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Modeling and Analysis of Heat Pipe in Drilling Application.


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ABSTRACT

The study is performed to analyze the feasibility, of using heat pipe cooling in drilling applications. The effect of different geometrical parameters expected for a heat pipe drill configuration such as depth of the heat pipe within the drill, heat pipe diameter, heat flux input magnitude and length of the heat input zone is considered. In this model, it is assumed that the drill is subjected to a static heat source which verifies the model and feasibility of using heat pipe cooling in drilling operations. The performance of the heat pipe drill model is approximated using a solid cylinder model of pure conduction.

To validate the results, 3D modeling of the twist drill without and with heat pipe was modeled. The heat flux is given to the surface of the twist drill tool tip and the maximum transient temperatures of twist drill (without and with heat pipe) are calculated. The results show that the use of heat pipe in a twist 1rill can reduce the temperature significantly.

1, INTRODUCTION

The major functions of cutting fluids are to minimize friction between the cutting tool and work piece as well as aid in thermal management. They are also used for corrosion control, chip ejection, and washing. The use of cutting fluids is prevalent in most machining processes unless there is a strict incompatibility between the coolant and the work piece, or if the cutting insert is susceptible to thermal shock.

Industries across the world are increasingly becoming aware of the environment. This has led them to turn towards a sustainable and environment friendly approach. This approach has been spearheaded by many organizations across the globe to spread awareness on preserving the environment and the resources for the future generations and not recklessly using up resources and destroying the quality of environment.

The most common method of applying cutting fluids is flooding; others include jet impingement, mist cooling, etc. This exposes the working environment to fluids that may cause significant contamination to the environment and health hazards for the workers. The cutting fluids cause significant damage to the environment

Heat pipe

Heat pipes offer an effective alternative for removing heat without significant increase in operating temperatures. A heat pipe is a passive device that transports energy with relatively low temperature difference without the need for an external power supply. The physical configuration of a heat pipe is illustrated in Figure. 1.1. The components of a heat pipe are a sealed container (pipe wall and end caps), a

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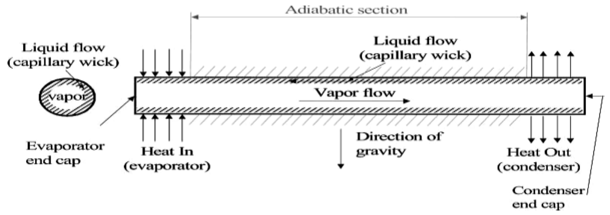
wick structure, and a small amount of working fluid in equilibrium with its own vapour. Typically, the heat pipe can be divided into three sections: Evaporator section, adiabatic (transport) section, and condenser section.

Heat transfer in the liquid-wick region is pure conduction, and that a steady state solution can be established.



FIG; - Heat pipe

Drilling process

Machining operations such as turning, grinding, boring, milling and drilling are used to manufacture a diversity of mechanical products in industry. Drilling is one of the most important machining processes that have been widely applied in manufacturing area.

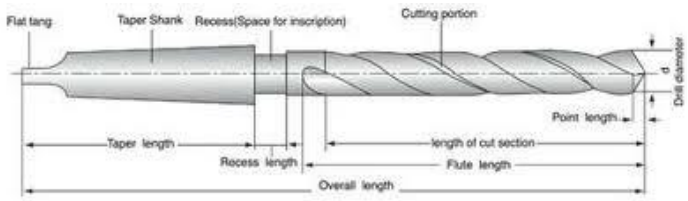


Figure. Drill Tool

2, LITERATURE REVIEW

Matthew Boone.et al. [1], The temperature profile along the cutting edges of a drill and provides a theoretical explanation for the fact that the maximum temperature can occur near the chisel edge. Analytical equations are developed to calculate the heat flux loads applied to a finite element model of the drill. For each of the elementary cutting tools on the drill, the heat generated on the shear plane directly affects the temperature of the chip at the shear plane and the flow of heat at the rake face of the tool. The drilling scenario analyzed in this study exemplifies that the manner in which this heat source is treated in the analysis affects the shape of the predicted temperature profile along the cutting edges. In this study, the results predicted by the model are consistent with experimental observations, in which the temperature near the chisel edge is larger than on the primary cutting edges.

