Numerical Analysis to Determine the Distribution of Tool Forces and Temperatures of Single Point Cutting Tool

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Abstract: ***This paper presents a methodology to determine tool forces, distribution of temperatures to estimate distribution of stresses and deformation on the single point cutting tool in the process of metal cutting. In mechanism of metal cutting a cutting tool exerts a compressive force on the work piece. Under this compressive force the material of the work piece is stressed beyond its yield point causing the material to deform plastically and shear off. The sheared material begins to flow along the cutting tool face in the form of small pieces called chips .The flowing chips causes the wear of cutting tool. Heat is produced during shearing action the heat generated raises the temperature of tool, work and chips. The temperature rise in cutting tool tends to soften it and causes loss of keenness in the cutting edge leading to its failure. This temperature during metal cutting is to be maximum at the tip of the tool, is too measured by experimental set up and which are required as input to the software and analyzes the stresses and deformation on the single point cutting tool. Now manufacturing industries are mostly concentrating on a cost reduction. When it is not possible to reduce the fixed cost, it is necessary to concentrate on variable cost like electricity, cutting fluids, cotton waste, oil grease, welding rods, cutting tools etc.***

Keywords: forces, temperatures, yield point, deform plastically, wear, analyses, stresses, deformation, variable cost.

1. Introduction

There has been a considerable amount of research devoted to develop analytical and numeric models in order to simulate metal cutting processes to predict the effects of machining variables such as speed, feed, and depth of cut on tool geometry, stresses and deformations of tool. Especially, numerical models are highly essential in predicting chip formation, computing forces, distributions of strain, strain rate, temperatures and stresses on the cutting edge and the machined work surface. Advanced process simulation techniques are necessary in order to study the influence of the tool edge geometry and cutting conditions on the surface integrity especially on the machining induced stresses. It has been repeatedly overstressed that a good understanding of metal cutting mechanics and reliable work material flow stress data and friction characteristics between the work material and the cutting tool edges must be generated for high-speed cutting conditions. The objective is to analyze the effect of machining variables such as speed, depth of cut, temperature, and cutting forces on the tool by using modeling and analysis software ANSYS.

2. Types of Cutting Tool

There are two types of cutting tool:

a. Single point cutting tool
b. Multi point cutting tool

2.1 Single Point Cutting Tool

A single point cutting tool has only one cutting point or edge. A single point cutting tool consists of a sharpened cutting part called its point and shank. The single point cutting tool used for turning, boring, shaping and planning operations, that is, tool used on lathes, boring machines, shaper, planer etc. are single point cutting tool.

2.2 Geometry of Single Point Cutting Tool

Tool geometry concerns with the basic tool angles, i.e. angles ground on tool to make it efficient in cutting. A single point tool has only one cutting edge and is most widely used in industries. It is designed with sharp edges to minimize rubbing contact between tool and work-piece. Factors like cutting tool life, surface finish on work piece, force required to shear a chip are affected by variations in shape of cutting tool.

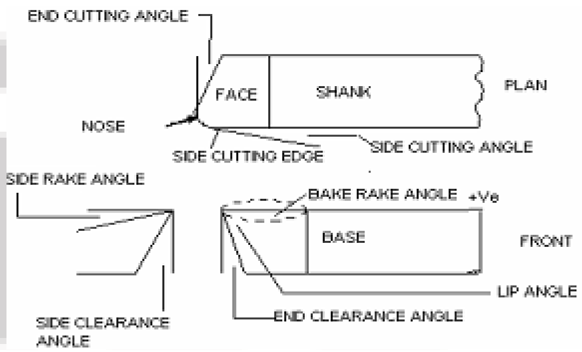


Figure 2.1: Cutting Angles of Single Point Cutting Tool

2.3 Selection of Tool Material

Requirement of tool material:

To get a reasonable tool life, the tool material should meet the following requirements:

1) Hot hardness, so that the tool does not lose its hardness and strength at the high temperatures developed during machining.
2) Wear and abrasion resistance, so that the tool retains its shape and cutting efficiency for a reasonably long time before it is reconditioned or replaced.
3) Impact toughness, so that the fine cutting edge of the tool does not break or chip, when the tool is suddenly loaded.

