ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 7, July 2015

Experimental Investigation on the Cutting Forces of a Single Point Cutting Tool over Dry Turning Operation

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Abstract: Quality and productivity play significant role in present manufacturing market. From customers viewpoint quality is very important because the extent of quality of the procured item or product influences the degree of satisfaction of the consumers during usage of the procured goods. Therefore, every manufacturing or production unit should concern about the quality of the product. Apart from quality, there exists another criterion, called productivity which is directly related to the profit level and also goodwill of the organization. To achieve maximum advantage in producing a good quality product, a good cutting tool is required. This paper aims at finding out the best cutting tool among the commonly used tools used in lathe machines for various operations. The different tools used are HSS(S-400), silicon carbide and tungsten carbide. Control chart technique is being implemented to find the best cutting tool on the basis of cutting forces exerted by the tools.

Keywords: Cutting force, cutting tools and control chart.

I. INTRODUCTION

A. Oblique Cutting

Oblique cutting: when chip flow deviates from orthogonal plane, i.e. $\rho c \neq 0$. But practically ρc may be zero even if $\lambda = 0$ and ρ_c may not be exactly equal to λ even if $\lambda \neq 0$. Because there are some other (than λ) factors also which may cause chip flow deviation. In contrary to simpler orthogonal cutting, oblique cutting causes the following effects on chip formation and mechanics of machining:
Chip does not flow along the orthogonal plane; Positive λ causes Chip flow deviation away from the finished surface, which may result lesser further damage to the finished surface more inconvenience to the operator reduction of mechanical strength of the tool tip increase in temperature at the tool tip more vibration in turning slender rods due to increase in PY (transverse force)

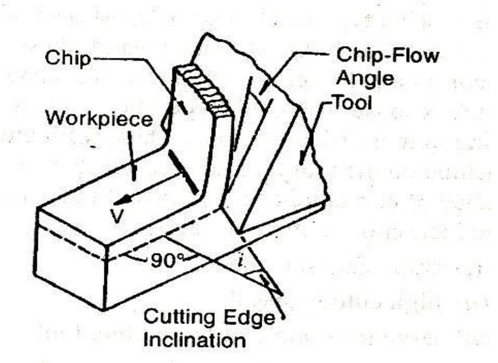

Fig 1 Oblique cutting position of tool

B. Cutting tool materials

The classes of cutting tool materials currently in use for machining operation are high-speed tool steel, cobalt-base alloys, cemented carbides, ceramic, and polycrystalline cubic boron nitride and polycrystalline diamond. Different machining applications require different cutting tool materials.

The Ideal cutting tool material should have all of the following characteristics:

- Harder than the work it is cutting
- High temperature stability
- Resists wear and thermal shock
- Impact resistant

Chemically inert to the work material and cutting fluid
To effectively select tools for machining, a machinist or engineer must have specific information about:

- The starting and finished part shape
- The work piece hardness
- The material's tensile strength
- The material's abrasiveness
- The type of chip generated
- The work holding setup
- The power and speed capacity of the machine tool

Some common cutting tool materials are described below:

1. Single Grade of High speed steels (HSS) S-400:High alloyed molybdenum high speed steel with good resistance and high toughness.It's applications are turning, taps, twist drills, reamers, milling tools, broacher tools, cold extrusion dies.

Table-1 Chemical Composition of S-400

Chemical composition (Average Percentage) %						
C	Si	Mn	Cr	Mo	V	M
1.02	0.40	0.30	3.80	8.60	1.9 0	1.8 0

2. Carbides: Also known as cemented carbides or sintered carbides were introduced in the 1930s and have high hardness over a wide range of temperatures, high thermal conductivity, high Young's modulus making them effective tool and die materials for a range of applications.

The two groups used for machining are tungsten carbide and silicon carbide; both types may be coated or uncoated.

3. Silicon Carbide: Silicon Carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electrochemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, ceramics, and numerous high performance applications. The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components. Structural and wear applications are constantly developing. Silicon carbide is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon carbide is not attacked by any acids or alkalis or molten salts up to 800°C. In air, SiC forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C. The high thermal conductivity coupled with low thermal expansion and high strength give this material exceptional thermal shock resistant qualities. Silicon carbide ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600°C with no strength loss.

