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Geometric Optimization of 'U'-Drill Cutting Edge by Finite Element Analysis (FEA) and its Experimental Validation

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Abstract— **Drilling is one of the most important processes in metal machining. Where Indexable 'U' Drills are one of the tools uses for Drilling Short Length Holes at the lower cost. The Carbide Inserts Mounted on at front of 'U' Drill as a Cutting Edge. There are a lot of factors associated with Drilling performance, Drilling load on machine Spindle and Insert edge life i.e. Chip Cutting Angle, Center Height of Cutting edge, Working Length, Clearance, Vibrations generates while drilling Process etc. Therefore, the good prediction Cutting forces in drilling are essential to obtain the good description of the Drilling process to optimize the tool and insert geometry. In this paper, our aim is to finding a 'U' Drill body which produces minimum drilling forces on carbide drilling edge & on tool Body. Computer Aided Engineering (CAE) comparison is carried out between different 'U' Drills models having individual Drilling Geometry in which factors consider are as Cutting Forces, Strains & Stresses on Insert Edge of different models of 'U' Drill. By comparison of 'U' Drill Models on Finite Element Analysis we found a 'U' Drill Model which produces lower Drilling forces on Drilling Edge as well as on tool Body. With refer to obtained Computer Aided Engineering (CAE) results a drilling life for 'U' Drill is compared experimentally.**

Keywords— Center Height, Computer Aided Engineering, Cutting Forces, Drilling, Drilling Load, Indexable Carbide Inserts, 'U' Drill

I. INTRODUCTION

Mechanical drilling are one of the necessary machining process to remove material in circular form. Drill type is chosen by considering hole size, material of work piece, and cutting condition, In indexable 'U' Drill two or more than two inserts are used uses for making a hole, but majorly most of 'U' Drill having only two inserts for drilling a hole, In which a one insert uses for cutting the center, and another insert uses for the cutting the Peripheral part of the hole. Generally, this two insert are not same in geometry – even if the inserts are same. The reason behind this is the cutting conditions of this two inserts are not same as they are working in a different average cutting speed and a particular and different load conditions. Thus, each inserts having its own cutting Geometry [3]. The efficiency of drilling Process can be improved by continuous improvement in carbide Insert Geometry. For a particular material under a suitable mechanical machining condition requires an optimal set of parameter – Machining and Cutting Tool Geometry. Tools Cutting life can be found by cutting test under actual operating conditions [7].

In this paper to finding the optimal cutting Geometry; Finite Element Analysis (FEA) analysis has carried out of six different models with different drilling Geometry while kept Drilling Speed & Feed Constant, where the aim is to find & study the zones on drilling edge where the larger and lower drilling forces generate, and the geometry which gives less drilling forces on drilling edge of inserts can considered as the optimized drilling geometry, the experimental test has been carried out to find the Finite Element Analysis (FEA) result is satisfactory or not.

This paper proposes a study of Different samples 'U' Drill models (Table No.VI) by keeping Drilling Speed & Feed Constant. In this work a study of a number of holes drilled for 'U' Drills are studied and a drilling life (maximum drilled holes) of 'U' Drill is studied for the result of Maximum number of drilling cycles is founded for every 'U' Drill model.

The tools studied in this work are an Indexable type 'U' Drills with two Indexable inserts. The paper proposes Computer Aided Engineering (CAE) comparisons of 'U' Drill Models, and validation of 'U' Drill Sample for drilling life experimentally i.e. Maximum number of drilled holes, for a particular 'U' Drill sample. (Table No. VIII)

II. NOMENCLATURE

TABLE I

Symbol	Description
n	Spindle speed [rpm]
V_c	Cutting speed [m/min]
D_c	Drill diameter [mm]
V_f	Penetration rate [mm/min]
f_n	Feed per revolution [mm/rev]
P_c	Power consumption [kW]
K_{c1}	Specific cutting force [N/mm2]
M_c	Torque [Nm]
f_z	Feed per edge [mm]
K_r	Cutting Approach angle from rotational Axis [degree]
γ_0	Chip Clearance angle of Insert [degree]
F_t	Feed force [N]
Y_o	Positive Center Height of Peripheral Cutting Insert[mm]
Y_i	Negative Center Height of Center Cutting Insert[mm]
A_o	Cutting Approach angle of Peripheral Cutting Insert[degree]
A_i	Cutting Approach angle of Center Cutting Insert[degree]
X_d	Dimensional Difference between Peripheral & Center Cutting Insert[mm]

