INFLUENCE OF THE CUTTING PARAMETERS ON THE SURFACE HARDNESS AND DEPTH OF PENETRATION OF THE HARDENED LAYER IN MACHINING DUCTILE MATERIALS

A THESIS

by

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This is to certify that the thesis work was done by me and this work has not been submitted elsewhere for award of any degree or diploma.

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ABSTRACT

The physical properties of the working materials like, surface hardness, depth of penetration through which the influence is observed, tensile strength etc. are subjected to change during any machining operation. Like physical properties, the chemical composition and microstructure of the metal are also changed in such operation. Machining of metal involves forcing of a cutting tool through the excess material of the work piece. This excess material is progressively separated from the work piece in the form of chip, thereby rendering the work piece to a desired shape and size. Cutting force causes plastic deformation of the metal which results in strain or work-hardening of the metal and thus makes it harder and stronger.

The forces in the metal cutting process varies with the cutting conditions. So, at different cutting conditions the properties of the work material are found to be different.

In this experiment, Mild Steel was turned off on a lathe machine at different cutting conditions using a cemented carbide tool of a particular geometry. Then specimens were taken from the machined surface for each set of cutting conditions and their

surface hardness and depth of penetration both were measured. It was observed that the surface hardness and depth of penetration both were the functions of cutting speed when the feed and depth of cut were kept constant. Surface hardness was found to be maximum at the critical cutting speed, where cutting forces and co-efficient of chip shrinkage both are maximum. Feed and depth of cut also affect the hardness. Surface hardness increased with the increase of feed, but it reduced with the increase of depth of cut. Depth of penetrntion of the change is maximum at low speed and high feed. It was found that surface hardness increased near about sixty to seventy percent after machining mild steel with respect to the base metal.

The objective of this project is to establish the relationships between the surface hardness and the depth of penetration of the hardened layer with the cutting parameters like feed, speed and depth of cut etc., and to identify the critical cutting conditions and compare the machining process with the case hardening process

CONTENTS

NOMENCLATURE

h	-	Tool wear, mm
T_l	-	Tool life, min
r	-	Nose radious, mm
ϵ	-	Plan angle
α	-	Side rake angle
α_l	-	Back rake angle
ϕ	-	Shear angle
θ	-	Side cutting edge angle
μ	-	Frictional angle
δ	-	Cutting angle plane
λ	-	Inclination angle
Fs,Fn	-	Force component acting on shear plane
Fc	-	Cutting force; force component acting in direction of tool travel.
Ft	-	Thrust force, force component acting in direction perpendicular to surface generated.
F_μ	-	Friction force acting between tool face and sliding chip.
N_l	-	Normal force
R	-	Resultant cutting force.
Fr	-	Radial force.
Fa	-	Axial force.
Ao	-	Cross sectional area of chip before removal from work piece.
K1,X1,Y1,		Constants for mild steel.
Pz,Px,Py,		Components of cutting force,Kgf.
MRR	-	Metal removal rate,cu.in./min
HPm	-	Horse power required at the motor.
Uhp	-	Unit horse power,
C_l	-	Feed correction factor,

HV	–	Vickers hardness no.
B	–	Brinell hardness no.
DP	–	Depyh of penetration,mm
t_c	–	Chip thickness, mm.
t_u	–	Uncut chip thickness,mm.
N	–	Speed of the workpiece (spindle), rpm
F	–	Rate of feed mm/rev.
V_c	–	Critical cutting speed, m/min.
n_1	–	Exponent depending upon cutting conditions
C_2	–	Constant – the cutting speed for a tool life of one minute
d	–	Workpiece diameter, mm corresponding to the point being considered on the cutting edge of the tool
V	–	Cutting velocity, m/min.
D	–	Depth of cut, mm

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CHAPTER 1

INTRODUCTION

1.1General Introduction: Mankind has been confronting with problems of material since the time Adam and Eve felt the need of some sort of apparel after eating the prohibited apple.

In the olden days people had relatively simple material problems of clothing and construction of shelter. But in this age of advanced technology we are in need in of a variety of materials along with the materials for clothing and shelter. In old days few metals and their alloys like iron, copper, brass, tin, and zinc, ceramics, wool, cotton, asbestors, cellulose etc. were sufficient to fulfill man's needs for several centuries. But the end of 19th Century and the beginning of 20th Century is a new age of materials. During this time, steel and aluminum have become the major engineering materials. The most exciting group of modern day engineering materials are the celluliod .

To meet the challenges imposed on manufacturing engineers, it is desirable for him to have a thorough knowledge of material science, design and manufacturing processes. A successful design depends upon the selection of materials having the most desirable properties for a given function, whilest at the same time taking into consideration the cost of the materials and the problems with machining of the materials to the required shape. Present day manufacturing demands high degree of accuracy. For these reasons the engineer needs to know a great deal about the metal cutting processes and the influence of machining conditions on the properties of materials.

The economic importance of the cutting processes may be appreciated by the single observation that nearly every device in our complex society has one or more machined surfaces or holes. There are several reasons for developing a rational approach to the metal cutting problem:

i)To improve the cutting techniques – even minor improvements are of significant in high volume production.

ii)To produce products of greater precision and of greater useful life.

iii)To increase the rate of production and produce a greater number and variety of products with the tools available.

iv)To predict what will happen under an as yet untested set of circumstances.

v)To catalogue the large volume of empirical information that is available.

In this treatment of the subject we shall consider the cutting in fundamental terms. The objective is to explain a number of commonly observed results rather than to present a large mass of empirical constants and a large number of empirical relationships of limited applicability.

1.2 Literature Review

Research in metal cutting had already been carried out by the French Scientist Terrace [1] as far back as 1873, although fundamental theories have been developed only during the past three or four decades. Beginning with Malcolm[2] in 1881, and through 1900, several contributions were made towards the understanding of the metal cutting processes by determining cutting forces and the effects of tool geometry and cutting environments.

In 1907, the classical work of Taylor [3], "On the Art of Cutting Metals", stimulated considerable experimental work in metal cutting. Taylor's work emphasized the role of temperature of the tool on its life. However, from that time until 1925 the

Fundamental research on the metal cutting mechanism has been continued since 1930. And it has been influenced by similar researchers. In 1955 Ernst and Marplot [4] confirmed the role of the built-up edge in metal cutting and presented their theories on the mechanics of its formation and breaking and its effects on tool temperature and on the surface finish of the machined part. Considerable stimulus was given to the theory of metal cutting by Ernst and Martellottin in 1935, in Ernst [5] 1958, and Ernst and Merchant[6] in 1940. This group explained the mechanics of metal cutting and the interrelated effect of tool geometry, tool temperature, chip formation, cutting fluid and surface finish.

By the year 1950 it was realized that the customary methods of solving machining problems, which used the rule-of-thumb, must give way to a scientific method. In metal cutting the requirements are changing and they result in continually changing interrelated compromises which involve new materials, better surface finish and higher rates of production. Thus, it is necessary that objectives be achieved in the very near future. This requirement has led to the extensive developments in metal cutting since the year 1950.

Regarding wear process of the cutting tool, life, testing method, etc. many reports have been presented by many researchers. Merchant, Ernst and Krabacher [7] presented a scientific method of tool life testing, for cemented carbide tool. The mechanical aspect of metal cutting was investigated by Zorro [8] in 1952. Laladsee[9], a leading scientist in USSR, presented a well-recognized theory of chip formation during the metal cutting process. Considerable effort has been expended after the year 1950 on developing the optimum machining variables. In 1955, Ernst [10], Gilbert [11] optimized the cutting condition with respect to minimum cost of production. The cost of production is a function of the cost of the tool and machining operation. In 1956, Rozenberg and Ermine [12] carried out experiments on basic metal cutting principles and established a relationship between machining variables and metal cutting theory. Rozenberg also developed the relation of cutting force co-efficient of chip-shrinkage with cutting force. Laladze [13] presented the role of tool wear for optimization in metal cutting process. This was confirmed by Clashing [14] in the same year after investigating the metal cutting process. Brewer [15] also worked on the basic turning operation to optimize the cutting variables for maximum production rate. According to this objective function, production time depends on machining time, idle time, etc.

Macaroon [16] carried out investigations on tool wear and optimization of metal cutting process. In this year, Armerego and Russell [17] used the maximum profit rate as the criterion for optimizing machining variables and have proved that maximum profit depends on both tool cost and idle time. Zorro, Gronovsky, Lamina and Tritiakov[18] explained the mechanics of metal cutting. In this year, Bekes [19] identified the restrictive conditions of optimization and presented a method for calculating the optimum cutting condition within these conditions. In this method production rate was only the objective criterion. In the same year, Basu [20] modified this method by developing a new approach for choosing optimum cutting variables. Boothroyed, Engle and Chisholm [21] determined the effect of tool flank wear on metal cutting process.Bjorke [22] developed a mathematical model for calculating the cutting condition during truing operation.

The nature of chip-tool contact process is an important factor in chip formation and it is one the most significant factors determining the process of tool wear. Talantov [23] presented a relationship between chip-tool contact process and tool wear for Cemented Carbide tools to improve metal cutting process. Nadai [24] in his study developed an equation with the help of which critical cutting speed can be determined. Considerable support was given to this theory by Roznikov [25] .In 1970, Time [26] explained the resistance of metal during cutting operations and in

1975, Babrov [27] presented the fundamental theory of optimization of the metal cutting process. In 1978, Talantov, Cheriomoshnikov(28) presented the relationship between cutting speed, metal cutting process and tool life. This work attempted to present a method of selecting maximum surface hardness and depth of penetration during turning operation on the basis of earlier progress in optimizing the metal cutting process, and it also attempts to establish a relationship between the surface hardness and the depth of penetration with the cutting variables.

1.3 General Theory

Extensive research works were carried by the scientist in the field of Metal- cutting. French scientist Tresca, Mallock, Taylor, Ernst and Merchant, Zerov, Rozenberg and many other scientist had developed several theories and empirical formulae and equations. But, all of these theoretical models are not relevant and applicable to the work. In this project work attempt has been made to explain a number of commonly observed resnlts. Some common theories of metal-cutting processes relevent to this project work are discussed here.

1.3.1 THE EFFECT OF PLASTIC DEFORMATION ON THE PROPERTIES OF METAL :

Deformation is the change in dimensions or form of matter under the action of applied load or forces. This is caused either by the mechanical action of external forces or by various physical and physio-chemical processes(for example, change in volume of separate crystallites in phase transformation or as aresult of temperature gradient). Plastic deformation significantly affects all physio-chemical properties of a metal. It is evident from Figure.1 and Figure 2. That, with increase of the degree of deformation, metal's ultimate strength and hardness increases. Plastic deformation causes strain or work-hardening of the metal and makes it harder and stronger. Before plastic deformation the dislocation density may be from 10^6 to 10^8 dislocations per cubic centimeter (as in the annealed condition). The density in strain hardened metal may reach 10^{12} per cubic centimeter. Deformed metal posses less corrosion resistance than undeformed metal. Cold deformation of iron substantially increases its coercive forces and decreases its magnetic permiability.

Any process of deformation will end in fracture if the stresses are increased to a high enough value. Two types of fracture are distinguished: brittle and

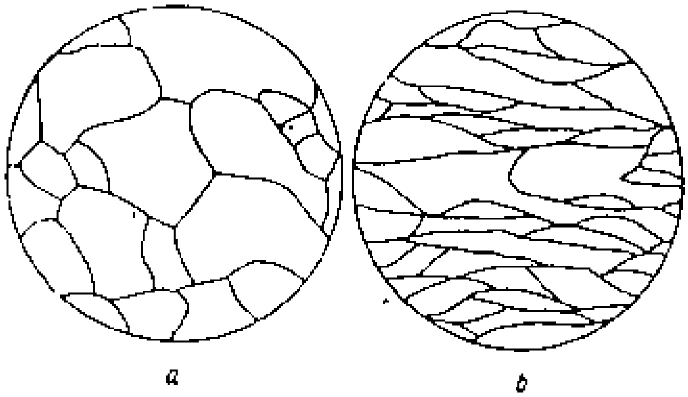


Fig.1 Effect of plastic deformation on the micro-
structure of a metal, x 300; a-before
deformation, b - after deformation.

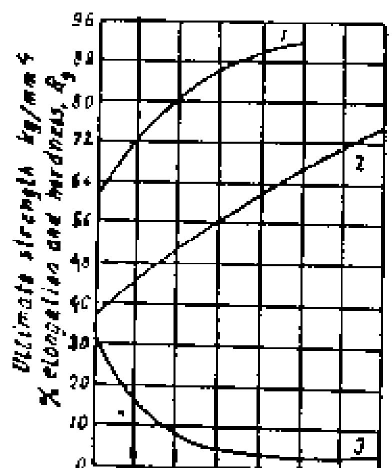


Fig-2. Effect of cold working on the mechanical
properties of low-carbon steel : 1 - hardness,
2-tensile strength,3-elongation.

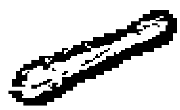
ductile. Fracture due to tangential stresses, resulting from plastic deformation, will of course, always be ductile. Normally machining of a material is accomplised by plastic deformation But most frequently, metal fracture does not occur as pure separation or shear but as a complex combination of this two types of fracture.

1.3.2 Theory of Metal Cutting:

Machining of metal involves forcing of cutting tool through the excess material of the work piece. In the form of chips, this excess material is progressively separated from the work piece, thereby rendering work piece to a desired shape and size. It may be emphasi ed here that the cutting tool never peels of chips or the excess material from the work piece, but the chips are generated because of plastic deformation of metal just ahead of the cutting edge of the tool.

Elements of cutting process(Mechanism of metal cutting):

Machining process involves work piece, a cutting tool (including holding devices), chips and cutting fluid For removing the metal, wedge shaped cutting tool is constrained to move relative to the work piece so that it removes the metal in the form of chips The first requiremnet of all metal cutting tools is that the tool be harder than the material being cut. The second is that the tool and material being cut must be held rigidly in a manner that will cause the fool to penetrate the work piece when forces are applied. When these conditions are satisfied metal will be displaced, providing there is sufficient force and power to overcome the resistance of the work piece material. Fig. 3 shows the progressive formation of a chip using a single point tool.



At Fig. 3(a), the tool contacts the work piece material. Compression in the work piece material takes place at the point of contact at (b). At (c), the cutting force overcomes the resistance to penetration of the tool and begins to deform by plastic flow. As the cutting force increases, either a rapture or a plastic flow in a direction generally perpendicular to the face of the tool occurs, and the chip is formed as shown at (d). The formation of a new chip segment begins, and the sequence of compression, plastic flow, and rapture is repeated. The cycle is repeated indefinitely. This process of chip formation is basic to edged matel cutting tools.

According to the position of the tool metal cutting process can be classified into two proups- 1) Orthogonal or two dimensional process. In it the cutting edge of the tool is at right angles to the direction of the relative motion between the tool and work piece. Examples of orthogonal cutting are: cut off or turning operation on Lathe. ii) Oblique or three dimensional cutting process, in which the cutting edge of tool is located at 90° to the motion of the work piece.

Fig. 4 shows the position of cutting tool in relation to work piece in a orthogonal cutting process in order to cut metal with less effort.

From figure it will be seen that three are three basic angles of importance, viz. rake angle, relief angle or clearence angle and setting angle. Figures 5,6,7 illustrate the effect of variation of this angles.

In any cutting operation, following observations can be made:

a) Metal is cut by removal of chips which may be in the form of continuous ribbon or discontinuous chips composed of individual segments, which depends on the work material and cutting conditions. The chip is thicker than the actual depth of cut and it is corrospondingly shortened. The hardness of the chip is usually much greater than the hardness of the parent material.

b) There is no flow of metal at right angles to the direction of chip flow.

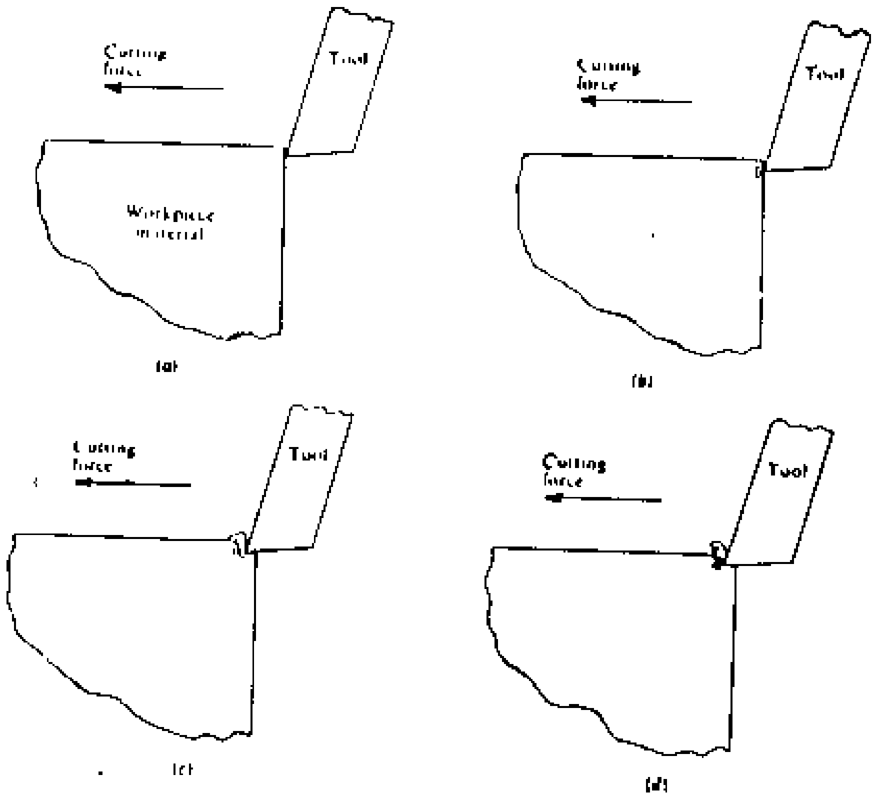


Fig-3.Progressive formation of a metal chip.

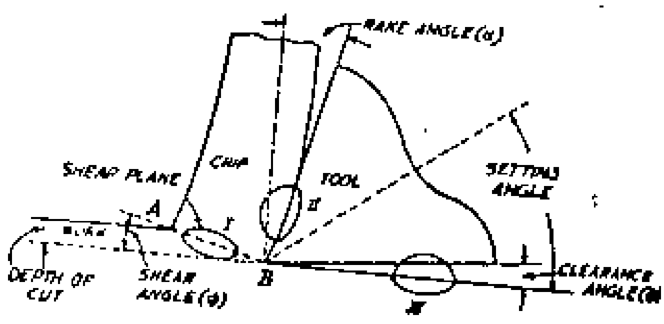


Fig-4. Position of tool in relation to work.

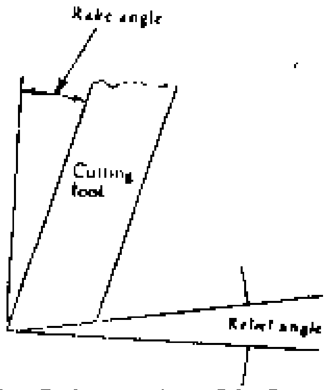


Fig-5. Rake and relief angles of a cutting tool

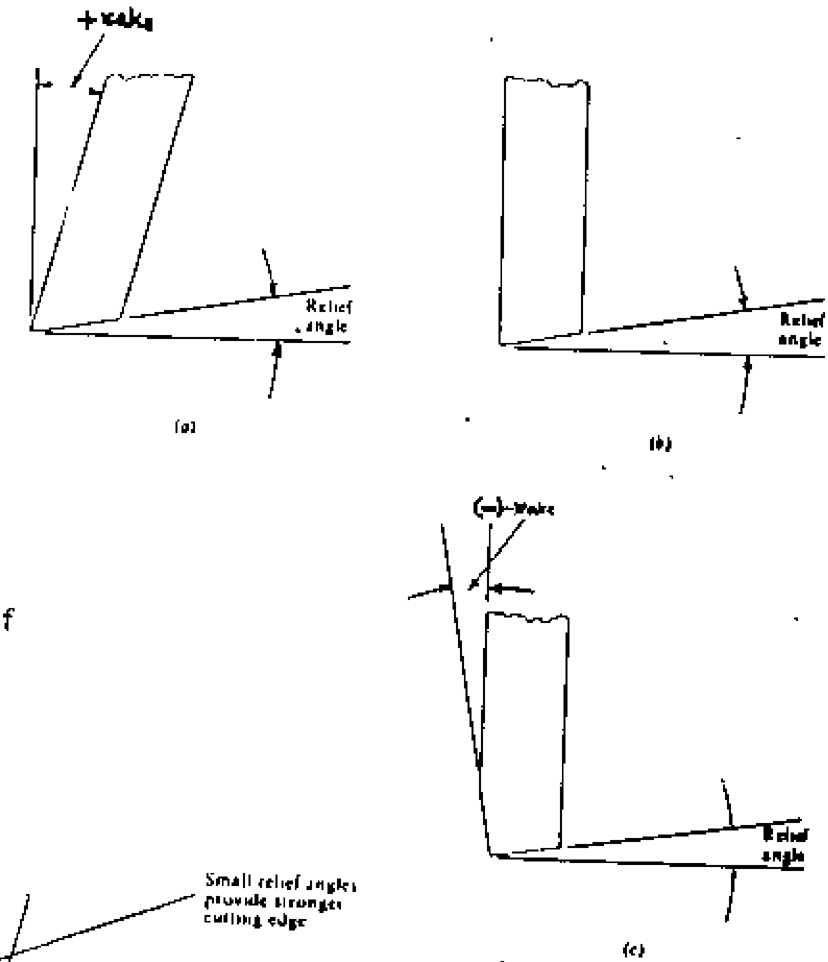


Fig-6. Variation of rake angles from positive to negative: (a) positive, (c) negative, and (b) zero rake angles.

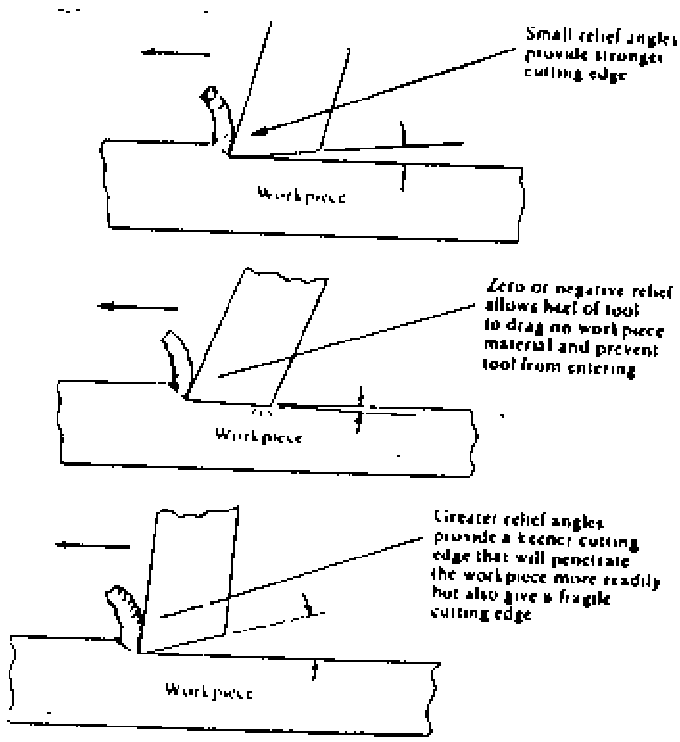


Fig-7. Effect of variation in relief angles.

c) Flow lines are evident on the side and back of a chip, which suggests that cutting involves a shearing mechanism. On observing the flow lines on the surface it will be obvious that chips are formed by, block wise slip of metal. However, the front surface is usually smooth due to a burnishing action. It is important to note that chips are formed due to the process of of deformation or plastic flow of material, which takes place by means of a phenomenon called "slip." Generally there are three basic types of chips (a) discontinuos (b) continuous and c) continuous chip with built up edge. Fig. 8 and Fig. 9 show the basic mechanism by which all chips are formed.

