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Determination of Minimum Surface Roughness of Different Materials Using High speed Cutting Tool and Cemented Carbide Cutting Tool at Different Oblique Cutting Angle

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Abstract— The cutting forces depend upon the oblique cutting angle during turning. So, the angle should be determined with minimum roughness. A range of oblique cutting angle can be recommended from the performance study of the project report. But for a particular optimum oblique cutting angle may be determined from a brief analysis of every oblique cutting angle to apply commercially for a particular metal, tool, cutting speed, depth of cut, feed rate and cutting fluid.surface roughness (Ra) were measured. The roughness was measured with the same direction and dimension. The cemented carbide and high speed cutting tool were used. The material used were high carbon steel, mild steel and cast iron. Facing and turning were performed on the material. Carbide tool can cut high carbon steel, mild steel and cast iron while high speed tool can cut high carbon steel, mild steel but cannot cut cast iron because of it's hardness.

Index Terms— Cemented Carbide Cutting Tool, High Speed Cutting Tool, Tool Signature, Brinell Hardness Number, Cutting Ability, Oblique Cutting Angle, Average Surface Roughness.

1 INTRODUCTION

Cutting is a collection of processes wherein material is brought to a specified geometry by removing excess material using various kinds of tooling to leave a finished part that meets specifications. The net result of cutting is two products, the waste or excess material, and the finished part. If this were a discussion of woodworking, the waste would be sawdust and excess wood. In cutting metals the waste is chips or excess metal [1].

Depending upon the number of cutting edges, the cutting tools used in metal cutting are two types. They are single point cutting tool and multipoint cutting tool [2]. The machinability of a material can be defined as the ease with which it can be cut (machined) by a tool to the required quality of finish.Tool material, tool geometry, speeds, rigidity of machine, surface topography, vibration and chatter, effect of temperature are cutting parameters on machinability. They have greater impact on surface roughnes also [3]. Roughness can be measured by manual comparison against a "surface roughness comparator", a sample of known surface roughness, but more generally a surface profile measurement is made with a profilometer that can be contact (typically a diamond stylus) or optical (e.g. a white light interferometer) [4].

The traditional model for oblique cutting has two shortcomings, one being that it involves only one machining case where the tool major cutting edge angle is limited to be 90°, i.e. the un-deformed chip thickness is equal to the feed of the tool; whilst the other is that it takes no account of the influence of the tool feed velocity on the resultant cutting velocity [5].

2 DESIGN OF THE TOOLS

The design of a cutting tool means determination of all the dimensions and shapes of all the elements of a cutting tool by carrying out calculations and graphical construction. The cutting of metals with a single point cutting tool is fully applicable to any kind of cutting tool since all tools remove a certain layer of stock and impart the required shape, size and surface finish to the machined part. The cutting teeth of all cutting tools whatever may be their shapes and purpose resemble to the point of single point tool.

The common procedure carried out during the design of cutting tool consists of following calculations:

- To determine forces acting on cutting surface of the tool.
- To find out optimum tool geometry.
- To select suitable material for making cutting elements of the tool.
- To find suitable shapes of cutting and mounting elements of tool and to determine the tolerance on the dimensions of cutting and mounting elements of depending on machining accuracy required on work piece.
- To determine strength and rigidity of mounting and cutting elements to tool.
- To prepare a working drawing of tool.

Cutting tool design depends on the following factors:

- Working material
- Cutting tool material
- Cutting force
- Accuracy desired

- Surface treatment of cutting tool
- Machining variables such as
    1. Cutting speed
    2. Feed
    3. Depth of cut

The design on the cutting tool depends upon the cutting forces acting on the cutting surfaces of the tool and rigidity of the machine on which cutting tool is used. The shank of a single point tool may be rectangular, square or rounding cross-section. The rectangular cross-section is commonly used because the reduction in strength of shank is less than for a square shank when a seat is cut for a tip.

Here, F_H = Cutting force
Let, B = Width of shank
H = Height of shank

For rectangular cross-section the relations between B and H are as follows:
H/B = 1.25 for roughing operations
H/B = 1.6 for semi-finishing and finishing operations

The minimum permissible size of the shank cross-section on strength basis is calculated by equating the actual bending moment to the maximum moment permitted by cross-section of the shank.