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III. THEORY

Cutting Speed (V_c) for an indexable Drills increases zero at center to 100% at periphery[3], where central Insert operates from cutting speed zero to 50%of maximum $V_{c.,}$ While peripheral insert works between 50% to 100% of maximum $V_{c,.}$ V_c effects on Power Consumption and Torque, It is the largest factor which determines tool life [3].

High cutting speed causes plastic deformation, poor surface finish of hole, improper hole tolerance, rapid flank wear; where low cutting speed creates buildup edge, long time to cut material etc. [3].

Feed rate (F_n) affects the feed force (F_f), Power (P_c) and Torque (T_c). It controls chip formation on top of the insert, and contributes in mechanical &Thermal stress. High feed rate causes harder chip breaking, reduces time of cut, where low feed rate causes higher risk of drill breakage and low hole quality [5].

By the help of imperial formulas [4], we can able to find Cutting Speed (V_c), Rate of penetration (V_f), Approximate Calculations for Power Consumption (P_c), Theoretical Torque (M_c), Feed Force (F_t) etc. the use of this theoretical calculation in necessary for first assumption of applying load on ‘U’ Drill while carrying FEA analysis.

The calculations for Cutting Speed (V_c), Rate of penetration (V_f), Approximate Calculations for Power Consumption (P_c), Theoretical Torque (M_c), Feed Force (F_t) are stated below.

- Cutting Speed (V_c) :

$$V_c = (\pi \times D \times n) / 1000 \quad (m/min)$$

$$= (\pi \times 35.0 \times 780) / 1000$$

$$V_c = 857.65 \ (m/min)$$

- Rate of penetration(V_f)

$$V_f = fn \times n \ (mm/min)$$

$$= 0.0939 \text{ x } 780$$

$$V_f = 73.3 \ (mm/min)$$

- Theoretical Power Consumption (P_c)

$$P_c = (fn \times Vc \times Dc \times Kc1) / (240 \times 10^3) \quad (Kw)$$

$$= (0.0939 \times 85.76 \times 35.00 \times 3050) / (240 \times 10^3)$$

$$= 859643.232 / (240 \times 10^3)$$

$$P_c = 3.582 \ (kW)$$

- Theoretical Torque (M_c)

$$M_c = (Pc \times 30 \times 10^3) / (\pi \times n) \quad (Nm)$$

$$= (3.582 \times 30 \times 10^3) / (\pi \times 780)$$

$$= 107460 / (\pi \times 780)$$

$$M_c = 190.03 (N.m)$$

- $K_c = K_{c1} \ (f_z \times \text{Sin } K_r)^{-mc} \times (1-(\gamma_0 / 100))$

$$= 3050 \times (73.3 \times \text{Sin } 86)^{-0.25} \times (1-(8 / 100))$$

TABLE II

SPECIFIC CUTTING FORCE, K_c FOR SAMPLES OF ‘U’ DRILL

Sample	K_r [degree]	K_c [N/mm2]
Sample 1	85	205875.9
Sample 2	86	205805.2
Sample 3	87	205750.3
Sample 4	88	205711.1
Sample 5	89	205687.6
Sample 6	90	205609.8

- Actual Power Consumption (P_c)

$$P_c = (fn \times Vc \times Dc \times Kc) / (240 \times 10^3) \ \ kW$$

$$= (0.0939 \times 85.76 \times 35.0 \times Kc)/(240 \times 10^3)$$

TABLE III

ACTUAL POWER CONSUMPTION PC FOR SAMPLES OF ‘U’ DRILL

Sample	K_r [degree]	Pc [kW]
Sample 1	85	2.48
Sample 2	86	2.42
Sample 3	87	2.42
Sample 4	88	2.42
Sample 5	89	2.41
Sample 6	90	2.41