In addition to the above basic requirements, the tool material should possess the following properties: increased thermal conductivity, lower co-efficient of thermal expansion, lower chemical and mechanical affinity for the work material and it should be easy to form, grind and sharpen to the desired tool geometry.

The selection of a proper tool-material depends upon a number of factors such as: type of cutting operation, material of the work piece, machine tool to be used and surface finish required. Usually, a compromise has to be made in the selection of tool-material, since the requirements to be met by tool material are often contradictory in nature. Over the years, a wide variety of cutting tool materials has been developed to meet the ever increasing demand of machining harder and harder materials. The various cutting tool-materials can be grouped as follows:

1. Plain Carbon Steels
2. Medium Alloy Steels
3. High Speed Steels (H.S.S.)
4. Non-ferrous Cast alloys
5. Cemented Carbides
6. Ceramics or Oxides
7. Cermets
8. Diamond
9. Cubic Boron Nitride (CBN)
10. UCON
11. Sialon
12. Coronite

Plain carbon steels, Medium alloy steels and High speed steels are known as "Tool Steels". Medium alloy steels and high speed steels contain one or more alloying elements to impart the desired properties to the cutting tools.

2.4 Function of Each Alloying Element Is Given Below

(i) Carbon
Carbon combines with iron to form carbide which makes it respond to hardening, thus increasing the hardness, strength and wear resistance. The percentage of carbon varies from 0.6 to 1.4%.

(ii) Manganese
It is added to steels as a deoxidizing and desulphurizing agent. It lower the critical range of temperature .It increases the time required for transformation, so that, oil quenching, becomes practicable. Its content is about 0.5 to 2%.

(iii) Chromium
The addition of chromium results in the formation of various carbides on chromium which are very hard, yet the resulting steel is more ductile than a steel of the same hardness produced by a simple increase in carbon content. Chromium also refines the grain structure so that, these two combined effects result in both increased toughness and hardness. The addition of chromium increases the critical range of temperature and raises the strength at high temperatures. Alloy of chromium resists abrasion and wear. Its content ranges from 0.251 to 4.5%.

(iv) Molybdenum
Molybdenum is a strong carbide forming element and its action is very much like chromium but is more powerful. It increases strength, wear resistance, hardness penetration and hot hardness. It is always used in conjunction with other alloying elements. Its content ranges up to about 10%.

(v) Cobalt
Cobalt is commonly used in high speed steels to increase the hot hardness so that the cutting tools can be used at higher cutting speeds and temperatures and still they retain their hardness and a sharp cutting edge. Its content ranges from 5 to 12%.

(vi) Vanadium
It increases hot hardness and abrasion resistance. As vanadium has a very strong tendency to form carbides, hence, it is used only in small amounts (0.2 to 0.5% in alloy carbon tool steels and I to 5% in H.S.S).

(vii) Tungsten
It is widely used in tool steels because the tool maintains its hardness even at red heat. Tungsten produces a fine dense structure and adds both toughness and hardness effect is similar to molybdenum except that it must be added in greater quantity (1.5 to 20%)

Note: Most of the tool-steels contain two or three alloying elements, as the combine action of several elements is more effective than that of one element even when its content it steel is considerable.

2.6 Cutting Tool Materials

a) Plain Carbon Tool Steels
b) Alloy Tool Steels
c) High Speed Steel (H.S.S.)
d) Non Ferrous Cast Alloy (stelIite)
e) Sintered or Cemented Carbides
f) Cubic Boron Nitride (CBN)
g) UCON
h) Sialon (SiAION)
i) Coronite
j) Ceramics (Cemented Oxides)
k) KYON
l) Diamond

3. Tool Life

3.1 Introduction

When it is not possible to reduce the fixed cost, it is necessary to concentrate on variable cost like, electricity, cutting fluids, cotton waste, oil grease, welding rods, cutting tools, etc. Of all the factors, the cost of the cutting tool is very high. Tools of H.S.S., carbide, diamond tip are costing very high. Therefore, it is necessary to pay attention to increase the tool life. As tool life increases, the variable cost decreases. The tool life depends upon the following factor,

1. Speed.
2. Feed.
3. Depth of Cut.
4. Various Angles.

To increase the tool life the above factors should be optimized. From the several years, these factors have been calculated analytically by Taylor's Equation with some assumption. However, it is not too, reliable for real time information.