M_1 =Bending moment due to cutting force F_H

$= F_H \times l$

Where l = Cutting tool overhang
(l = 1 to 1.5 H)

M_2 = Maximum moment permitted by the cross-section of the shank

$= f \times Z$

Where f = Permissible bending stress for the shank material
Z = Section modulus of the tool shank

$M_1 = M_2$

$F_H \times l = f \times Z$

For rectangular cross-section of tool shank

$Z = (BH^2)/6$

$F_H \times l = f \times (BH^2)/6$

$BH^2 = 6F_H \times l/f$

$H = \sqrt{6(F_H \times l)/(f \times B}$

For square cross-section shank

B =H

$F_H \times l = f \times (BH^2)/6 = (fB^3)/6$

$B^3 = (6 F_H \times l)/f$

$B = \sqrt[3]{(6 F_H \times l)/f}$

For round cross-section shank

$Z = (\pi f \times D^3)/32$

Where D = Diamond of shank

$F_H \times l = f \times Z = (\pi f \times D^3)/32$

$D = \sqrt[3]{(32 F_H \times l)/\pi f}$

Square shank tools are commonly used for boring machines, screw, machines and turret lathes. Round shank tools are generally used for boring and thread cutting operations.Appropriate reliefs and clearances are ground on carbide inserts.Shank sizes for single point carbide tools vary from 12 mm to over 50 mm. The shank size should be large enough to support the load of the tool for a given tool over hang. A typical shank size for a single point carbide tool as follow:

Shank size	= 12 mm $\times$ 24 mm
When depth of cut	= 3 mm
Feed	= 0.375
Over hang	= 36 mm

The tool flank must be designed in such a way as to minimize sharpening costs. The flanks of almost all carbide tips are beveled to an angle of 20^0. Brazed tips are positioned at an angle varying between 12^0-18^0. The flank can be shaped to three angles namely angle $\alpha +3^0$ on the rest of the tip and angle $\alpha +5^0$ on the shank for a tip without overhang and for a tip with overhang.

Tipped tools are preferable when expensive cemented carbides or high speed steels are used. The point is made of a metal cutting material, while the shank is of structural carbon steel. Cemented carbide tips are brazed or clamped mechanically, while tips of high speed steel are clamped. An as brazed tip may protrude from the shank for as much as 1.5 millimeters, but in tool sharpening this overhang should be reduced to within 0.8 mm. This will enable carbide tips to be sharpened by diamond wheels, keeping the latter out of touch with the shank.

So, the selected design of a V-shaped cemented carbide and high speed cutting tool is
Back rake angle = 5^0
Side rake angle = 5^0
End relief angle = 60^0
Side relief angle = 60^0
Front cutting edge angle = 7^0
Side cutting edge angle = 7^0
Nose radius = 2 mm
And the tool signature is 5, 5, 60, 60, 7, 7, 2

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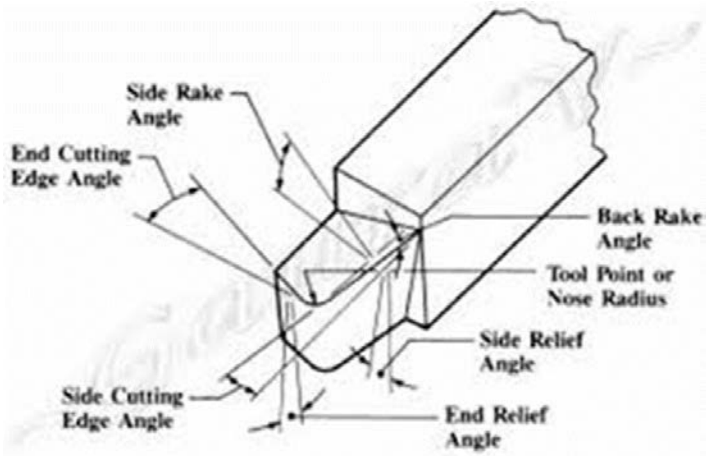

Fig. 2.1: Geometry of a V-shaped cutting tool

3 PERFORMANCE TEST OF THE TOOLS

Table 3.1: Hardness test of the material

Type of material	Indentation (in mm)
High carbon steel	3.2
Mild steel	3.15
Cast iron	2.8

We know that,
Brinell Hardness Number (B.H.N.) = $P/ (\pi D/2)(D-(D^2-d^2))^{0.5}$

Here,
Load P =750 kg
Larger diameter D =5 mm
Smaller diameter = d

For high carbon steel,
Smaller diameter d = 3.2 mm
So Brinell Hardness Number (B.H.N.) = $P/ (\pi D/2)(D-(D^2-d^2))^{0.5}$
$= 750/ (\pi 5/2)(5-(5^2-3.2^2))^{0.5}$
= 82.5 B.H.N.