Finite element model of the drill

This study analyzes the case in which a high-speed steel drill of diameter 9.92 mm machines a hole in a work piece of aluminum 319. The temperature distribution in the drill is calculated using a finite element analysis created with the commercial finite element code ABAQUS Standard. A three-dimensional finite element model of the drill consisting of eight-node diffusive heat transfer elements of type DC3D8 is illustrated in Figure. 2.1. The model is identical to the drills used in the experiments. The heat that enters the drill is modeled by applying heat flux to the elements on the chisel edge and primary cutting edges of the drill. All other surfaces of the model are adiabatic.

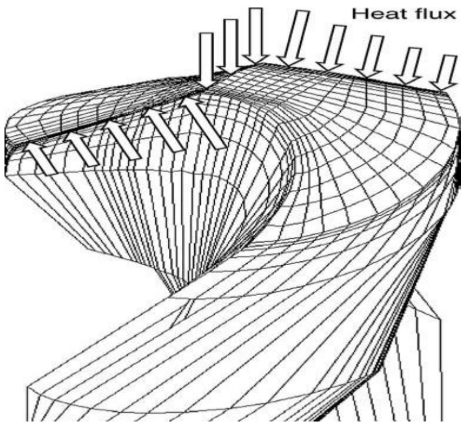


Figure. Finite element models of the drill and heat flux loads.

Investigation of the effect of drilling conditions on the twist drill temperature during step-by-step and continuous dry drilling;-

EyupBag ci.et al.[2],The drill bit temperature distributions measured by the thermocouple for twist drills method are presented experimentally during step-by-step and continuous dry drilling operation. In the drilling processes, cutting conditions have different spindle speed, drilling depth and feed rate are used. Drill temperatures are measured by inserting standard thermocouples through the

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coolant (oil) hole of TiAlN-coated carbide drills. Experimental study was conducted by using two different work piece materials, AISI 1040 steel and Al 7075- T651 alloy materials.

3, FINITE ELEMENT METHODS

The finite element method is numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering schools and industries. In more and more engineering situations today, we find that it is necessary to obtain approximate solutions to problems rather than exact closed form solution.

It is not possible to obtain analytical mathematical solutions for many engineering problems. An analytical solutions is a mathematical expression that gives the values of the desired unknown quantity at any location in the body, as consequence it is valid for infinite number of location in the body. For problems involving complex material properties and boundary conditions, the engineer resorts to numerical methods that provides approximate, but acceptable solutions.

The fundamental areas that have to be learned for working capability of finite element method include:

- MATRIX ALGEBRA.
- SOLID MECHANICS.
- VARIATION METHODS.
- COMPUTER SKILLS.

General Description of FEM:

In the finite element method, the actual continuum of body of matter like solid, liquid or gas is represented as an assemblage of sub divisions called Finite elements. These elements are considered to be inter connected at specified points known as nodes or nodal points. These nodes usually lie on the element boundaries where an adjacent element is considered to be connected. Since the actual variation of the field variables (like Displacement, stress, temperature, pressure and velocity) inside the continuum are is not know, we assume that the variation of the field variable inside a finite element can be approximated by a simple function. These approximating functions (also called interpolation models) are defined in terms of the values at the nodes. When the field equations (like equilibrium equations) for the whole continuum are written, the new unknown will be the nodal values of the field variable. By solving the field equations, which are generally in the form of the matrix equations, the nodal values of the field variables will be known. Once these are known, the approximating function defines the field variable throughout the assemblage of elements.

Limitation:

One limitation of finite element method is that a few complex phenomenons are not accommodated adequately by the method as its current state of development. Some examples of such phenomenon form the realm of solid mechanics are cracking and fracture behavior, contact problems, bond failures of composite materials, and non-linear material behavior with work softening. Another example is transient, unconfined seepage problems. The numerical solution of propagation or transient problem is not satisfactory in all respects. Many of these phenomenon's are presently under research and refinements of the methods to accommodate these problems better can be expected

4, MODELING AND MESHING

Catia modeling;- The setup is modeled using the CATIA V5 R20 modeling package – Then CATIA modeling is converted to STEP file (stp) format processing by the solver package.

