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CAD based Predictive Models of the Undeformed Chip Geometry in Drilling

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Abstract**—**Twist drills are geometrical complex tools and thus various researchers have adopted different mathematical and experimental approaches for their simulation. The present paper acknowledges the increasing use of modern CAD systems and using the API (Application Programming Interface) of a CAD system, drilling simulations are carried out. The developed DRILL3D software routine, creates parametrically controlled tool geometries and using different cutting conditions, achieves the generation of solid models for all the relevant data involved (drilling tool, cut workpiece, undeformed chip). The final data derived, consist a platform for further direct simulations regarding the determination of cutting forces, tool wear, drilling optimizations etc.

Keywords**—**Drilling, CAD based simulation, 3D-modelling.

I. INTRODUCTION

DRILLING operation is the most popular machining process used today. The most commonly used tool in the conventional drilling of materials is the twist drill, which is made up of a cylindrical shank, into which two opposite helical groves have been cut, forming two distinct cutting regions; a. the main cutting edges (lips), b. the chisel edge, which is near the drill axis and connects the two cutting lips. Both of these regions contribute to material removal, although the chisel edge's contribution is both inefficient and mainly responsible for geometric errors in drilling, coupled to high thrust loads [1].

The main cutting edges are responsible for a relatively conventional chip formation. An oblique cutting action occurs to the direction of motion. Such an oblique cutting action serves to increase the twist drill's effective rake angle geometry. Under the chisel edge area, the material removal mechanism is extremely complex. Near the bottom of the flutes, where the radii intersect with the chisel edge, the drill's clearance surface from the cutting rake surfaces, forms a cutting rake surface that is highly negative in nature. An indication of the inefficient material removal process is evident by the severe workpiece deformation occurring under the chisel point, where such deformed products must be ejected by the drill to produce the hole. These products are extruded, then wiped into the drill flute, where they blend with the main cutting edge chips. This fact has been substantiated by force and energy analysis, based on a combination of cutting and extruding behavior under the chisel point, where agreement has been confirmed with experimental torque and thrust measurements [2].

In the past, different researchers in order to simulate the drilling operation, used either a mathematical approach in which the tool was described analytically by extremely complicated equations or an experimental one, where a large amount of experiments were carried out in order to gather all the different pieces of information required [3], [4]. Both methods required a considerable amount of time in order to develop accurate drilling models and in a number of cases, a combination of both approaches was necessary. Most of them encompass a variety of restrictions and limitations mainly because they were based on 2D strategies and the geometry of the tools was defined using the principles of projective geometry [5], [6], [7], [8], [9], [10], [11], [12], [13].

The present paper is based on the concept that the increasing use of modern CAD systems, provide an excellent platform for the development of CAD based tools for machining simulations and optimizations. In order to proceed to simulation, the Application Programming Interface (API) of a general purpose CAD system was used. That strategy reveals the powerful modeling capabilities and the versatility of up to date CAD software environments.

The programming language used in the API was VBA (Visual Basic for Applications) and it was used for the development of the DRILL3D software routine. This routine can simulate the drilling operation using 3D solids for both the drilling tool and the work piece. Those models were used in order to simulate the penetration of the tool inside the work piece and subsequently led to the generation of 3D solid models for the undeformed chip and the cut work piece. The construction of a CAD based geometry for the undeformed chip can be used further to a number of calculations i.e. cutting force components, tool wear, drilling optimizations etc. Using a friendly interface, a user can easily introduce a number of different tool geometries and cutting conditions parameters. As a result, a number of different virtual drilling experiments can become readily available.

