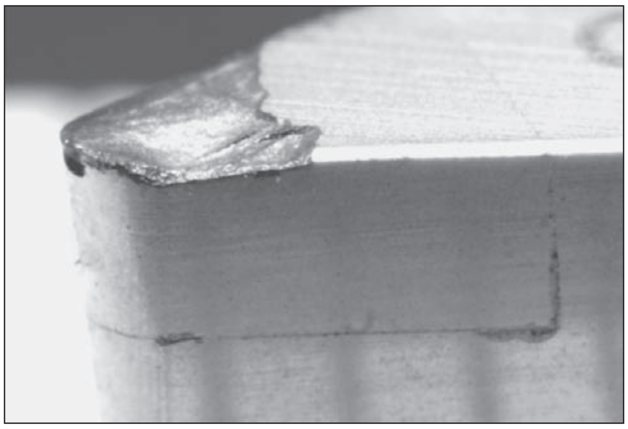

Figure 4 Cutting wedge fracture for q = 0,3 mm, f_z = 0,09 mm

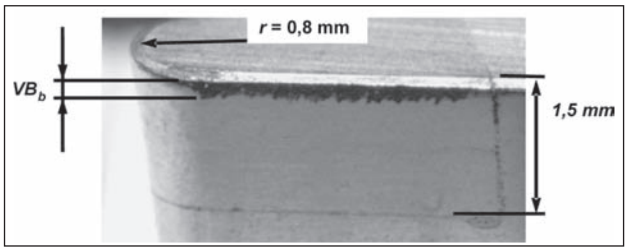

Figure 5 A CBN insert wear image where: L = 64 m, f_z = 0,09 mm

In Figure 5, one also see increased wear of the CBN insert with the body of the multiedge insert made of sintered carbides. As a result of the increase of the removed allowance thickness up to 0,2 mm, the tool life decreased by about 25 %. The value of 25 % has been obtain by interpolation of the results shown in Figure 3. The increase of the removed allowance up to 0,2 mm is

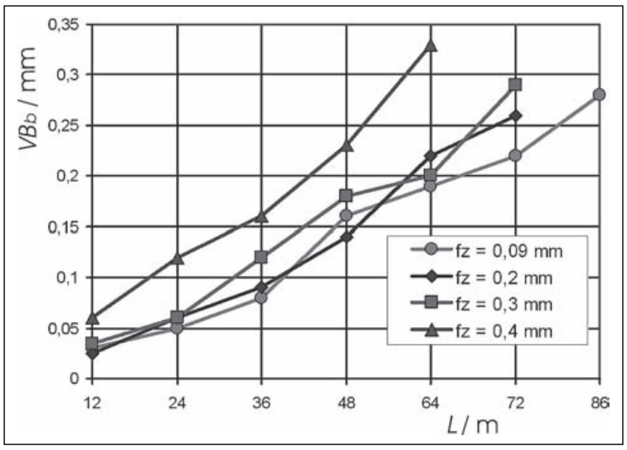

Figure 6 Tool wear as a function of the feed value f_z/mm; q = 0,1 mm

justified because productivity increase by 100 % results in an increase of the cost of the multiwedge plates by 25 %. However the allowance thickness of 0,2 mm on each tooth side can be found in gear wheels with module pitch of over 12 mm.

The durability tests of the tool as a function of the feed per toth f_z have been carried out, similarly like in the case of thickness of removed allowance (Figure 6). Increasing the feed rate has not led to a sharp intensification of wearing processes destructing of cutting inserts.

The tool life time differences obtained in machining with the feed values of 0,1 mm to 0,3 mm have reached the level of over a dozen per cent. Increase of the feed value results in only minor increase of the layer removed in one revolution of the tool. When the feed value is increased, the edge is in the material being cut for a longer time during one revolution of the tool. On the other hand, however, less revolutions are necessary to machine the required length. Significantly larger mechanical load of the tool took place when machining with the feed of 0,4 mm. The condition predetermining the feed value is not the tool wear resistance but the structure of the machined surface.

The stability of the process of machining was monitored by measuring the values of the vibrating fixture accelerations, sampling the signals at the frequency of 10 kHz per each of the two channels (Figure 1). For that purpose a trial of machining a gear wheel with a head provided with one cutting wedge has been performed. The assumed feed value per tooth was f_z = 0,1 mm. During cutting of the 0,1 mm thick allowance, the fixture acceleration amplitude in the plane perpendicular to the machined wheel axis did not exceed 14,7 mm/s^2.When the thickness of the allowance to be removed was increased up to q = 0,3 mm, the maximum amplitude of the fixture acceleration has risen up to 49,8 mm/s^2. Three times thicker allowance has resulted in approximately three times as high acceleration values. This can prove linear relationship between the thickness of the removed allowance and the forces imposed on the cutting wedges. Another purpose of the acceleration measurements was to make sure that the fixture was sufficiently stiff. Considering the fixture accelerations occurring while removing 0,3 mm thick allowance, the deviation from the gear wheel balance condition did not exceed 0,2 µm. The conversion of the acceleration to the amplitude of deviation from the balance position has been performed in accordance with the methodology described in [5].