MODELLING OF TWIST DRILL WITHOUT HEAT PIPE

- Dimensions of twist drill:
- Total length = 268 mm
- Flat tang (breath) = 18.2 mm
- Flat tang (width) = 7.8 mm
- Shank length = 81mm
- Shank small diameter = 20.1 mm

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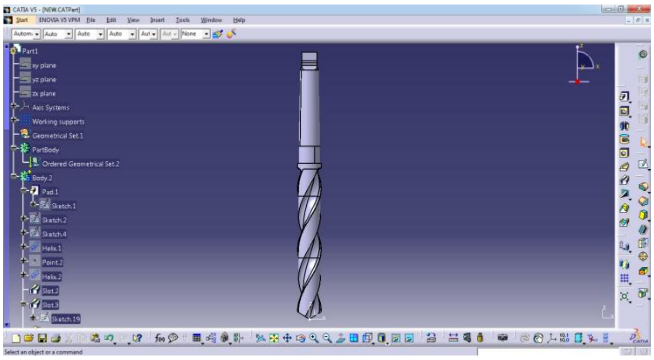
- Shank large diameter = 23.6 mm
- Cut shank length = 18 mm
- Cut shank diameter = 23.1 mm
- Flute length = 154.6 mm
- Drill diameter = 25.4mm



MODELLING OF TWIST DRILL WITH HEAT PIPE

Dimensioning of the heat pipe

- Diameter of heat pipe = 6.35 mm
- Length of the heat pipe = 236.6 mm
- Clearance of tip and heat pipe = 25.4 mm

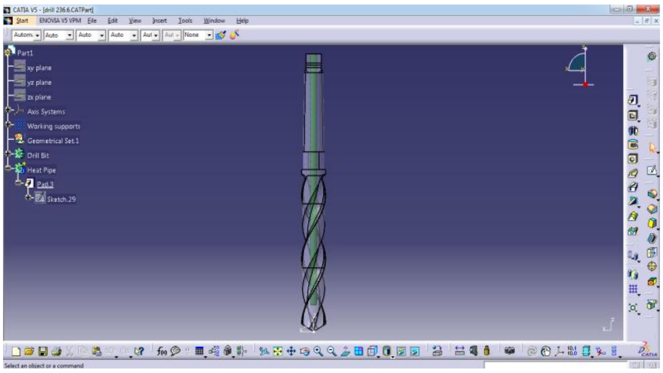


Figure. Modeling of Twist Drill with Heat Pipe

DENSITY OF HEAT PIPE:

$V_1 = \pi r^2 h$, For unit length:

V_1 -Volume of COTS wall

r - Radius of heat pipe

h - Height of heat pipe

Wall thickness =1mm

$$V_1 = [\pi\,(6.35 \times 10^{-3})^2(1) - \pi\,(5.35 \times 10^{-3})^2\,(1)]$$

$= (10^{-6} \times \pi)\ m^3$

Water – Working fluid,

V_2- Volume of working fluid

$V_2 = [\pi(5.35 \times 10^{-3})^2(1)]$

Mass = Volume × Density

Mass of Heat pipe = Mass of COTS wall + Mass of water

$= [(10^{-6} \times \pi \times 8940) + (\pi \times (5.35 \times 10^{-3})^2 \times 1000)]kg$

$$\text{Density of heat pipe} = \frac{\text{mass of heat pipe}}{\text{volume of heat pipe}}$$

$$= \frac{[(10^{-6} \times \pi \times 8940) + \{\pi \times (5.35 \times 10^{-3})^2 \times 1000\}]}{\pi \times (6.35 \times 10^{-3})^2 \times (1)}$$

$= 931.5\ kg/m^3$.

$$= \frac{[(10^{-6} \times \pi \times 8940) + \{\pi \times (5.35 \times 10^{-3})^2 \times 1000\}]}{\pi \times (6.35 \times 10^{-3})^2 \times (1)}$$

$= 931.5\ kg/m^3$.