For mild steel,
Smaller diameter d = 3.15 mm
So Brinell Hardness Number (B.H.N.) = $P/ (\pi D/2)(D-(D^2-d^2))^{0.5}$
$= 750/ (\pi 5/2)(5-(5^2-3.15^2))^{0.5}$
= 85.5 B.H.N.

For cast iron,
Smaller diameter d = 2.8 mm
So Brinell Hardness Number (B.H.N.) = $P/ (\pi D/2)(D-(D^2-d^2))^{0.5}$
$= 750/ (\pi 5/2)(5-(5^2-2.8^2))^{0.5}$
= 111.41 B.H.N.

Table 3.2: Hardness test of cutting tool

Type of cutting tool	Indentation (in mm)
High speed tool	1.9
Carbide tool	1.1

We know that,
Brinell Hardness Number (B.H.N.) = $P/ (\pi D/2)(D-(D^2-d^2))^{0.5}$

Here,
Load P =750 kg
Larger diameter D =5 mm
Smaller diameter = d

For high speed tool,
Smaller diameter d = 1.9 mm
So Brinell Hardness Number (B.H.N.) = $P/ (\pi D/2)(D-(D^2-d^2))^{0.5}$
$= 750/ (\pi 5/2)(5-(5^2-1.9^2))^{0.5}$
= 254.73 B.H.N.

For carbide tool,
Smaller diameter d = 1.1 mm
So Brinell Hardness Number (B.H.N.) = $P/ (\pi D/2) (D-(D^2-d^2))^{0.5}$
$= 750/ (\pi 5/2)(5-(5^2-1.1^2))^{0.5}$
= 779.93 B.H.N. (85 R.H.N.)

Performance Test by Cemented Carbide Cutting Tool:

1. Here, for turning

Rotational speed of job = 350 rpm
Feed rate (auto feed) = 0.172 mm/rev

a. For Mild Steel, at cutting angle 0^0,15^0, 30^0, 45^0, 60^0, 75^0, 90^0

b. For High Carbon Steel , at cutting angle 0^0,15^0,30^0,45^0,60^0,75^0,90^0

c. For Cast Iron , at cutting angle 0^0,15^0,30^0,45^0,60^0,75^0,90^0

2. Here, for facing

Rotational speed of job = 350 rpm
Feed rate (auto feed) = 0.158 mm/rev

a. Mild Steel

b. High Carbon Steel

c. Cast Iron

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Performance Test by High Speed Cutting Tool:

1. Here, for turning

Rotational speed of job = 350 rpm
Feed rate (auto feed) = 0.172 mm/rev

a. For Mild Steel, at cutting angle $0^0, 15^0, 30^0, 45^0, 60^0, 75^0, 90^0$

b. For High Carbon Steel , at cutting angle $0^0, 15^0, 30^0, 45^0, 60^0, 75^0, 90^0$

2. Here, for facing

Rotational speed of job = 350 rpm
Feed rate (auto feed) = 0.158 mm/rev

a. Mild Steel

b. High Carbon Steel

For turning,

Table 3.3: Comparison of cutting ability with respect to turning

Operation by Cemented Carbide tool (Hardness No. 779.93 B.H.N.)	Operation by High Speed tool (Hardness No. 254.73 B.H.N.)
a. Mild Steel (85.5 B.H.N.)	a. Mild Steel (85.5 B.H.N.)
b. High Carbon Steel (82.5 B.H.N.)	b. High Carbon Steel (82.5 B.H.N.)
c. Cast Iron (111.41 B.H.N.)	c. Cannot do so

For facing,

Table 3.4: Comparison of cutting ability with respect to facing

Operation by Cemented Carbide tool (Hardness No. 779.93 B.H.N.)	Operation by High Speed tool (Hardness No. 254.73 B.H.N.)
a. Mild Steel (85.5 B.H.N.)	a. Mild Steel (85.5 B.H.N.)
b. High Carbon Steel (82.5 B.H.N.)	b. High Carbon Steel (82.5 B.H.N.)
c. Cast Iron (111.41 B.H.N.)	c. Cannot do so