- Feed Force (F_t)

$$F_t \approx 0.5 \times K_c \ (Dc / 2 \ fn) \times \text{Sin } K_r \ (N)$$

$$F_t \approx 0.5 \times K_c \ (35.0 / 2 \times 0.0939) \ \text{Sin } K_r \ (N)$$

TABLE IV

FEED FORCE (FT) FOR SAMPLES OF ‘U’ DRILL

Sample	K_r [degree]	Kc [N/mm2]	F_t [N]
Sample 1	85	205875.9	168509.1
Sample 2	86	205805.2	168602.8
Sample 3	87	205750.3	168817.9
Sample 4	88	205711.1	168914.4
Sample 5	89	205687.6	168972.3
Sample 6	90	205609.8	168934.0

IV. COMPUTER AIDED ENGINEERING (CAE) OPTIMIZATION USING ‘ANSYS 14.5’

Nowadays CAE has become the important tool for pre-manufacturing Analysis. CAE of cutting tool plays a major role due to cost and time consumption took by actual cutting test and gives nearby results to the actual experimental results[9], hence it is preferred than the experimental work. CAE prove to be an effectively helpful technique for analysis of chip formation, temperature distribution, stress & strains produced in Cutting tools when it is in working condition.

CATIA- A 3D modeling application used for modeling of Drilling Process Tool & Components.

TABLE V
MATERIAL PROPERTIES DETAILS [2]

Description	EN 47	SAE1030	Tungsten Carbide	Stainless Steel 304
Density [kg/m3]	7700	7850	14200	8000
Poisson's Ratio	0.29	0.3	0.31	0.29
Thermal Conductivity [W/m.K]	25	51.9	96	16.2
Coefficient of Linear Thermal Expansion [μm/m°C]	4.19	11.7	5.9	17.3
Specific Heat[J/kg.K]	460	450	945	500
Young's modulus[GPa]	200	210	615	203
Shear modulus[GPa]	80	80	274	86
Ultimate tensile strength [MPa]	670	525	344	505
Yield strength [MPa]	415	440	550	215
Thermal expansion [μm/m-K]	10	11.9	5.9	18

Ansys 14.5 – a CAE application used for the analysis of cutting loads, stress and strains, Forces Generated while cutting in 'U' Drill as well as a workpiece[8],[9].

The workpiece material used for the drilling analysis is SAE1030 Steel. The material is used in construction & engineering adequate strength is required in static loading. The material of Carbide Insert used in study is TiN Coated Tungsten Carbide Insert.

Based on characteristics as per Table No VI a CAE is carried out considering output characteristics as Loads on Cutting Edge, Resultant cutting forces, Principal Stresses[7].

By the comparison of load factors, we find the 'U' Drill sample No.3 is found with the lower cutting forces generates while working. The Quality Characteristics obtained given below table.

TABLE VI
QUALITY CHARACTERISTIC OF OPTIMIZED TOOL GEOMETRY

Sample	Inter-face Temp. [˚C]	Interface Cutting Pressure. [MPA]	Cutting Force (Fx) [N]	Cutting Force (Fy) [N]	Cutting Force (Fz) [N]
Sample No.3	491	9731	32.18	328.06	49.660

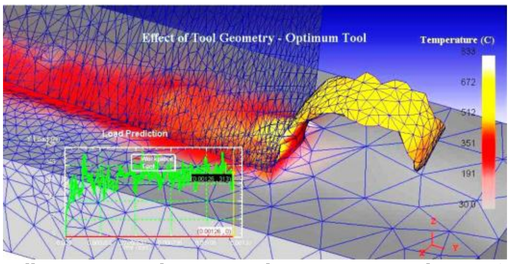

Fig. 1.Drilling, Optimized cutting angle Geometry Sample No.3 (A_O=3˚).

Fig. 1 shows a chip formation in the case of drilling SAE 1030 steel with optimized tool geometry, the loads acted on the cutting edge shows, at the start of drilling the load acting on cutting edge is higher, which get uniform further drilling.