4. Tungsten Carbide: Tungsten carbide particles (1 to 5 micrometer) are bonded together in a cobalt matrix using powder metallurgy. The powder is pressed and sintered to the required insert shape. Sintered carbide tips are the dominant type of material used in metal cutting. The proportion of cobalt (the usual matrix material) present has a significant effect on the properties of carbide tools. 3 - 6% matrix of cobalt gives greater hardness while 6 - 15% matrix of cobalt gives a greater toughness while decreasing the hardness, wear resistance and strength. Tungsten carbide tools are commonly used for machining steels, cast irons and abrasive non-ferrous materials. Tungsten Carbide is suitable for machining at higher speeds than those which can be used for tungsten carbide. Typical cutting speeds are: 30 - 150 m/min or 100 - 250 when coated.

C. Cutting tool parameters

1. Material Removal Rate (MRR): The material removal rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm3/min. For each revolution of the work piece, a ring-shaped layer of material is removed. MRR= (v.f.d×1000) in mm^3/ min

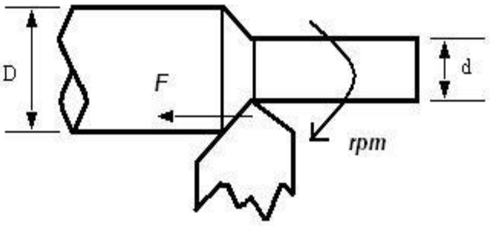

Fig-2: MRR in turning

2. Surface finish in machining: The resultant roughness produced by a machining process can be thought of as the combination of two independent quantities:
Ideal roughness and Natural roughness.

Ideal roughness: Ideal surface roughness is a function of feed and geometry of the tool. It represents the best possible finish which can be obtained for a given tool shape and feed. It can be achieved only if the built-up-edge, chatter and inaccuracies in the machine tool movements are eliminated completely. For a sharp tool without nose radius, the maximum height of unevenness is given by:

$$R_{max} = \frac{f}{\cot ø + \cot \beta}$$

f is feed rate, φ is major cutting edge angle and βis the minor cutting edge angle. The surface roughness value is given by, Ra = Rmax/4

Idealized model of surface roughness has been clearly shown in Figure 3.

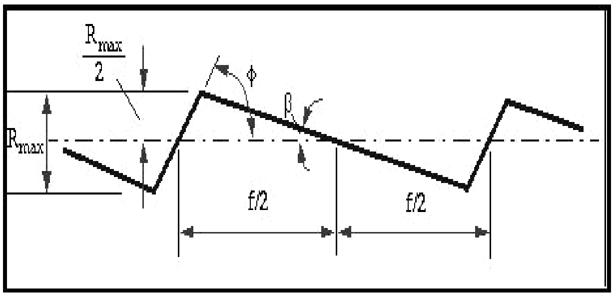

Fig-3 Idealized model of surface roughness

Practical cutting tools are usually provided with a rounded corner, and figure below shows the surface produced by such a tool under ideal conditions. It can be shown that the roughness value is closely related to the feed and corner radius by the following expression:

$$Ra = \frac{0.0321f}{r}$$

where r is the corner radius

Natural roughness: In practice, it is not usually possible to achieve conditions such as those described above, and normally the natural surface roughness forms a large proportion of the actual roughness. One of the main factors contributing to natural roughness is the occurrence of a built-up edge and vibration of the machine tool. Thus, larger the built up edge, the rougher would be the surface produced, and factors tending to reduce chip-tool friction and to eliminate or reduce the built-up edge would give improved surface finish.

D. Adjustable cutting factors in turning

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

DOI 10.17148/IARJSET.2015.2705

1. Speed: Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

$$v = \frac{\Pi D N}{1000} \text{ rad/s}$$

Here, v is the cutting speed in turning, D is the initial diameter of the work piece in mm, and N is the spindle speed in RPM.

2. Feed: Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

$$Fm = f\,.N \text{ mm/min}$$

Here, Fm is the feed in mm per minute, f is the feed in mm/rev and N is the spindle speed in RPM.

3. Depth of Cut: Depth of cut is practically self-explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.

$$d\,cut = \frac{D - d}{2} \text{ mm}$$

D and d represent the initial and final diameter (in mm) of the work piece.

E. Control Charts

The basic theory of the control chart was developed by Walter Shewhart in the 1920s.

The power of the control chart lies in its ability to distinguish assignable causes from random variation. It is the job of the individual using the control chart to identify the underlying root cause responsible for the out-of-control condition, develop and implement an appropriate corrective action, and then follow up to ensure that the assignable cause has been eliminated from the process. There are three points to remember.

- A state of statistical control is not a natural state for most processes.
- The attentive use of control charts will result in the elimination of assignable causes yielding an in-control process and reduced process variability.
- The control chart is ineffective without the system to develop and implement corrective actions that attack the root causes of the problems. Management and engineering involvement is usually necessary to accomplish this.