The process of plastic deformation occuring along the plane elongates the individual crystals of metal in the general direction indicated by share angle. This action tends to produce a chip that is thicker than the layer of parent material from which it originates. The chip material moves up the tool face in layers of distorted material. Each layer is pushed outward a fixed amount with respect to an adjacent layer and retain this position as the whole chip slides up the tool face. A large amount of energy is needed for chip formation and to make it move across the tool face. Avery large amount of strain also takes place in the shear region in a very short interval of time, which result in fracture of the metal. Fig. 10(a), 10(b) and Fig.11 show the action of tool during cutting operation and the formation of chips.

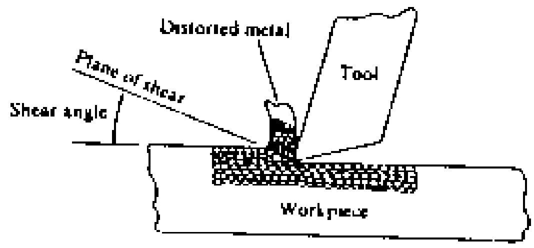


Fig-8. The basic mechanism by which all chips are formed.

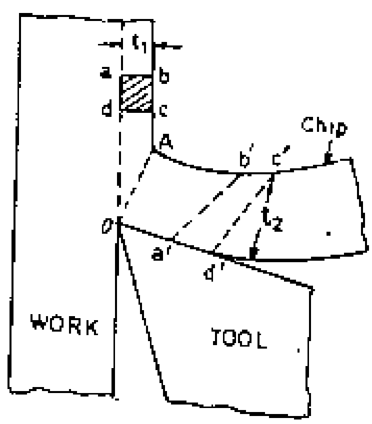


Fig-9. Formation of chip(turning).

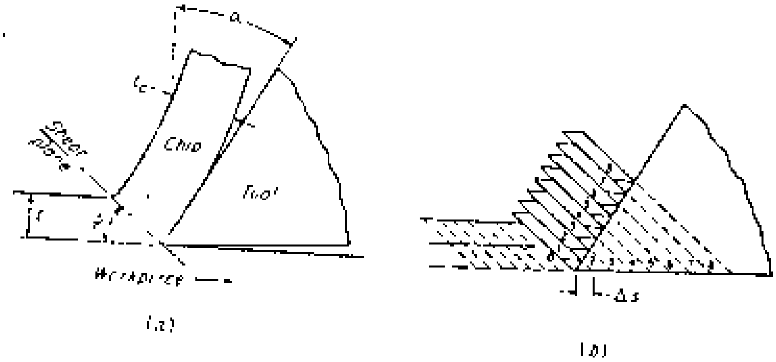
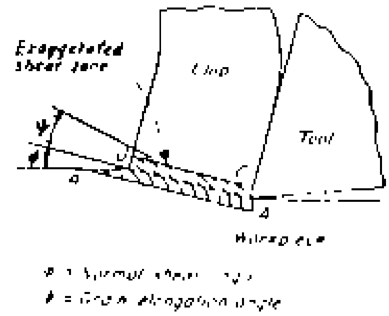
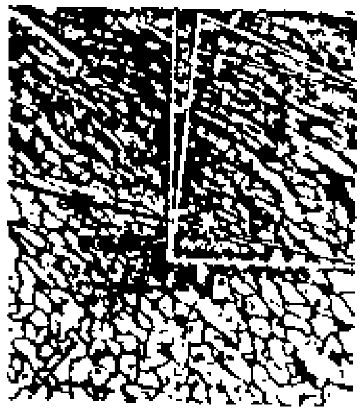


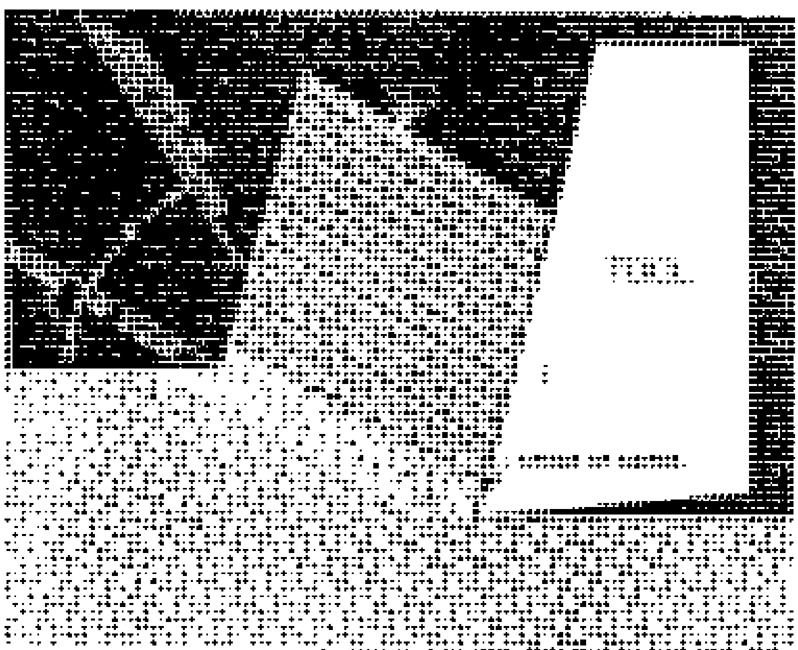
Fig-10. (a) The shear plane ; (b) Piispanes card analogy.



(a)



(b)



(c)

Fig-11. Shear zone. (a) Geometry ; (b) Photomicrograph(Allischalmers Co.)
(c) Model employing Piispanens card analogy to demonestrate mechanism of chip formation, showing difference between direction of shear and of "flow lines" in chip. Compare with photograph at (b).

Discontinous chips are formed as the result of machining brittle materials, like gray cast iron and high-lead bronze. Machining of these materials chip may come off in completely individual segments or the segments may adhere to each other to form a loose chip which fractures easily.

Continuous chips are associated with relatively ductile materials where definite successive ruptures do not take place. The planes tend to slip and weld and produce a continuous plastic flow of the metal without fracture ahead of the tool, followed by a smooth flow up the face of the of the tool. This type is usually associated with higher cutting speeds, as low cutting speeds some times cause certain ductile materials to pile up ahead of the tool and come off in small lumps similiar to discontinuous chip. However it is often referred to as an "ideal" chip because it produces excellent surface finish,the power consumption is low, fiction between tool and chip is low, and excessive heat is not generated. It does create a chip disposal problem and this is usually taken care of by incorporating chip breakres behind the cutting tool edge.

Although continuous chips are sometimes considered ideal, they are often difficult to obtain when machining the usual ductile materials. More often than not, ductile materials appear to be "gummy" and tend to adhere to the face and flank of the tool. This is the result of high friction between the face of the tool and the chip. The metal piles up on the tool point untill it appears

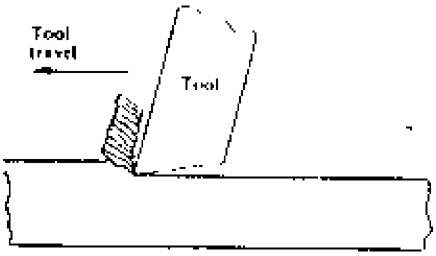


Fig-12. Formation of discontinuous chip.

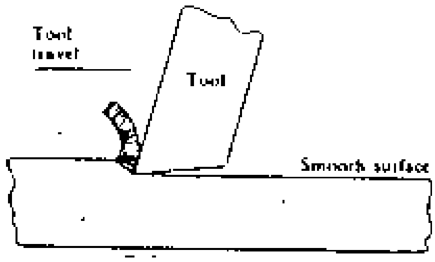


Fig-13. Continuous chip.

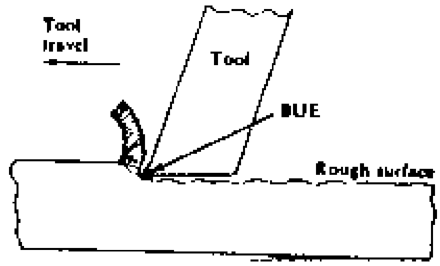


Fig-14. Continuous chip with built-up edge.

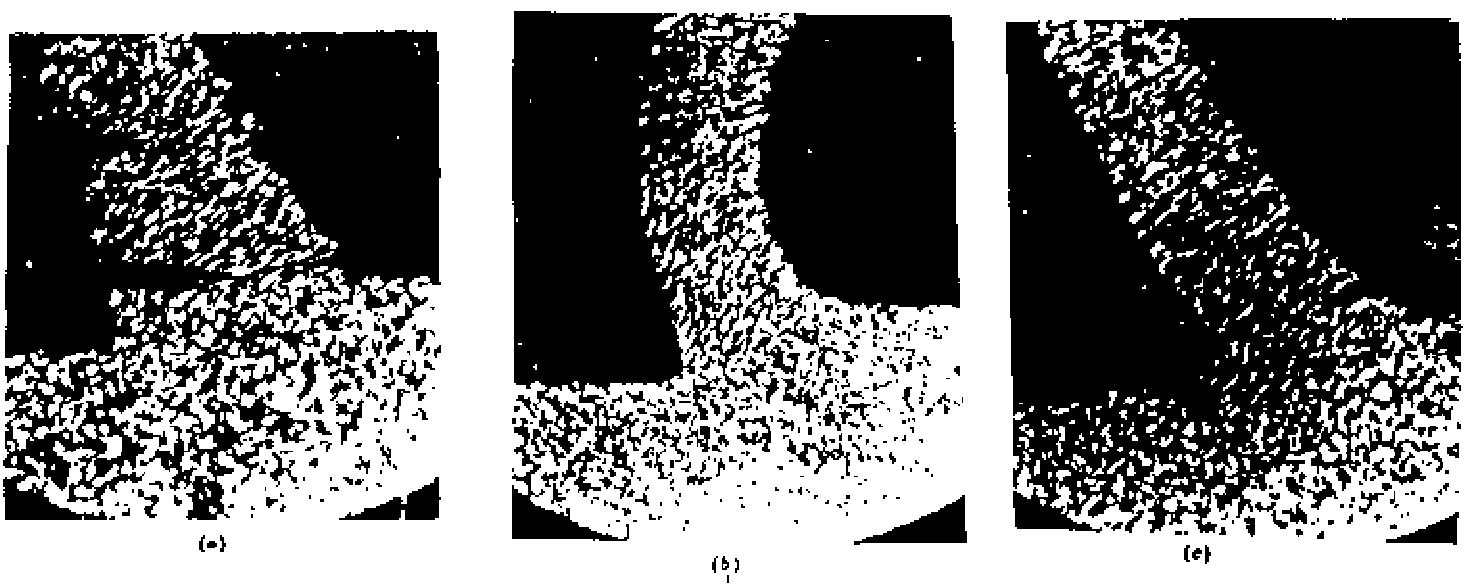


Fig-15. Basic chip types : (a) discontinuous, (b) continuous, (c) built-up edge.

to resemble a cutting edge and is sometimes incorrectly referred to as a "false cutting edge". More correctly, it is referred to as a built up edge (BUE), and the result is a continuous chip whith a build up edge. The formation of these chip is presented in Fig.12,13,14 and Fig.15.

d) A lot of heat is generated in the process of cutting due to friction between chip and the tool. The temperature of the cutting tool reaches a high value when taking a heavy cut at a high speed. Fig.16 shows the distribution of heat in metal cutting process and Fig.17 shows the effect of temperature at tool - chip interface associated with cutting speed and feed and effect of temperature on the hardness of the cutting tool material.

e) In front of the cutting tool point, generally no crack is observed. Due to strain hardening, the hardness of metal in chip, the built up edge and near the finished surface is usually greater than that for the parent metal. Fig. 18 shows the hardness distribution for ductile chip.

f) Formation of build up edge singificantly alters the cutting process. It deteriorates the surface finish and rate of tool wear is increased. Fig.19 shows the tool wear.

g) The inclination of plane AB in Fig. 20 with respect to the surface of work is known as shear angle. This angle increases when the tool friction is decreased; and increase of share angle means that share plan will be

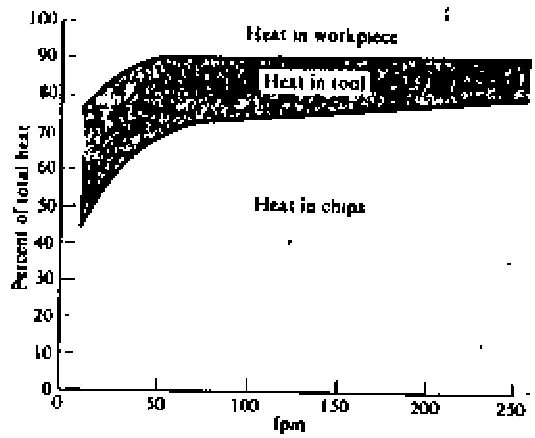


Fig-16. Distribution of heat in work, tool, and chips at various cutting speeds.

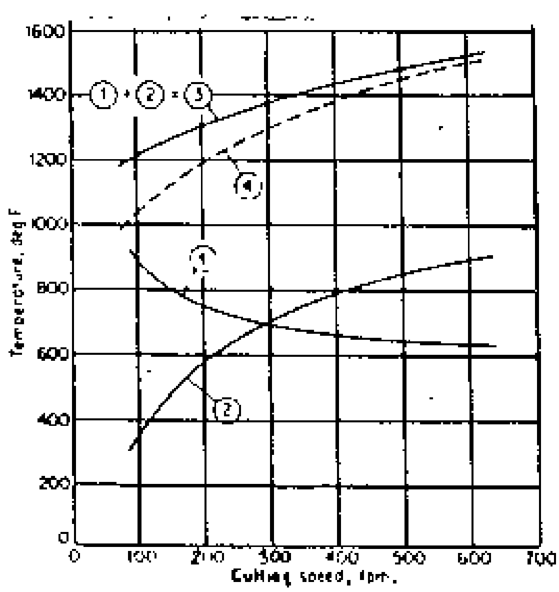


Fig-17. Average temperature at tool-chip interface.
Curve-1: Temperature at chip body due to main chip shear.
Curve-2: Temperature occure due to tool chip sliding.
Curve-3: Cutting temperature as calculated.
Curve-4: Cutting temperature measured by tool work thermocouple.

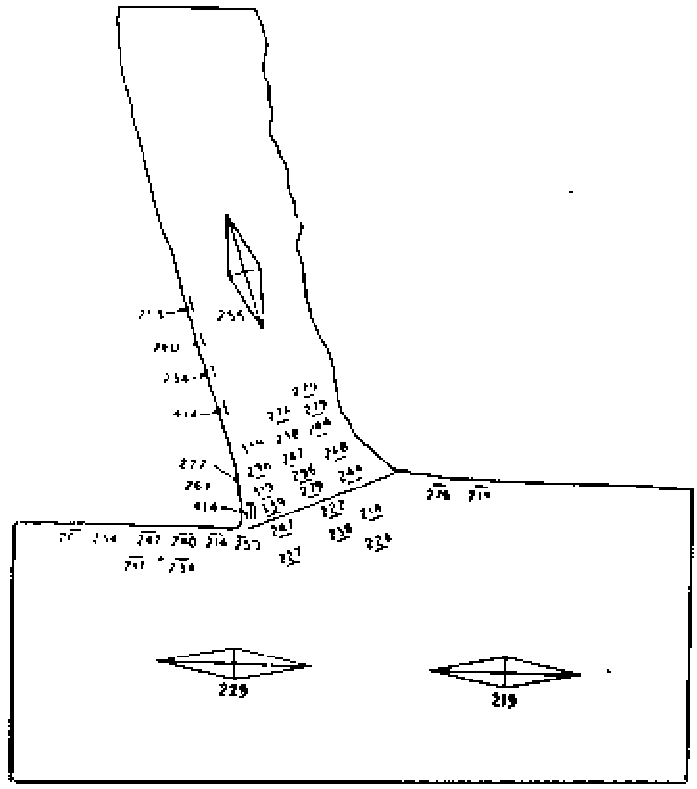


Fig-18: Hardness distribution for ductile chip.

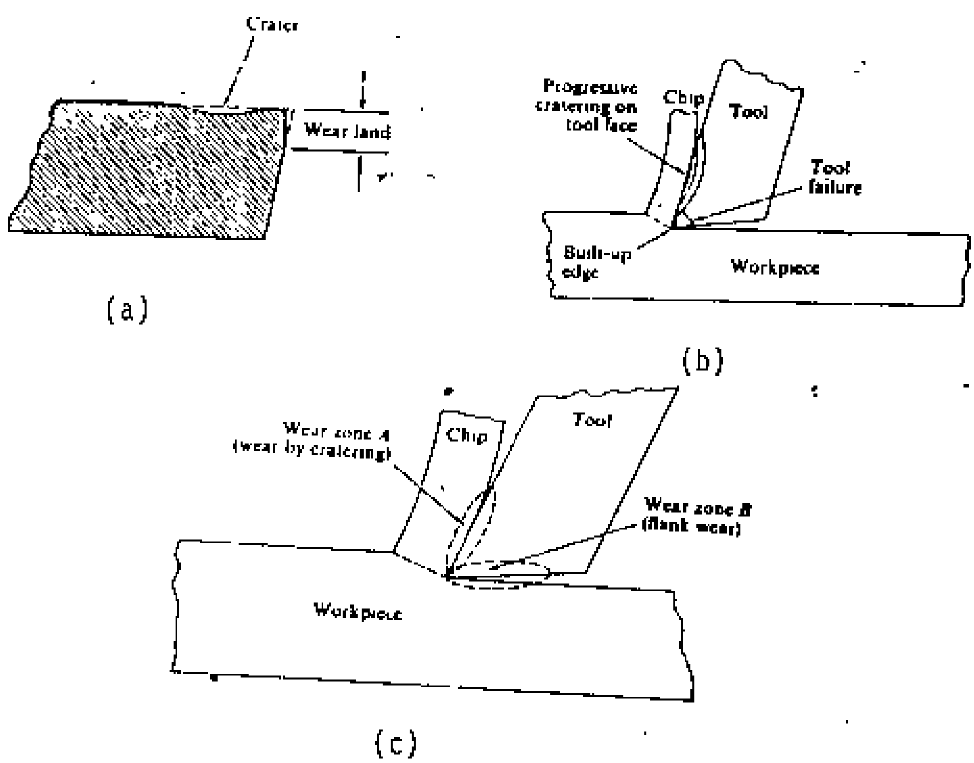
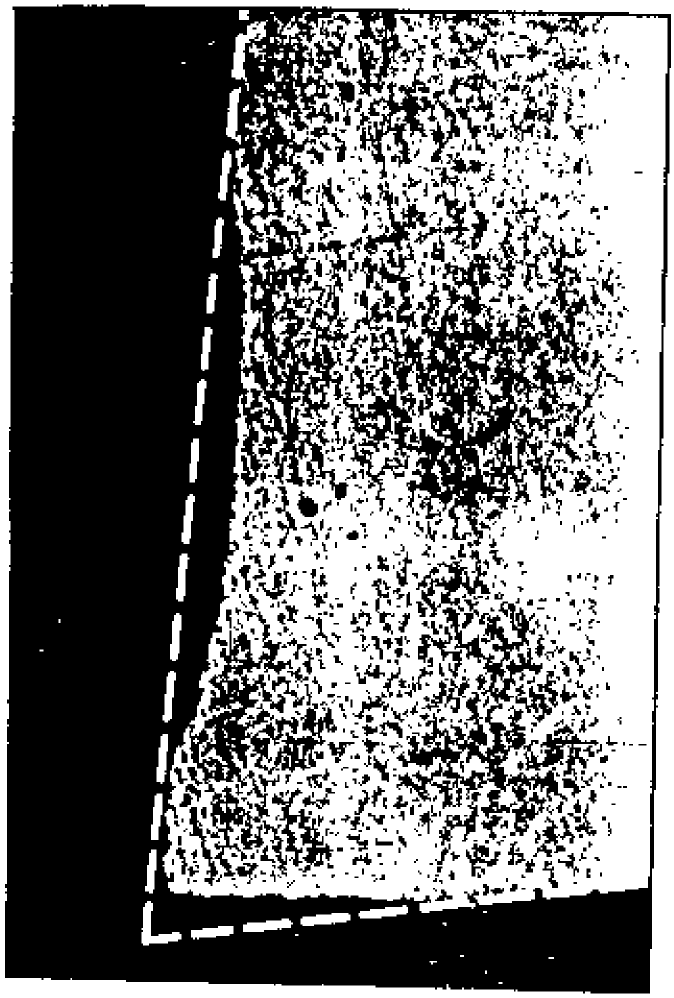
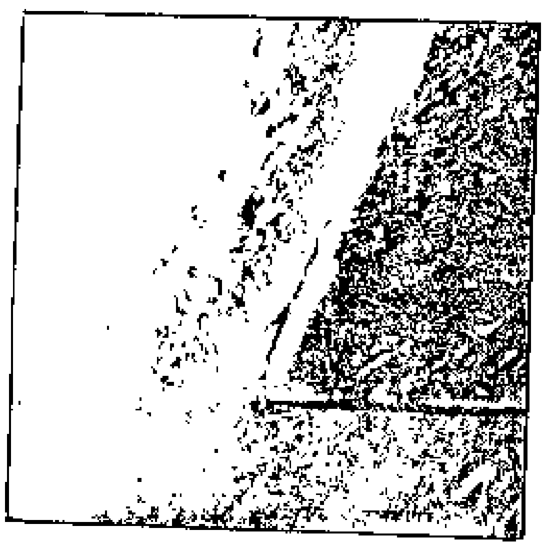


Fig-19: Tool wear in metal cutting: (a) Typical tool wear, (b) Areas of tool wear, (c) Cratering wear.



(d)



(e)

Fig-19: Tool wear in metal cutting: (d) Cross-section of a worn carbide tool showing wear land and crater. (e) Rubbing of chip on tool to form crater.

smaller length and thickness of chip will also be less. When the angle of shear is small, the path of shear will be longer and the resulting chip will be thicker and will require greater cutting forces to separate the chip from the work piece material. Fig. 20 shows the effect of variation of shear angle.

In practice every effort should be made to keep the shear angle as large as possible. Even if the shear stress on the shear plane is assumed to remain constant, the force acting along the shear plane also varies with the area of the shear plane. Further the amount of plastic deformation to which the chip is subjected also decreases as the shear angle increase.

The amount of plastic deformation or shear strain is related to the shear plane angle and the rake angle as shown in Fig. 21. From Fig. 21 it will be noted that for each rake angle. there is a minimum strain when the mean chip thickness is equal to feed ($t_C=t_U$). For zero rake angle it occurs at shear plane angle of 45°. Also at zero rake angle the minimum shear strain is 2 and becomes less and less as the rake angle is increased. Fig. 22 and Fig. 23 shows how the change of shape of a unit cube after passing through the shear plane occurs for different values of the shear plane angle.

h) In the cutting process, three areas of interest requiring due consideration are shown in Fig 4 by circle I,II and III. In thermal aspects of metal machining these three zones play vital roles. the first one is along the

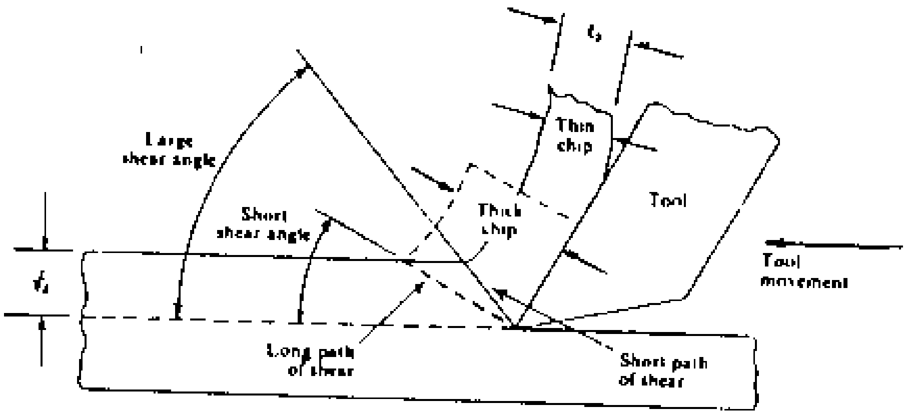
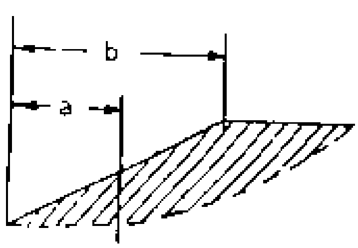


Fig-20: Orthogonal cutting showing the effect of large and small angles on chip thickness and length of shear planes.



