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Effective Parameters For Improving Deep Hole Drilling Process By Conventional Method - A Review

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Abstract

In this study, a review of the literature on the conventional deep hole drilling process to produce small deep holes was conducted. In order to bore holes having large length to diameter ratio, deep hole drilling process is used in industries. Deep hole drilling process encounters various threats like tool wear, friction, Built up Edge(BUE) and tool deflection depending upon the material being machined. During the drilling process the friction generated will tend to blur the cutting edge of the tool and if left unnoticed, it results in tool wear and ends in tool breakage. The problem imposed due to friction can be controlled by the supply of coolant. The coolant can reduce the friction between the rotating tool and the work piece if the drilled depth is considerably small. But when drilling deep holes, after drilling to certain depth, the drill bit tip and the coolant are separated by more amount of broken chips, as a result the friction between the rotating tool and the work piece gets increased. This may increase the tool wear and thus it is very difficult to achieve dimensional accuracy and good surface finish in a reasonable time. Various factors like tools torsional rigidity, tool geometry, cutting edge preparation, tool coating, coolant supply and proper chip disposal are to be considered for effective deep hole drilling process.

Keywords*: Coolant supply, Cutting Edge preparation, Chip size ,Deep Hole Drilling, Tool Geometry*

1. Introduction

Deep hole drilling is a method of drilling holes with the hole depth greater than five times the diameter of the hole size. The Strategies for deep-hole drilling address three primary issues: (i) evacuating chips without damaging the surface finish (ii) delivering coolant to keep the drill and workpiece material cool (iii) minimizing the cycle time. Higher the length-to-diameter ratio of the drill bit, higher will be the tendency of the tool to be deflected, which causes the hole to be misplaced.Frazao, et al. (1986) pointed out that "the machining of holes of high length to diameter ratio to high standards of size, parallelism, straightness and surface finish has always presented problems". Low machinability of difficult-to-cut materials makes it more difficult to achieve the process efficiently and economically, especially in the solid drilling of small deep holes. Currently, there are three main techniques available for conventional deep hole drilling, i.e. the gun, the BTA (from Boring Trepanning Association) and the ejector drilling systems.

Ernst and Haggerty. et al. (1958) pointed out that the inability of the conventional twist drill to drill difficult-to-cut is due to insufficient torsional rigidity of the conventional twist drill. In order to investigate the effect of the cross-sectional shape on the torsional rigidity Spur and Masuha, et al. (1981) in his work pointed out that the design of the cross-sectional shape of a twist drill involves a proper balance between the size of the cross-sectional area and the area of the flute.

Generally, in the drilling operation, the by-products of rotational energy of the drill are the chips and heat. Matthews, et al. (1984) found that the drill-bit geometry was also responsible for the heat generation during the drilling process. The author in his work figured the three sources which are mainly responsible for heat generation (i) friction between the rake face of the cutting tool and the chip (ii) friction between the flank face of the cutting tool and the newly created surface of the work piece.(iii) primary shear portion of heat generated during the drilling process.

Deep hole drilling process is widely used in many engineering applications like manufacturing hydraulic cylinders, automotive industry for the production of injectors used in fuel injection, medical and biomedical products, aircraft structures, heat exchangers of the nuclear energy centrals (Jozef Jurkoa 2012;Fang 2005)

Zhang, et al. (1999) pointed out that as more and more automotive or computer controlled machines are employed, manufacturers need to increase the service life of cutting tools in order to increase the machining effectiveness and lower the cost of manufacturing. They also mentioned that the study on the wear rates and wear mechanisms of cutting tools drilling die-cast aluminum alloys are still not enough to meet the industrial requirements of manufacturing.

Jozef Jurkoa, et al. (2012) pointed out that the present market requires high quality products and the corresponding properties. Requirements that are imposed on these products(eg. resistance to various aggressive environments, resistance to heat and temperature effects, resistance to high mechanical loads, etc.) they can meet only materials with special physical, chemical, mechanical and other properties. As a result it results in low machinability

In case of deep holes with small diameters, different unconventional manufacturing processes like, laser drilling, electro discharge machining, electron beam machining and electro chemical machining are used Biermann, et al. (2005). But due to certain limitations in the unconventional machining process like the need of conducting material in EDM process, precise control of chemical reaction in Electro chemical process which has a great impact on accuracy , High cost and also the increasing need for miniaturization of components the conventional machining process is found to be economical method for producing deep holes. The need of high performance cutting tools is driven by continuously improved mechanical properties of new workpiece materials, which often results in difficulty in machining of those materials with the existing tools.

Therefore, this paper aims to present a literature survey on producing small deep holes by conventional manufacturing technique. Attention will be focused on selection of effective parameters for improving deep hole drilling process like cutting edge preparation, tool geometry and their effects on the cutting forces, role of cutting fluid and the chip removal process.