A control chart, whether for measurements or attributes, consists of a centreline, corresponding to the average quality at which the process should perform when statistical control is exhibited and two control limits, called the upper and the lower control limits(UCL and LCL). The control limits are chosen so that values falling between them can be taken to indicate a lack of statistical control. The general approach consists of periodically random sample from the process, computing some appropriate quantity and plotting that quantity on that control chart. When a sample value falls outside the control limit, we search for some assignable cause of variation. However, even if a sample value falls between the control limit, a trend or some other systematic pattern may indicate that some action is necessary, usually to avoid some serious trouble. The samples should be selected in such a way that each sample is as homogeneous as possible and at the same time maximizes the opportunity for variation due to an assignable cause to be present. This is usually called the rational subgroup concept. Order of production and source (if more than one source exists) are commonly used based for the obtaining rational subgroups. The ability to interpret control charts accurately is usually acquired with experience. It is necessary that the user be thoroughly familiar with both the statistical foundation of control chart and the nature of the production process itself. Finally, the set of parameters including the above mentioned parameters that are thought to influence surface finish, have been investigated from the various researchers.

II. MATERIALS AND METHODOLOGY

A. Working procedure

At first, the various spindle speeds of the lathe are noted by the help of a tachometer. The three spindle speeds that are noted and further used in the project are:
Spindle speed1: 174 rpm
Spindle speed2: 288 rpm
Spindle speed3: 465 rpm
Then the various feed rates of the lathe are being noted. The feed rates of the lathes used in the project are:
Feed rate A: 0.145 mm/rev
Feed rate B: 0.070 mm/rev
Feed rate C: 0.035 mm/rev
The mild steel work piece is then cut to the initial dimensions that are 25mm in diameter and 100 mm in length.

Then the tool is being fixed in the tool holder of the lathe tool dynamometer. The tool post being clamped to the tool post of the lathe. The dynamometer is helpful for showing the cutting force at a particular feed rate and spindle speed for a particular tool machining the work piece.

As the tool machines the work piece surface the dynamometer shows the various forces applied namely as x, y, z force. The y force depicts the cutting force. The cutting force is noted for an observation by taking the maximum y force during turning in consideration.

There are in total 9 samples of work piece as being machined at constant parameters for three different tools.

DOI 10.17148/IARJSET.2015.2705

The parameter cutting forces are solely responsible for determining the best tool in this experiment. The calculation and implementation of control chart determines the best cutting tool.

B. Cutting tools

The tools used in this experiment for dry turning operation are:
- HSS(S-400)
- Silicon carbide
- Tungsten carbide

The mechanical properties of high speed steel that makes it widely applicable are:
- High working hardness
    - High wear hardness
    - Excellent toughness
    - Gives better surface finish
- The mechanical properties of silicon carbide tool are:
    - Low density
    - High strength
    - Low thermal expansion
    - High thermal conductivity
    - High hardness
    - High elastic modulus
    - Excellent thermal shock resistance
    - Superior chemical inertness
- The mechanical properties of tungsten carbide are:
    - High stiffness
    - High hardness
    - High toughness

Tungsten being very hard material is less susceptible to wear.

Fig 4: Tungsten carbide, Silicon carbide and S-400

C. Lathe machine

Lathe is being used in the project for dry turning operation. The basic specifications of the engine lathe are:
Length of bed -2’5”
Height of center from bed -10”
Width of bed-10”
Spindle travel distance-7”
Motor-1H.P, 1425 RPM
Swing over bed-20”
Main spindle bore-2”
Tail-stock spindle bore-2”
3Speed gear box -3step Cone pulley

Fig 5 Lathe machine

D. Measuring instruments

Tachometer and Lathe Tool Dynamometer are basically the two measuring Instruments used for measuring spindle speed and three cutting forces respectively.