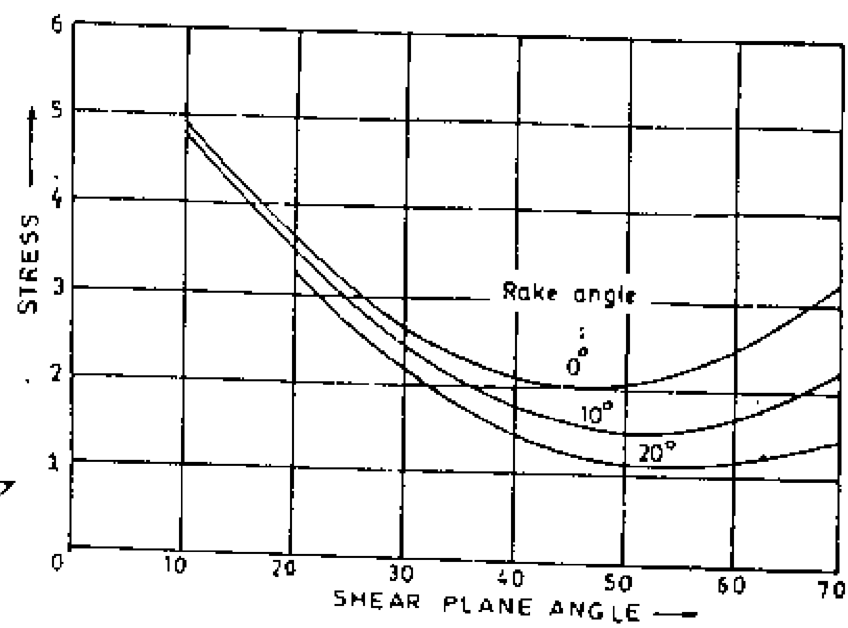


Fig-21. Variation of shear strain with the shear plane angle and rake angle.

Fig-23: Shape of a unit cube after deformation.

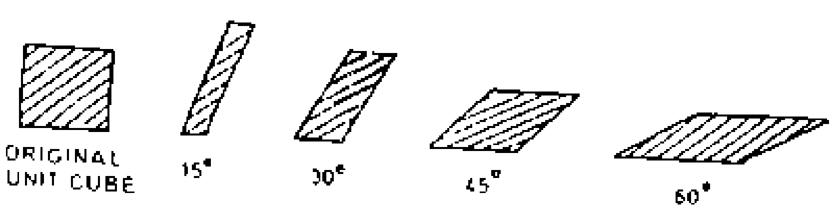


Fig-22: Change of shape of aunit cube after passing through the shear plane occurs for different values of the shear plane angle.

shear plane, where maximum heat is generated because of the plastic deformation of metal, and practically all of this heat is carried away by the chip as machining is a rapid and continuous process. The second zone is the interface between the chip and the fool face. This zone is known as friction zone. Heat is generated here mainly due to friction between moving chip and fool face and partly due to secondary deformation of the build up edge. The thrid zone is along the finished surface and the material of tool adjacent to that surface. Heat in this zone goes on increasing with time as the wear land on the tool develops and goes on increasing, Fig. 17 shows the distribution of heat.

i) The steady state conditions on which the cutting theories are based often get changed by the formation of discontinuous chips. The tool geometry is also altered by the presence of build up edge.

1.3.3 MECHANICS OF MACHINING:

a) Cutting Force In Turning: (29) Cutting forces in orthogonal cutting process are shown in the Fig. 24 Here the forces are all on one plane and the components of the forces can be added algebraically as in elementary mechanics.

Referring to Fig. 24 the resultant force R has two basic components F_c and F_t. F_c determines the amount of work required to move the cutting tool a given distance. F_t does not work, *but* both components produce deflections of the tool relative to the work piece. At the tool face, the force components F_f and N_t act on the chip. F_μ is known as friction force between chip and tool. The force components acting at the shear plane are F_s and F_n. F_s is the shearing force and represent the force required to shear the metal on the plane of shear. F_n acts normal to the shear plane.

(30) From the geometry of Fig. 24, equations can be derived from which various mechanical quantities can be calculated if certain quantities are known. These are shear angle ϕ, rake angle α, the force component F_c and F_t, chip cross - sectional area A_0, and cutting spced V. The equations for making such calculations from these known quantities are summarized in Table - 1.

b) Cutting Force in the Lathe -Turning operations:

(31) The cutting forces experienced in turning operation can be resolved into three components:

i) Tangential Force, F_t

ii) ·Radial Force, F_r

iii) Axial orce, F_a

Fig. 25 shows the components of the cutting forces on lathe.

Tangential forces F_t: (31)Acts in the direction of cutting velosity vector and is some times reffered to as turning force. It is mainly responsible for the cutting power needed. It is usually the highest of the three forces and constitutes approximately 99 percent of the total power required by the tool. It can be expressed as

$$F_t = K_1 f^{x_1} d^{y_1} (kgf \times 9.81) \text{ Newton.}$$

where, f and d are feed and depth in mm.

K_1 = 162 for 0.2% carbon steel.

x_1 and y_1 are constants and their values are 0.38 and 0.98 for 0.2% carbon steel.

Radial Forces F_r: acts in a radial direction from the centre of the work. It is the force that holds the tool to the correct depth of cut. It is the smallest of the three tool forces only 50 percent as large as the longitudinal or Axail force. (31) The radial force plays no part in horse power requirement and is given by

$$Fr = K_2 f^{x_2} d^{y_2} (Kgf \times 9.81) N$$

Where, K_2 = 34, x_2 = 0.8 and y_2 = 1.42 for 0.2% carbon steel.

Axial Force F_a: acts in the direction of longitudinal feed. It is also known as longitudina force or feeding force. It is about 40 percent as high as the tangential force. Power required on account of this is very less compared to F_t. (31) It is given by

$$F_a = K_3 f^{x_3} d^{y_3} (Kgf \times 9.81) N.$$

where, K_3=40, x_3=0.67, y_3= 0.67 for 0.2% carbon steel.

Whenever a single points tool is cutting the metal, the resultant cutting force 'P' acting in oblique directions can be resolved in three directions at right angles.

i) Vertical chip pressure (tangential components P_z)

ii) Horigental work pressure across lathe (axial component P_x)

iii) Horigental feeding pressure across lathe (radial components P_y)

Out of these three, the first one i.e. P_z is most predominant as regards to power absorbed and the other two although absorbing power, are generally neglected. In order to account for these two and account for the friction to overcome, generally 30% of power is added to the power calculated on the basis of P_z.

(3i) From the numerous experiments performed, the following relation for the cutting pressure on a single point tool has been established.

$P = C_1 d^a f^b$

where,

P= Pressure

f = feed

d = depth of cut

c_1= constent

and 'a' and 'b' are constant depending upon the metal being cut and other factors.

(3i) But generally for most of the practical purpose, it has been observed that the following relation also gives very good results:

P=k x d x f

= k x (area fo cut)

Where k is constant i.e. pressure on the tool in kg per square cm of cut area and depends upon the metal being cut and its value for vrious metal is given in table-2

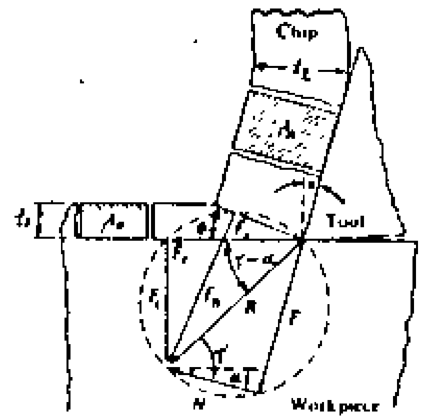


Fig-24: Schematic diagram of force system acting in orthogonal cutting with a continuous chip (from ASTME, "Tool Engineers Handbook" 2nd) edition, 1959

TABLE-1. Equations for calculating important mechanical quantities.

Quantity	Equation	
Coefficient of friction	$\mu = \frac{F_t + F_c \tan \alpha}{F_c - F_t \tan \alpha}$	(1)
Friction force	$F = F_t \cos \alpha + F_c \sin \alpha$	(2)
Mean shear strength	$S_s = \frac{F_c \sin \phi \cos \phi - F_t \sin^2 \phi}{A_o}$	(3)
Work done in shear	$W_s = S_s [\cot \phi + \tan (\phi - \alpha)]$	(4)
Work done in overcoming friction	$W_f = \frac{F}{A_o} \frac{\sin \phi}{\cos (\phi - \alpha)}$	(5)
Total work done in cutting	$W_n = \frac{F_c}{A_o}$	(6)

where, Ao= cross-sectional area of chip before cutting.
Fu= friction force; acting between tool face and sliding chip.
Fc= cutting force; in direction of tool travel.
Ft= thrust force ; in direction perpendicular to surface generated.
Ss= mean shear stress on shear plane.
Wf= work done in over coming friction between tool and chip.
Wn= total work done in cutting per unit volume of metal removed.
Ws= work done in shearing of metal per unit volume of metal removed.

x =effective rake angle of tool.

o =shear angle;

Source: "Tool Engineers Handbook" 2d ed., 1959.

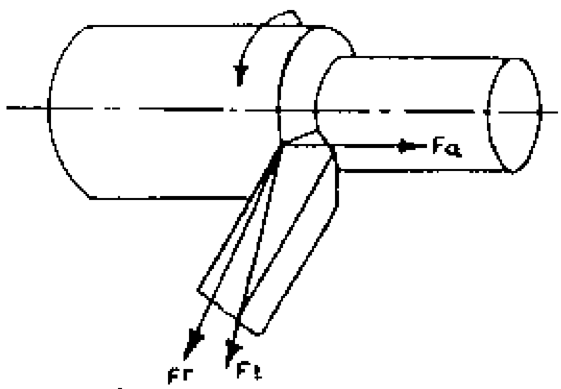


Fig-25: Components of the cutting forces during turning operation on lathe machine.

TABLE-2. Values of the constant k , for different metal.

Metal being cut	Steel 100—150 Brinell	Steel 150—200 Brinell	Steel 200—300 Brinell	Steel 300—400 Brinell	Cast iron	Brass	Bronze	Aluminium
K	11,000	15,300	22,000	26,700	8,600	12,000	16,000	6,700

if v is the cutting speed of the tool in m/min. then work done per munite will be pxv and the horse power required is given by

$$H.P = \frac{pxv}{4500}$$

These cutting forces of the tool points are usually measured with dynamometers.

Influence of cutting speed, feed, depth of cut and work material upon cutting forces:

The cutting forces depend upon several factors like work material, cutting speed, feed rate, Depth of cut, approach angle, side rake angle, back rake angle, nose radious and tool wear. Here machining operation off Mild steel will be performed by using Cemented carbide tool of particular geometry and tool life. So, the factors which should be given more importants are as follow:

i) Cutting speed (v): In lathe, cutting speed means the number of meters measured on the circumference of job that passed the cutting edge of the tool in one minute. Methematically cutting speed v is expressed as-

$$V = \frac{\pi DN}{1000} \text{ m/minutes.}$$

Where, D = Dia of job, mm

N = rpm (spindle or job speed)

The amount of power used in a machining operation is generally proportional to the cutting speed in that the rate of metal removed is proportional to speed. [32]Metal removal rate is given by-

MRR= (Feed x Depth of cut x 12 x Speed) cubic inch/minute

where, Depth of cut = inch,

Feed=inch/rev.

Speed = feet permin.

Mthod of calculating MRR is obtained by Table. 3

Horse power of the motor[32] HPm is given by

$$HPm = \frac{uhp \times c \times MRR}{Efficiency}$$

$$= \frac{\text{Unit horse power} \times \text{feed correction factor} \times MRR}{\text{effeciency of the motor}}$$

where, c= is feed correction factor.

MMR = Metal removal rate

Unit horsepower, uhp can be obtained form Table-4 and feed correction factor can be found from Fig. 29.

Speed, however, has little effect on cutting forces within the normal cutting range. Fig. 26 shows how the tangential force P_Z varies with increase in cutting speed.

Similar curves are applicable for cutting force components P_Z and P_y also. It will be noted that cutting forces first increase with increase in cutting speed and on further increase in speed reach a maximum value and start decreasing and become fairly establish at higher speed range. The initial rise in cutting force upto about 70 m/min is due to the effect of built up edge which does not occurs at high speeds. The cutting forces at high speeds beyond 70 m/mi decreases because of high temperatures involved which tends to make the material plastic.

For all practical purpose, the change in cutting forces due to increased speed may be ignored as long as the speed is with in the normal cutting range.

ii) <u>Feed</u>: It is the amount of tool advancement per revalution of job paralled to the surface being machined.

The tangetial component of cutting force is greatly in fluenced by the feed rate. Other two corce components are also increased with increse of feed. It has been observed that cutting force change linearly with feed of higer speed, but at slower speeds the change is exponential. Fig.27 shows the effect of feed on the tool forces.

iii) Depth of cut: It is the advancement of tool in the job in a direction perpendicular to the surface being machined. Fig.28 shows that depth of cut increases tangential and logitudinal forces but it makes no change in the radial forces. Depth of cut has the most direct effect on cutting forces. Thereby it will be possible to remove metal more effficiently at heavy feeds since less unit horse power required.

So, from the above discussion it whould be found that, cutting speed has the greatest influence on tool temperature, followed by feed and depth of cut.

Depth of cut has the greatest influence upon cutting forces, followed by feed, with cutting speed having the least influence.

Feed has the greatest effect on surface funish when it is set according to the nose radious. Considering these relations tool designers and manufacturing engineer select the best suitable cutting conditions for machining of metal.

The most common empirical formula [33] that has ben developed to give the cutting speed on the basis of relationship between steel hardness, depth of cut, cutting speed and feed a specific tool life is as follow.

$$S = \frac{225.000}{D \times 0.2 \times F \times 0.58 \times B \times 12}$$

Where, S = recommended cutting speed fpm = ·3048 mpm
D = depth of cut. inch = ·0254m.
F = feed, ipr = ·0254 meter/rev.

B = Brinell hardness.

The nomograph in Fig.30 was developed by using this empirical formula as the basis for cutting-speed recommendation for steel using a single point Carbide tipped tool.

iv) Work material: One of the important factors in determining tool forces and power is the work material itself. Ductility, hardness, co-efficient of friction and work hardening all have definite effects on tool forces. Increased ductility results in increased chip thickness and therefore increased forces. Higher hardness causes higher unit power or force, as shown in Fig.31, 32 material at different point during machining process. The co-efficient of friction can be reduced by additions such as sulfur and lead, and lower forces will result. Austeritic material work hardens and requires higher forces and unit power. Fig. 33 shows a comparetive relations with factors influencing tool forces, feed, cutting speed and power requirement.

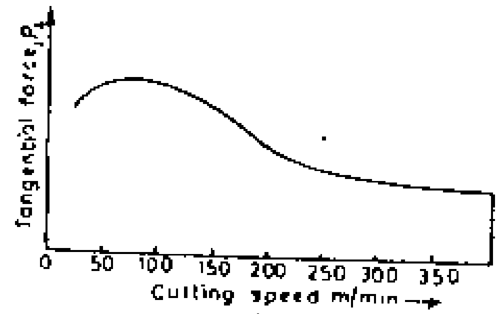


Fig-26: Variation of cutting forces with cutting speed.

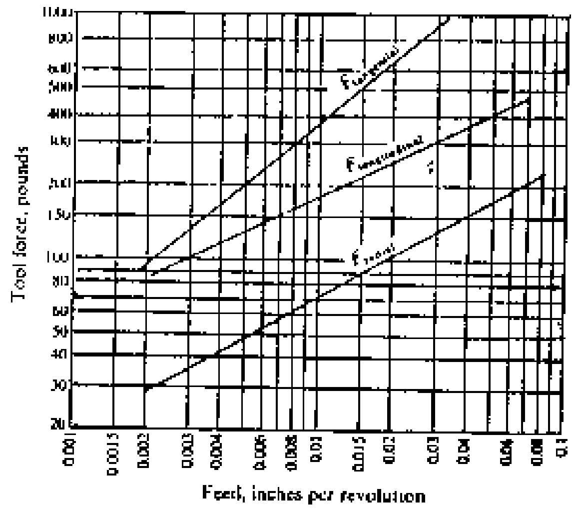


Fig-27: Effect of feed on the components of the tool forces when turning carbon steel.

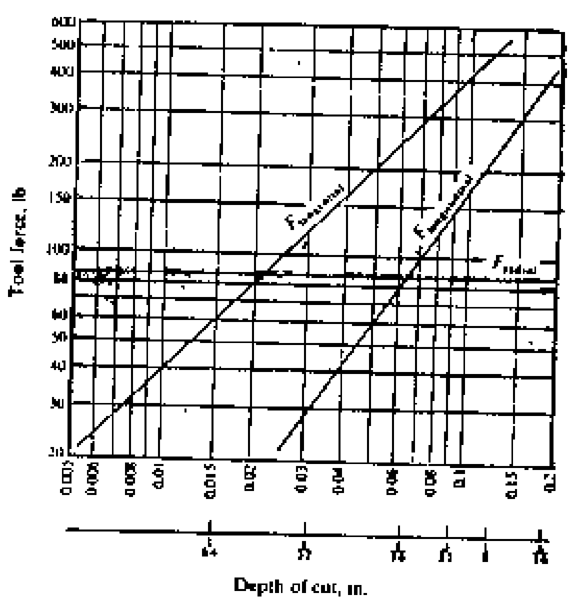


Fig-28: Effect of depth of cut on tool-force components.

TABLE-3. Method of calculating volume of metal removed per minute.

Operation	Formula for volume, cu in./min
Turning*	FD × DC × fpm × 12
Face milling	W × DC × TT
Slot milling	W × DC × TT
Planing or shaping	DC × FD × L × S

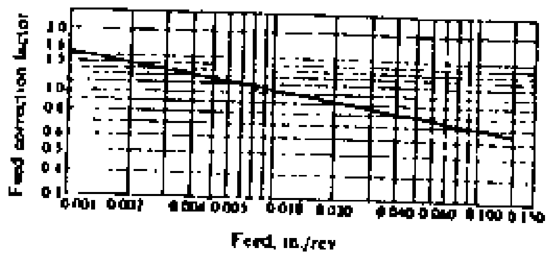


Fig-29: Feed correction factor based on tool geometry.

TABLE-4. Average unit horse factors.

Material	Ferrous metals and alloys — Brinell hardness number: 150-175	175-200	201-250	251-300	301-350	351-400
AISI:						
1010-1025	0.58	0.67				
1030-1055	0.68	0.67	0.80	0.98		
1060-1096	—	—	0.76	0.88	1.0	
1112-1120	0.50					
1314-1340	0.42	0.46	0.50			
1330-1360		0.57	0.76	0.92	1.1	
2015-2115	0.67					
2316-2336	0.64	0.68	0.62	0.78	0.92	
2340-2360	..	0.60	0.68	0.70	0.83	1.0
2512-2515	0.60	0.58	0.67	0.80	0.92	
3116-3130	0.60	0.68	0.70	0.83	1.0	
3160-3450	..	0.60	0.62	0.78	0.87	1.0
4130-4345	.	0.46	0.68	0.70	0.83	1.0
4616-4820	0.46	0.60	0.58	0.70	0.83	0.87
5120-5160	0.46	0.50	0.62	0.76	0.87	1.0
52100	..	0.58	0.67	0.83	1.0	
6115-6140	0.46	0.54	0.67	0.83	1.0	
6145-6195	..	0.70	0.83	1.0	1.2	1.3
Plain cast iron	0.30	0.33	0.42	0.60		
Alloy cast iron	0.30	0.42	0.54			
Malleable iron	0.42					
Cast steel	0.62	0.67	0.80			

Cutting speeds are based on the following conditions:

Material: Carbon steel

Surface conditions: heat-treat scale.

Coolant: none

Cutting tool: Carbide grade37

Style:B; Tool life:60min based on 0.020in Reak wear-lan

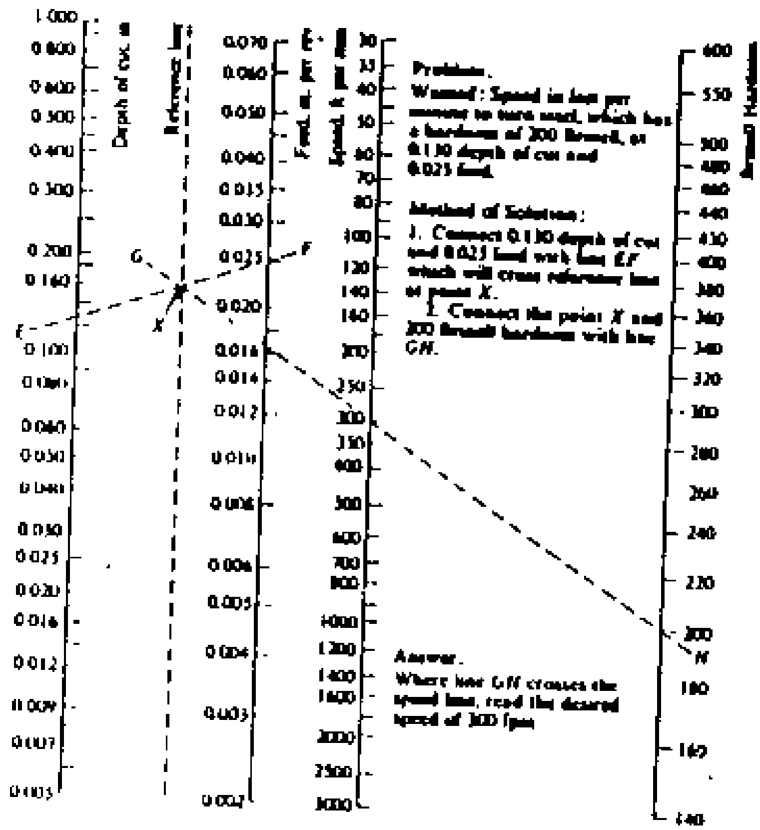


Fig-30: Speeds for machining steel with carbide tools. (from "Carboloy Application data manual", Metallurgical Products Department, General Electric Company.).