4 SURFACE ROUGHNESS CUT BY THE TOOLS

Value of R_a for Turning:
(Here, all the R_a are taken by portable surface roughness tester TR200)

For cast iron by carbide tool:

Table 4.1: Value of R_a for cast iron by carbide tool

Oblique Cutting Angle	Average Surface Roughness (R_a)
At 0^0	4.068
At 15^0	0.165
At 30^0	0.109
At 45^0	0.074
At 60^0	5.445
At 75^0	3.387
At 90^0	0.01

For high carbon steel by carbide tool:

Table 4.2: Value of R_a for high carbon steel by carbide tool

Oblique Cutting Angle	Average Surface Roughness (R_a)
At 0^0	0.180
At 15^0	0.073
At 30^0	0.069
At 45^0	0.066
At 60^0	0.046
At 75^0	0.155
At 90^0	0.187

For high carbon steel by high speed tool:

Table 4.3: Value of R_a for high carbon steel by high speed tool

Oblique Cutting Angle	Average Surface Roughness (R_a)
At 0^0	0.04
At 15^0	2.860
At 30^0	0.051
At 45^0	0.088
At 60^0	0.022
At 75^0	0.024
At 90^0	0.027

For mild steel by carbide tool:

Table 4.4: Value of R_a for mild steel by carbide tool

Oblique Cutting Angle	Average Surface Roughness (R_a)
At 0^0	0.8
At 15^0	0.093
At 30^0	0.123
At 45^0	0.046
At 60^0	0.057
At 75^0	0.054
At 90^0	0.053

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For mild steel by high speed tool:

Table 4.5: Value of R_a for mild steel by high speed tool

Oblique Cutting Angle	Average Surface Roughness (R_a)
At 0^0	0.02
At 15^0	0.697
At 30^0	0.04
At 45^0	0.048
At 60^0	0.043
At 75^0	0.035
At 90^0	0.066

Value of R_a for Facing:

Table 4.6: Value of R_a of different cutting

Type of Cutting	Average Surface Roughness (R_a)
For cast iron by carbide tool	2.003
For high carbon steel by carbide tool	3.069
For high carbon steel by high speed tool	1.392
For mild steel by carbide tool	2.378
For mild steel by high speed tool	2.625

Maximum Value of R_a:

Table 4.9: Maximum value of R_a

Type of Cutting	Maximum Average Surface Roughness (R_a)
For cast iron by carbide tool (At 60^0)	5.445
For high carbon steel by high speed tool (At 15^0)	2.860
For high carbon steel by carbide tool (At 90^0)	0.187
For mild steel by high speed tool (At 15^0)	0.697
For mild steel by carbide tool (At 0^0)	0.8

Minimum Value of R_a:

Table 4.10: Minimum value of R_a

Type of Cutting	Minimum Average Surface Roughness (R_a)
For cast iron by carbide tool (At 90^0)	0.01
For high carbon steel by high speed tool (At 60^0)	0.022
For high carbon steel by carbide tool (At 60^0)	0.046
For mild steel by high speed tool (At 0^0)	0.02
For mild steel by carbide tool (At 45^0)	0.046

5 Results and Discussion

For high carbon steel turning by carbide tool:

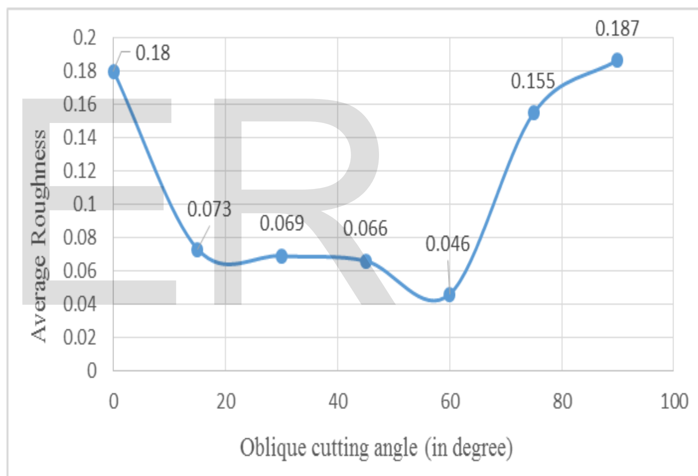


Fig. 5.1: Average surface roughness Vs cutting angle of high carbon steel turning by carbide tool