2. Cutting Edge Preparation

The geometry and sharpening of the cutting edges is crucial to the performance of the drill bit. Fang, .et al. (2005) pointed out that in order to eliminate the sharp edge and reduce edge-related problems during machining, such as edge chipping, cracks, and tool breakage, tool manufacturers provide various types of modifications of the tool edge geometry, which are commonly referred to as 'tool edge preparation

The cutting edge is subject to high stresses and strains during the cutting process. So this area is the initial point for tool wear. The form and the surface of the cutting edge also have an influence on the drilled work piece quality. Shaw, et al. (1957) pointed out that the chisel edge of a conventional twist drill contributes some 50-60% of the total thrust forces.Denkena, et al. (2011) pointed out that the need of high performance cutting tools with special cutting edges is driven by continuously improved mechanical properties of new work piece materials, which are very difficult to machine.

Furthermore, cutting edge preparation has positive effect on the coating adhesion on the drill bit which can extend the life of the tool. Yung-Chang Yen, et al (2004) pointed out that the purposes of edge preparation are to strengthen the cutting edge and to prepare a surface for deposition of coatings. The design of tool edge geometry influences process parameters such as the shape of deformation zones, distributions of temperature and stresses on the tool face, and cutting forces. These effects in turn affect the changes in chip flow, machined surface integrity, tool wear resistance, and tool life.

Dirk Biermanna and Mark Wolf, et al.(2012) investigated on the cutting edge preparation to optimize the tools performance. They observed an increase in mechanical tool load due to cutting edge rounding .The surface roughness was greatly affected due to the deflection of the cutting edge. With the optimized cutting edge design, reduction in drilling time of more than 60 % was achieved by increasing the feed rate from f = 0.03 mm/rev to f = 0.05 mm/rev.

Endres, et al. (2002) investigated on the effect of nose radius on tool flank wear. Their experimental results showed that by using moderate nose radius the tool flank wear both at the lead edge and tool tip were minimized. However the author didn't focus on the use coating material upon the tool which showed a positive result in Yung-Chang Yen, et al (2004)

There are different industrial techniques for the cutting edge preparation, such as slip grinding, brushing or abrasive jet blasting.Dirk Biermann, et al. (2008) used abrasive water jet blasting technique to prepare different cutting edge designs. The chisel edge, major cutting edge and the corner of the carbide twist drills were prepared. They observed that the prepared twist drills to be more effective than tools without cutting edge preparation. The drilled borehole quality, tool life was also increased substantially.

Cheung, et al. (2008) investigated the effects of cutting edge preparation on tool life and tool wear on HSS drills.They used magnetic polishing method for cutting edge preparation on HSS drills.The polished edge-radiused drills demonstrate a remarkable improvement in tool life compared to unpolished sharp drills. The performance of drills was assessed by the measurement of thrust and torque, hole diameter, surface roughness and drill wear. They found that large edge-radiused drills were prone to produce undersized holes. M2 high-speed steel split-point twist drills, 6mm in diameter with point angle of 118° and helix angle of 31° was experimented.

Finite Element Analysis (FEA) has played an important role in simulating and understanding the metal cutting process by having an insight looking at what is going on during the cutting process, which reduces the time taken for real time machining. In the literature, both the Lagrangian and Eulerian Finite Element techniques have been used in studying the effects of tool-edge preparation in orthogonal cutting.Kim, et al. (1999) studied the effect of the edge radius for a cemented carbide tool on the cutting forces and temperature using an FE orthogonal cutting model based on the Eulerian formulation, and compared the results with the experiments. Their simulation results showed that increased tool edge radius alters the temperature distribution of the tool and shifts the position of maximum temperature closer to the tool tip. The simulation results were validated by experimentation. The experimental results showed that increased tool edge radius causes an increases in the cutting forces of the tool.Shatla, et al. (2000) applied the Lagrangian FEM simulation to study the influence of edge preparation on tool temperature and stress in orthogonal cutting of H13 tool steel (46 HRC). Simulation results showed that the effective stress of the tool reached a minimum when a moderate edge radius (0.1 mm) was used. They showed that the tool with an excessive edge radius resulted in a significant increase of the tool stress and shifted the stress concentration close to the flank face, due to the increasing ploughing force component in the direction normal to the machined surface. In the same study, the effects of different chamfer geometries on the tool rake and flank temperatures were also summarized

3. Drill Geometry

Drill geometry is a key factor in successful deep-hole drilling. Galloway, et al. (1957) pointed out that even very small variations in the geometry of the drill point can have a very significant influence on the performance of the drill. Hence the drill point geometry, which is uniquely defined by the shapes of the flute and flank surfaces, is a primary factor to be considered when attempting to improve the drill's machining performance and the quality of the holes drilled. The drill points has four main features: (a)Point Angle;(b)Rake angle and Clearance angle;(c) Cutting Lips and (d)Chisel Edge.