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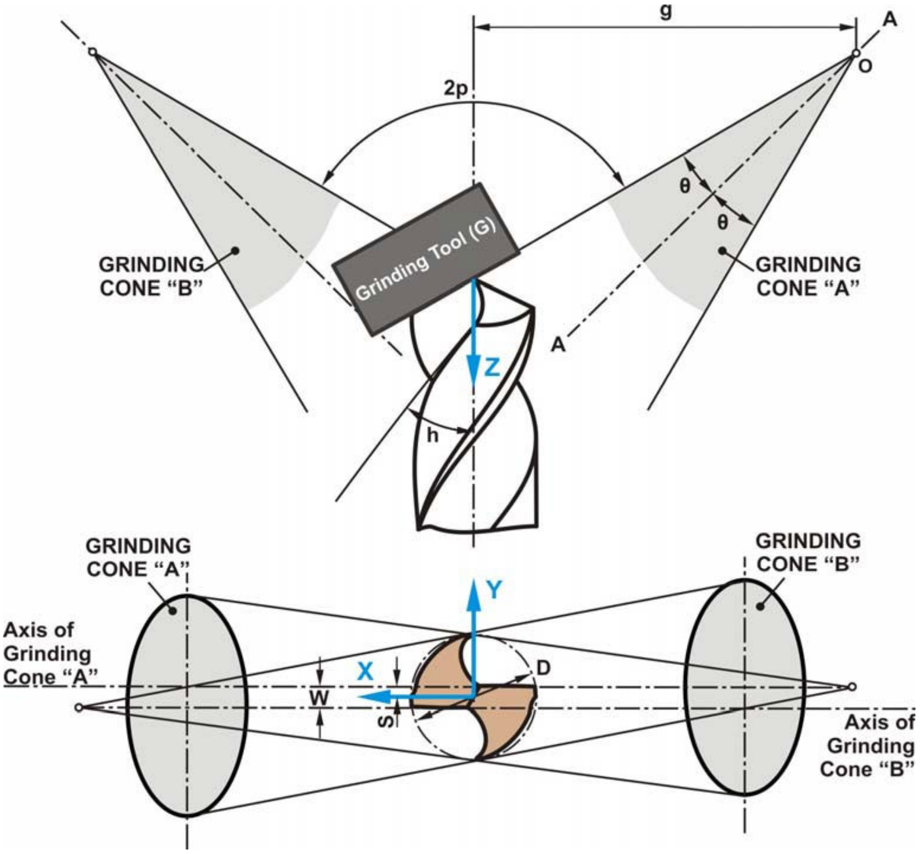

Fig. 1 Conventional twist drill tool geometry [14]

II. Solid Model Of A Twist Drill Tool

A common method of grinding the flank surfaces of the point of a twist drill is shown in Figure 1. The drill is rotated about the axis AA, which is fixed in space and the flank is ground by the plane face of the grinding wheel G. The axis AA and the plane of the grinding wheel face intersect in the point O. The motion of the wheel face in relation to the drill point may be deduced by considering the drill point as fixed and the wheel face rotating about the axis AA, the virtual motion of the wheel face being equal and opposite to the actual motion of the drill. A plane rotating about the fixed axis envelops a cone, so that the grinding wheel face envelops part of a conical surface in its motion relative to the drill point and the flank surface produced on the drill point is part of the surface of the cone. The vertex of the cone is the point O and the cone semi angle is the angle θ between the axis AA and the wheel face. The cone may be termed the grinding cone and this method of drill point grinding is referred to as conical grinding. A right hand coordinate system was used based on the following principles: a) the z-axis lies along the drilling tool axis (towards the drill shank), (b) the y-axis lies along the common perpendicular which intersects with the extensions of the two cutting edges and (c) the x-axis is perpendicular to the y and z-axes [14].

According to the model described above, a number of parameters have to be chosen in order to produce a great deal of different drilling tools. Those are separated in two main categories. First, the following geometrical parameters are used to determine the main shape of the tool:

R: tool radius in mm,
W: tool web thickness in mm,
p: half point angle in deg (i.e. $2p=118^o$),
h: helix angle.

Second, manufacturing parameters are used, for the detail shape of the tool based on the conventional grinding method:

g: distance of cone vertex along the x axis,
s: distance of cone vertex along the y axis,
θ: half cone angle.