3.2 Tool life of Cutting Tools

"The life is defined as the time elapsed between two successive grindings of the tool." During this period the tool cuts efficiently and effectively. Cutting tool life is one of the most important economic considerations in metal cutting. The cutting tool should have longer life. Conditions giving a very short tool life will be uneconomical because tool grinding & tool replacement cost will be high. There are number of ways of expressing tool life such as;

1) Volume of metal removed
2) Number of work pieces machined
3) Time unit

It is most commonly expressed in 'Minutes'

3.3 Factors affecting the tool life

The life of cutting tool is affected by the various factors mentioned below;

1) Machining Variables
  i) Cutting speed.
  ii) Feed
  iii) Depth of Cut.
2) Type of cutting such as conditions and intermittent cutting.
3) Tool geometry
4) Tool material
5) Machining Condition
  i) Temperature of the work & tool.
  ii) Type of cutting fluid used.
6) Properties of material being cut.
  i) Microstructure of work pieces material
  ii) Tensile strength and hardness of material.
  iii) Degree to which the material cold works.

3.4 The life of cutting tool is expressed by 'TAYLOR'S EQUATION'

$VT^n = C$

Where

V = Cutting speed in meter/minutes

T = Tool life in minutes.

n & C are constant.

For High speed steel cutting steel – n = 0.1 & C = 50

For cemented carbide tool – n = 0.125 & C = 100.

3.5 Tool Wear

The temperatures over the contact surfaces are pretty high. Each time the tool enters or exits from the cut, it is subjected to mechanical as well as thermal shock. Under such adverse conditions, the hard tool materials like HSS and carbides, etc. Gradually wear out and even fracture, necessitating a tool change. The machine has to be stopped during the time the tool is being retracted, changed and returned into the cutting position. Precious machining time is lost in the process. Tool wear and the time between two successive tool changes (tool life) are, therefore, subjects of great importance in the theory and practice of metal cutting.

TOOL WEAR or tool failure may be classified as follows:

(a) Flank wear.
(b) Crater wear on tool face.
(c) Localized wear such as the rounding of the cutting edge, and
(d) Chipping off of the cutting edge.

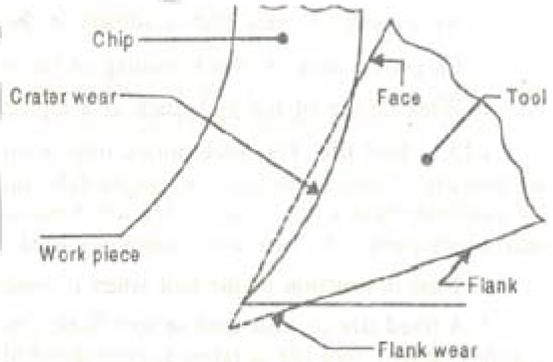


Figure 3.1 Tool wear

(a) FLANK WEAR is attributed usually to the following reasons:

1. Abrasion by hard particles and inclusions in the work piece.
2. Shearing of the micro welds between tool and work-material.
3. Abrasion by fragments of built-up edge plowing against the clearance face of the tool.

(b) CRATER WEAR usually occurs due to:

1. Severe abrasion between the chip and tool face
2. High temperatures in the tool-chip interface reaching the softening or melting temperature of tool resulting in increased rate of wear. The sharp increase in wear rate after the Interface temperature reaches a certain temperature is attributed to 'diffusion'. Diffusion is the movement of atoms between tool and chip materials resulting in loss of material from the face of the tool. It depends upon the chemical composition and microstructure of tool and work piece materials, in addition to temperature.

(c) NOSE WEAR may be one or more of the reasons discussed above. Chipping of the tool may occur due to the following factors:

1. Tool material is too brittle.
2. As a result of crack that is already in the tool.

3. Excessive static or shock loading of the tool.
4. Weak design of the tool, such as a high positive rake angle.

3.6 Tool Wear Mechanism

Shearing at High Temperature
The strength of hard metal decreases at high temperatures. Therefore, its shear yield stress becomes much smaller than what it is at room temperature.