Meshing

Meshing is done by using ANSYS Workbench 12.0. ANSYS used tetrahedrons method with smoothing medium. The nodes and elements as varied based on with and without heat pipe of twist drill model. By Comparison of the different models, with heat pipe has more number of nodes and elements.

TWIST DRILL WITHOUT HEAT PIPE

- Relevance : 100
- Nodes : 24814
- Elements : 15244

TWIST DRILL WITH HEAT PIPE

- Relevance : 100
- Nodes : 27173
- Elements : 15928

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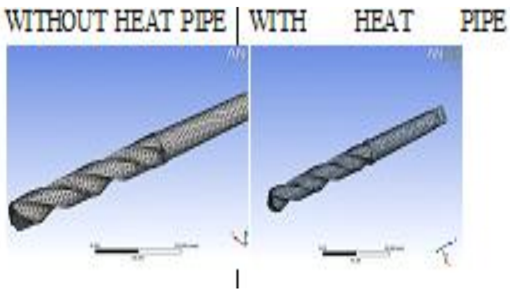

Figure. Meshing of with and without Heat Pipe-Twist Drill

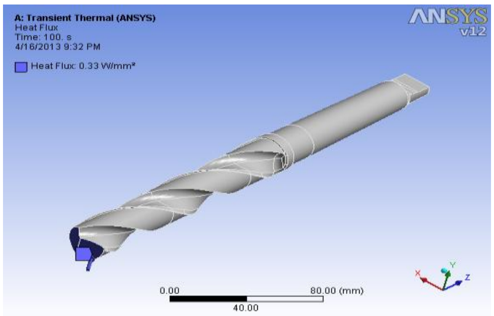

Figure. Heat flux Load on Twist Drill

5, ANALYSIS OF TWIST DRILL WITH AND WITHOUT HEAT PIPE

TRANSIENT THERMAL ANALYSIS

The transient thermal analysis was based on the following common assumption

- Heat flow inside or outside the system.
- Rate of change of temperature with time, and
- Rate of change of energy within the system.

MATERIAL PROPERTIES

Table. Material Properties

Component	Material	Density(ρ) kg/m³	Specific heat capacity (Cₚ) J/kg-k	Thermal conductivity (k) W/m-k
Heat pipe	COTS	932	4187	10000
Twist drill tool	HSS	7850	460	40

BOUNDARY CONDITIONS

The Heat flux load and Initial temperature elements are the two main factors for the boundary conditions.

APPLYING HEAT FLUX LOAD

For transient thermal analysis, heat flux load will be applied in the tool tip of the surfaces.

- Heat flux load is given on the Z axis.
- All the other side is kept as a default value.
- Five different values of heat flux load are given as an input for with and without heat pipe and transient temperature analysis is performed to check the temperature.

6, RESULTS & DISCUSSION

Transient thermal analysis results

- Five different types of heat flux load are given and the transient temperature is found out (without and with heat pipe) in twist drill.
- For a comparison of without and with heat pipe of twist drill, graph has been plotted considering Time as X axis and Temperature as Y axis.
- The below graphs and tables are showing the results of without and with heat pipe in twist drill.

S.No	Heat flux, W/mm²	Temperature without heat pipe (°C)	Temperature with heat pipe (°C)	Temperature difference (°C)
1.	0.33	409	342	67
2.	0.50	605	504	101
3.	0.60	720	598	122
4.	0.80	951	788	163
5.	1	1181	978	203

Temperature of without and with Heat Pipe

7, CONCLUSION

In this study the transient thermal analysis is carried out by different heat flux loads in twist drill. The inserted heat pipe in a twist drill has a significant effect on the temperature drop at the drill tip surface. Transient thermal analysis shows that the use of a heat pipe inside the drill reduces the temperature field significantly. By the results it is concluded that with

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heat pipe modification on twist drill application, more cooling take place which reduces the twist drill temperature simultaneously.

FUTURE WORK

The results of this study have provided valuable preliminary information on the heat pipe cooling in drilling operations. Based on this analysis, several drills can be designed & manufactured to get the actual results on the physical application. In addition, further analysis of the heat pipe concept, particularly under the effect of rotation, is necessary.

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