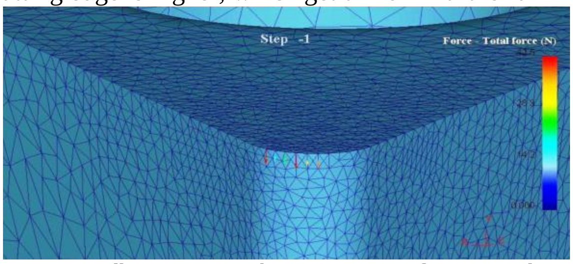

Fig. 2.Drilling Force Distribution in optimized cutting angle Geometry, Sample No.3 (A_O= 3˚).

Fig. 2 shows the cutting force distribution on cutting edge of the insert. It has been observed that maximum cutting forces produce at the center cutting zone of drilled hole.

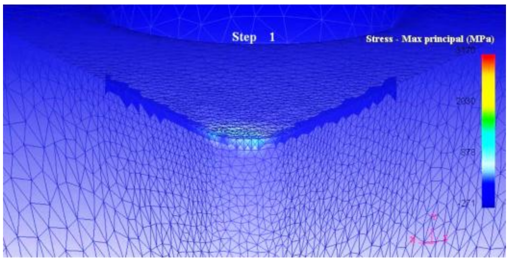

Fig. 3.Maximum Principal Stress in optimized Sample No.3 Cutting angle Geometry (A_O= 3˚).

Fig. 3 shows max. Principle stress acting on carbide cutting edge, it has been observed that maximum stress concentration is found at the center cutting zone, where drilling takes place.

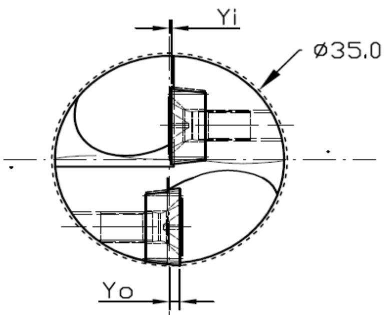

Fig. 4.Front View of 'U' Drill Body with Carbide Insert Mounted on it.

V. EXPERIMENTAL TESTS AND RESULTS

A set of experiments were conducted to measure the effective cutting life on a particular cutting geometry of the insert.

A Sharptech Corporation makes 'U' Drill with a diameter 35 [mm] was mounted on an SPM which is use for a drilling hole horizontally in a workpiece i.e. fixed in a fixture on a non-moving table as shown in "Fig. no . 01". And the spindle on which tool is mounted is rotating at fixed defined speed and also having a constant feed to 'Y' Axis which means A machine with a Rotating tool with a fix feeding movement in a single Direction. The carbide insert is used for the experiment is 'CERATIZIT' make SCLT 125008 with 'ISO-HC P40' Grade. The 'U' Drill sample details are given in table below,

TABLE VII
EXPERIMENTAL 'U' DRILL GEOMETRY DETAILS

Sample	Y_0 [mm]	Y_i [mm]	A_o [degree]	A_i [degree]	X_d [mm]
Sample 1	0.05	-0.01	5	-5	0.14
Sample 2	0.5	-0.10	4	-4	0.14
Sample 3	1.0	-0.20	3	-3	0.18
Sample 4	1.5	-0.30	2	-2	0.14
Sample 5	2.0	-0.40	1	-1	0.18
Sample 6	2.5	-0.50	0	0	0.17

The experiment carried out by keeping machining conditions constant, as per given in below table,

TABLE VIII
MACHINING CONDITIONS

Parameter	Value
Work Piece Material	SAE 1030 Forged Steel
Insert	SCLT 125008 –ISO-HC P40
Cutting Speed [V_c]	85.76 [m/min]
Feed Rate [V_f]	73.3 [mm/min]
Spindle Speed [n]	780 RPM
Drilling Length	52 [mm]

Fig.5.'U' Drill Models used for experimental work, Respective Details are in 'TABLE NO VI'.