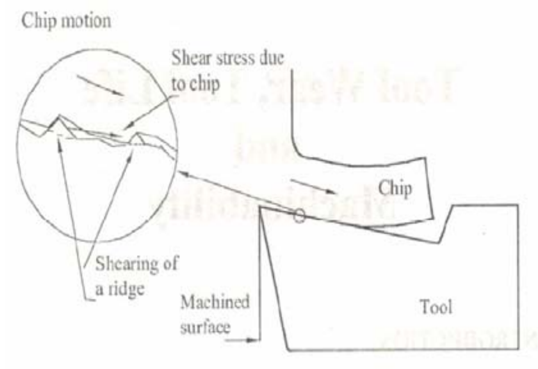


Figure 3.2 Wear by Plastic Yielding & Shear

3.6.1 Diffusion Wear

When a metal is in sliding contact with another metal and the temperature at their interface is high, conditions may become right for the alloying atoms from the harder metal to diffuse into the softer matrix, thereby increasing the latter's hardness and abrasive-ness (Fig.3.4). Diffusion phenomenon is strongly dependent upon temperature. For example, diffusion rate is approximately doubled for an increment of the order of 20°C in the case of machining steel with HSS tools. Fig.3.3 illustrates the diffusion process.

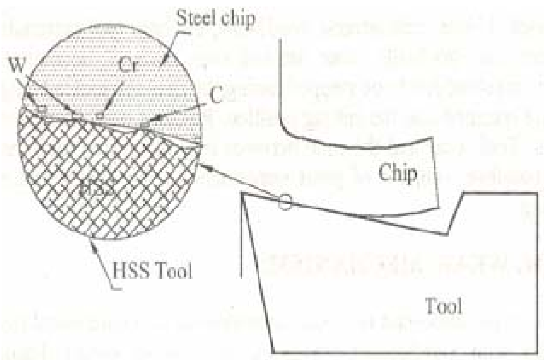


Figure 3.3 Diffusion wear Process

3.6.2 Abrasive Wear

The softer metal sliding over the surface of the harder metal may contain appreciable concentrations of hard particles. For examll1e, castings may have pockets of sand in them. In these conditions, the hard particles act as small cutting edges like those of a grinding wheel on the surface of a hard metal which in due course, is worn out through abrasion (Fig.3.4).

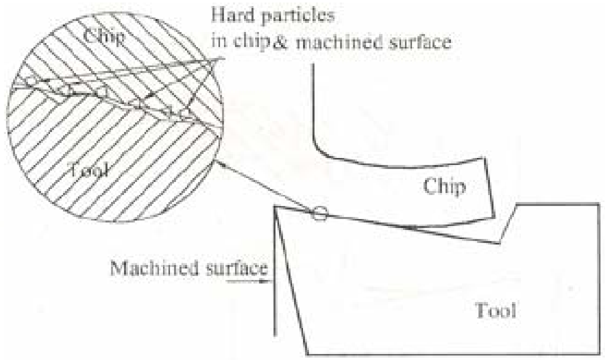


Figure 3.4 Abrasive Wear Mechanisms

3.6.3 Fatigue Wear

When two surface slide in contact with each other under pressure, asperities on one surface interlock with those of the other. Due to the frictional stress, compressive stress is produced on one side of each interlocking asperity and tensile stress on the other side (Fig.3.5). This phenomenon causes surface cracks which ultimately combine with one another and lead to the crumbling of the hard metal.

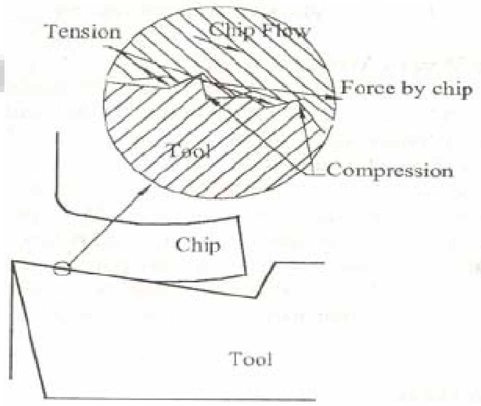


Figure 3.5 Fatigue Wear Mechanism

3.6.4 Electrochemical Effect

It has been argued that slice sufficiently high temperatures exist on the chip tool interface, a' thermoelectric emf is set up in the closed circuit due to the formation of a hot junction at the chip tool interface between the dissimilar tools and work materials.