For high carbon steel turning by high speed tool:

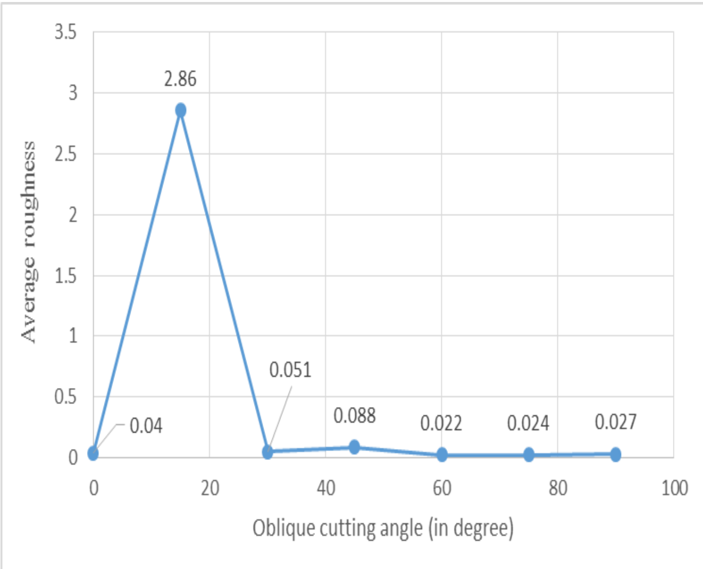


Fig. 5.2: Average surface roughness Vs cutting angle of high carbon steel turning by high speed tool

For mild steel turning by carbide tool:

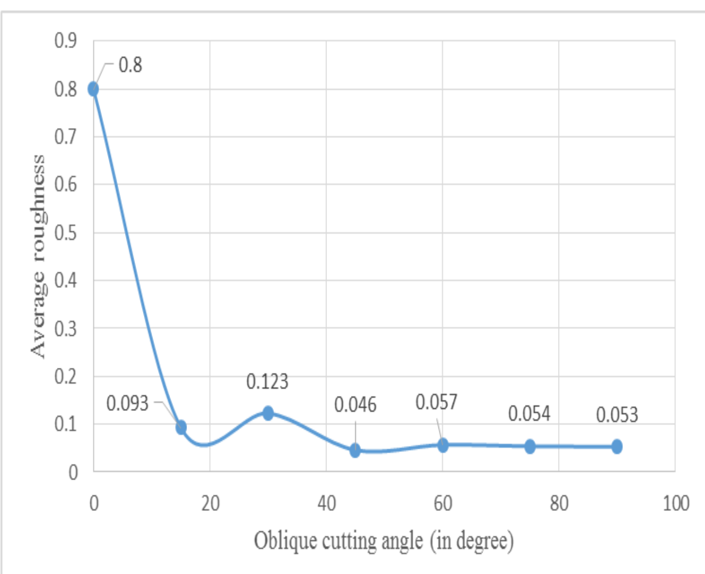
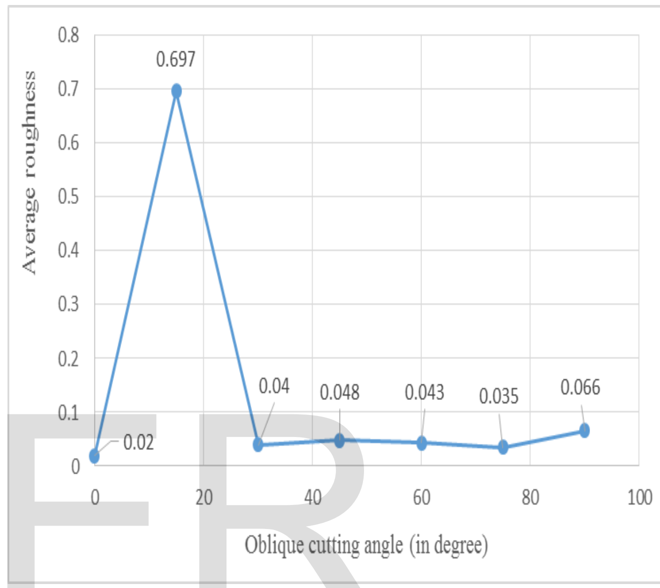