Todd, et. al (1994) pointed out that, the best geometry to use depends upon the properties of the material being drilled. The following table lists geometries recommended for some commonly drilled materials

Tool geometry			
Workpiece material	**Point angle**	**Helix angle**	**Lip relief angle**
Aluminium	90° to 135°	32° to 48°	12° to 26°
Brass	90° to 118°	0° to 20°	12° to 26°
Cast iron	90° to 118°	24° to 32°	7° to 20°
Mild steel	118° to 135	24° to 32°	7° to 24°
Stainless steel	118° to 135°	24° to 32°	7° to 24°
Plastics	60° to 90°	0° to 20°	12° to 26°

Table 1 source :Todd, et. al (1994)

Audy, et al. (2008) pointed out that the values of the geometrical drill point features such as point angle, helix angle, and web thickness vary from manufacturer to manufacturer and more importantly from batch to batch. The geometry of the chisel edge region also varies widely depending on the point sharpening method used and the control of the sharpener settings

Whitfield, et al. (1986) explored the effect of varying the drill geometrical features like point angle, helix angle, chisel edge angle and web thickness on the generated thrust and torque forces.

The following was their observation:

(a)The increase in drill diameter caused an increase in the area of cut of the drill which in turn increased the torque and thrust forces

(b)Increases in the web thickness caused an increase in both thrust and torque values

(c)Increase in the chisel edge angle and chisel edge wedge angle increased the thrust values but had only a marginal effect on the torque

(d)Increase in the point angle had a very little influence on the predicted torque but it increased the predicted thrust force

(e)Increase in the helix angle reduced the thrust and torque values

(f) Both thrust and torque decreased little when the drilling speed was increased.

(g)Increase in the feed rate resulted in the increase of both thrust and torque. However the author failed to reduce the cutting lip size for getting better results in reducing the thrust force during his experimentation.

Tuijthof, et al. (2013) measured the influence of drill bit geometry on imparting maximum thrust forces during drilling of cortical and trabecular bones of animals. They observed that, the drill bit geometry in terms of the flutes, sharpness of cutting edges, point angle and feed rate has a significant influence on imparting maximum thrust forces

3.1 Point angle and its effects

Point angle is the angle formed by the two flank surfaces with that of the axis of the drill. Point angle can be classified as High Point Angle (Flatter Point) and Lower Point Angle (Sharper Point).

3.1.1 High Point Angle (Flatter Point):

High point angle have a stronger cutting edge and a flatter Point , a shallower angle, such as 150 degrees, is suited for drilling hard and tougher materials like steel and other tougher materials. By using statistical linear regression analyses, Ali Faraz, et al. (2009) determined the magnitude of Cutting Edge Rounding (CER) and Flank wear in drilling Compound Fibre Reinforced Plastic (CFRP) composite using 4 different types of carbide tools. The drill T1 was a conventional type, helical-fluted bit with a very fine and tough grain structure K30F, recommended for applications with abrasive work materials like CFRPs. The drill T2 a specialized drill bit called as 'RatioDrill' with three helically fluted, near-to-zero geometry with a very high point angle of 150°. Drill T3 was also a three helically fluted drill bit with a special spiral cutting edge, having a high point angle of 135°. The drill T4 was a typically a modern, specialised drill bit with a complex shape having four straight flutes with an acute point angle of 20°. From the experimental results,they observed that , Drill T2 showed a relatively higher thrust magnitude and flank wear compared to the other that of its counterparts due to its largest point angle 150°. Whereas, drill type T4 showed the lowest rate of flank wear due to its smallest point angle.

3.1.2 Lower Point Angle (Sharper Point)

Lower Point Angle have a Sharper Point which are suitable For drilling softer materials .Points sharper than 118° are generally used for soft non-ferrous and non-metallic materials. A more aggressive angle, such as 90° are suited only for drilling plastics and other soft materials as the point angle is very sharp, it would wear rapidly when it is used on hard materials.Enemuoh et al. (2001) studied the effect of the tool point angle (ranging from 75°to 160°) on delamination at the drill exit and surface roughness after drilling carbon fibre reinforced epoxy composite. The results suggested that a point angle of 75°provided minimal delamination (due to the lower thrust force), but marginally acceptable surface roughness on contrary Uwe Heisel, et al. (2012) analyzed the influence of the point angle of the drilling tools on drilling forces and drill hole quality on machining CFRP.They observed that an increase in point angle had a significant influence on the delamination factor