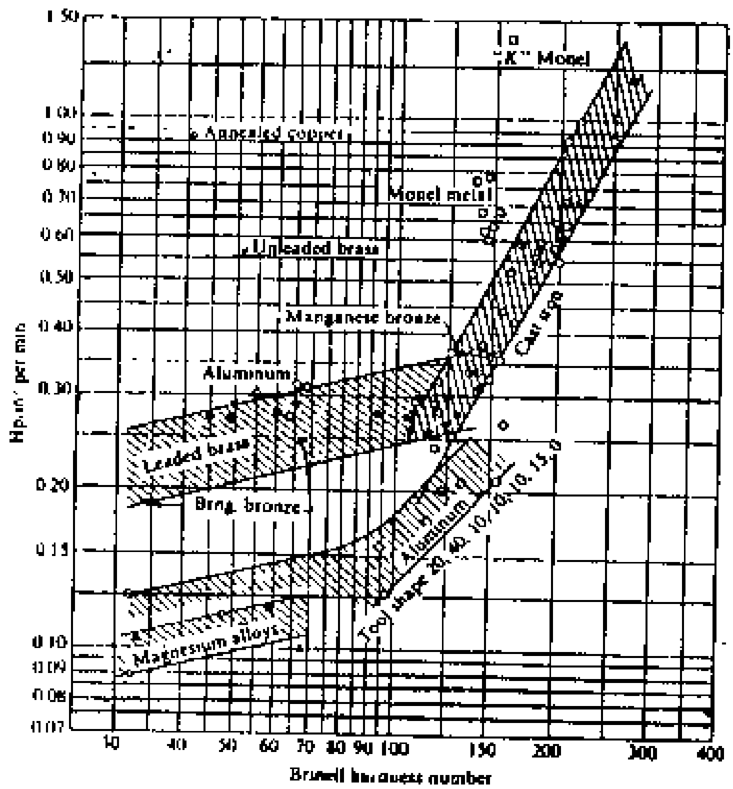


Fig-31: Horsepower per cu.in.per min. when turning various metals.

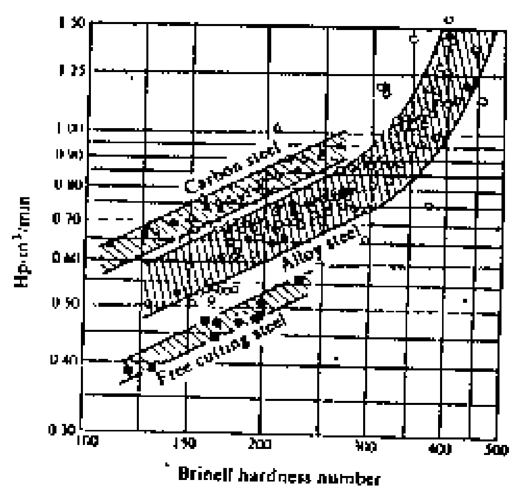


Fig-32: Horsepower per cu. in. per min. when turning steel.

(Metallurgical Products Department,General Electric Co.)

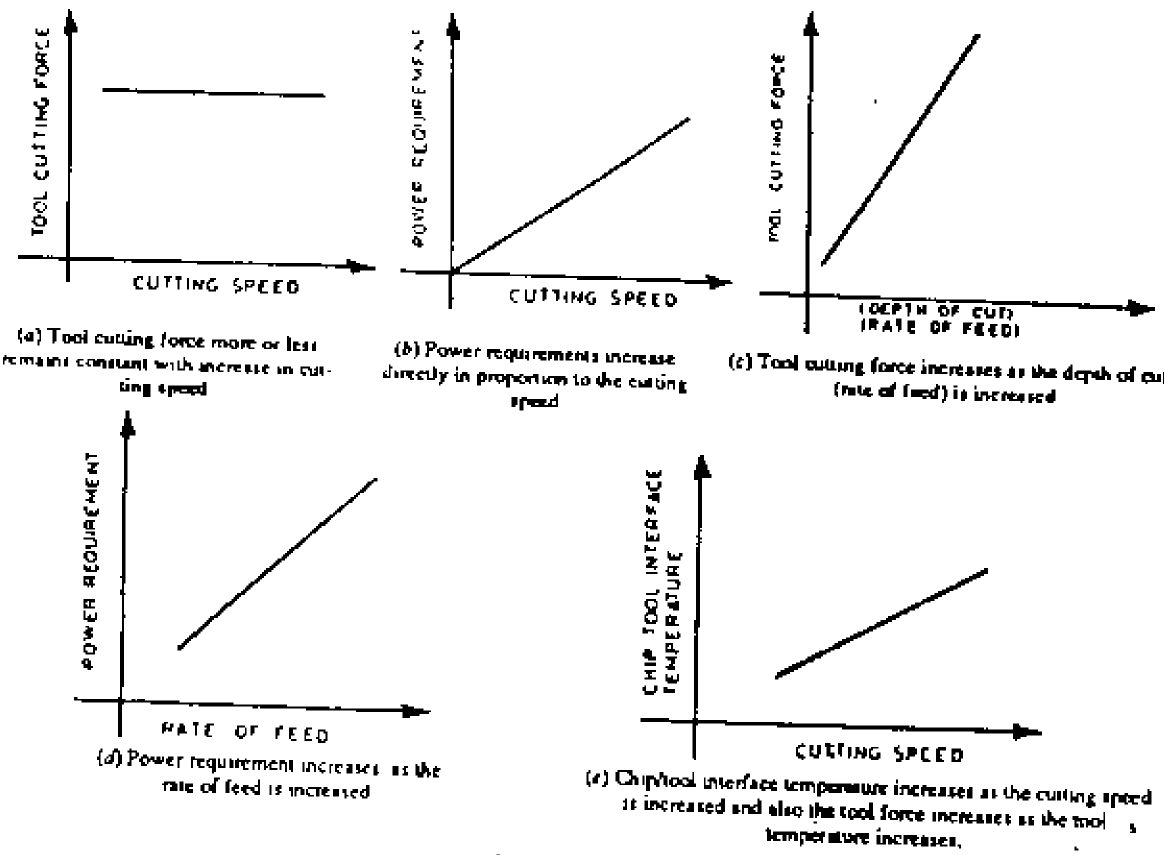


Fig-33: Factors influencing tool forces, feeds, cutting speeds, and power requirements.

TABLE-5: APPROXIMATE STEEL HARDNESS CONVERSION NUMBERS BASED ON ROCKWELL HARDNESS. (Source: "Ryerson Stock List", Joseph T. Ryerson and Son, Inc.,)

Rockwell		Brinell		Vickers	Shore sclero-scope	Tensile strength, 1000 psi
C scale, 150 kg, 120° cone	B scale, 100 kg, 1/16 in. ball	Hardness no.	Diam., 3000 kg, 10-mm ball			
68	...	...	...	940	97	
67	...	...	...	900	95	
66	...	...	...	865	92	
65	...	739	...	832	91	
64	...	722	2.28	800	88	
63	...	705	2.31	772	87	
62	...	688	2.33	746	85	
61	...	670	2.36	720	83	
60	...	654	2.40	697	81	...
59	...	634	2.43	674	80	326
58	...	615	2.47	653	78	315
57	...	595	2.51	633	76	305
56	...	577	2.55	613	75	295
55	...	560	2.58	595	74	287
54	...	543	2.62	577	72	278
53	...	525	2.67	560	71	269
52	...	512	2.71	544	69	262
51	...	496	2.75	528	68	253
50	...	481	2.79	513	67	245
49	...	469	2.83	498	66	239
48	...	455	2.87	484	64	232
47	...	443	2.91	471	63	225
46	...	432	2.94	458	62	219
45	...	421	2.98	446	60	212
44	...	409	3.02	434	58	206
43	...	400	3.05	423	57	201
42	...	390	3.09	412	56	196
41	...	381	3.12	402	55	191
40	...	371	3.16	392	54	186
39	...	362	3.19	382	52	181
38	...	353	3.24	372	51	176
37	...	344	3.28	363	50	172
36	109*	336	3.32	354	49	168
35	...	327	3.37	345	48	163
34	108*	319	3.41	336	47	159
28	104*	271	3.49	286	41	134
27	103*	264	3.74	279	40	131
26	...	258	3.78	272	38	127
25	...	253	3.81	266	30	124
24	101*	247	3.84	260	37	121
23	100	243	3.88	254	36	118
22	99	237	3.93	248	35	115
21	...	231	3.98	243	35	113
20	98	226	4.02	238	34	110
18*	97	219	4.09	230	33	106
16*	95	212	4.15	222	32	102
14*	94	203	4.24	213	31	98
12*	92	194	4.33	204	29	94
10*	91	187	4.42	196	28	90
8*	90	179	4.51	188	27	87
6*	87	171	4.60	180	26	84
4*	85	165	4.67	173	25	80
2*	83	158	4.77	166	24	77
0*	82	152	4.84	160	24	75

* Values are beyond normal range: given for information only.

SOURCE. "Ryerson Stock List," Joseph T. Ryerson and Son, Inc., by permission.

1.3.4 Critical cutting speed :

It is known that, cutting force, P_Z is a function of cutting variables[14] .

$$P_Z = f(V, F, D)$$

Expression of tool life, $$T_L = \frac{C_V}{V^{1/n} \times F^{yv/n} \times D^{Xv/n}} (Kg \times 9.81) N.$$

For a particular cutting condition, where values of F and D are remain constant, Pz is a function of only cutting speed , Pz = f (V) .Rozenberg [12]established an expression of cutting force, Pz,

$$Pz = \frac{T_s \times F \times D \times \dfrac{\cos X}{\sin \theta \times \cos(\theta - x)}}{1 - \dfrac{\sin u}{K . \cos(u - x)}} \times 9.81 N$$

[14]This indicates that Pz depends on the value of K , F , D and V . K is the 'chip-reduction co-efficient ' or 'chip shrinkage ' , where

$$K = \frac{\cos(\theta - x)}{\sin x}$$

$$K = \frac{\text{actual chip thickness, } t_C}{\text{uncut chip thickness, } t_U}$$

From Figure. 34 uncut chip thickness is -

$$t_U = \text{Feed} \times \cos\theta$$

where = 0 is the side cutting edge angle of the tool .

Actual chip thickness can be measured by using high magnification microscope .

The value of k is affected by:-

i) Cutting variables, i.e v, etc.

ii) Cutting environment and auxiliary variables

The behavior of k as influenced by cutting variables fully depends on cutting force, P_z. For determination of cutting force and explaining cutting tool performance, the value of chip shrinkage, k and its behavior with respect to cutting variables is very important. And also, measurement of k is very easy and needs no costly and precise instrument. But on the other hand, cutting force, P_z measurement is very troublesome and the instrument is also very costly. In Fig. 35, Rozenberg [12] has demonstrated that the behavior of cutting forces with respect to cutting speed is identical with chip-shrinkage characteristics. So, to find out the critical cutting speed, V_c, chip-shrinkage, K is used instead of cutting force, P_z.

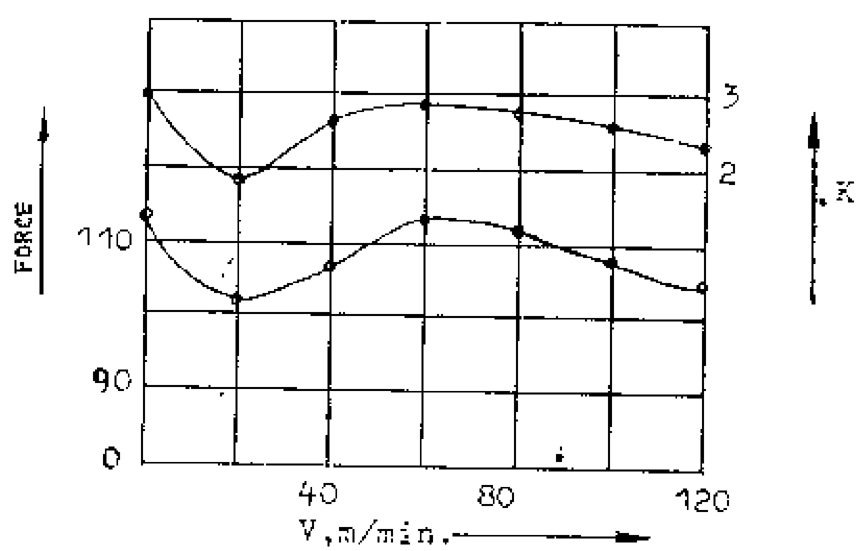


Fig. 35. The behaviour of cutting force, P_z and chip-shrinkage, K with respect to cutting speed, V. (after Rozenberg)

So, according to Rozenberg's[11] theory it can say's that 'K' is a function of cutting velocity .

$$K = f(V)$$

If a curve K= f (V) is plotted with the values of 'K' and corresponding values of 'V' , then Critical cutting speed, Vc will be at the point where 'k' will be maximum . The point Vc plays a significant role in 'Economics of metal cutting' as the nature of the curves and 'Chip-tool-contact' processes changes drastically at this point . Many authors denote this point as 'Critical point' or 'Critical cutting speed' or 'V-critical' or simply as 'Vc' . For single carbide tool 'Vop $\leq$ 'Vc'

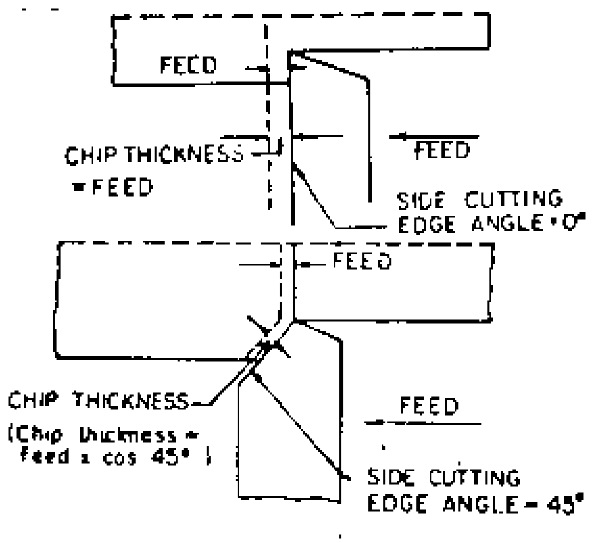


Fig-34: The effect of varying side cutting edge angle on chip thickness.

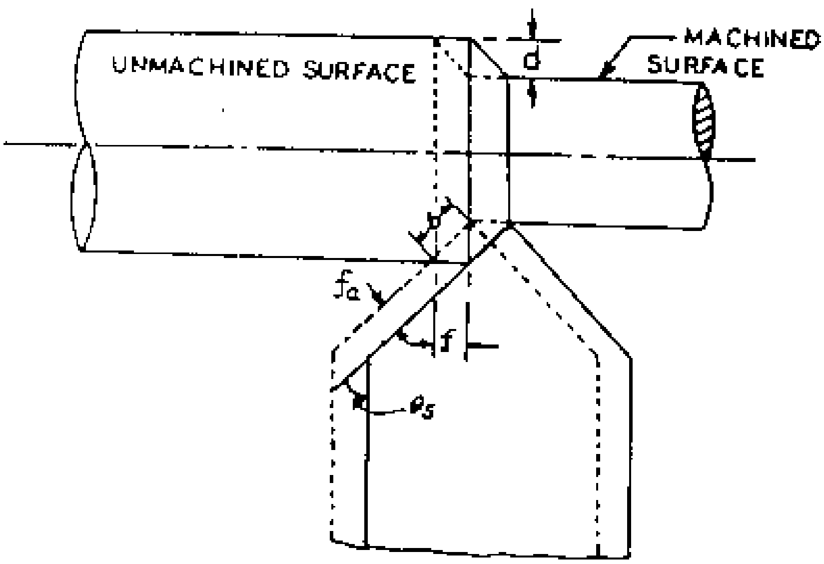


Fig-36: The effect of varying cutting edge angle on chip thickness.

1.4 Aims and objective :

The objective of this project is to study and established the relationship between the surface hardness and depth of penetration of the hardened layer with cutting parameters like feed, speed, and depth of cut etc. while cutting ductile material like Mild steel using Cemented carbide tool of particular geometry . To attain this the following aims were set :

1. To determine the surface hardness and depth of penetration at different cutting conditions .
2. To determine the critical cutting speed for different cutting conditions .
3. To determine the maximum surface hardness and depth of penetration at the optimum cutting conditions .
4. To determine the effect of cutting parameters like feed, speed, and depth of cut upon the surface hardness and depth of penetraion .

1.5 Restrictions :

When the objective is carried out, it is necessary to consider the factors which impose restrictions on the cutting conditions. There are various restrictions used by various authors and systematically stated by Bjorke (4) are given below:

1. **Power:** Power absorbed by cutting process can not exceed the power capacity of the main drive .

2. The **torque** absorbed by the cutting process must not exceed the torque capacity of either of the main drive, or of the work piece, or of clamping .

3. **Speed** : For chip breaking and safety of the operator, the cutting speed must not exceed an upper limit . And, also lower bound of the cutting speed is limited by built up edge formation.

4. **Feed** : The product of feed and speed must be listed to keep the validity of wear criterion .

5. **Depth of cut** : The maximum depyth of cut is restricted by the length of the main cutting edge, machining allowance, power of the machine, deflection of the work piece,etc.

6. **Force & vibration** : Forces and vibrations in tool and work piece also restricted the cutting conditions .

7. **Machine feed & speed steps** : The restrictions in this case depend on the machine used .

CHAPTER-2

METHODOLOGY

2.1 Plan of work : Plastic deformation of work material occures during cutting operation. Mild Steel possess good plastic properties. Morever, Mild Steel possesses good machinability. It is also readily available in the local market. That is why Mild Steel was chosen as the work material. Cemented carbide tool with particular geometry and tool life was chosen for the turning operation of the work metal because carbide tool can withstand to a very high temperature without any plastic flow or thermal expansion throughout the operation. Variation of the cutting parameters depends on the capacity and range of the Lathe machine. For this reason cutting parameters were chosen within the working range of the Lathe.

Carbide tools were chosen with the following geometry :

Side rake angle, $\alpha = 0^0$

End rake angle, $\alpha_1 = 0^0$

Side clearance angle, $\gamma_e = 10^0$

End clearance angle, $\gamma_1 = 10^0$

Side cutting edge angle, $\theta = 45^0$

End cutting edge angle, $\theta_e = 25^0$

The following range cutting parameters were found suitable for the chosen

lathe machine : **Feed, F=0.05 to 0.2 mm/rev.**
Depth of cut, D=1 to 2 mm,
Cutting velocity, V=30 m/min to 150 m/min.

And the cutting conditions which has been selected for the experiments are listed on the following pages. Machining has been done at these four conditions and specimens were taken for each condition. Specimens were taken from the surface of the job. They were cut off from the parent material in a directiou parallel to the cutting velocity. The specimens collected were very small and were in 'V' shaped. Such a small and odd shaped specimen was very difficult to handle for finishing. So, cold die operation was performed to fix or set the specimen into a suitable shaped die. The chemical clay made of simplex powder and simplex liquid was die material. This chemical clay hard quickly. The specimens were fitted within the die in such a manner, that the specimens fitted within the die in such a manner, that the specimens first brought to shape using files and then special coarser emery paper, successively by finer and grades until the finest available grade was reached. The specimens were polished by a rotating disc, covered with broad cloth, felt or velvet, to which a very finely ground abrasive material (alumina, chromium oxide etc.) was sprayed.

Following cutting conditions were chosen for Turning operation and to investigate the change of properties of the work-piece material :

Cutting condition-1:

a) F = 0.2 mm/rev
D = 1 mm
V = 30 m/min .

b) F = 0.2 mm/rev
D = 1 mm
V = 60 m/min .

c) F = 0.2 mm/rev
D = 1 mm
V = 100 m/min .

d) F = 0.2 mm/rev
D = 1 mm
V = 150 m/min .

Cutting condition-2:

a) F = 0.05 mm/rev
D = 2 mm
V = 30 m/min .

b) F = 0.05 mm/rev
D = 2 mm
V = 60 m/min

c) F = 0.05 mm/rev
D = 2 mm
V = 100 m/min .

d) F = 0.05 mm/rev
D = 2 mm
V = 150 m/min .

Cutting condition-3:

a) F = 0.05 mm/rev
   D = 1 mm
   V = 30 m/min

b) F = 0.05 mm/rev
   D = 1mm
   V = 60 m/min .

c) F = 0,05 mm/rev
   D = 1 mm
   V = 100 m/min .

d) F = 0.05 mm/rev
   D = 1 mm
   V = 150 m/min .

Cutting condition-4:

a) F = 0.2 mm/rev
   D = 2 mm
   V = 30 m/min.

b) F = 0.2 mm/rev
   D = 2 mm
   V = 60 m/min .

c) F = 0.2 mm/rev
   D = 2 mm
   V = 100 m/min .

d) F = 0.2 mm/rev
   D = 2 mm
   V = 150 m/min .

Measurement of microhardness and depth of penetration: The Vickers hardness and depth of penetration of the specimens were measured at different points from surface to core successively by increasing depth using Microhardness tester. The first point was selected at a distance of 0.1mm from the surface. Because, below this point it was difficult to measure the accurate hardness of the specimens. After this point, the next points were selected by increasing depth 0.05mm successively and carefully measured their hardness until a depth of penetration of each cutting conditions were measured and recorded. The obtained data were listed on a tabular form for analyzing the results.

After taking the measurements of the microhardness the specimens were polished again to remove the rusted layer. Then special reagents etched them.

Etching reagents for mild steel:

i) **Nital:** 2 to 5% Nitric acids in Methyl or Ethyl alcohol.

ii) **Picric:** 4% Picric acid in Ethyl alcohol.

The etching time varies from a few seconds to one minute.

Micrography: It reveals the size, form and arrangement of crystallites, shrinkage porosity, gas cavities, and cracks appear in the deformed metal. It consists of the study of the structure of metals and their alloys under a microscope at magnifications from x 75 to x 1,500. The observed structure is called the microstructure. After etching with proper etching photograph of the structure of the hardened layer and also of the unreformed layer of the core of the specimen have been studied.

Critical cutting velocity (Vc): Chips were collected separately for each cut and the value of chip-shrinkage , K was calculated after measuring the chip thickness, t_u carefully and accurately. But it was very difficult to measure the chip thickness preciesely due to the roughness of the back surface of the chip. Using Photographic Microscope at higher magnifications chip thickness,t_u were measured. The data obtained were listed on the following pages. With these values of **K** and corresponding values of V, a curve **K = f (V)** was plotted in Fig.2.1. This curve is similiar to that of the previously established 'Pz' Vs ' V' curve. Here, value of chip-shrinkage, **K** reaches a maximum value at a certain cutting speed and decreases with further increase in the cutting speed. It is known that a reduction of the chip-shrinkage usually is associated with the reduction in the cutting forces and also with an increase in temperature and vice-versa.Thus at maximum chip-shrinkage **K**, Pz is also maximum and at minimum **K**, value of Pz is minimum. From Fig-2.1 critical cutting speed was found at that point where **K** was maximum .

EXPERIMENTAL DATA FOR CHIP THICKNESS & CRITICAL SPEED.

DATA FOR CUTTING CONDITION-1
CUTTING CONDITION:
FEED,F=0.2mm/rev.
DEDTH OF CUT,D=1mm.
SPEED,V=30,60,100,150m/min.

TABLE-2.1(a)

Experimental Data: t_u =Uncut chip thickness,
=feed/ $\sqrt{2}$ mm.
=0.1414 mm.
t_c =Chip thickness,mm
K =t_c/t_u ,co-efficient of chip cotruction.
v =cutting speed,m/min

t_c,mm	0.155	0.210	0.180	0.177
K= t_c / t_u	1.1	1.5	1.3	1.25
v,m/min	30 m/min	60 m/min	100 m/min	150 m/min

DATA FOR CUTTING CONDITION-2
CUTTING CONDITION ;
FEED=0.05 mm/rev .
DUPTH OF CUT, D=2 mm.
CUTTING VELOSITTY V=30,60,100,150 m/min.

TABLE-2.1(b)

Experimental Data :t_u =Uncut chip thickness
= Feed/ $\sqrt{2}$ mm
=0.353 mm
t_c = Chip thickness, mm .
K = t_c / t_u ,
= Co-efficient of chip contruction.
v = Velosity

t_c ,mm	0.065	0.050	0.045	0.040
K =t_c /t_u	1.09	1.40	1.28	1.43
v ,m/min	30 m/min	60 m/min	100 m/min	150 m/min

EXPERIMENTAL DATA FOR CHIP THICKNESS & CRITICAL SPEED.