Fig.5.3: Average surface roughness Vs cutting angle of mild steel turning by carbide tool

For mild steel turning by high speed tool:

Fig. 5.4: Average surface roughness Vs cutting angle of



mild steel turning by high speed tool

For cast iron turning by carbide tool:

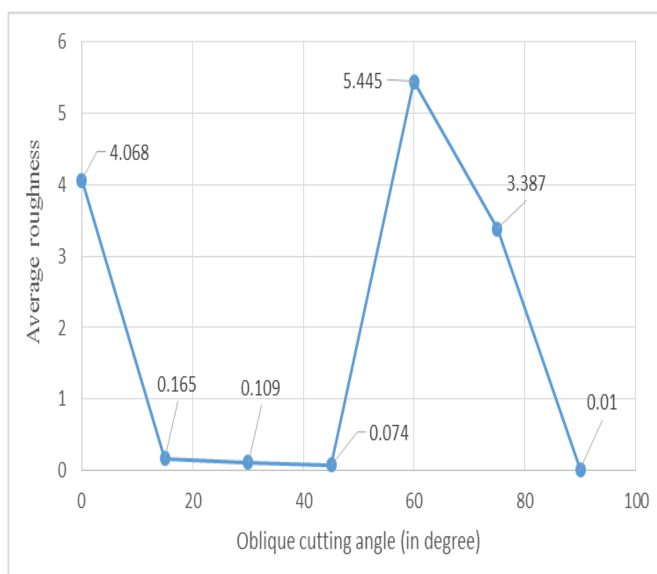


Fig.5.5: Average surface roughness Vs cutting angle of cast iron turning by carbide tool

For turning by carbide tool (for maximum value of R_a):

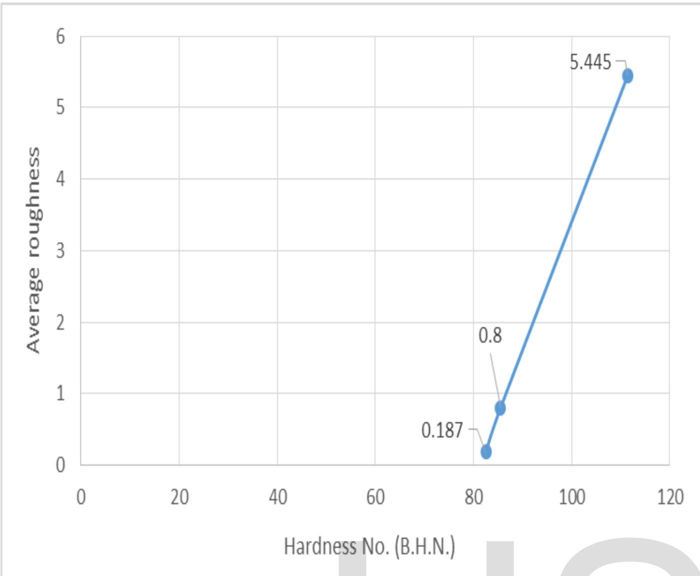


Fig.5.6: Average roughness (max.) Vs hardness no. (B.H.N.) for turning by carbide tool

For turning by carbide tool (for minimum value of R_a):

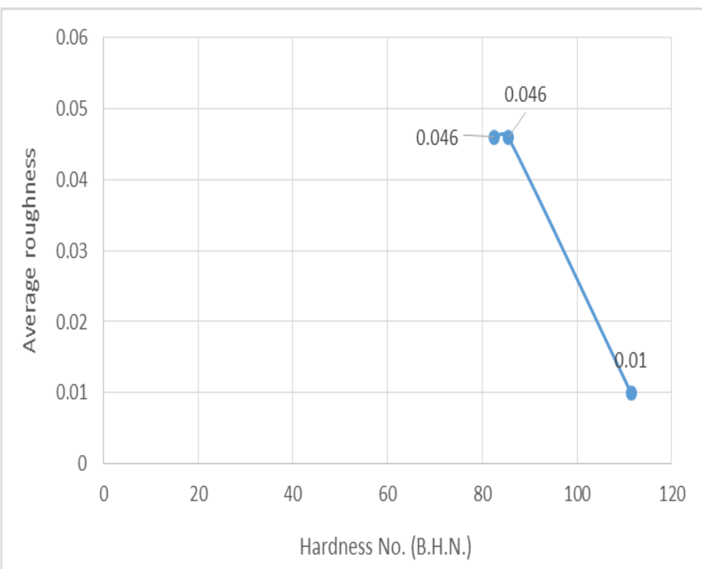


Fig. 5.7: Average roughness (min.) Vs hardness no. (B.H.N.) for turning by carbide tool