3.2 Rake angle and Clearance angle

Rake angle and clearance angle are the most significant factors for all the cutting tools. Rake angle are provided for ease of chip flow and overall machining. Rake angle may be positive or negative or even zero. Clearance angle are essentially provided to avoid rubbing of the tool (flank) with the machined surface which causes loss of energy and damages of both the tool and the job surface. The rake angle and clearance angle are affected and are altered due to the formation of Built up Edge(BUE) on the cutting tool edges. Built up Edge(BUE) is a slight accumulation of the material from the work piece which adheres to the cutting edge of the tool. (BUE) has profound effects on the cutting forces, cutting temperatures, tool-wear, tool life, surface roughness, and geometric dimensions of machined products Fang, et al. (2005) developed a new slip-line model for predicting the length , height of the BUE, cutting and thrust forces, chip up-curl radius, chip thickness, and tool–chip contact length. They proposed that BUE are formed on the tool rake face when cutting ductile metals and alloys, such as steels and aluminum alloys, under a certain range of low-to-moderate cutting speeds.

3.2.1 Positive rake angle and its effects

Positive or increased rake angle helps to reduce the cutting force, friction and reduces the cutting power requirement.

Positive rake angle are more effective when cutting tough, alloyed materials that tend to work harden, such as stainless steel and when cutting soft or gummy material.Mustafa Gunay, et al.(2004) studied the influence of tool rake angle on the main cutting force for machining of AISI 1040 material. Five different cutting speeds (80, 100, 120, 150, and 180 m/min) was selected. Main cutting force (Fc) was measured for eight different rake angles ranging from negative to positive rake angles (-5,-2.5, 0, 2.5, 5, 7.5, 10, and 12.5). The depth of cut (2.5mm) and feed rate (0.25mm/rev) was maintained constant. They observed that the Cutting force was reduced by increasing rake angle in positive and was increased by increasing rake angle in negative values. They showed that, increasing the rake angles in positive direction through +10°till +12.5°caused decreasing tendency of cutting force by 1.48 and 2.3% for all cutting speeds.

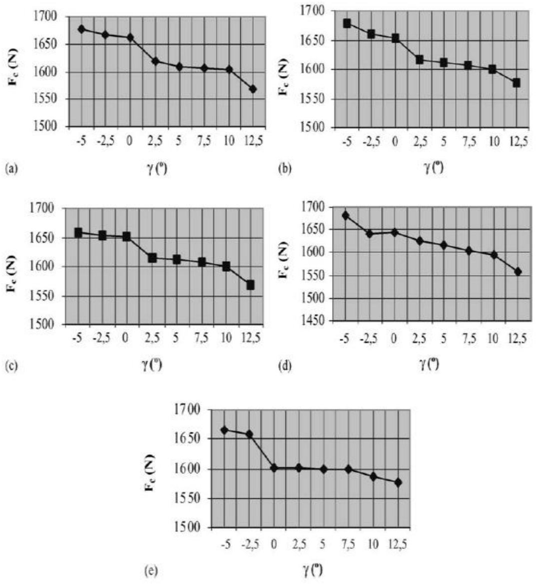

Figure 1 Main cutting force (Fc) alteration due to rake angle (γ); V = 80 m/min, (b) V = 100 m/min, (c) V = 120 m/min, (d) V = 150 m/min and (e) V = 180 m/min. Source : Gunay, et al. (2004)

3.2.2 Negative rake and its effects

Negative rake angles provide better heat conductivity and greater strength on the cutting edge of the cutting tool. (Mustafa Gunay, et al. 2004 , N. Fang , et al. 2005).Negative rakes are recommended on tool like carbide, ceramic, polycrystalline diamond, and poly crystalline cubic boron nitride cutting tools which does not possess good toughness (low transverse rupture strength). On contrast to the positive rake angle, the Negative rake angle increases the tool forces. Galloway, et al. (1957) pointed out that a large negative rake angle increase the cutting forces and tool wear.

Mustafa Gunay, et al. (2004) investigated on the influence of tool rake angle on main cutting force . He pointed out that Sharp edges of cutting tools in machining operations result in enormous stresses in cutting region, which enhance the cutting tool wear.They found that, Main cutting force increases with increased negative rake angle values and decreases with increased positive rake angle values. Fang, (2005) pointed out that the tool–chip friction can be decreased by increasing the negative rake angle and cutting speed. EmreOzlu, et al. (2009) analyzed the friction behaviour in metal cutting operations using a thermo mechanical cutting process model which investigates the rake angle contact and friction behaviours during the metal cutting operations. From their experimental results, they showed that with an increase in the negative rake angle caused an increase in the tool force.