DATA FOR CUTTING CONDITION-3
CUTTING CONDITION:
FEED, F=0.05mm/rev.
DEDTH OF CUT, D=1mm.
SPEED, V=30,60,100,150m/min.

TABLE-2.1(c)

Experimental Data: t_u =Uncut chip thickness, =feed/$\sqrt{2}$ mm. =0.0353 mm.
t_c =Chip thickness, mm
K =t_c/t_u ,co-efficient of chip cotraction.
v =cutting speed, m/min

t_c , mm	0.030	0.038	0.0345	0.0290
K= t_c/t_u	0.85	1.07	0.97	0.821
v, m/min	30 m/min	60 m/min	100 m/min	150 m/min

DATA FOR CUTTING CONDITION-4
CUTTING CONDITION ;
FEED=0.2 mm/rev .
DUPTH OF CUT, D=2 mm.
CUTTING VELOCITTY V=30,60,100,150 m/min.

TABLE-2.1(d)

Experimental Data : t_u =Uncut chip thickness = Feed/ $\sqrt{2}$ mm =0.1414 mm
t_c = Chip thickness, mm .
K = t_c/t_u, = Co-efficient of chip contraction.
v = Velocity

t_c , mm	0.180	0.240	0.210	0.200
K=t_c/t_u	1.27	1.69	1.48	1.414
v , m/min	30 m/min	60 m/min	100 m/min	150 m/min

Fig.2.1: Behaviour of chip shrinkage, K with respect to cutting speed, V.

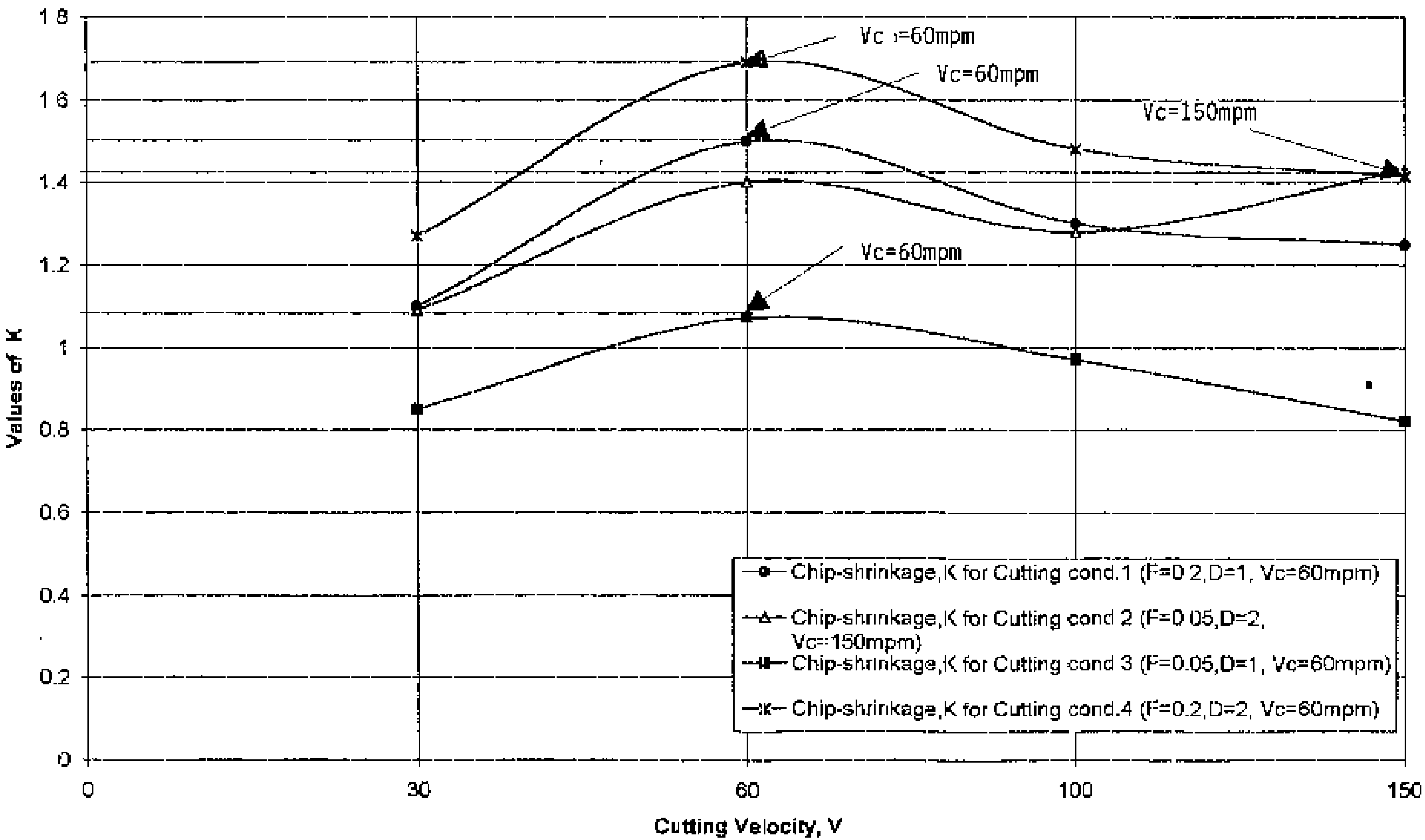


Fig.2.1(a): Behaviour of chip shrinkage, K with respect to cutting speed, V.

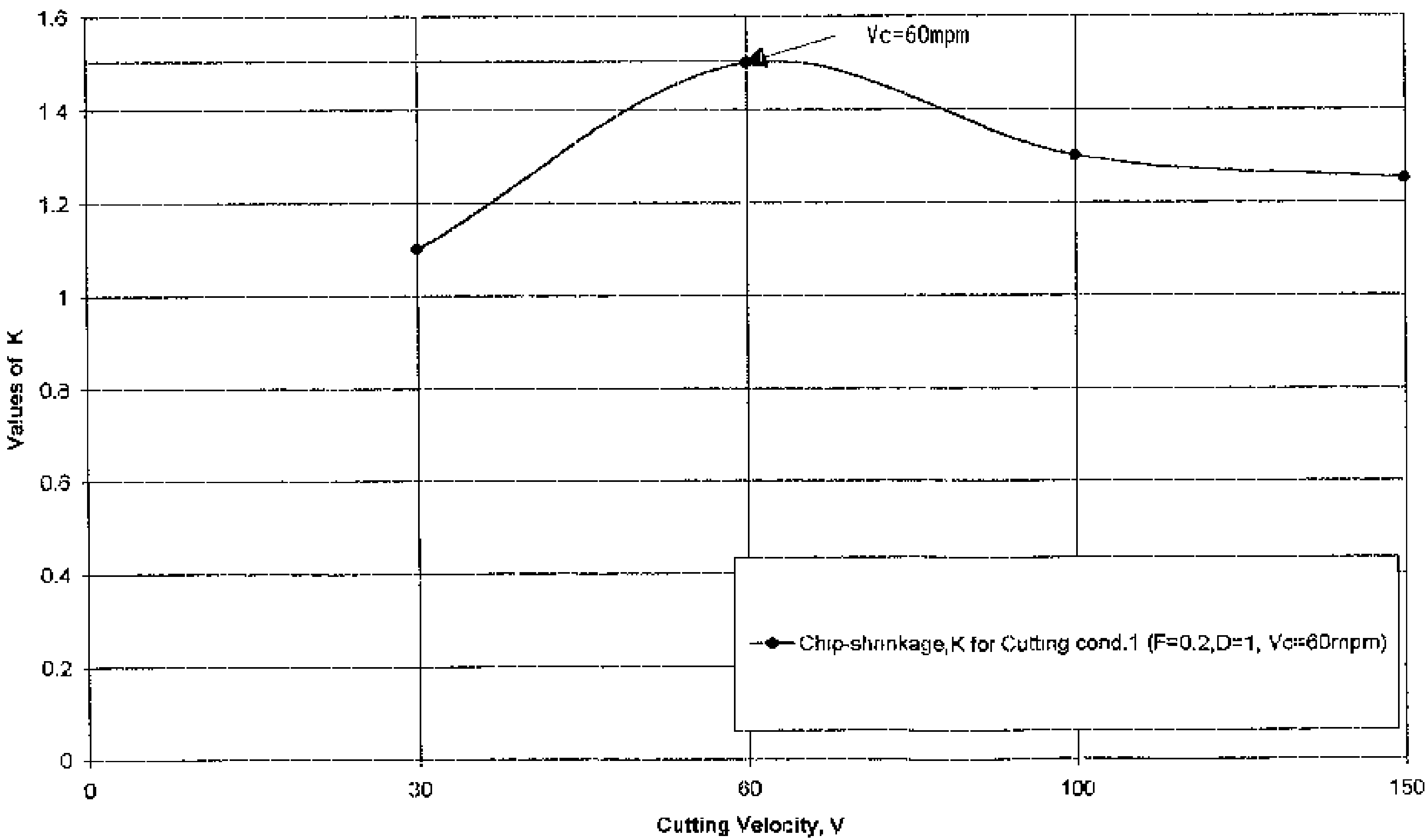


Fig.2.1(b): Behaviour of chip shrinkage, K with respect to cutting speed, V.

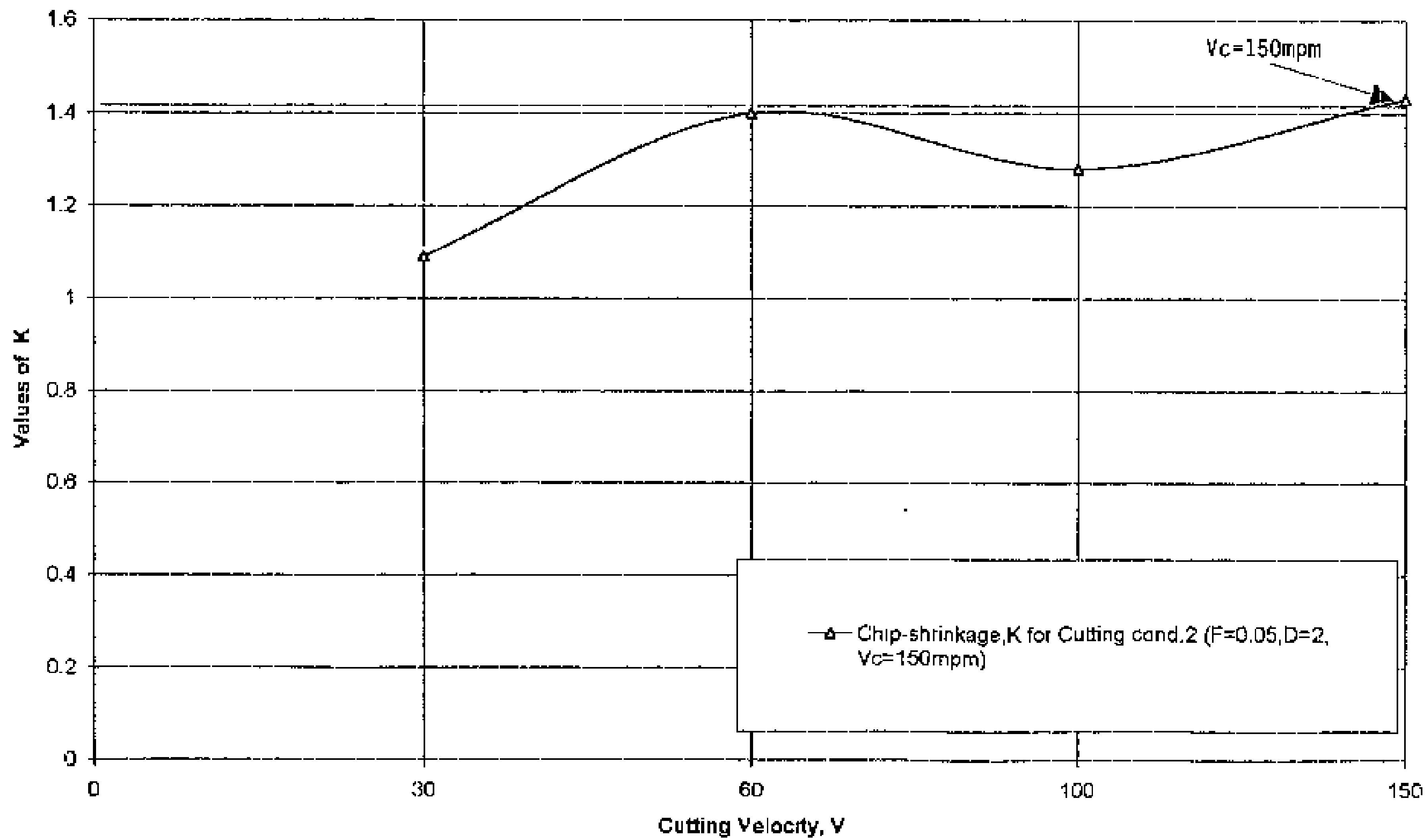


Fig.2.1(c): Behaviour of chip shrinkage, K with respect to cutting speed, V.

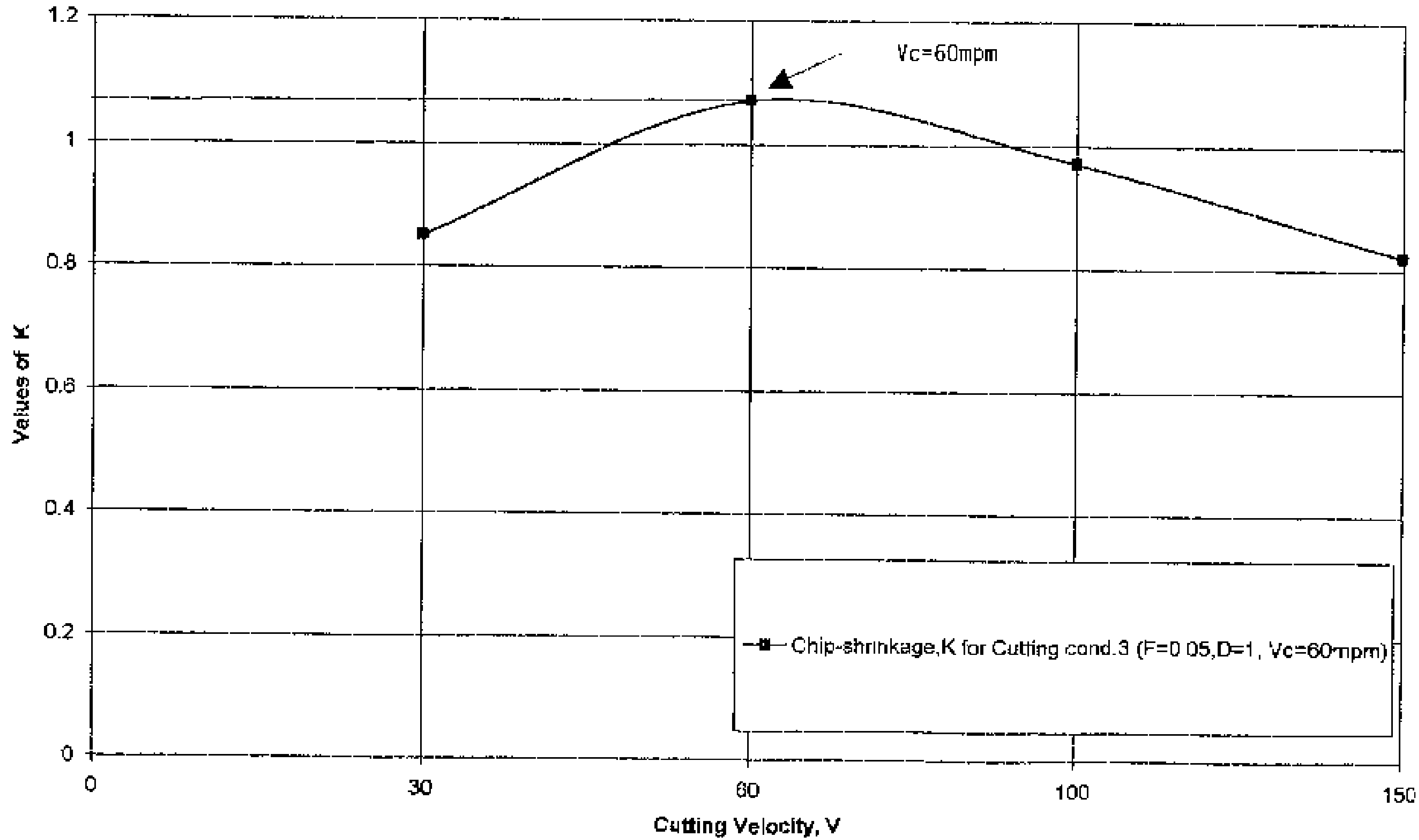
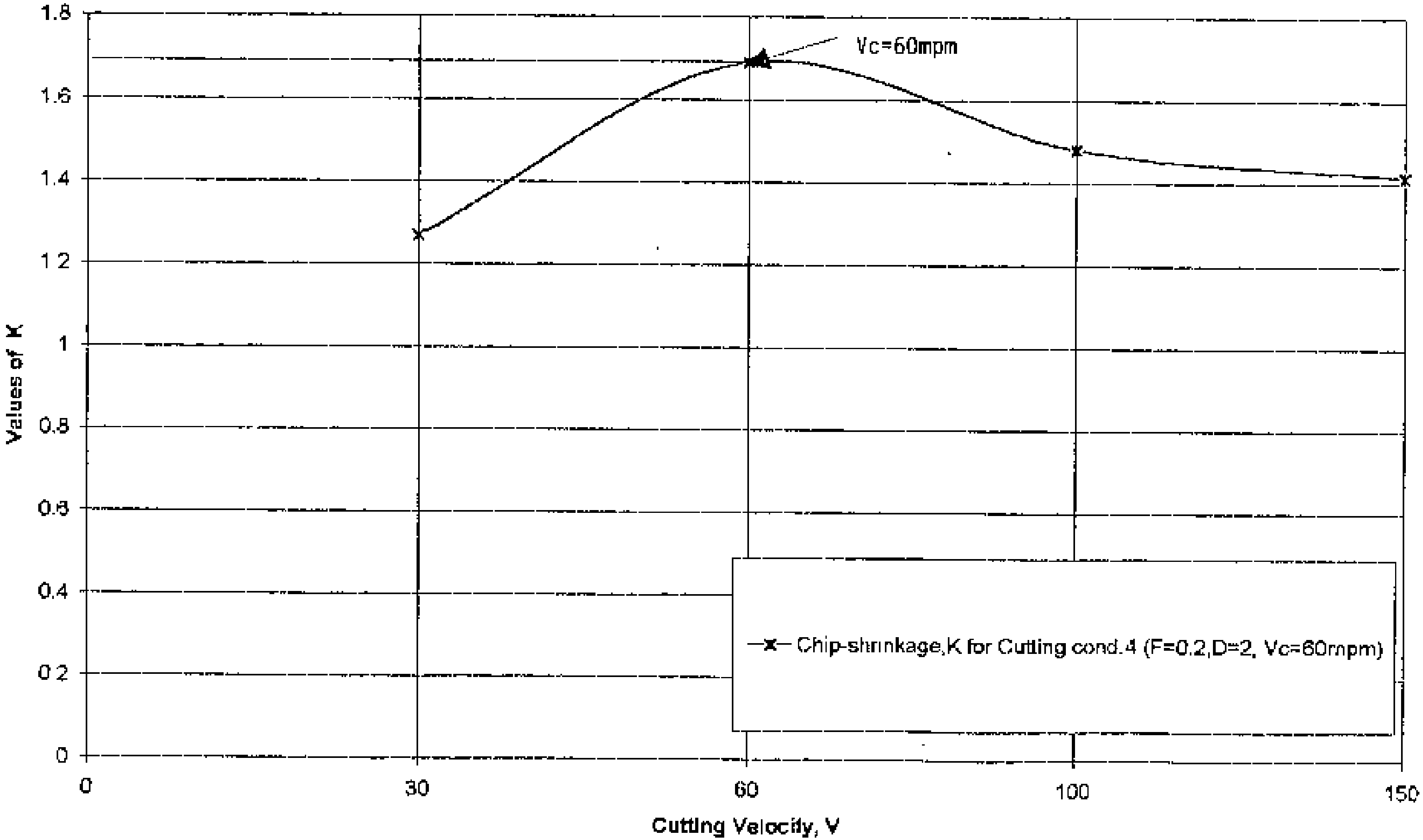


Fig.2.1(d): Behaviour of chip shrinkage, K with respect to cutting speed, V.



CHAPTER-3

RESULTS AND DISCISSION

The data obtained at different cutting conditions were plotted against different cutting parameters for analyzing the result .

For Cutting condition-1: Feed, F=0.2 mm/rev;Depth of cut,D=1mm, Speed,V=30,60,100,150m/m.

AT Fig.3.1.1 Surface hardness and depth of penetration has been plotted found at different cutting speed.From Fig.3.1.1 it was found that maximum surface hardness within this condition obtained at cutting speed 60 m/min and maximum depth of penetration obtained at 30 m/min.

Fig.3.1.2 shows the comparison between the surface hardness and cntting speed . From Fignre it was found that for this cntting conditions the maximum hardness was 193 HV (vickers hardness number) and it was obtained at cutting speed 60 m/min. Beyond this point hardness starts to decrease.Hardness first increase with increase in cutting speed and on further increase in speed reach a maximum value and start decreasing and become fairly established at higher speed range. The figure is similiar to the curve, Pz=f(V), which shows the variation of the cutting forces with cutting speed. For this cutting conditions the critical cutting speed was found by the curve K =f(V) , which shows the variation of chip shrinkage with cutting speed . From Fig.2.1(a) shows that critical cutting condition is 60 m/min for this cutting conditions where the value of "K" were maximum. So, at cutting speed 60 m/m the value of chip shrinkage, cutting forces (Pz), and surface hardness (HV) were maximm.

The curve K = f(V) shows the behaviour of chip shrinkage with cutting speed. From the curve it was found that 'K' reached a maximum value at critical cutting cutting speed and decreased with a further increase of the cutting speed. The reduction of the value of 'K' was associated with the reduction of the cutting forces and with the increases of the temperature. 'K' starts to increase from a low cutting speed and with increases in speed reaches at maximum value. The initial increases of 'K' was due to the formation of the built up edge, which does not occure at high cutting speed. At low cutting speed heat dessipation rate was low and the surface of the work material experienced more localized action of heat. This should have increased the the depth of penetration as shown in Fig-3.1.2. Referring Fig.3.1.1 maximum depth of penetration at cutting condition-1 was 0.4mm and it was found at cutting speed, V=30m/min. But at the speed of 30m/min surface hardness was found 183 HV.

Fig.3.1.3. shows that the surface hardness and depth of penetration at the critical cutting speed were 193 HV, and 0.3mm respectively for cutting condition-1.

Similiarly, for **Cutting condition-2** :

Critical cutting speed, Vc were 150m/min. Maximum surface hardness and depth of penetration at critical cutting speed were found 170.3 HV and 0.2mm respectively. Maximum depth of penetration was 0.25mm and obtained at speed 60m/min. But, at that speed surface hardness were reduced to a value of 143.1 HV.

EXPERIMENTAL RESULTS & TABLE OBTAINING BY DIFFERENT CUTTING CONDITION.

FOR CUTTING CONDITION-1:
Feed,F=0.2mm/rev.
Depth Ofcut,D=1mm.
Cutting Speed,V=30,60,100,150m/min.