While carrying experiment we keep machining condition constant thoroughly, and the main aim of keeping this conditions uniform is to avoid wrong observation [3]. The result obtained by the experiments are given below

TABLE IX
EXPERIMENTAL RESULT AND REMARK

Sample	No. of drilled holes per cutting edge effectively	Remark for cutting edge by visual inspection
Sample 1	219 Nos.	Inner Insert wears more than Peripheral insert
Sample 2	239 Nos.	Inner insert warns out little bit more than the peripheral insert
Sample 3	276 Nos.	Wearing Occurred same for both insert Excluding Center Cutting Zone
Sample 4	194 Nos.	Wearing of peripheral insert is more than the center cutting
Sample 5	162 Nos.	Wearing occurred at higher rate at end life for outer insert
Sample 6	145 Nos.	Wear rate is highest for both inserts

By the results obtained by experiment we observed that while keeping insert angle '0' to '2' Degrees we get comparatively more life (Sample No. 1 to 3) then the remaining samples (Sample No. 4 to 6), as the angle increases the tool gets drilling stability and roughness

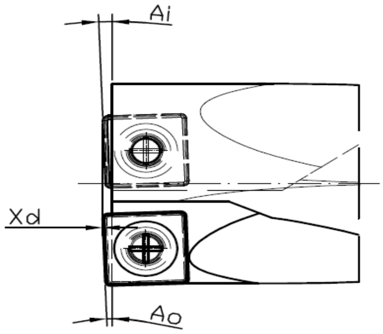

Fig. 6.Top View of 'U' Drill Body with Carbide Insert Mounted on it.

of machined surface is acceptable, due to low center height of Cutting edge vibrations in drilling is lower in this tools, this is the main reason which affects the tool life, In case of other three samples (Sample No. 4 to 6) the center height is more and cutting angle is lower which causes instability in drilling process, due to which vibrations occur at a higher rates hence causes lower cutting life.

The cutting load at a center side is much higher than the peripheral insert, due to which wearing starts too early in center side of the hole then the peripheral side, the above observation is applicable for every sample of 'U ' Drill.

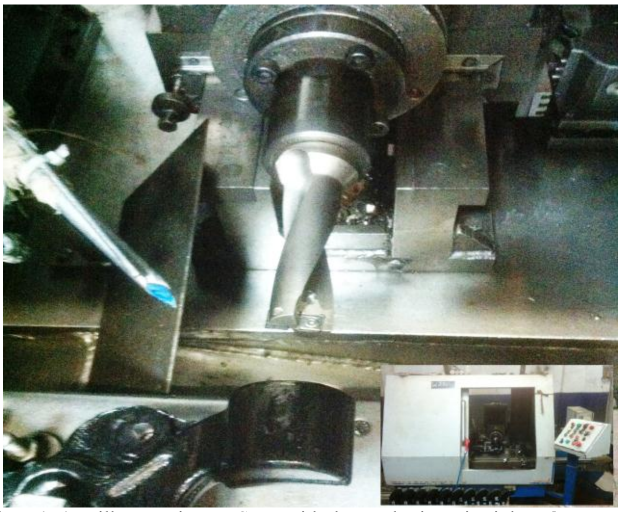

Fig. 7.'U' Drill Mounting on SPM with the work piece, in right side Bottom inset view of Actual view of SPM Machine.

VI. CONCLUSION

This work attempts to find the optimized 'U' Drill, by CAE Analysis &validation by Experimental results, following conclusions can be drawn

1. From the Computer Aided Engineering (CAE) analysis as well as experimental observation we found by compering all of 'U' Drill Sample, Sample No. 3 is found with optimized drilling geometry which gives a highest Drilling Life with lower drilling loads on Cutting Edge and 'U' Drill Inserts.
2. Increase in Center Height from its axial Center causes vibrations in Drilling Process.
3. The 'U' Drill found as an Optimum for Drilling by Finite Element Analysis and validated by experimental analysis, this is found correct as optimized Tool ('U' Drill Sample No.3).
4. By the study we also find that the wear rate of insert is higher at the Center of Drilled hole while at coming towers periphery wear rate Decreases.
5. Angular Inclination of insert (A_o & A_i) causes stability of 'U' Drill in Drilling & gives Distributed Cutting Forces in Two Perpendicular directions which is Plane created by axial & Radial Directions.

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