Another main element for the correct twist drill geometrical representation is the shape of the flute cross section. An appropriate drill flute surface for straight cutting lips was considered. Galloway was the first to derive the condition which the flute surface must satisfy in order to have a straight cutting lip under conventional conical grinding conditions. That condition is described by the following equation:

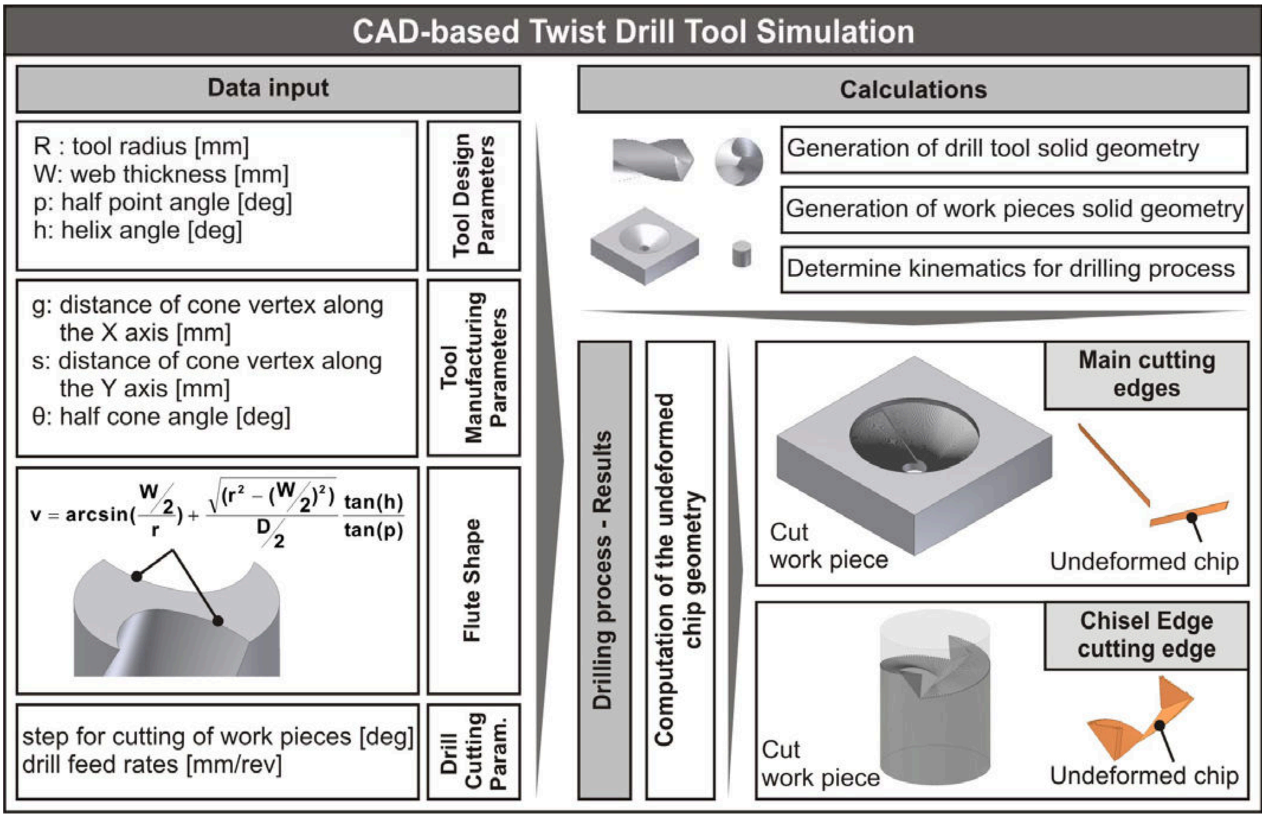

Fig. 2 The flow chart for the drilling simulation

$$v = \arcsin\left(\frac{W/2}{r}\right) + \frac{\sqrt{(r^2 - (W/2)^2)}}{D/2}\,\frac{\tan(h)}{\tan(p)} \qquad (1)$$

where (r, v) are the necessary polar coordinates for the flute cross section, with r varying from W/2 to D/2. The profile for the secondary (non cutting lips) flute can be defined in a manner to perform easy chip removal, while at the same time ensures sufficient strength of the tool.

It is worth mentioning that Galloway's approach is purely geometrical, which means that it allows the analytical calculation of all the necessary characteristics of the tool (rake angle, nominal relief angle etc) based on 2D analysis of a variety of geometrical planes.

The DRILL3D is used in order to produce the aforementioned geometrical description of the tool. The solid model of the twist drill fluted part is formed by sweeping helically the flute cross section described by equation 1. The twist drill point geometry is finalized by the boolean subtraction of the grinding cones mentioned earlier. The software creates automatically the appropriate work piece 3D solid model and allows the user to select the step for the work piece cutting (in degrees) and the feed rate (in mm/rev). In addition, a number of parameters for setting up the initial conditions, before the cut is started, is made available (drill kinematics parameters). Based on the data referred previously, DRILL3D produces two more 3D solid models, one for the description of the drilling action on the main cutting edges and another for the application of drilling in the area of the chisel edge (Figure 2).