Fig 6 Tachometer and Lathe tool dynamometer

III.RESULTS AND DISCUSSSION

A. Calculation
1. For HSS(S-400):
Cutting speed (Vc)

$$Vc= \pi DN/1000 \quad m/ min$$

For, 465, π * 0.40 *465/1000 = 0.584 m/min.
For, 288, π* 0.30 *288/1000 = 0.271 m/min.
For, 174, π* 0.25*174/ 1000 = 0.136 m/min.
Power required

$$P = Fc*Vc/4500*1.36 \text{ KW}$$

For 465, 18 *0.584/4500*1.36 = 1.717*10^{-3} KW
For 288, 21*0.271/4500*1.36 = 0.929*10^{-3} KW
For 174, 35*0.136/4500*1.36 = 0.778*10^{-3} KW
Work done

$$W= Fc*Vc \text{ kgf m/min}$$

For 465, 18*0.584 = 10.512 kgf m/min
For 288, 21*0.271 = 50691 kgf m/min
For 174, 35* 0.136 = 4.76 kgf m/min
Heat generated

$$Q= Fc*Vc/427 \quad \text{K Cal/min}$$

For 465, 18*0.584/427 = 0.024 K Cal/min
For 288, 21*0.271/427 = 0.013 K Cal/min
For 174, 35* 0.136/427 = 0.011 K Cal/min

2. For silicon carbide:
Cutting Speed(Vc):--
Vc = (πDN) ÷1000 m/min
For 465, (π×0.40×465) ÷1000=0.584 m/min
For 288, (π×0.30×288) ÷1000=0.271 m/min
For 174, (π×0.25×174) ÷1000=0.136 m/min

Power Required (P):--
P = (Fc×Vc) ÷ (4500×1.36) KW
For 465, (20×0.584) ÷ (4500×1.36) =1.908×10^-3 KW
For 288, (26×0.271) ÷ (4500×1.36) =1.151×10^-3 KW
For 174, (36×0.136) ÷ (4500×1.36) =0.800×10^-3 KW
Work done (W):--
W =Fc×Vckgf m/min
For 465, 20×0.584=11.68 kgf m/min
For 288, 26×0.271=7.046 kgf m/min
For 174, 36×0.136=4.896 kgf m/min
Heat Generated (Q):--
Q = (Fc×Vc) ÷427 Kcal/min
For 465, (20×0.584) ÷427=0.027 Kcal/min
For 288, (26×0.271) ÷427=0.016 Kcal/min
For 174, (36×0.136) ÷427=0.011 Kcal/min

3. for tungsten carbide

Cutting speed (Vc)
$V_c = \frac{\Pi D N}{1000}$ m/min
For 465rpm, $v_c = \frac{\Pi\times0.40\times465}{1000} = 0.584$m/min
For 288 rpm, $v_c = \frac{\Pi\times0.80\times288}{1000} = 0.271$m/min
For 174 rpm, $v_c = \frac{\Pi\times0.25\times174}{1000} = 0.136$m/min
Work done
$W=F_c*V_c$ kgf/min
For 465, W= 19*0.584= 11.096
For 288, W= 25*0.271=6.775
For 174, W=48*0.136= 5.984
Heat generated(Q)
$Q=F_c*V_c/427$ kcal/min
For 465, Q= 19*0.584/427= 0.025kcal/min
For 288, Q= 25*0.271/427= 0.015kcal/min
For 174, Q= 44*0.136/427=0.014kcal/min
Power required(p)
$P= \frac{F_c \times V_c}{4500\times1.36}$ KW
For 465, $P= \frac{19 \times 0.584}{4500\times1.36} = 1.813\times10^{-3}$
For 288, $P= \frac{25\times0.271}{4500\times1.36} = 1.107\times10^{-3}$
For 174, $P= \frac{44\times0.136}{4500\times1.36} = 0.977\times10^{-3}$

B. Tabulation for finding out the best cutting tool for cutting forces

$$X = \frac{x_1 + x_2 +\ldots\ldots+x_n}{n}$$

Where , R= range (largest value in the subgroup-smallest value in the subgroup)
$\bar{X}$ = The average of measurements at different spindle speed
n = No of measurements

For HSS: $\bar{X} = \frac{35+21+18}{3} = 24.67$,R= (35-18) =17
For Sic: $\bar{X} = \frac{36+26+20}{3} =27.33$, R= (36-20) =16

Spindle speed / Cutting Tool	Spindle speed1 (174 rpm)	Spindle speed2 (288 rpm)	Spindle speed 3 (465 rpm)	$\bar{X}$	R

Table-2 Evaluation of various parameters of control chart for cutting force

For WC: $X=\frac{44+25+19}{3}=29.33$, R= (44-19) =25
In order to plot the graph we have to find out the grand mean which will become the centre line, and then the upper control limit along with lower control limit

$$\bar{\bar{X}} = \frac{(\bar{x}_1+\bar{x}_2+\ldots\ldots+\bar{x}_n)}{n}$$

Where: $\bar{\bar{X}}$ =grand mean
$\bar{x}_1$=mean of each subgroup
k = no of subgroups