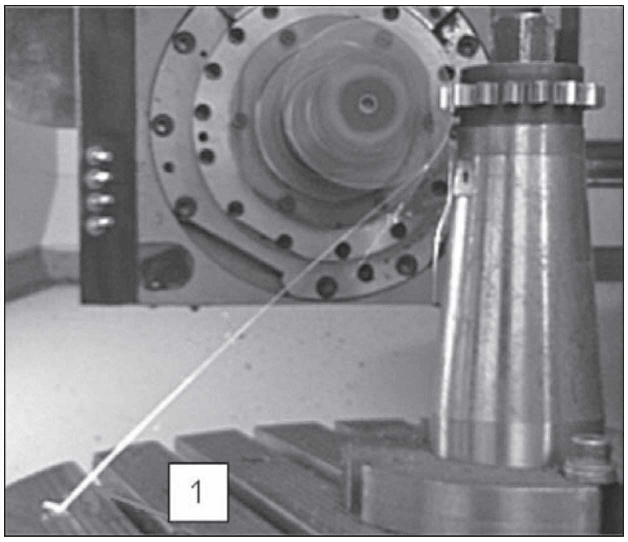

Figure 7 Backward machining of the left tooth sides

In the case of removing a 0,1 mm thick allowance, the value of deviation from the point of balance of the gear wheel fixed in the fixture did not exceed 0,05 µm. Consequently, it has been determined that the fixture is sufficiently stiff for machining 0,1 mm thick allowance. When an allowance of over 0,1 mm thickness is to be removed, the gear wheel vibrations can be reflected on the machined surface increasing the values of the parameters of surface roughness.When machining the left sides of teeth, the tool wedges cut the material backwardly (Figure 7). The opposite right sides are machined forwardly (Figure 8). The difference of life time of tool machining only the right tooth sides has been compared to that of the ones machining only the left tooth sides.

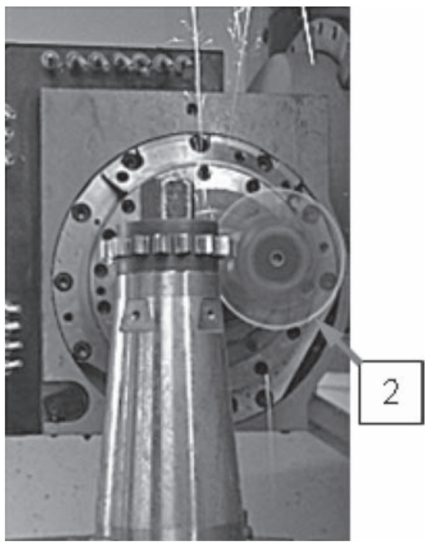

Figure 8 Forward machining of the right tooth sides

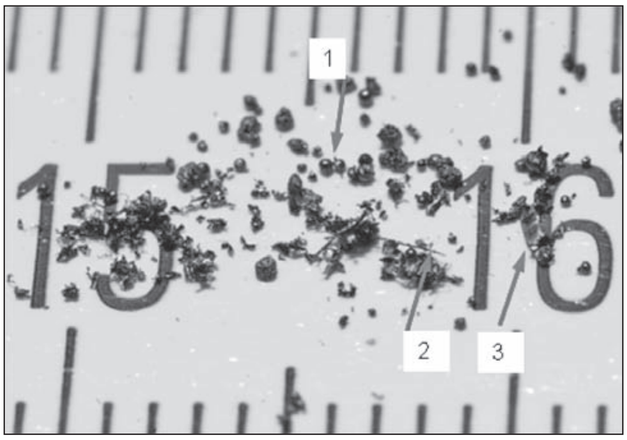

Figure 9 Geometrical forms of the chips

Due to the small cross sections of the removed layers, no statistically significant differences of the tool life have been stated.

During machining, particularly with tool of VB_b value over 0,1 mm, the temperature of the chips was high enough to cause their melting. Melted chips often stuck to the cutting edge (Figure 8, item 2), others were ejected, at an incidental angle, to the working space of the machine tool (Figure 7, item 1), which can jeopardize easily melting elements of the machine equipment.

Depending on the thickness of the allowance to be removed, the chips had various forms. When an allowance of over 0,08 mm was machined, the chips got melted and took an oval shape which can be seen in Figure 9, item 1. Machining an allowance of 0,03 mm to 0,08 mm resulted in formation of chips with the shapes of wound ribbons (Figure 9, item 3).

When an allowance of a thickness below 0,03 was machined, the chips had the form of needles (Figure 9, item 2). Despite high temperatures in the zone of machining, the gear wheel and the tool body got heated to a moderate extent only. The temperature of the fixture, the gear wheel being machined and the tool has been measured prior to the start of machining and immediately after its completion. The measurement has been performed by means of the FLUKE 572 pyrometer. The maximum recorded increase of the gear wheel temperature between the start and the end of machining has not exceeded 18 °C. The variations of the tool body temperature (after stabilization) could not be able to measurement with the pyrometer. They were so small. The wheel temperature increase, even in the small range as recorded, can increase the deviation of the toothing run-out F_r. The temperature change of gear between the beginning and end of the final finishing operation at 10 °C will increase the outer diameter of 0,01 mm, which may increase the value of the toothing run-out F_r, by additional 4 µm.

In order to compare the deformations resulting from the temperature variations, finish machining of gear wheels with a CBN coated grinding wheel has been performed under the conditions of oil emulsion cooling. Intensive flushing of the working space with the coolant of stable temperature keeps the elements of system: the machine tool – the fixture – the workpiece – the tool in a quasi stable thermal state. As compared to machining with defined wedges, no vibrations due to the intermittent operation of the wedges have occurred during machining with the grinding wheel; the values of the cutting forces are also much lower.

CONCLUSIONS

The experimental investigation performed has proved the possibility of machining hardened gear wheels with inserts of defined geometry made of CBN. Machining with CBN inserts is more stable than with sintered carbide inserts due to moderate wear intensity. The roughness parameters and lack of defects in the machined surface can prove high load capacity of the bearing surfaces of the machined gear wheels.

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Note: Responsible translator: Natalia Trawinska, The Poznan College of Modern Languages, Poznan, Poland