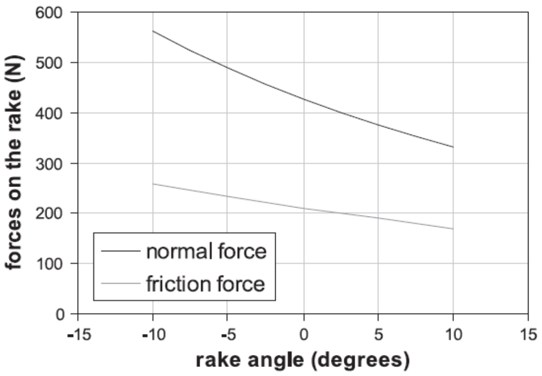

Figure 2 The cutting forces variation with the rake angle for AISI1050 steel using coated carbide tool. Source : EmreOzlu, et al. (2009)

3.3 Cutting Lips

Cutting Lips are the Cutting edges that extend from the center of the drill to the outer diameter. In most of the standard drills the cutting edge are a straight line but in some special and high performance drills posses curved cutting lips. Maximum rate of penetration into metal occurs only when the full length of the cutting lips are involved in the material.

3.4 Chisel Edge :

Chisel edge of the drill does not function as efficiently as the cutting lips. The cutting ability of the chisel edge is controlled by three different dimensions they are
(a)the thickness of the web
(b)the chisel edge angle and
(c) the relief or clearance angle on the chisel edge

The chisel edge angle on drills can be varied from 105° to 135°. Obviously, the smaller angle would reduce the length of the chisel edge. A reduction in the chisel edge angle will permit closer tolerances on drilled hole size.

3.5 Web thickness and its effects

The web is the center part of the drill body which joins the lands..Web is typically thinned to 8% to 12 % of the drill diameter for shortening chisel edge length in order to reduce the thrust force and for proper chip evacuation.Thornley, et al. (1987) showed that, the web thickness as a significant geometry factor influencing the torsional rigidity of the drill. They pointed out that a thicker web drill increases the polar moment of the cross-sectional area, which in turn increases the torsional rigidity of the drill.

The extreme ends of the web form the chisel edge. The thickness of the web is not uniform; it increases from the point to the shank. Galloway, et al. (1957) pointed out that, web thickening increases the chisel edge length of the drill bit. As a result, higher thrust forces are generated which results in the tool wear.

Muhammad Aziz , et al. (2012) developed a micro long flat drill made of ultra-fine grained cemented carbide containing WC particles with an average particle diameter of 90 nm. A micro long flat drill with a web thickness of 7μm, 10μm and 14μm was fabricated by precision grinding using a diamond grinding wheel. The effect of web thickness on tool life, chip removal Capability and wear rate was analysed. Both duralumin and stainless steel work pieces was experimented. The drilling capability of micro long flat drill was observed in some different drilling conditions including the application of ultrasonic vibration (USV) and step feeding method to find the optimal conditions for drilling.

The following was their observations

(a)Drilling without the assistance of Ultra sonic Vibration, broke the micro long flat drill almost during drilling the first hole. They found that the drill bit breakage was due to the poor chip removal capability and the large drilling resistance created between the drill bit and work piece.

(b)Drilling with step feeding in micro deep drilling may Shorten the tool life due to the interference between the drill tip and the hole entrance.

By using finite element method, Wen-Chou Chen, et al. (1997) designed a twist drill with special cross-sectional shape in order to improve the unfavorable distribution of the total orthogonal rake angle along the primary cutting edge of a thick web drill, a thick web drill with curved primary cutting edges was devised based upon drill deformations. They pointed out that the web thickness as a predominant factor affecting the torsional rigidity of a drill. They observed that a thick web drill with curved primary cutting edges required 7.2% less thrust force and 7.9% less torque than the thick web drill with straight cutting edges for the normal drilling of JIS $50C heat treated steel.

3.6 Helix Angle and its effects

Helix angle determines the rake angle at the cutting edge of the drill. The helix angle is chosen such that there is a compromise between the strength of the cutting edge and efficient chip ejection through the flutes.

Helix angles generally fall into three categories:
(a)Slow Spiral
(b)Regular Spiral and
(c)Fast Spiral

In Slow Spiral drills the helix angle is between 12° to 22°.They are stronger, but have less chip lifting power. These types of drills are used for drilling materials such as brass or bronze, or cast iron.

In Regular Spiral drills,the helix angle is maintained between 28° to 32°. Regular Spiral are used in a wide variety of drilling applications and found on most general purpose and cobalt drills

In Fast Spiral drills, the helix angle is maintained between 34° to 38°. Fast Spiral Drills Provides greater lifting power for chips, but are weaker. These type of drills are suitable for softer ferrous and non-ferrous materials producing stringy chips.

In practical operation, for drilling easy-to-cut materials (e.g., aluminum alloys), the helix angle may be chosen even larger.