III. THE 3D CAD-BASED PENETRATION PROCESS

The virtual drilling process is separated in two actions. The first is based on the cutting action of the cutting lips and the second on the cutting action of the chisel edge. Both are treated in a similar way but analyzed individually. The final result is the creation of 3D solid models representing the undeformed chip and the shape of the remaining work piece geometries for each case. The tool is virtually moved transitionally towards the –Z axis (feed) while at the same time, it is rotated around its Z axis of symmetry using a constant step. In every step, a boolean subtraction of the tool model from the remaining work piece model is carried out. The step value, for both cases, is selected comprising the motion accuracy, the calculation complexity and the CAD system capacity.

At the beginning, a work piece specially shaped in order to achieve the cutting lips to be directly engaged (steady state case) and with a small hole in the middle (chisel edge area), is used. A rotation step of one degree can be successfully incorporated into the model.

Following that, another work piece of pure cylindrical shape having a diameter equal to each tool's chisel edge is used. The step selected in that case, is in the range of three to five degrees in order to achieve the appropriate motion accuracy without encountering software limitations due to extremely small size of the chip involved. Once more, the produced undeformed chip and the remaining work piece involved consist the outcome of the virtual cutting process in the area that comes in contact with the chisel edge. Both cases are very computing intensive and the simulations need to run for a significant amount of cycles in order to achieve constant chip geometry and simulate the steady state condition.

The selected approach, in contrast to former modeling efforts, is primitively realistic, since the produced remaining cut work piece and the chips 3D geometry are the results of the material removal of the cutting tool into a solid model of the work piece. DRILL3D is able to output formats provided from the "host" CAD system (.ipt, .sat, .iges, .stl, .dxf etc) and offer realistic solid parts, chips and cut work pieces, which can be easily managed for further investigations individually, or as an input to other commercial CAD, CAM or FEA environments.

IV. RESULTS

The determination of the undeformed chip geometry, together with the number of constant coefficients stored in material databases depending on the couple of material used (tool and work piece), is of great importance because it leads to the calculation of the applied cutting forces during the drilling process. A representative number of simulations were performed by DRILL3D with various different tools and three different values of feed rate for each one: 0.18 mm/rev, 0.36 mm/rev and 0.72 mm/rev. Every figure depicts the chip width in both areas involved in the cutting action (main cutting edge and chisel edge) and uses four variants of tools with all three feed values. In all of the following figures, both the main cutting edges average chip width and the chisel edge maximum chip width are increasing with the feed rate as expected.

Figure 3 presents the influence of the tool diameter (8mm, 10mm, 16mm and 20mm) on the chip widths for the three feed rates. It denotes that the value of the chip average width (main cutting edges) depends on two main characteristics; 1)the continuous change of the rake and relief angles from the outer corner to the chisel edge (which depends on the tool diameter) and 2)the value of the feed used. In addition to these, the maximum chip width in the area of chisel edge increases mainly because of the constant ratio W/D which is selected for every tool.

Figure 4 depicts the influence of the tool web thickness (1.2mm, 1.5mm, 1.8mm and 2mm) on the chip widths for the three feed rates. When the web thickness increases, the cutting action of the main cutting edges remains basically constant because there is no significant influence, of that parameter, in their cutting geometry. Contrary to that, in the area of chisel edge, the size of the undeformed chip increases substantially. The cutting mechanism involved is not a traditionally described cutting action, but an extrusion as well. This is the reason that the webs in twist drills are made as thin as possible (i.e. proposed constant W/D ratios from manufacturers).

The influence of the tool half point angle (59^o, 65^o, 67.5^o and 70^o) on the chip widths for the three feed rates is presented in figure 5. Again, the increase of the point angle does not affect the main cutting geometry of the main cutting edge and as a result the undeformed chip remains relatively constant. On the other hand, it affects drastically the size of the undeformed chip produced by the chisel edge since it creates a less pointy tool.