TABLE-3.1(a)

Experimental Data for:F=0.2,D=1,V=30									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	o.30 mm	0.35 mm	0.40 mm	0.45 mm	0.5m m
HV	185.30	147.10	147.10	143.10	143.10	135.50	128.40	128.40	128.40

TABLE-3.1(b)

Experimental Data for:F=0.2,D=1,V=60.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	0.50 mm
HV	193.00	147.10	135.60	128.10	128.10	125.10	125.10	125.10	125.10

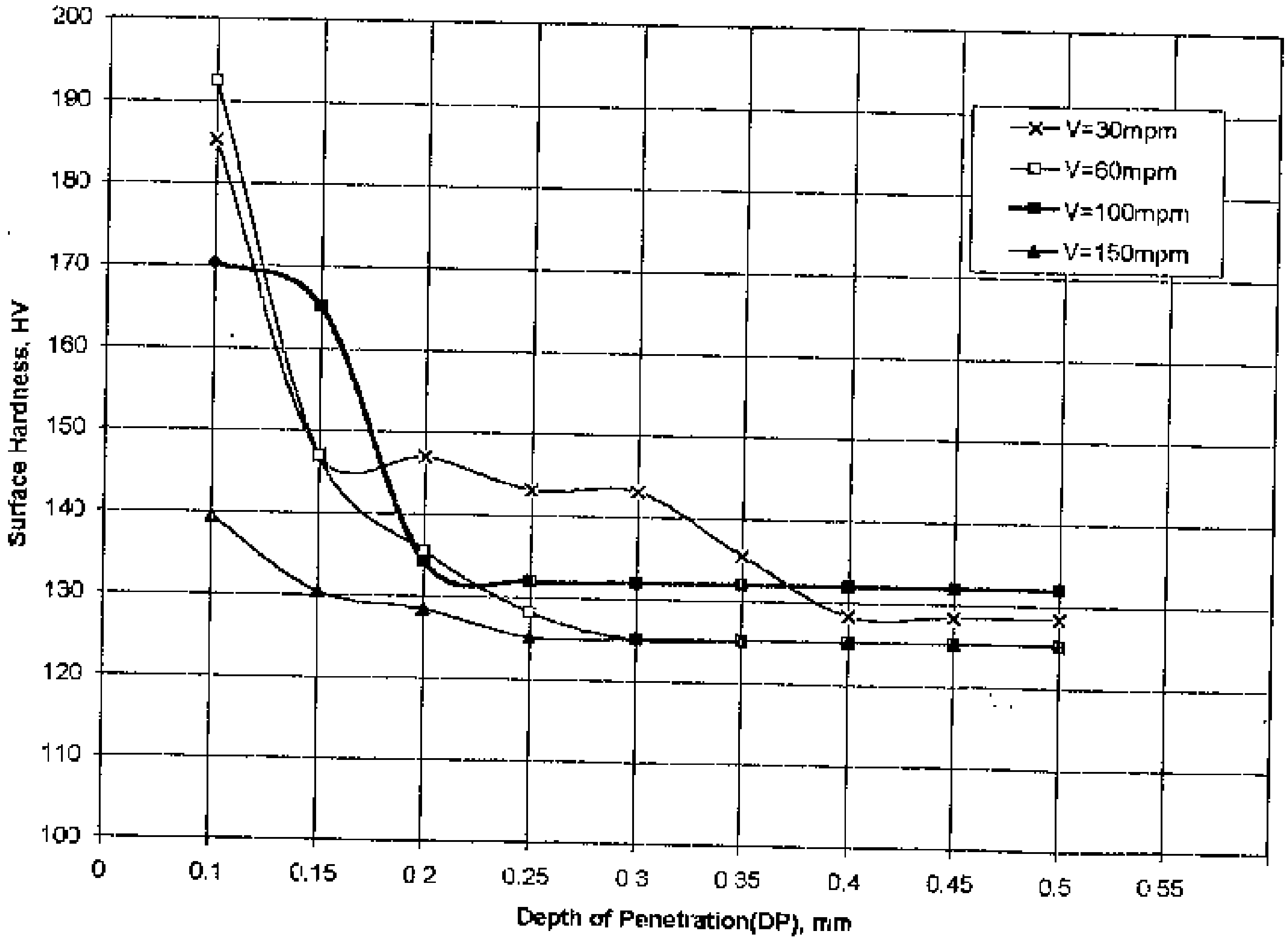
TABLE-3.1(c)

Experimental Data for:F=0.2,D=1,V=100.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	o.45 mm	0.50 mm
HV	170.30	165.20	134.30	131.90	131.90	131.90	131.90	----	---

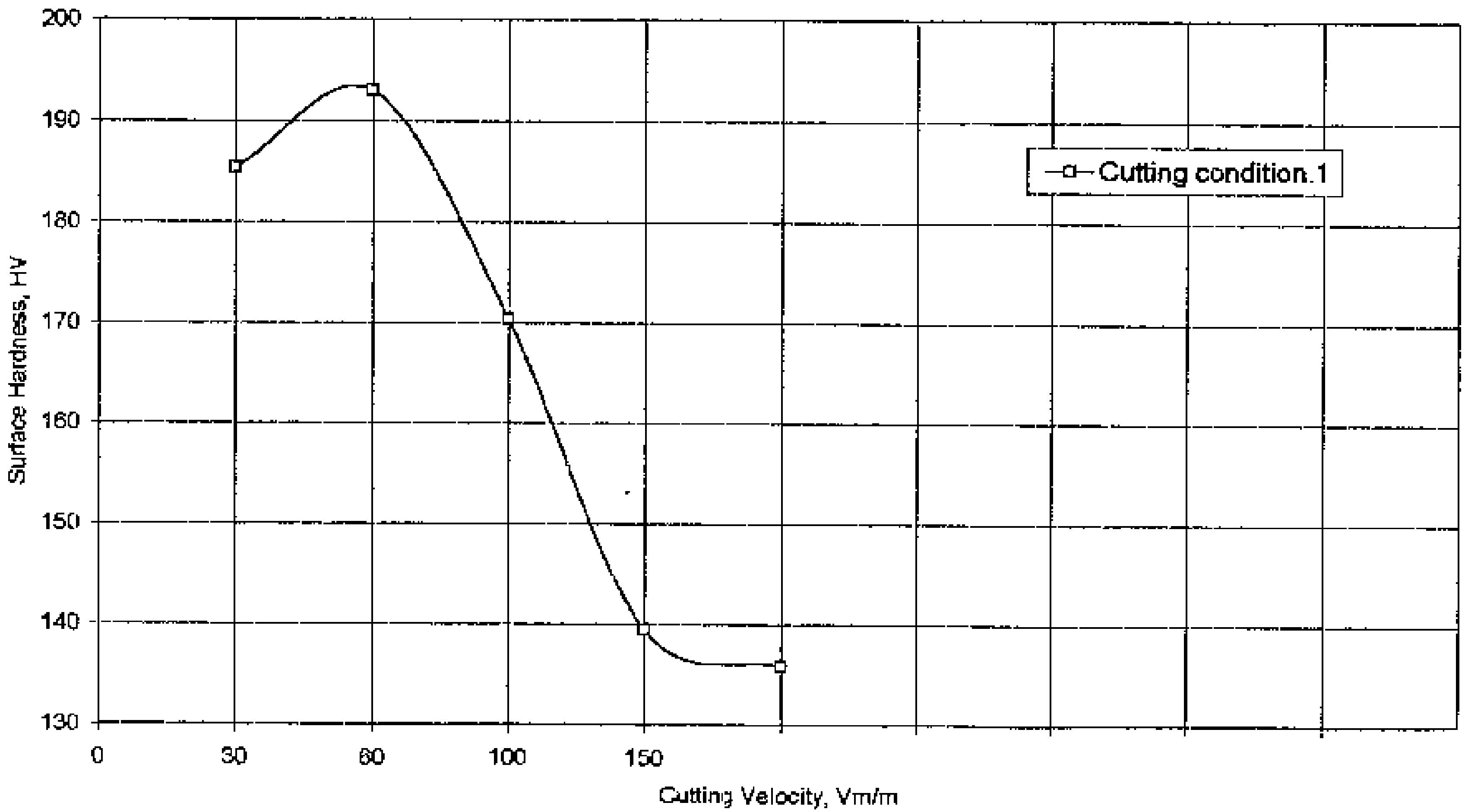
TABLE-3.1(d)

Experimental Data for:F=0.2,D=1,V=150.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	0.50 mm
HV	139.50	130.50	128.40	125.40	125.10	125.10	125.10	125.10	125.10

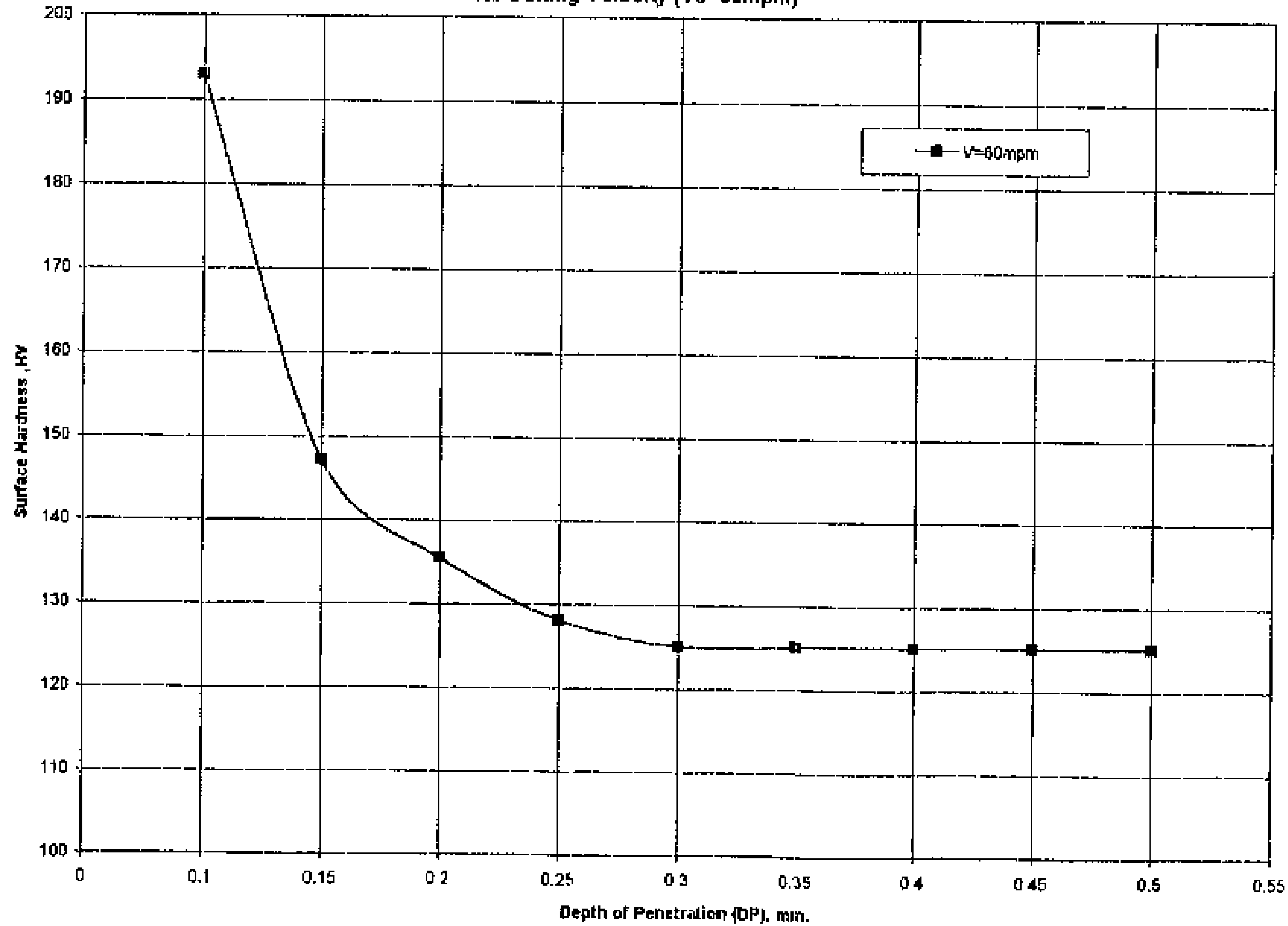
Fig(3.1.1) : Depth of Penetration Vs Surface Hardness for Cutting Condition-1(F=0.2mm/rev, D=1mm).



FIG(3.1.2): Cutting Velocity Vs Maximum Surface Hardness at CuttinCutting condition.1 (F=0.2mm/rev, D=1mm).



FIG(3.1.3): Depth ofPenetration Vs Surface Hardness
at Critical Cutting Velocity (Vc=60mpm)



EXPERIMENTAL RESULTS & TABLE OBTAINING BY DIFFERENT CUTTING CONDITION.

FOR CUTTING CONDITION-2:
Feed,F=0.05mm/rev.
Depth Ofcut,D=2mm.
Cutting Speed,V=30,60,100,150m/min.

TABLE-3.2(a)

Experimental Data for:F=0.05,D=2,V=30									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	
HV	1431	1319	1284	1319	1319	1319	----	----	

TABLE-3.2(b)

Experimental Data for:F=0.05,D=2,V=60.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	
HV	1471	1431	1355	1284	1284	1284	1284	---	

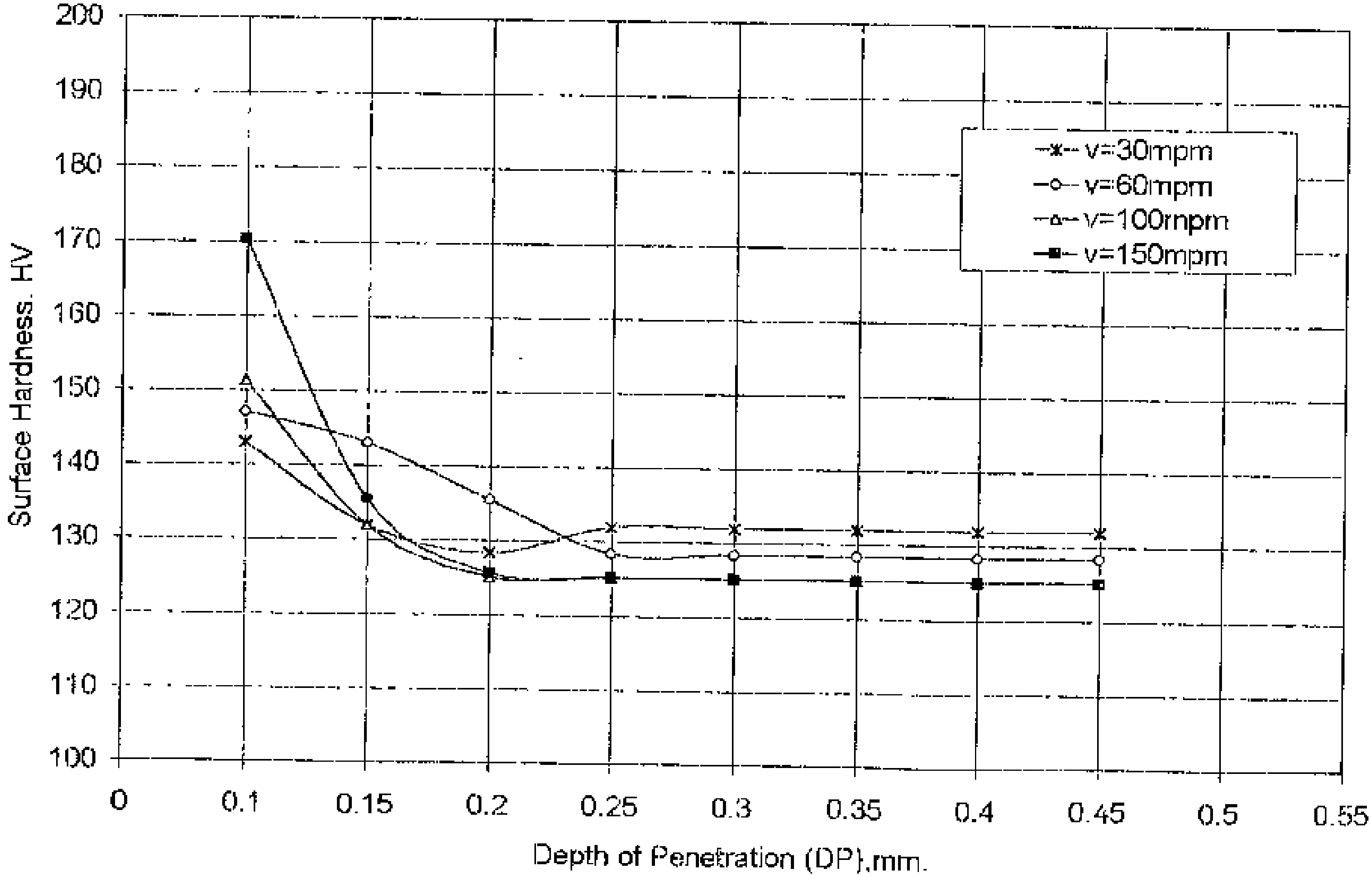
TABLE-3.2(c)

Experimental Data for:F=0.05,D=2,V=100.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	0.50 mm
HV	1514	1319	1251	1251	1251	1251	1251	----	---

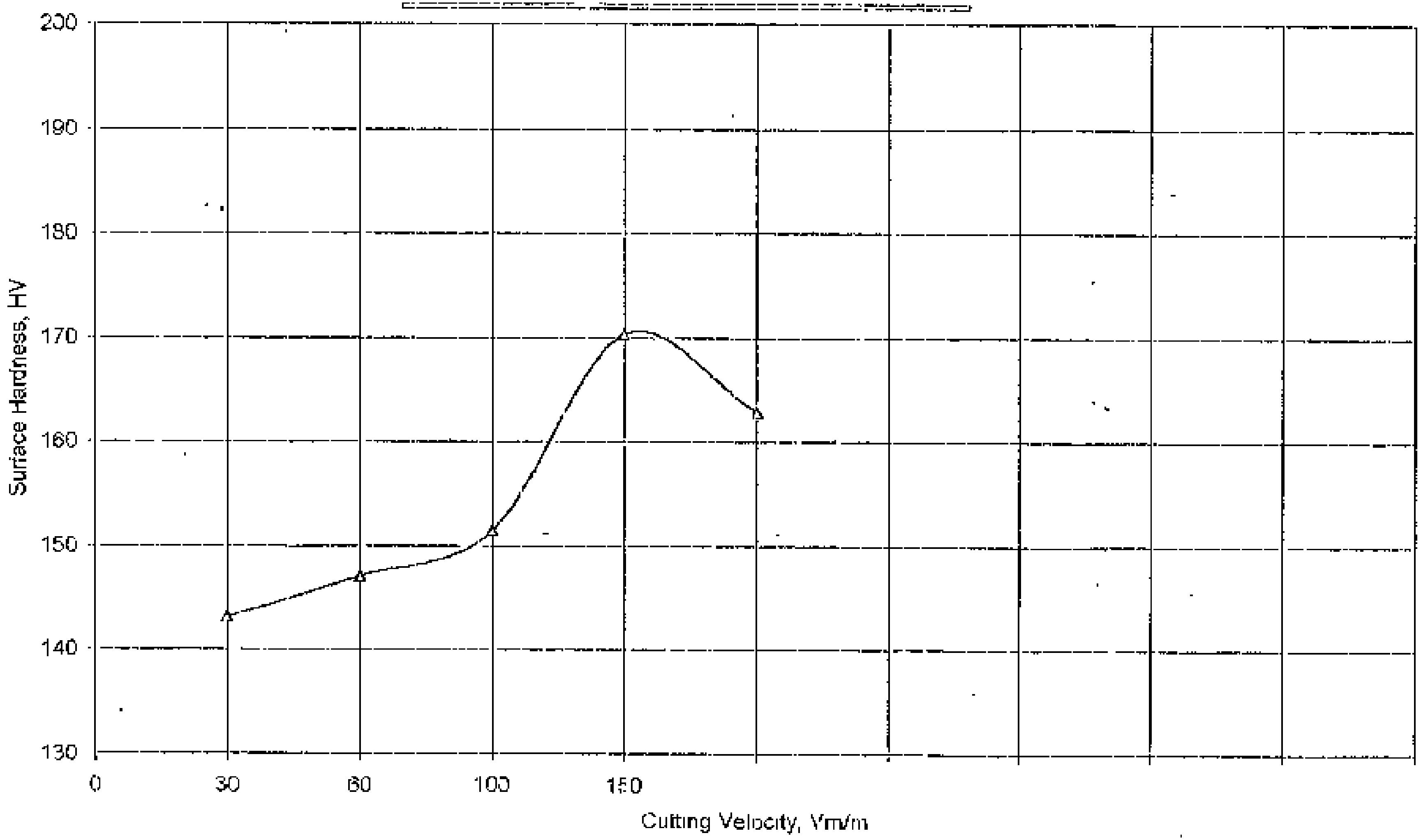
TABLE-3.2(d)

Experimental Data for:F=0.05,D=2,V=150.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	0.50 mm
HV	1703	1355	1251	1284	1251	1251	1251	----	---

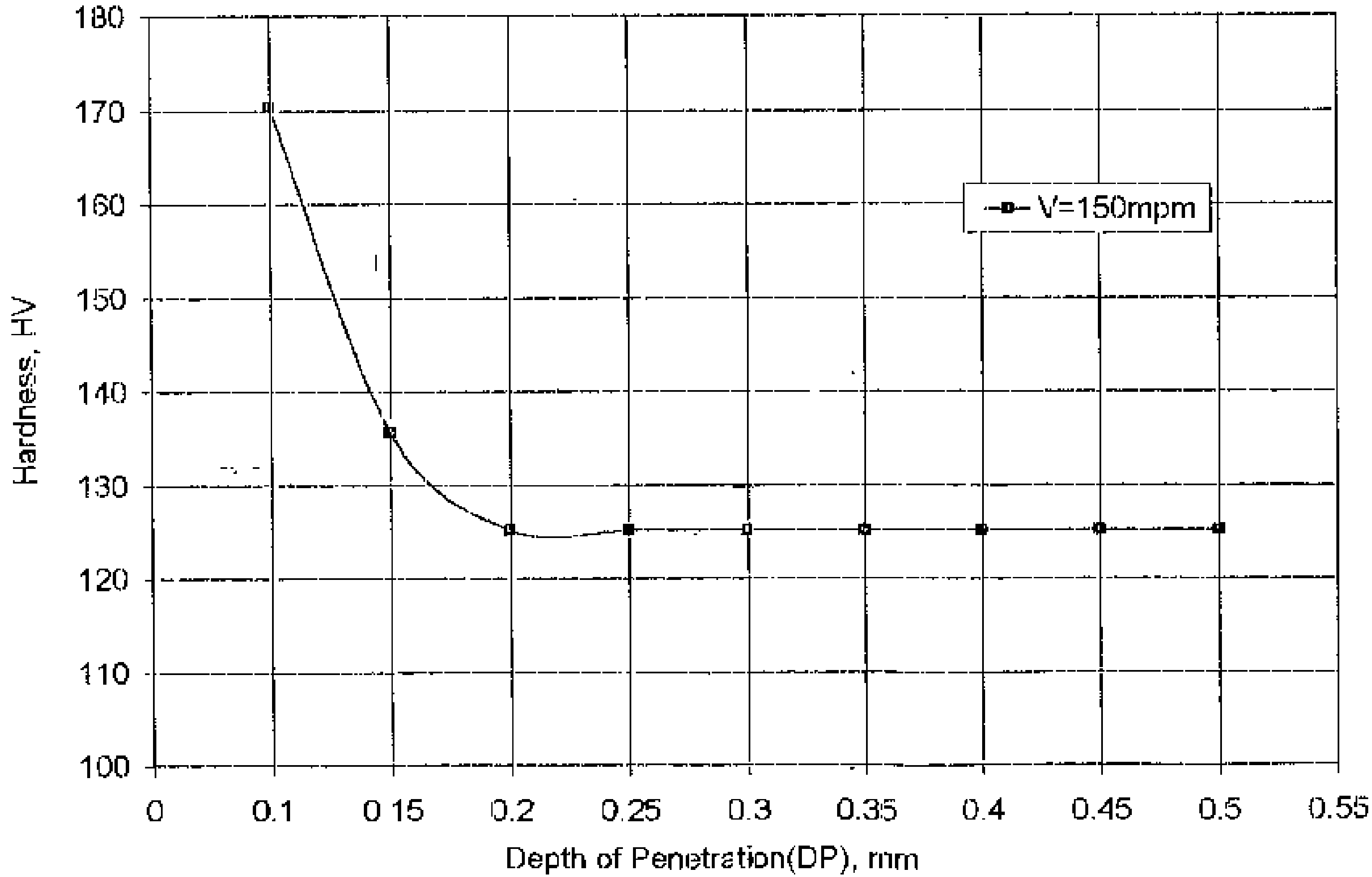
FIG(3.2.1): Depth of Penetrarion Vs Surface Hardness for Cutting COndition-2 (F=0.05mm/rev, D=2mm).