In order to validate the FEM results,Wen-Chou Chen, et al. (1997) carried out an experiment on the designed twist drill with special cross-sectional shape to find the effect of the helix angle variations on drill deformations. They observed that, when the helix angle was increased from 20 ° to 45 °, the angular displacement of the drill was decreased by 30.5% and the maximum radial displacement of the was decreased by 19.4% and axial displacement of the drill increased rapidly. They pointed out that the helix angle may be chosen to be 35 ° for the thick web drill in order to improve the distribution of the tool orthogonal rake angle along the primary cutting edge and for better chips removal capacity.C.J Oxford (1967) explored the effect of the flute length on the drill life when cutting cobalt-based high-temperature alloy. The test results have shown that the drill life increased 80 times as the flute length decreases from 70 to 35 mm. This may be explained by the fact that the drill has a shorter flute length and a greater torsional rigidity.

4. Role of Cutting Fluid

The cutting fluid plays a vital role in deep hole drilling. Shaw,(1986) pointed out that besides cooling, cutting fluids also aid the cutting process by lubricating the interface between the tool's cutting edge and the chip By preventing friction at this interface, some of the heat generation is prevented

This lubrication also helps prevent the chip from being welded onto the tool, which interferes with subsequent cutting. The ability of the cutting fluid to sweep away the chips from the drilling zone depends upon its viscosity, volume flow and the type of chip formed. Sweeping the chips away from the cutting zone is a very important function of the cutting fluid. Brandao, et al. (2008) pointed out the effects of cutting fluids are flushing chips away and preventing the machined surface and cutting tool from corroding.

Hamade (2005) Pointed out that, the properties that are sought after in a good cutting fluid are the ability to:

(a)Keep the work piece at a stable temperature;(b)maximize the life of the cutting tip by lubricating the working edge and reducing tip welding;(c)Ensure safety for the people handling it (toxicity, bacteria, fungi) and for the environment upon disposal.;(d) to protect the machine tool and work piece against corrosion.

In order to avoid problems during deep-hole drilling process, different types of coolant delivery strategies are common in Vertical Machining Centres; they are flood coolant, low-pressure through-spindle coolant and high-pressure through-spindle coolant.

With flood coolant, the deeper the drill penetrates the work piece only less and less coolant reaches the tool tip eventually, no coolant can get to the bottom, and machining occurs dry. As a result, chips become impacted in the flutes of the tool even though coolant is visibly flowing over the top of the hole. In fact, the hole ends up being dry cut, while the tool heats up and is subjected to premature wear or breakage.

With low-pressure coolant-through-spindle systems, the programmer can safely increase the depth of pecks and in some cases completely eliminate pecking cycles altogether, saving production time. With high-pressure coolant-through-spindle systems, not only is pecking eliminated or reduced, but higher feed rates and spindle speeds also can be used. As a bonus, this system extends the life of the tool.

High-pressure coolant-through-spindle systems provide the best scenario for decreasing cycle time and increasing tool life. The high pressure of the coolant breaks up chips and forces them up the flutes and out of the hole. Cycle times go down, because the pecking process is eliminated while spindle speeds and feed rates can be increased. With higher feed rates, chips tend to form better.

Xiaozhong Song, et al. (2007) explored on small-hole dry drilling in a bimetal material (powder metal steel and aluminium alloy).From the experimental results, they pointed out that the build up on the tool surface was resulted from high temperature in the cutting zone because of the lack of coolant for heat removal and lubrication. However their work didn’t focus on the hole surface quality rather focused only on the number of holed drilled.

Heat from the drill may also work harden or “heat treat” the workpiece in the vicinity of the hole. Friction from the drill heats the workpiece, and when coolant finally reaches the heated material, the coolant quenches it. On the subsequent peck, the drill encounters the hardened material, causing excessive tool wear or a broken tool and damaged part. The essence of successful deep-hole drilling requires a method of getting coolant down to the tip of the drill where it can remove heat and evacuate chips.

Shaw (1986) defines that one of the main issues that affects machinability is the heat generated during machining. Cutting fluids have been used in machining operations for decades in order to increase the machinability through lubricating the contact areas between rake face and chips, flank face and machined surface and reducing the friction induced heat and removing the generated heat from the cutting zone as a result of severe plastic deformation. Dudzinski (2004) pointed out that the cooling effect of cutting fluids increases the tool life by maintaining temperature below the thermal softening temperature of the tool material and decreasing the thermally induced tool wear such as diffusion and adhesion. In addition, the lubrication effect of the cutting fluids could reduce the mechanical wears such as abrasion on the rake face. Oberg, et al. (2004) proposed that, proper selection of cutting fluids is particularly important as it could affect the tool life, cutting forces, power consumption, machining accuracy, surface integrity etc. For instance cutting fluids with a greater lubrication effect are usually employed in severe machining operations such as low speed machining and machining difficult-to-machine materials. However coolants are more favourable in high speed machining with low cutting forces and high temperatures. Haan, et al. (1997) conducted experiments on Aluminium alloys and Grey Cast iron to determine the function of cutting fluid in drilling. They used 5types of 6mm diameter drill bits and drilled 25mm deep holes.They explored the effect of speed, feed, hole depth, tool, work piece material, workpiece temperature and drill geometry on drilling torque, thrust force, hole quality, and build up edge. They found that the cutting fluid as a significant factor in the surface finish and the drilled hole quality.