Figure 6 illustrates the influence of the tool helix angle (22^o, 25^o, 28^o and 32^o) on the chip widths for the three feed rates. As expected, the increase of the helix angle provides the same width of undeformed chip in the area of the chisel edge (its geometry remains the same) and a small increase of width in the area of the main cutting edges is achieved (the rake angle is closely related to the helix angle and decreases progressively with it from the outer corner to the chisel edge).

V. SUMMARY

Former research work was traditionally mainly based on 2D projective geometry principles or extremely complex 3D mathematical calculations, in order to achieve reliable results. The novelty of the current research is that the algorithm has been developed and embedded in a commercial CAD environment, by exploiting its modeling and graphics capabilities. DRILL3D software routine produces pure 3D solid models of both tools and work pieces. These 3D geometric definitions provide the data required for a number of downstream applications i.e. finite element analysis, 3D scanning of tool geometry.

In addition, the full 3D geometry of the undeformed chip produced can be derived from the tool and work piece models. Using this information, prediction of the cutting forces and optimization of the drilling process can be achieved. It is expected a newer version of the software to incorporate these capabilities and provide a complete application for executing a virtual drilling process.

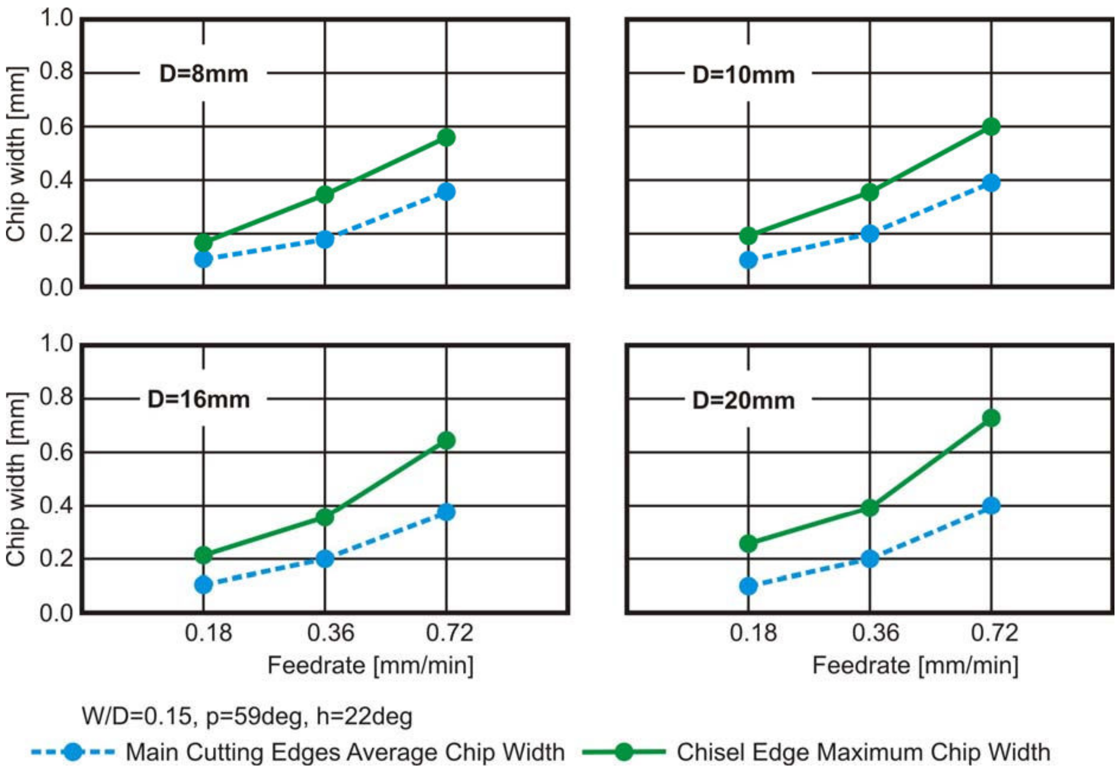

Fig. 3 The effect of the tool diameter variation on the chip width

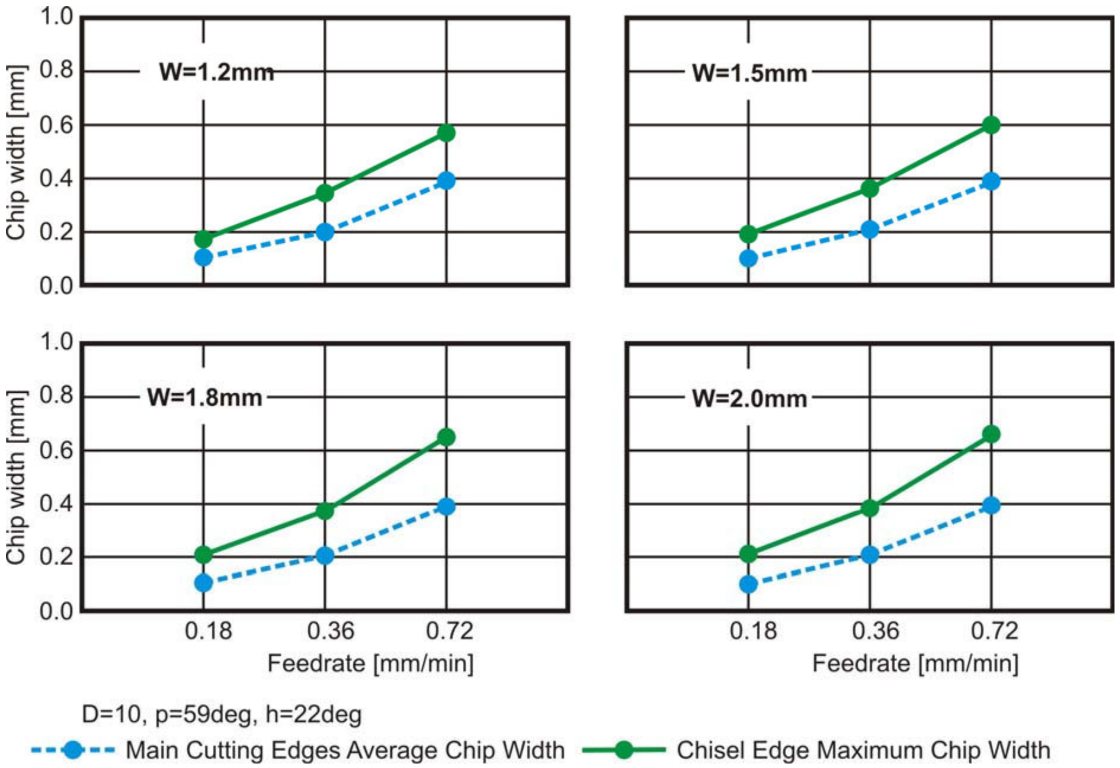

Fig. 4 The effect of the tool web thickness variation on the chip width

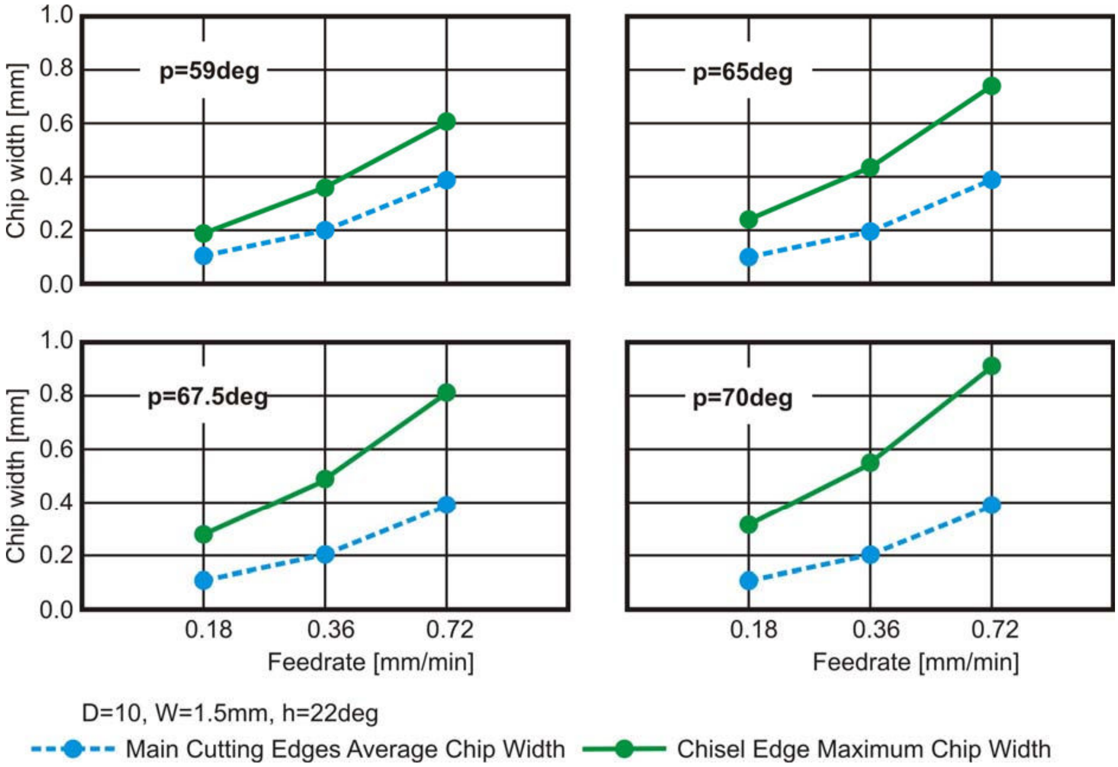

Fig. 5 The effect of the tool half point angle variation on the chip width

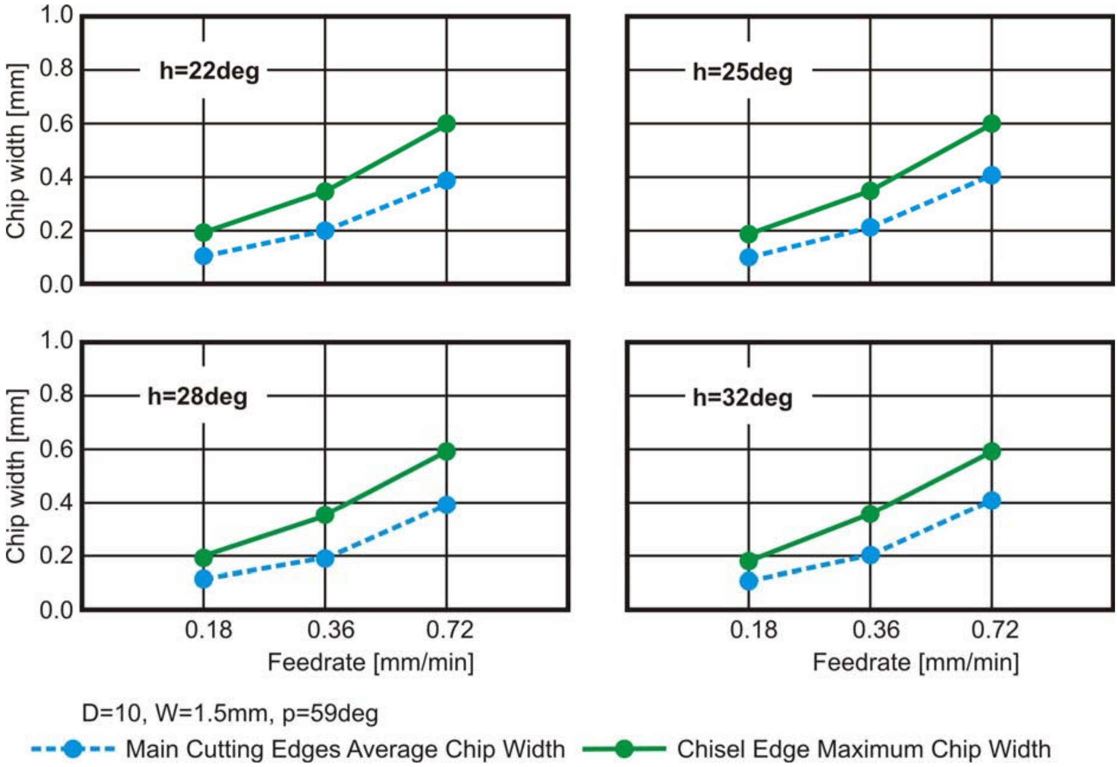

Fig. 6 The effect of the tool helix angle variation on the chip width

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