For facing by carbide tool:

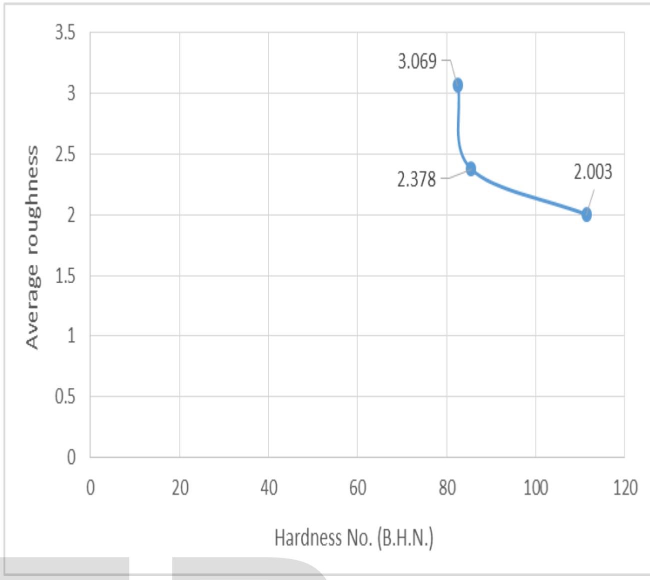


Fig. 5.8: Average roughness Vs hardness no. (B.H.N.) for facing by carbide tool

For facing by high speed tool:

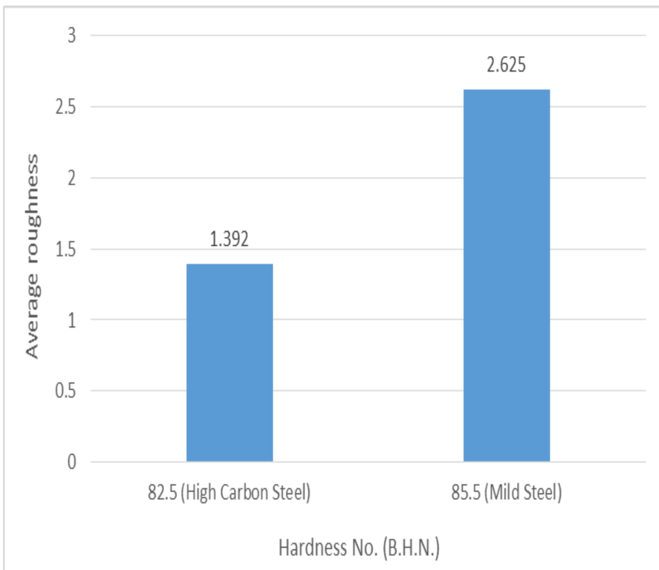


Fig. 5.8: Average roughness Vs hardness no. (B.H.N.) for facing by high speed tool

6 Conclusion

A range of minimum roughness can be recommended from the analysis. But there should have a particular angle for which the roughness will be minimum for a defined tool and metal to cut. This angle may change with respect to cutting speed, depth of cut, feed rate, cutting fluid, initial dimension as well as diameter for a particular tool and metal to cut. To determine the optimum angle it is required to measure the roughness for every oblique cutting angle. To do so, the analysis should be done with minimum error. Then it will be applicable for the commercial production purpose. Different cutting tool material of different hardness may also be analyzed to this purpose.

The roughness was measured with the same direction and dimension. The cemented carbide and high speed cutting tool were used. The material used were high carbon steel, mild steel and cast iron. Facing and turning were performed on the material. Carbide tool can cut high carbon steel, mild steel and cast iron while high speed tool can cut high carbon steel, mild steel but cannot cut cast iron because of it's hardness. Different roughness were compared among the angle and the material and the tool and also turning and facing. A range of minimum roughness can be recommended from the experiment. It vary metal to metal and also with respect to cutting tool. But 0^0, 45^0, 60^0, 90^0 may be recommended as the lowest roughness of oblique angle and 45^0 is the optimum cutting angle of all poeratoins of oblique cutting.

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