The use of cutting fluids is essential during drilling with low strength tools, like high speed steel. This is due to the fact that the heat generated during the drilling process increases the tool temperature, reducing its mechanical strength and, thus, making easier the occurrence of plastic deformation and finally ends up in tool failure. In this case, cutting fluids reduce the temperature, not allowing the tool to loose its strength and making possible the use of relatively high cutting speeds. Baradie, (1996) pointed out that, one of the effects of cutting fluids is to remove generated heat at the cutting zone by conduction. Thus, the desired cutting fluid used particularly for cooling should have high thermal conductivity and specific heat.

When drilling materials that generate discontinuous chips, like grey cast iron, cutting fluid application becomes fundamental, mainly in deep drilling.

5. Controlling Chip Size and Shape

In the deep hole drilling process, small well-broken chips are desirable. During the drilling operation, some materials form very small chips that flow out through the flutes easily and other materials form chips that are long and stringy. Worthington, et al. (1979) pointed out that, when the chips are larger it becomes very difficult for the chips to move easily through the flutes. It increases the torque requirements, causing the workpiece and drill to damage soon. This may be due to the fact that, the chips rotates along with the drill and impact the hole wall or interior of the flute. This impact produces a bending moment in the chip. Once the bending moment causes the chip to exceed a critical strain, it will fracture the tool.

One of the approach to control the chip size and shape is the use of special machining cycles. Deep-hole cycles and peck drilling cycles are used to break chips so that they are broken small enough to flow up through the flutes on the tool without causing damage to the surface or promoting premature tool wear.

Generally, there are two types of deep-hole cycles. One uses equal pecking depths to reach the final depth. The other uses variable pecking depths, wherein each peck is followed by pecks of successively shorter increments. As the drill goes deeper into the hole, the decreasing peck depths help eliminate chip impaction around the tool. The deeper in the hole that the drill gets, the more difficult it is for coolant to get to it, so pecks are used both to evacuate chips and get more coolant to the tool tip. The disadvantage of deep-hole and peck cycles is that they take longer time to finish each hole. On long production runs, deep hole drilling efficiency is diminished and seems to be inefficient. Peck drilling, although not solely a deep hole cycle, is used to break chips by withdrawing the tool only a small distance after each peck, eliminating the problem of chips falling back into the hole. The length of the peck determines the chip length. These chips cause coolant to dribble down the hole only to be thrown off and out by the drill, thus allowing heat to build up in the drill and cause excessive tool wear. Ultimately, this condition can lead to catastrophic tool failure.

Batzer, et al. (1998) pointed out that the impact of cutting fluid on chip size is really quite minimal in the case of deep drilling. They explored the effects of cutting fluid and other process variables on chip morphology when drilling cast aluminium alloys. They found that the significant variables affecting chip size were the feed, material, drill type and to a lesser extent, cutting-fluid presence and drill speed.

By using different drill bits (high-speed steel, carbide-tipped,and polycrystalline diamond- PCD), Ramulu, et al. (2002) conducted drilling studies on Al2O3 aluminum-based metal matrix composites.During the experiment, they observed that both the HSS and carbide-tipped drills could not break the chips properly but produced continuous chips.They pointed out that the formation of long, continuous chips are undesirable because the workpiece are likely to be damaged by them.Kahng and Koegler (1977) suggested that torque applied in the same direction as the chip rotation would break the chip easily. They also stated that the resulting friction torque opposed the rotation of the chip caused it to unfold. The chip would break until the strain produced reached the fracture strain. They further argued that the chip first generated was longer than the others because it encountered less resistance due to friction than subsequent chips, and the chips generated later tended to have interference with the slowed chips which were previously generated and thus were more susceptible to breakage. Another work on ejecting helicoidal chips was reported by Sakurai, et al. (1998) who investigated the breaking mechanism of the continuous cone-shaped spiral chips produced during intermittently decelerated feed drilling.From this work, it was found that chip breakage occurred when the resulting friction torque between the hole wall and chip exceed the breaking torque of the chips.