FIG(3.2.2): Cutting Velocity Vs Maximum Surface Hardness at CuttinCutting condition.2 (F=0.05mm/rev, D=2mm).



FIG(3 2.3): Depth of Penetration Vs Hardness
at Critical Cutting Velocity (Vc=150mpm)



EXPERIMENTAL RESULTS & TABLE OBTAINING BY DIFFERENT CUTTING CONDITION.

FOR CUTTING CONDITION-3:
Feed,F=0.05mm/rev.
Depth Ofcut,D=1mm.
Cutting Speed,V=30,60,100,150m/min.

TABLE-3.3(a)

Experimental Data for:F=0.05,D=1,V=30									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	o.30 mm	0.35 mm	0.40 mm	0.45 mm	0.5m m
HV	170.30	165.20	143.10	133.00	132.80	132.80	132.80	132.80	132.80

TABLE-3.3(b)

Experimental Data for:F=0.05,D=1,V=60.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	0.50 mm
HV	190.00	185.00	132.80	131.90	131.90	131.90	131.90	131.90	131.90

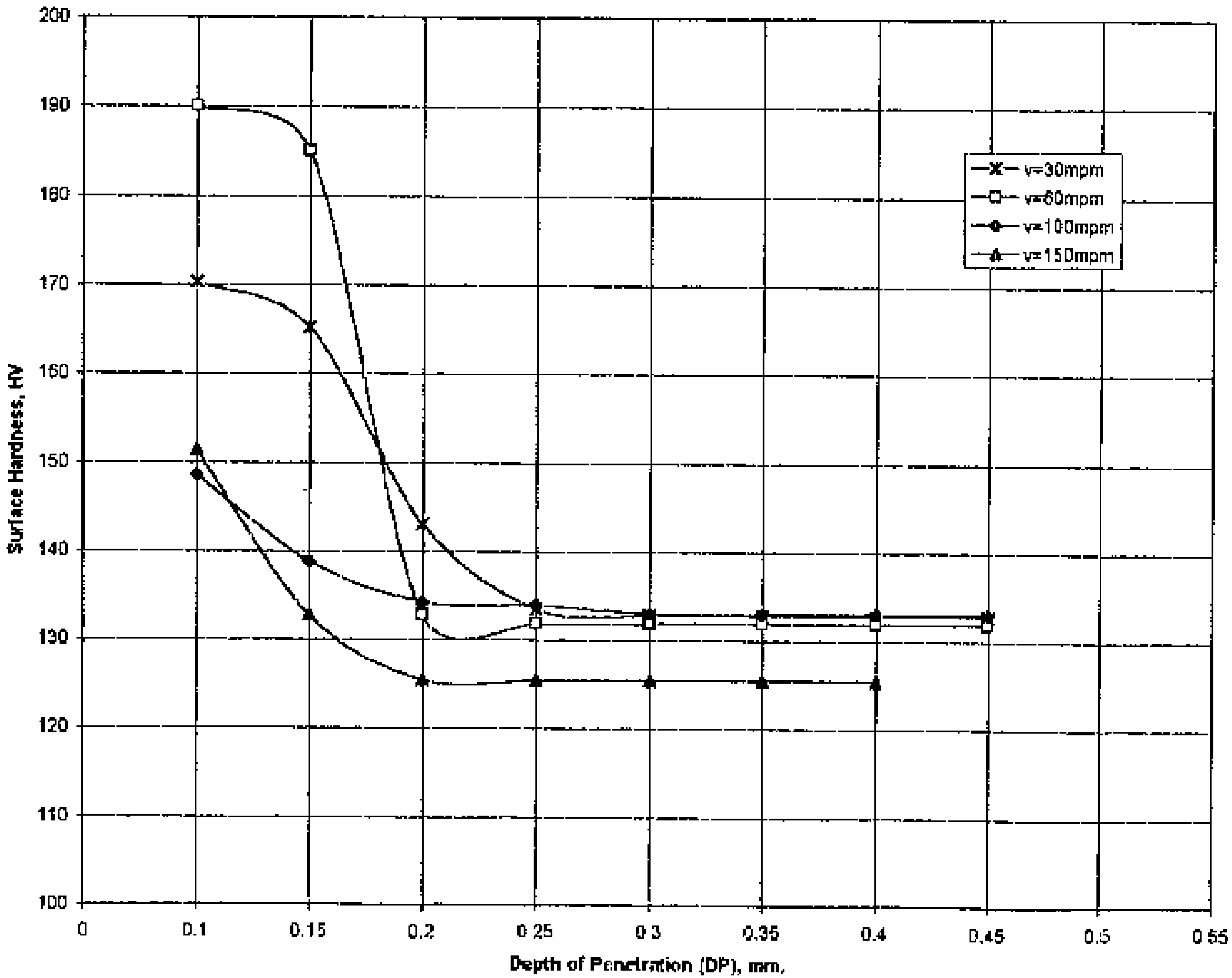
TABLE-3.3(c)

Experimental Data for:F=0.05,D=1,V=100.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	o.45 mm	0.50 mm
HV	148.60	138.60	134.30	133.00	133.00	133.00	133.00	133.00	133.00

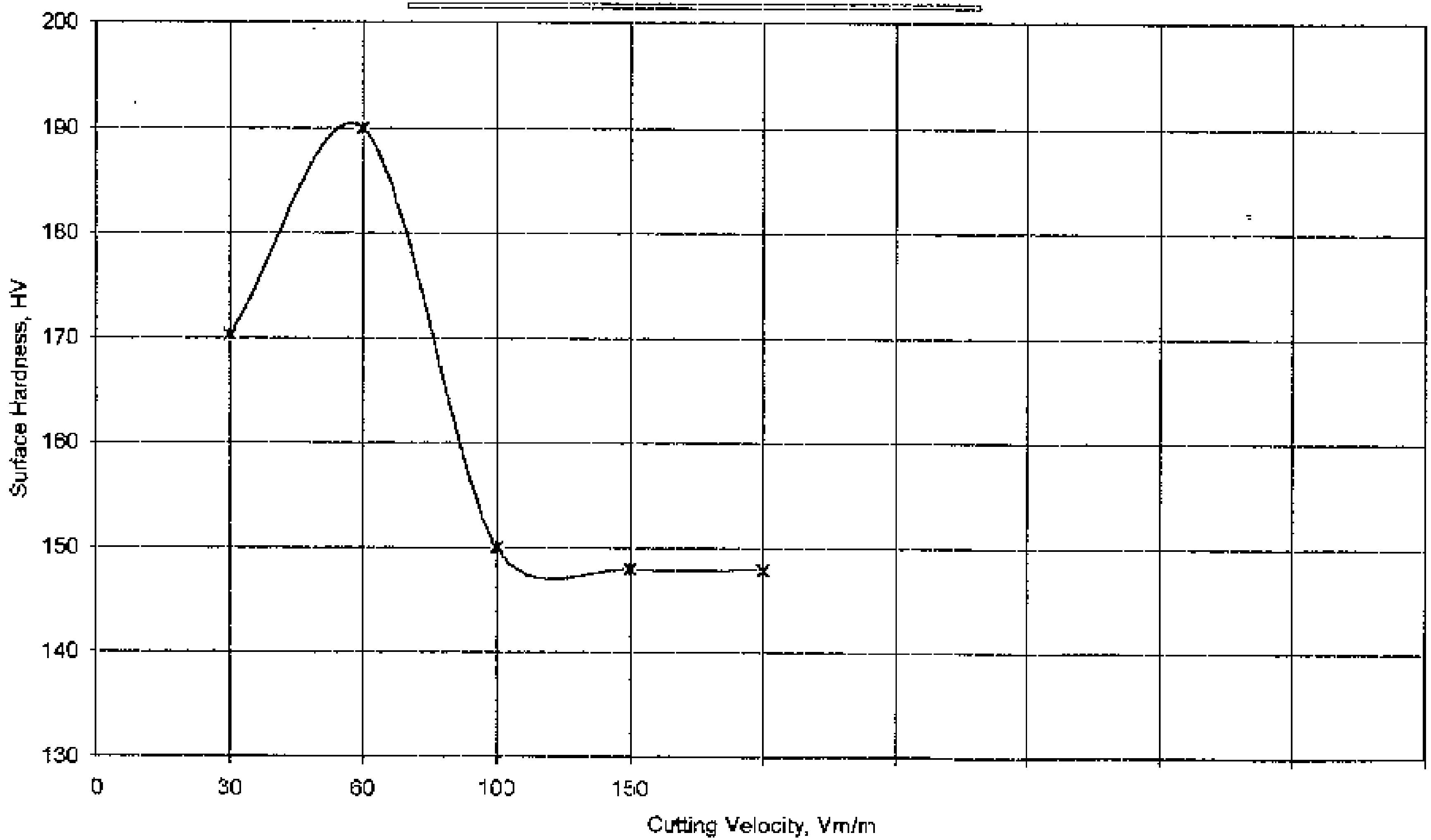
TABLE-3.3(d)

Experimental Data for:F=0.05,D=1,V=150.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	0.50 mm
HV	151.40	132.80	125.40	128.40	128.40	128.40	128.40	128.40	128.40

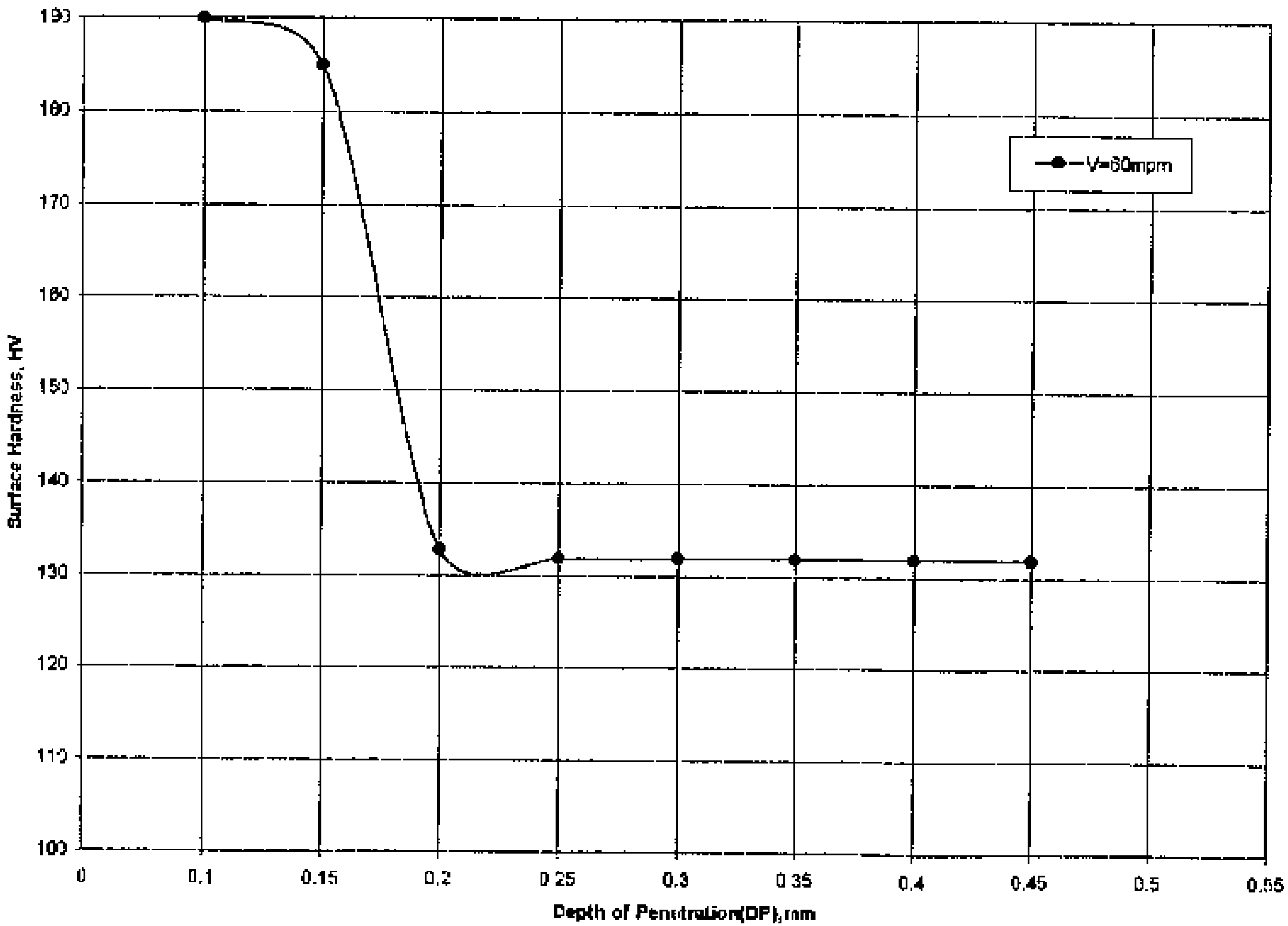
Fig(3.3.1). Depth of Penetration Vs Surface Hardness
at Cutting Condition-3 (F=0.05mm/rev, D=2mm).



FIG(3.3.2): Cutting Velocity Vs Maximum Surface Hardness at CuttInCutting condition.3 (F=0.05mm/rev, D=1mm).



FIG(3.3.3): Depth of Penetration Vs Surface Hardness at Critical Cutting Velocity(Vc=60mpm)



EXPERIMENTAL RESULTS & TABLE OBTAINING BY DIFFERENT CUTTING CONDITION.

FOR CUTTING CONDITION-4:
Feed,F=0.2mm/rev.
Depth Ofcut,D=2mm.
Cutting Speed,V=30,60,100,150m/min.

TABLE-3.4(a)

Experimental Data for:F=0.2,D=2,V=30									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	o.30 mm	0.35 mm	0.40 mm	0.45 mm	0.5m m
HV	147. 10	143. 10	131. 90	135. 50	131. 90	128. 40	128. 40	128. 40	128. 40

TABLE-3.4(b)

Experimental Data for:F=0.2,D=2,V=60.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	0.50 mm
HV	181. 10	170. 30	147. 10	135. 50	130. 50	130. 50	130. 50	130. 50	130. 50

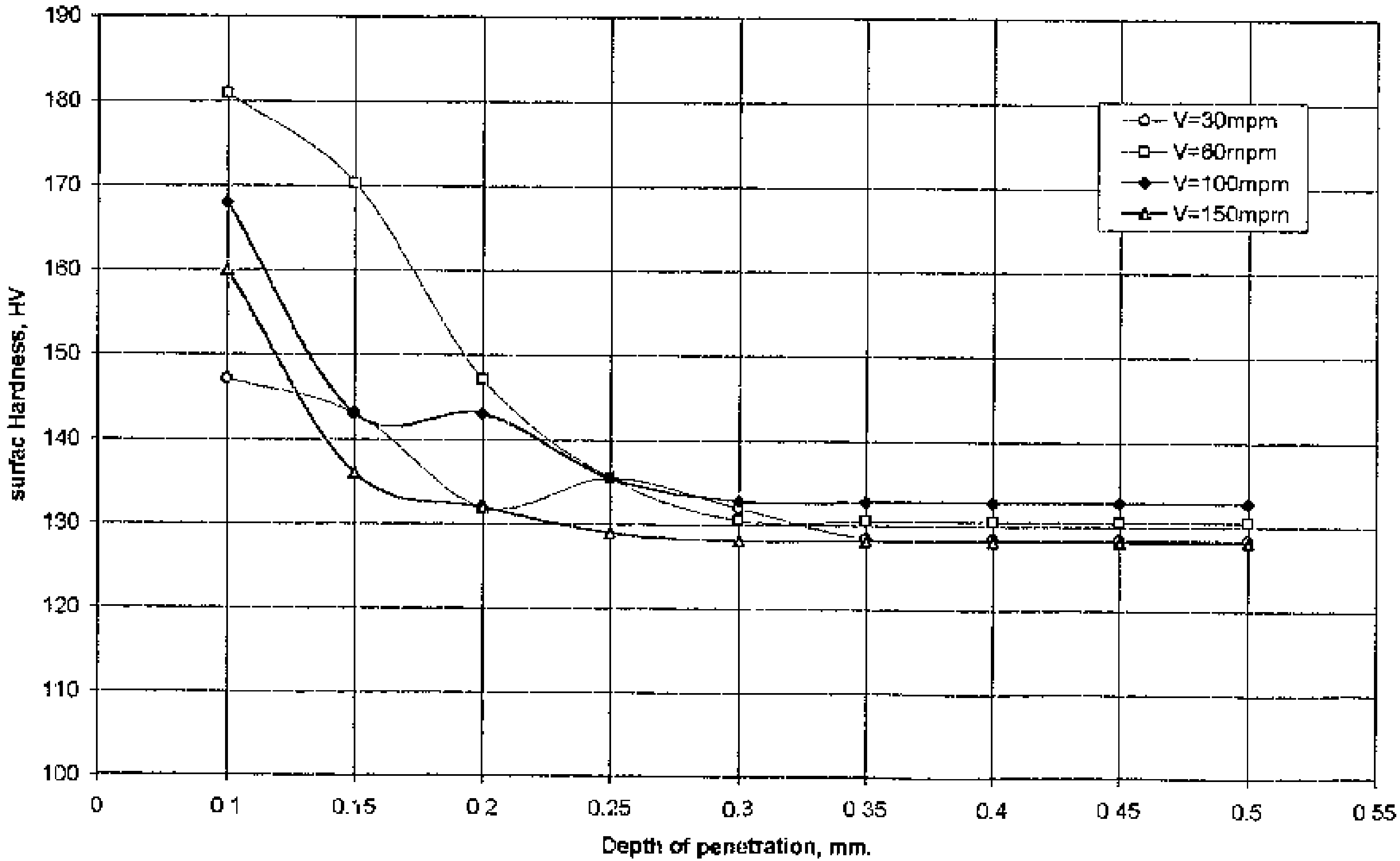
TABLE-3.4(c)

Experimental Data for:F=0.2,D=2,V=100.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	o.45 mm	0.50 mm
HV	168. 00	143, 10	143. 10	135. 50	132. 80	132. 80	132. 80	132. 80	132. 80

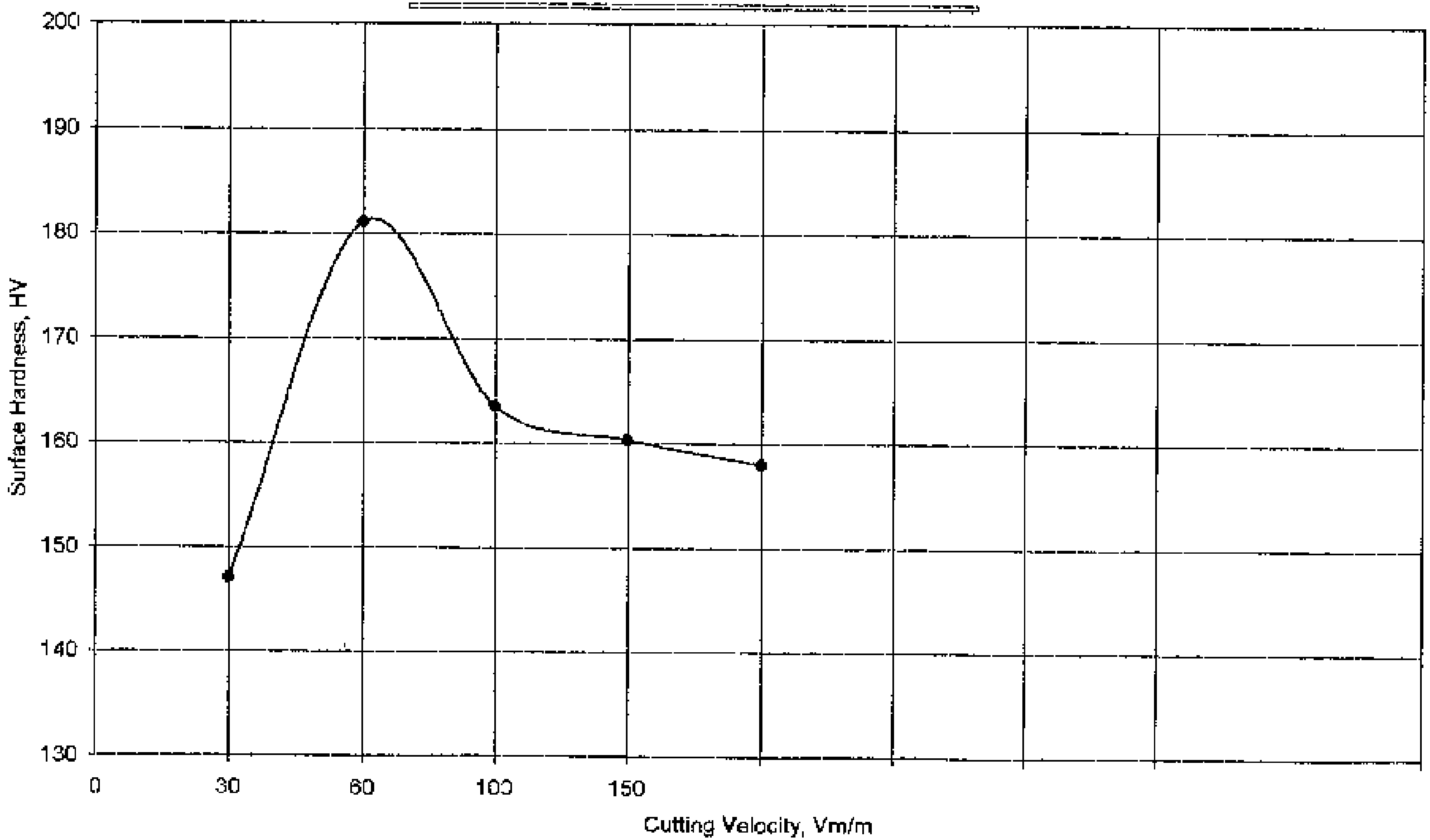
TABLE-3.4(d)

Experimental Data for:F=0.2,D=2,V=150.									
DP	0.10 mm	0.15 mm	0.20 mm	0.25 mm	0.30 mm	0.35 mm	0.40 mm	0.45 mm	0.50 mm
HV	160. 40	135. 50	131. 90	128. 10	128. 10	128. 10	128. 10	128. 10	128. 10

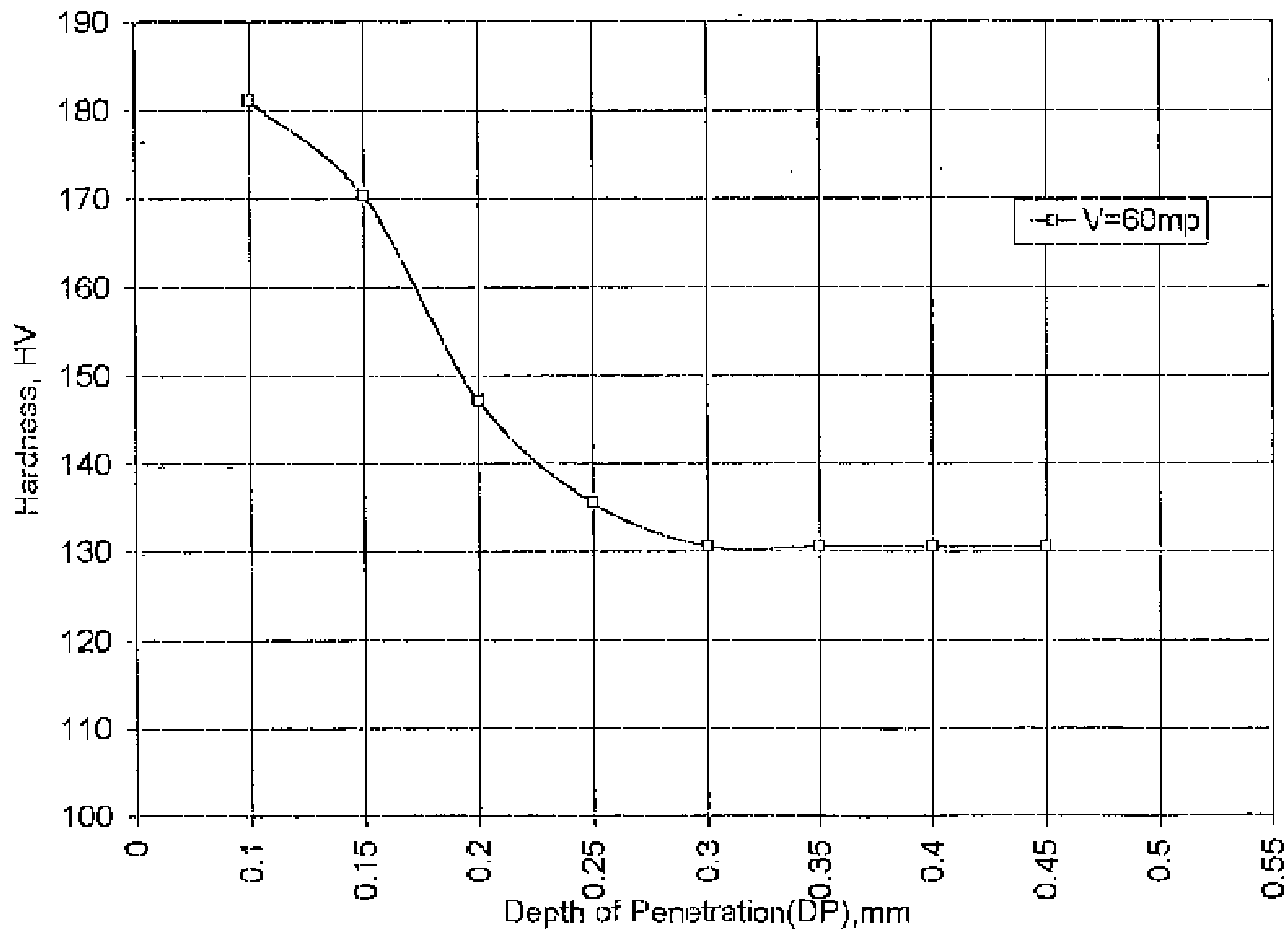
Fig(3.4.1) : Depth of Penetration Vs Surface Hardness For Cutting Condition-4 (F=0.2mm/rev, D=2mm).