3.6.5 Adhesive Wear (Attrition Wear)

Let a softer metal slide over a harder metal such that it always presents a newly formed (nascent) surface to the same portion of the hard metal. On account of friction, high temperature and pressure, particles of the softer material adhere to a few high spots of the harder metal (Fig.3.6). As a result, flow of the softer metal over the surface of the hard metal becomes irregular or less laminar, and contact between the two becomes less continuous.

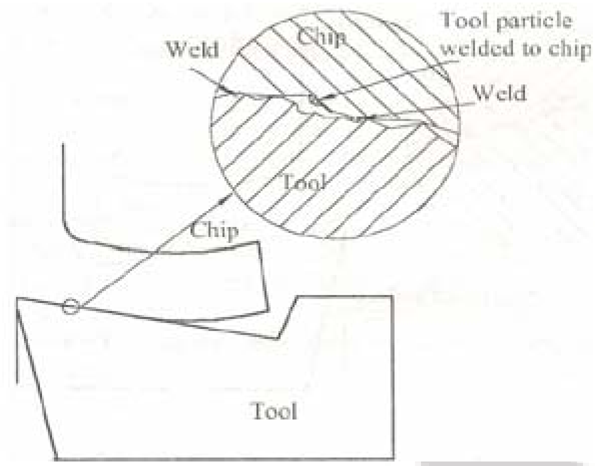


Figure 3.6 Adhesive Wear Mechanisms

3.6.6 Oxidation Effect

There is evidence to suggest that the formation of grooves or notches at the rake face and the flank is on account of the sliding of portions of the chip and t the machined surface which have reacted with the oxygen in the atmosphere to form abrasive oxides. For example, when machining a steel work piece with HSS or cemented carbide tools, groove formation is greatly accelerated if the cutting zone is subjected to a jet of oxygen.

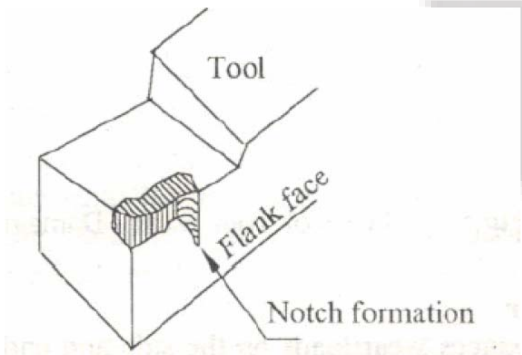


Figure 3.7 Formation of Notch or Groove

3.6.7 Chemical Decomposition

Localized chemical reactions may occur that weaken the tool material through formation of weak compounds or dissolution of the bond between the binder and the hard constituents in a carbide tool.

4. Experimental Work

A number of methods have been developed for the measurement of temperature in metal cutting, some of these methods only make it possible for average cutting temperature to be determined, but effective methods are available for determining temperature in the tool near the cutting edge.