Feng Ke, et al. (2005) pointed out that during deep hole drilling, chips usually do not maintain a uniform shape as drilling depth increases. The initial chip always has a spiral shape. When deeper drilling is done,because maintaining chip rotation becomes difficult, the spiral chip unwinds. The unwound spiral chip eventually becomes a string chip. During the transition of spiral chips to string chips, there are a few types of intermittent shapes,depending on the material, chip thickness and size of the drill , they will change into various shapes when drilling deeper due to the interactions of the drill flute and hole wall. They used 3.2 mm diameter drill drilling AICI 1038 with a speed of 3000 rpm and feed of 150 mm/min.The hole was finished with three pecks: 0–5, 5–15, and15–30 mm.They observed that Chips from each peck show the chip changing from spiral chips to string chips and finally irregular short chips

0–5.0 mm 5.0–15.0mm 15.0–30.0mm

Figure 3 Chip shape change in one deep hole drilling. Source: Feng Ke, et al. (2005)

Nakayama, et al. (1985) proposed the use of nicks on the cutting edges of the twist drill. The chips produced by the drill were split into narrower ones that could more easily carried out of the hole through the flutes. Although this resulted in lower drilling torque and better surface finish, the problem of long continuous chips was not solved. Sushanta, etal. (2003) in their work, designed a groove on the rake face of the drill near the cutting lip, to facilitate chip breaking and to reduce the drilling forces and chip clogging. An aluminum oxide grinding wheel (MA150-KV) was used to create the groove by using linear contour grinding process. Due to the space constraints on the rake face of the drill and the nature of the linear contour grinding process the groove produced was tapered at its ends. A Two-fluted conical point 10.72 mm dia HSS drills with 32° helix angle, 118° point angle, 7.5" overall length, 4.25" length of flute and 1018 steel workpiece was chosen for the proposed work. The Drill groove geometry parameters like radius of groove ,depth of the groove, width of the groove, back wall height of the groove ,groove entry angle have been examined in order to identify preferred parameter values for efficient drilling. The experiment was conducted by drilling a hole of 60 mm deep. Different combinations of the geometric parameters of the drill and process conditions were used for the experimentation. It was observed that the ungrooved drill broke after drilling 43 holes and the grooved drill was able to drill 67 holes and thus a 55% increase in the drill life was observed by using grooved drill bit. Also, they observed that by using grooved drills, the chips were small, broken and came out of the hole easily without clogging in the flute.

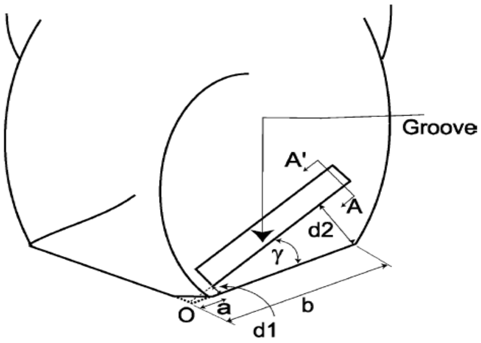

Figure 4 Groove orientation. Source: Sushanta, et al. (2003)

Jeff, et al. (2005) overcame the drawbacks in the work done by : Sushanta, et al. (2003) where they designed the groove on the 10.72mm drill by using linear grinding process. They were unable to control the shape of the groove and also the drill margin and chisel edge of the drill was damaged. Jeff, et al. (2005) used ram type EDM process for the groove fabrication on the drills by which they were able to control the shape of the groove. Two drills of diameter 6.35mm and 3.18mm was used for their experimentation.Two factors, flute shape (standard flute shape drill, Parabolic flute shape drill) and presence/absence of the groove, were varied in a two-level factorial design to investigate the groove performance.The observed that the drills with chip breaker groove was effective in reducing chip length. Further they recommended 0.4mm groove depth for 6.35mm diameter drill to maximize the drill strength and 0.3mm groove depth for 3.18mm diameter drills.

6. Conclusion

The following conclusions can be drawn with regard to the Deep hole drilling

1.Coolant through the spindle, drill tip geometry, carbide tooling, coatings and cycle selection are important factors when drilling deep holes. But in the case of drilling small holes (less than 1mm), where the coolant through the spindle/tool is not possible a new innovative method has to be adopted to the chip removal and coolant supply

2. Machine tool rigidity has a major impact on deep-hole drilling because the less stable the foundation of the machine, the more vibration the head and table will generate, causing the tool to break down. Due to the advent of new composite materials with increased mechanical properties, it is therefore necessary to focus

on designing new tools which are suitable for machining.
3. New optimized cutting edge design with multifaceted tool to reduce the thrust force, friction and for effective chip removal has to be designed.
4. The deep hole drilling is one of the technique used in the measurement of deep interior stresses. Due to the advent of difficult to machine materials, the existing tools have to be improved for measuring the interior stresses when used on those difficult to cut materials..

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