FIG(3.4.2): Cutting Velocity Vs Maximum Surface Hardness at CuttinCutting condition.4 (F=0.2mm/rev, D=2mm).



FIG(3.4.3): Depth of Penetration Vs Hardness
at Critical Cutting Velocity (Vc=60mpm).



For **Cutting condition-3** : Critical cutting speed, Vc was 60m/min. At Vc maximum surface hardness and depth of penetration were 195 HV and 0.25mm respectively. Maximum depth of penetration was found 0.3mm at the speedof 30m/min. But, at 30m/min surface hardness was found 170.3 HV.

For **Cutting condition-4** : Critical cutting speed, Vc was found 60m/min. At this speed surface hardness and depth of penetration were found 181.1HV and 0.3mm respectively. Maximum depth of penetration was 0.35mm and it was obtained at the speed of 30m/min where surface hardness was 147.1HV.

From the above discussion it has seen that for all the above four cutting conditions maximum surface hardness were obtained at their respective critical cutting speed. But, maximum depth of penetration were found below the critical cutting speed where surface hardness were smaller than the critical cutting point. It is due to the low heat dissipation rate which produce more localized action on the surface of the work material and makes it to flow plastically. If hardness are considered as the main factor, than machining at critical cutting speed is the optimum cutting condition to obtain maximum surface hardness.

Fig.3.5 shows the surface hardness and depth of penetration obtained at the critical cutting speed at the above four cutting conditions.

Referring Fig.3.5 it has seen that surface hardness and depth of penetration both are the function of feed and depth of cut at critical cutting speed .Surface hardness, HV – f(F,D) at critical cutting speed.

For, **Cutting condition-1** (F–0.2,D–1,Vc–60) : Maximum surface hardness obtained is = 193HV.

For, **Cutting condition-2** (F=0.05,D=2,Vc=150) : Maximum surface hardness obtained is – 170.3HV.

For, **Cutting condition-3** (F–0.05, D–1, Vc–60) : Maximum surface hardness obtained is =190HV.

For, **Cutting condition-4** (F=0.2, D=2, Vc=60) : Maximum surface hardness obtained is –181.1HV

Referring Fig.3.5 it is obvious to say that machining of Mild Steel (0.3 to 0.8% C) within the following cutting range: F=0.05 To 0.2 mm/rev, D– 1mm to 2mm and V–30 To 150mpm will improves the surface hardness about 46% to 66% with respect to the base metal hardness and provides a case depth about 0.2 to 0.3mm approximately.

Referring Fig3.6 it has found that hardening of the same metal (i.e. heating above upper critical temperature) and quenching in oil and water increases the surface hardness about 280% and 80% respectively with respect to the base metal hardness.

FIG (3.5): CASE DEPTH Vs HARDNESS CURVE OF THE SELECTED FOUR CUTTING CONDITIONS AT THEIR RESPECTIVE CRITICAL CUTTING SPEED.

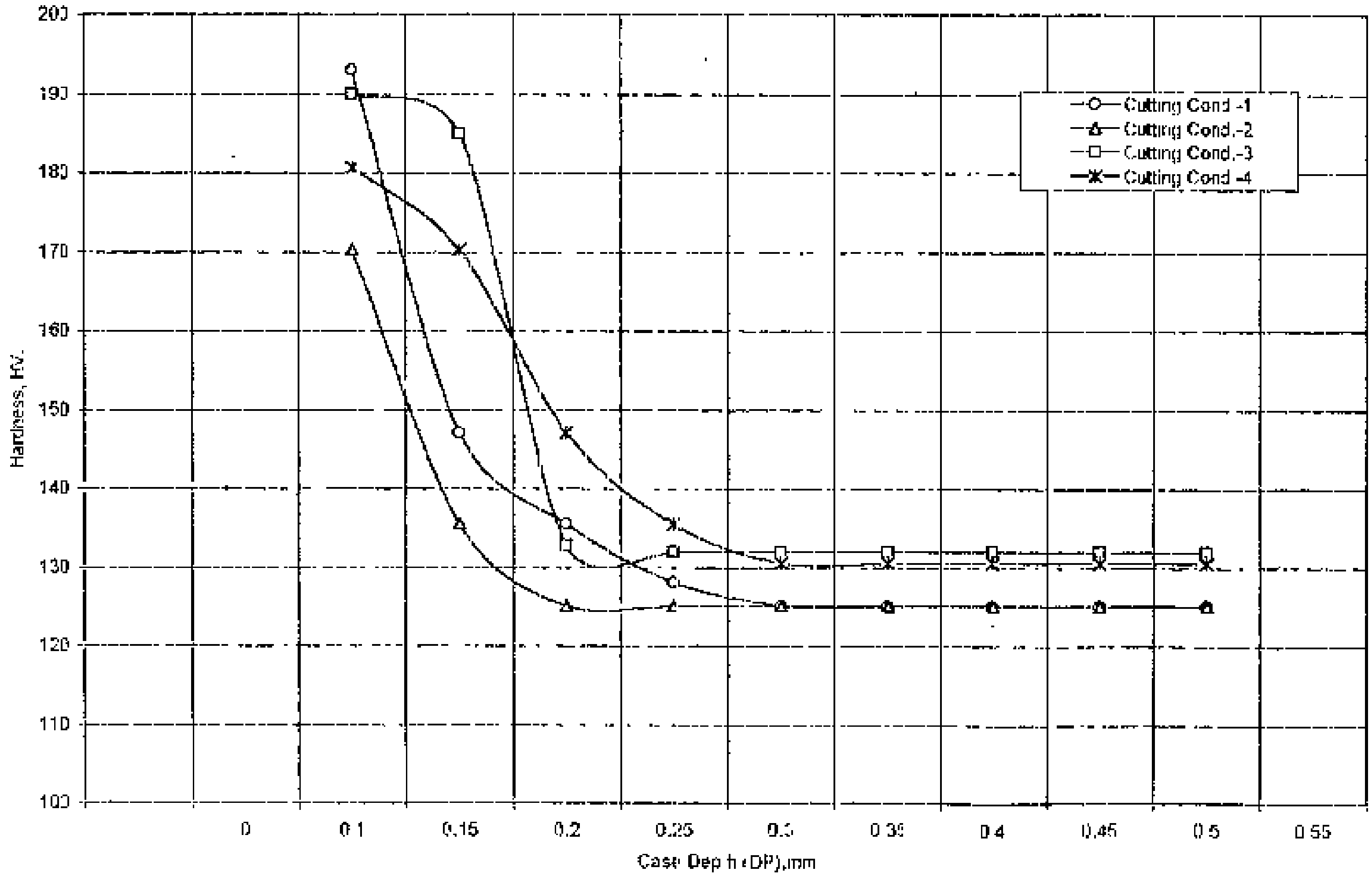
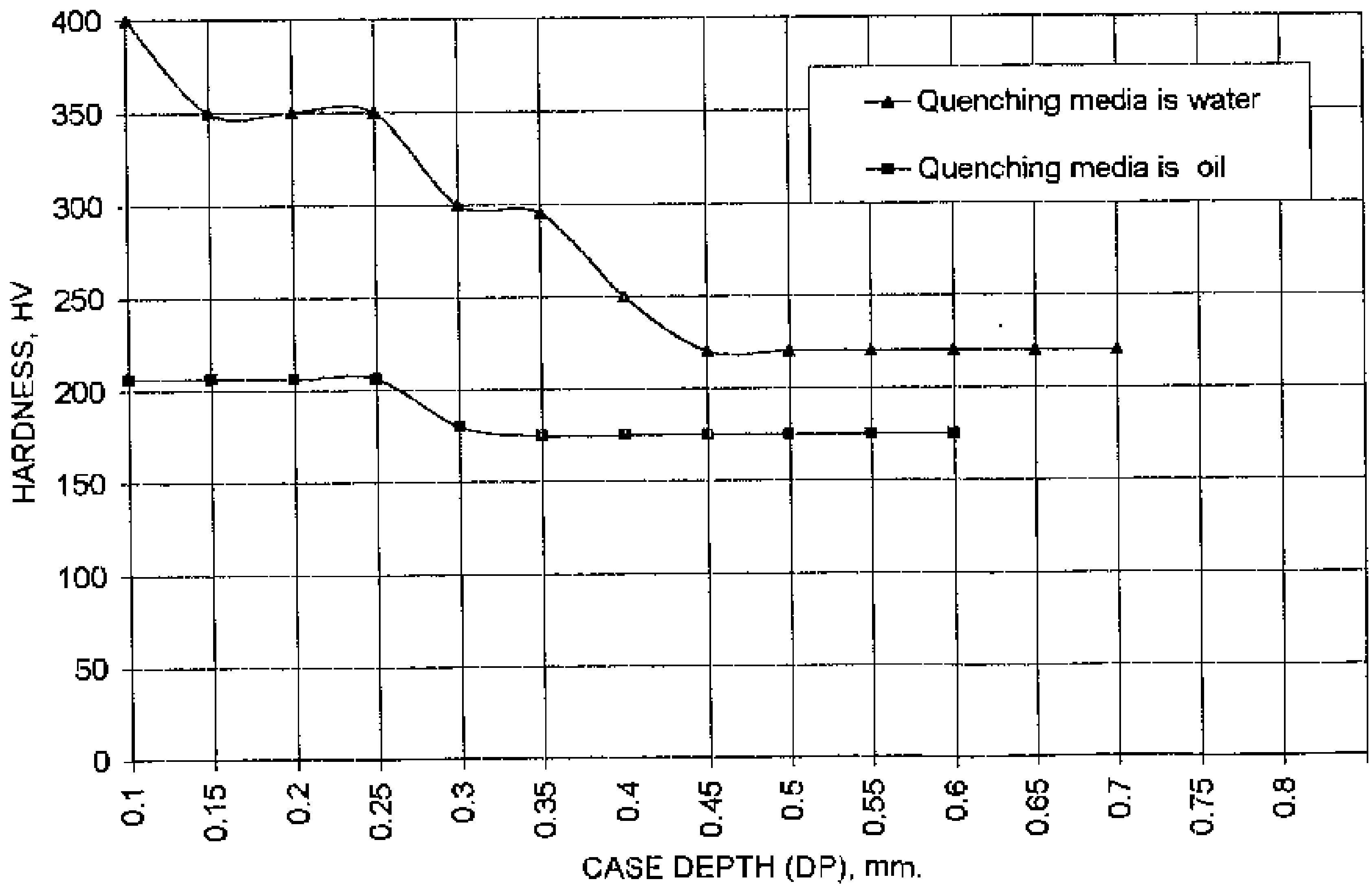


FIG.3.6:DEPTH OF PENETRATION Vs SURFACE HARDNESS OBTAINED AT HARDENING PROCESS



3.2 Discussion : Experimental result show that machining of metal possess the cold deformation (Work hardening or strain hardening) on the metal which substantially effect all physicochemical properties of the metal. Machining of Mild steel increase its surface hardness and decrease its ductility. High hardness and strength and low ductility result in good surface finish. The most suitable and economic method of obtaining the highest surface hardness and depth of penetration is to machining the metal at critical cutting speed with a heavier feed and the lowest depth of cut. Experimental results show that surface hardness and depth of perpetration both are the function of the cutting parameters. Numerous industrial applications require a hard wear-resistance surface called the case and are relatively soft, tough inside called core. For this purpose ductile materials like mild steel containing 0.1 to 0.8% C were subjected to case-hardening process, which other wise will not respond to direct hardening process. Case-hardening process consists of carbonizing and subsequent heat treatment. There are several other processes of case hardening, such as, nitriding, cyaniding, induction hardening etc. By these processes the surface of the mild steel were saturated by carbon and then subsequent heat treatment were done to produce a hard wear-resistance surface and a soft core. These process are costly and time consuming. From the experimental results it has found that machining of mild steel also increase its surface hardness to a certain limit.

S0,due to the work hardening of metal, machining can be considered as a case-hardening process upto a certain limit.

A comparison between machining and case-hardening process of mild steel were shown below:

Machining	Carburizing	Cyaniding	Hardening(quenching in oil)	Hardening (quenching in water)
Strain or work-hardening occured.	Surface is saturated by C, and is hardened by quenching.	Surface is saturated by C & N and is hardened by quenching.	Surface is hardened by heating & cooling only.	Surface is hardened by heating & cooling only.
No extra C req	Extra C req	Extra C req	No extra C added	No extra C added.
Hardness obtained is about 193 HV, and case depth is 0.3mm.	Hardness obtained is about 1000 to 1100 HV, & case depth is about 1.25mm.	Hardness obtained is about 1000 to 1100 HV, & case depth is about 0.25mm	Hardness obtained is about 206 HV.	Hardness obtained is about 400 HV.
Hardness increased= 68% w.r.t base mat.	Hardness increased=900% w.r.t base mat.	Hardness increased=900% w.r.t base mat	Hardness increased=280%w.r.t base mat.	Hardness increased=780%w.r.t. base mat.
Time req. is low	Time req.is high.	Time req.is high	Less time req.	Less time req.

From above discussion it can say that machining of mild steel improves its surface hardness near about one twelfth times than case-heardening process, near about one fourth times than hardening process followed by quenching in water, and near about equal to the hardening process followed by quenching in oil .

Though the investigation was performed only on Mild Steel with a Cemented carbide tool of particular geometry and using only the facilities of BUET and limited test data, this experimental result will act as a guide line and also will encourage every one to determine the surface hardness & depth of penetration at optimum condition for any other tool & work material, and working condition. Quantitative value of this work is less, but to evaluate this work properly, qualitative value must be considered.

The test results may deviate slightly during practical application due to its various limitations of experimental facilities. In spite of all the hindrances, the experimental study was carried out carefully.

It is hoped that the experimental investigation has analyzed some aspects of determining the surface hardness and depth of perpetration at different. Cutting condition within its limitations and finally has enabled the establishment of a method of predicting the maximum surface hardness and depth of cut at the optimum cutting condition in machining mild steel with cemented carbide tools

CHAPTER-4

Conclusions and Remarks

4.1 Conclusions: On analysing the results of the experimental investigations the following conclusions can be drawn :

1. There exists a relationship between the co-efficient of chip shrinkage, K and the critical cutting speed, Vc and the maximum value of K is found to the critical cutting speed, Vc.
2. There also exists a relationship between the Surface Hardness(HV) and the depth of penetration with the cutting parameters. Surface Hardness is maximum at the Critical cutting speed where Chip Shrinkage is maximum. If feed and depth of cut changes "K" will change and so as the Surface hardness will do. Generally, high feed will provide high surface hardness and high depth of cut will results low surface hardness and poor surface finish. Power requirements will also be higher at greater depth of cut.
3. The hardness attained is about one twelfth of the hardness obtained at the Case - hardening process and about one fourth of the hardness observed at hardening of Mild Steel where quenching medium is water.The hardness is compareble to the hardness observed at the hardening process where oil is used as a quenching medium.
4. Cutting conditions can be adjusted to achieve a desired hardness level of mild steel within the observed limits. So it may be possible to avoid or eliminate the heat-treatment processes where a comparable hardness is necessary to be developed for a particular application.

4.2 Recommendation for future works :

The present study was confined with Mild Steel as the work material. Although these results exhibited a trend, there remains a scope of similar investigations on other metals, composites etc. to establish the behaviour found in the present study. In this experiment , particular tool geometry was selected. Though these are recommended values for the used tool material, yet there remains a scope of further study by changing the values of tool geometry.

Throughout the experiment only carbide tool was used.Although the test results coincide with the theoretical one for this material there remains a scope for further study with tools of different other materials, to investigate the trend observed.

The research work was conducted without using any cutting fluid.This fluid may have effect on the finished surface. So there is a scope of study to evaluate the effects quantitatively through experiments.

The study experiments was conducted completely in the "laboratory condition" and the observation was made on the basis of the experimental results. Any change in experimental condition may affect the results.Though it is envisaged that the general pattern and trend of the curves developed from the test data should be similar, further investigation may be made to confirm and correlate the test results with the experimental conditions.

REFERENCES

1. Tresca, H. : "Memories Sur le Rabotage des Metaux", Bulletin De la Societe d' encouragement pour Lindustric national, 1973."

2. Mallock, A.,: "The action of cutting Tools", proceedings of the Royal Society of London, England, vol-33, no.1, 1981.

3. Taylor, F.W.: "On the Art of Cutting Metals" Transaction of the ASME, vol.28, no.119, 1907.

4. Ernst, H.and Martellotti, M. : "The formation of built-up-edge", Mechanical Engineering, vol.57, no.2, 1938.

5. Ernst, H. : "Physics of Metal Cutting", Machining of Metals in 'Machining Metal', American Society for Metal, Cleveland, Ohio, 1938.

6. Ernst, H. and Marchant M.E.: "Surface friction of clean metals - A Basic Factor in the Metal Cutting process", Proceedings of a special Summer Conference on friction and surface finish, Massachusetts Institute of Technology, Cambridge, Mass, 1940.

7. Ernst, H., Merchant, W.E. & Kranacher: "Radio active cutting tools for rapid tool life testing, A.S.M.E, Cincinnati, June 1952.

8. Zorev, N.M.: "Investigation of Mechanical aspects of Metal Cutting Process", Moscow, Mashgiz, 1952.

9. Laladze, T.N.: "Metal Cutting Toolwear", Moscow, Mashgiz,1958.

10. Ernest.H.
11. Gilbert. : "Economics of Machining" Publication No. M -1955, Cincinnati Milling Machine Co., Cincinnati Ohio.

12. Rozenberg, A.M. and Eremin, A.N., : "Eleents of Theory of Metal cutting", Mashgiz, Moscow, 1956.

13. Laladge, T.N., : "Chip formation during Metal Cutting Process", Moscow, Mashgiz, P-200, 1952(Translated From Russian into English).

14. Clushin, T.N. : "Metal cutting process", Moscow, Mashgiz, P -356,1958 (Translated from Russian into English).

15. Brewer, R.C. : "On the economic of the Basic turning operation", vol. 80, No.7, 1958.

16. Makarov, A.D.: "Tool wear and Tool-life, Moscow, "Machine Building", 1966.

17. Armarego, E.J.A & Russel, J.K. : "Maximum profit rate as a critirion for selection of machining condition", International journal of Machine Tool Design & Research, vol. 6, no.1, March 1966.

18. Zorev, N.M., Gronovsky, G.I., Larina, I.N., Tritiakov, I.P.,: "Development of the science of Metal cutting", Moscow, Machine building publication P-416, 1967(Translation from Russian into Engliag).

19. Bakes, Jan. B: "Calculation of optimum cutting conditions", S.N.T.L. Technical Digest, vol.9, No.3, March 1967.

20. Basu, S.K. : "A New Approach for Optimum Solution in Metal Cutting Experiments", proceedings first M.T.D.R. conference, India, Jadavpur University, 1967.

21. Bhoothroyd, G.,Eagle,J.M., and Chisholm, A.W.J., : "Effect of tool flank wear on the temperature generated during Metal cutting",Advances in machine tool Design Research,P667, 1967.

22. Bjork, Yvind: "Mathematical Models for calculation of cutting data in rough training, "Paper at C.I.R.P. General Assembly, 1968.

23. Talantov., N.V.: "Contact process and wear of tool surface : Improvement of the cutting process and accuracy of machine tools", Ejevsk, USSR, 1969.

24. Nadai, K.A. : "Plasticity and Fracture of Solid Bodies", Moscow, Mir publication, vol.2, 1965.

25. Reznikov, A.N.: "Heat Physics in Metal Cutting", Moscow, Machine Building, 1969.

26. Time, I.A. : "Resistance of Metal and Wood during Cutting", St-Peterburg, Russia, 1970.

27. Babrov,V.F.,: "Productions of theory of metal cuttng",Publication machine building, Moscow, P-344,1975.(Translation from Russian into English).

28. Talantov,N.V. Cheriomoshnikov.: "Influence of cutting speed on diffirent characteristics of metal cutting process and tool wear".Technology of machine building and automotion ofproduction process, Volgograd 78, p-29-49.

29. Cyrill Donaldson :" Tool Design",12th reprint,p-226,1987.

30. Cyrill Donaldson :" Tool Design"'12th reprint,1987,p-227.

31. Er.R.K. Jain :"Production Technology" ,4th edition, 1995,p-612.

32. Cyrill Donaldson :"Tool Design" ,12th reprint ,1987,p-234.

33. Cyrill Donaldson :"Tool Design" ,12th reprint ,1987,p-267.

34. Sankar Roy :"Experimental determination of optimum cutting conditions in turning low alloyed steel with cemented carbide tool" ,1984 ,IPE ,BUET.