Grand mean (centre line):

$$\bar{\bar{X}} =\frac{24.67+27.33+29.33}{3}= 27.11$$

Average range:

$$\bar{R}=\frac{R_1+R_2+\ldots.+R_n}{K} =\frac{17+16+25}{3}=19.33$$

Upper Control Limit for chart $\bar{X}$

$UCL_{\bar{x}}= \bar{\bar{X}}+ A_2\bar{R}$ (A_2 value can be determined by referring to table no.3)
=27.11+1.023 × 19.33
=46.88

LOWER CONTROL LIMIT $\bar{X}$ chart:

$LCL_x = \bar{\bar{X}} – A_2 \bar{R}$ (A_2 value can be determined by referring to table no.3)
=27.11-1.023 × 19.33
= 7.335

UPPER CONTROL LIMIT for $\bar{R}$ chart:

$UCL_{\bar{R}} = D_4 \times \bar{R}$ (For D_4 value refer table no.4)
= 2.574 × 19.33 = 49.755

LOWER CONTROL LIMIT for $\bar{R}$ chart:

$LCL_{\bar{R}} = D_3 \times \bar{R}$ (For subgroups ≥7)
In our case calculating LCL_R is not required because there is no lower control limit when the subgroup or sample size (n) is less than 7.

Table 3 Values of A_2

n	A_2	n	A_2	n	A_2
2	1.880	7	0.419	12	0.266
3	1.023	8	0.373	13	0.249
4	0.729	9	0.337	14	0.235
5	0.577	10	0.308	15	0.223
6	0.483	11	0.285		

n	D_4	n	D_4	n	D_4
2	3.267	7	1.924	12	1.717
3	2.574	8	1.864	13	1.693
4	2.282	9	1.816	14	1.672
5	2.114	10	1.777	15	1.653
6	2.004	11	1.744		

Table 4 Values of D_4

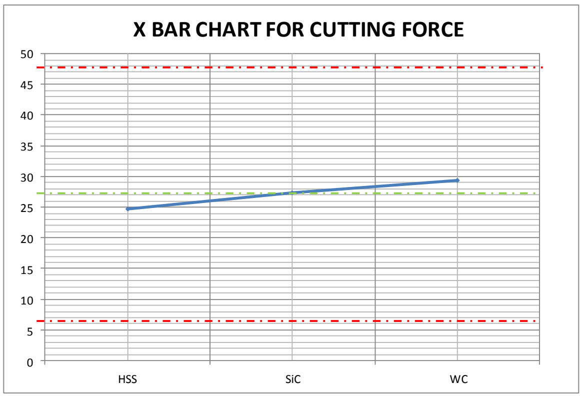

Fig 7 X bar chart of cutting force for HSS, SiC and WC

From the $\overline{X}$ graph, it is seen that HSS shows a minimum cutting force for which it could have been considered however, the cutting force of SiC lies on the central line of the graph which is the accurate value which makes it suitable to be used on mild steel. Tungsten Carbide shows the highest cutting force for which it is beyond consideration to be used.

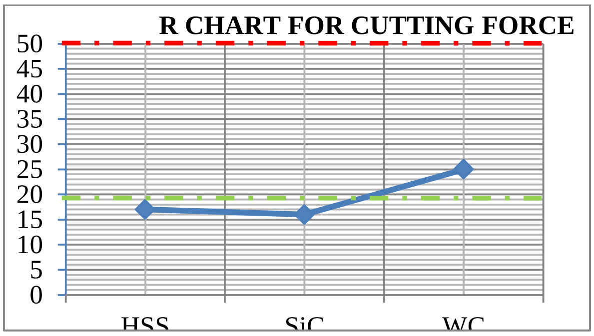

Fig 8 R chart of cutting force for HSS,SiC and WC

From the above R chart we get to know that HSS is closer to the mean which serves better as for cutting force whereas we can also observe that due to a comparatively higher distance from the mean , both SiC and WC do not serve best in case of cutting tool for cutting force.

IV. CONCLUSIONS

From the X graph for cutting force it is found that SiC is the appropriate cutting tool to be used on mild steel. However HSS shows the lowest cutting force among the three different cutting tools used, for which it makes suitable to be used on mild steel. From the R graph for cutting force it is found that HSS is the suitable cutting tool to be used on mild steel, showing a value of 17 considered being closest to the central line of the graph in comparison to SiC-16 and WC-25. Hence it is proved by the implementation of control chart technique in the data collected from the observations that HSS is the best cutting tool to be used on the mild steel as it has minimum cutting forces.

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