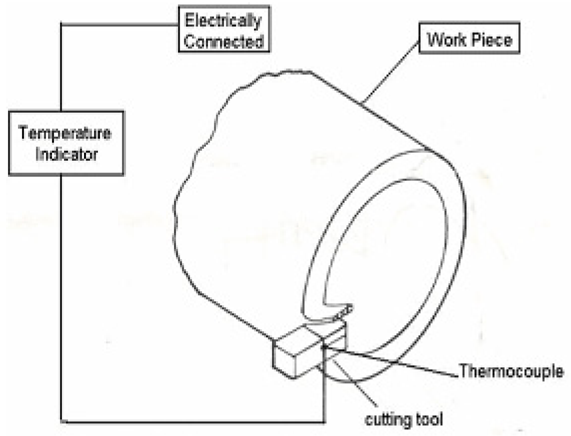


Figure 4.1 Temperature Measurements in Metal Cutting

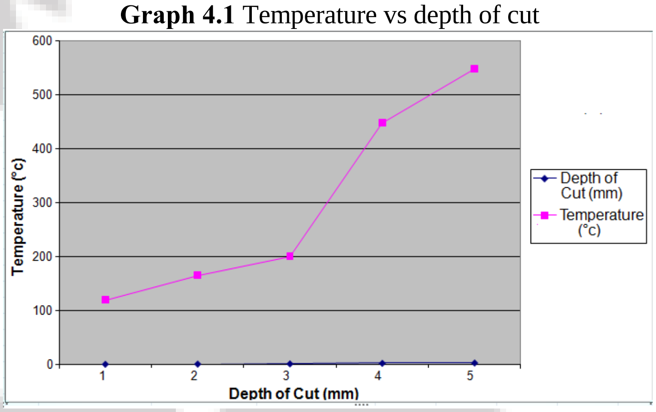
Figure 4.1 shows the temperature measurement set up. In this set up consist of Tool, Thermocouple, and Temperature indicator connected to the A.C supply.

4.1 Results from experimental setup

Table 4.1 Temperature at various depth of cut

Depth of Cut (mm)	*Maximum Temperature of tool tip (°c)*
0.2	119
0.5	165
1.0	200
2.0	448
2.5	548

Graph 4.1 Temperature vs depth of cut



5. Calculation of Cutting Forces

5.1 Determination of cutting forces acting on the tool in a lathe operation

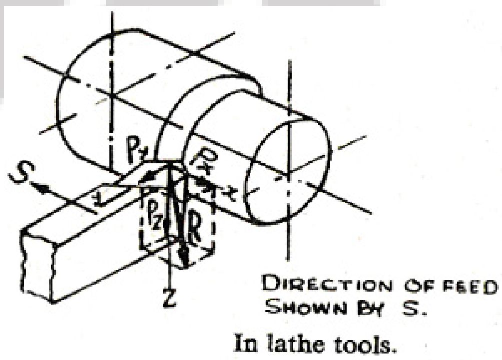


Figure 5.1: Components of Cutting Forces

In any metal cutting operation in a lathe there acts a force 'R' on the tool.
This
Force 'R' can be resolved into three components.
Py = in the horizontal plane, perpendicular to the direction of the feed;
Px = in horizontal plane against the direction of feed;
Pz = in vertical plane, perpendicular to both Py and Px

Empirical formula determining the Pz can be expressed as under
Pz= Cp×tx×Sy×K

Where,
Cp= coefficient, characterized by the work material and condition of working
Such as tool, coolant.
t = depth of cut
S = feed in mm/revolution
K = overall correlation, consisting of actual condition of working and tool angles, which varies from 0.9 to 1.0
K= Kc×Kσ×Kϕ×Km

Where,
Kc = Correction coefficient for coolant.
Kϕ = Correction coefficient depending upon the entering angle.
Kσ = correction coefficient depending upon the back rack angle.
Km = correction coefficient depending upon the material.

For Depth of cut = 0.2 mm
Feed = 0.521 mm/revolution
Cp = 225
x = 1.00
y = 0.75

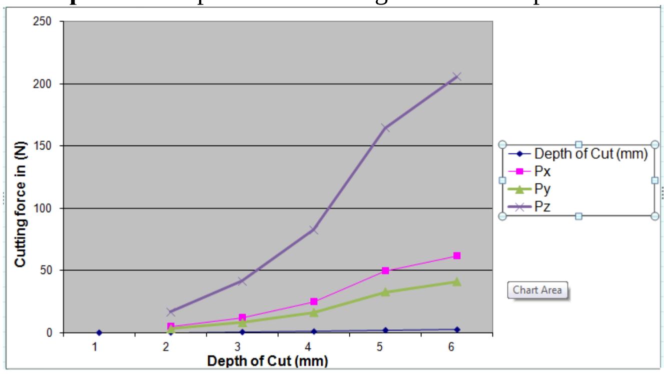
Pz = Cp× tx × Sy × K
= 225×0.2×1.00×0.5210.75×0.935
Pz =16.44 N

The components approximately connected by the following expression
Px / Pz = 0.3
Px = 0.3× Pz =0.3×16.45=4.932
and
Py /Pz = 0.2
Py =0.2 ×16.45 = 3.28

Table 5.1 Cutting Forces at Different Depth of Cut

Cutting force (N)	*Depth of Cut (mm)*				
	0.2	0.5	1.0	2.0	2.5
Px	4.932	12.33	24.66	49.32	61.65
Py	3.28	8.22	16.44	32.88	41.10
Pz	16.44	41.10	82.20	164.40	205.51

Graph 5.1 Components of cutting forces vs. Depth of Cut



From the graph 5.1, it is observed that the component of cutting forces (Px, Py and Pz) increases with different depth of cut.

6. Appendix

THE VALUES OF COEFFICIENTS AND INDICES[46]

Table 2.3

Material	σ_b *in Kg/mm²*	*Hardness Brinell* H_B	C_P	*x*	*y*	*Type of operation*
Steel	75	215	225	1.0	0.75	Turning and boring
			264	1.0	1.0	Facing and parting
Grey C.I.	—	190	98	1.0	0.75	Turning and boring
			135	1.0	1.0	Parting and facing

Table 2.1

Coolant	K_c	Φ	K_Φ	γ	K_γ
Dry	1	30°	1.05	−15°	1.40
Soda water+	1.03	45°	1.00	−10°	1.30
Emulsion	1.10	60°	0.96	+5°	1.23
Mineral oil	1.15	75°	0.94	0	1.13
				+5°	1.06
				+10°	1.00
Hard Mineral+	1.20-1.25	90°	0.92	+15°	0.94
				+20°	0.89

Table 2.2

Material	σ_b $\frac{Kg}{mm^2}$	K_m	*Material*	σ_b $\frac{Kg}{mm^2}$	K_m
Steel	40-50	0.76	C.I	140-160	0·88
	50-60	0.82		160-180	0·94
	60-70	0.89		180-200	1·00
	70-80	1.00		200-220	1·06
	80-90	1.10		220-240	1.12
	90-100	1.18		240-280	1.17
	100-120	1.28			

σ_b in this table denotes the ultimate strength of the material.

RECOMMENDED ANGLES FOR HSS SINGLE POINT TOOLS

Workpiece Material	Back rake angle Degrees	Side rake angle Degrees	End relief angle Degrees	Side [illegible] angle Degrees
STEELS :				
High speed, alloy and high Carbon tool steels and stainless steels	5 to 7	8 to 10	6 to 8	7 to 9
C15 – C40	10 to 12	10 to 12	8 to 10	8 to 10
C45 – C90	10 to 12	10 to 12	8 to 10	7 to 9
14 Mn 1 S 14, 40 Mn 2 S 12	12 to 14	12 to 14	7 to 9	7 to 9
40 Ni2 Cr 1 Mo 28,	6 to 8	8 to 10	7 to 9	7 to 9
T 50 Cr 1 V 23	6 to 8	8 to 10	7 to 9	7 to 9
Aluminium	30 to 35	14 to 16	8 to 10	12 to 14
Bakelite	0	0	8 to 10	10 to 12
Brass	0	1 to 3	8 to 10	10 to 12
Bronze	0	−2 to −4	8 to 10	8 to 10
Grey cast iron	3 to 5	10 to 12	6 to 8	8 to 10
Copper	14 to 16	18 to 20	12 to 14	12 to 14
Copper alloys, soft	0 to 2	0	8 to 10	10 to 12
Copper alloys, hard	0	0	6 to 8	8 to 10
Fibre	0 to 2	0	12 to 14	14 to 16
Formica	14 to 16	10 to 12	10 to 12	14 to 16
Monel, Nickel	8 to 10	12 to 14	12 to 14	14 to 16
Rubber, hard	0 to −2	0 to −2	14 to 16	18 to 20

From the experimental result following conclusion is made.

6. Conclusion and Future Work

The goal of this work is to present a methodology in order to determine tool forces and temperatures for use in finite element simulations of metal cutting processes. From the experimental set up, it is clearly observed that as depth of cut increases, the temperature generated in the tool at the tool tip also increases. It is also observed that, as the depth of cut increases, tool forces are also increases. It is main reason of tool failure. It is also observed that tool start vibrating at the depth of cut 2.5 mm. At this condition more heat is dissipated at the tool, due to which tool blunt. Experimental set up is made for force measurement during cutting using dynamometer and analyze the effect on the tool. Use ANSYS, NASTRAN software for analysis of single point cutting tool. Analyze the residual stresses developed in the tool. Optimizing the tool life for the maximum material removal in one "Tool Life"

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