EXPERIMENTAL DETERMINATION OF OPTIMUM CUTTING CONDITIONS IN TURNING LOW ALLOYED STEEL WITH CEMENTED CARBIDE TOOL

A Thesis

By

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C E R T I F I C A T E

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

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A C K N O W L E D G E M E N T

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ABSTRACT

In practice, the values of cutting speed, feed and depth of cut during machining operation are determined either by mere experience as usually done by machine tool operators or selected from the available engineering tables. In both the cases,the assigned values are, generally, too far away from the economic values. This Thesis presents a scientific method of predicting the optimum values of the machining variables for turning operations of steel with cemented carbide tool materials. Experiments have been carried out to determine the optimum values of cutting speed, feed and depth of cut, which lead to minimum manufacturing cost. It has been established that the critical cutting speed (V_c) corresponds to the maximum value of coefficient of chip-shrinkage (K) along the curve K = f(V) and that there exists a definite relationship between critical cutting speed (V_c) and optimum cutting speed (V_{op}). For single carbide tool material, there is one optimum cutting speed which is just before critical speed ($V_{op} \leq V_c$). But for double carbide tool material, there are two optimum cutting speeds; the first being just before V_c ($V_{op_1} \leq V_c$) and the second just above V_c ($V_{op_2} > V_c$).

NOMENCLATURE

C_P	Total machining cost/piece
C_I	Idle cost/piece
C_c	Machining cost/piece
C_t	Tool cost/grind
C_{tc}	Tool changing cost/piece
C_{tg}	Tool regrinding cost/piece
C_{td}	Tool depreciation cost/piece
C_v	Taylor constant
T_P	Time to complete a piece
T_i, t_I	Idle time/piece (including loading & unloading time)
T_c, t_m	Machining time/piece
T_{tc}, t_{ct}	Tool changing time
T	Time
T_L	Tool life
T_L	Maximum tool life available
P_R	Profit rate
I_P	Income/piece (excluding material cost)
M	Total machine and operator rate(including overhead)
N_t	Number of tools used for a piece
N_b	Number of pieces machined by a tool after each grind
S	Feed, mm/rev.
t	Depth of cut, mm.
V	Cutting speed, m/min.
V_c	Critical cutting speed, m/min.
[redacted]	[redacted]

n	Taylor exponent
x_V, y_V	Exponent for feed and depth of cut
K	Co-efficient of chip-reduction or chip-shrinkage
L_o	Length of metal being cut
L_c	Length of chip corresponding to L_o
P_z	Cutting force, Kg.
τ_s	Shear stress
h_f	Flank wear, mm.
h_{f_o}	Initial flank wear, mm.
ℓ	Intensity of wear, mm/m.
I	Wear per unit metal removal, mm/m^3
Z	Total metal removal, m^3
Z_w	Metal removal rate, m^3/min
S_{max}	Maximum feed available in machine
V_{max}	Maximum cutting speed available in machine
t_{max}	Maximum depth of cut available at the cutting edge
P_{max}	Maximum power available at the cutting edge.
W.R.T	With Respect To
γ_o	Side rake angle
β	Shear angle
η	Frictional angle
γ	Back rake angle
ψ	Side cutting edge angle
ψ_1	End cutting edge angle
α	Side clearance angle
α_1	End clearance angle

CHAPTER - 1

INTRODUCTION

1.1 Introduction

The country launched a programme of intensive industrialization including manufacturing of machine tools, cutting tools, spareparts, agricultural and general purpose machines which involves huge amount of metal cutting and processing. The Government, Semi-Govt., and private sectors have made a good head-way in developing the industrial potentialities. Although faced with numerous problems, the industrial sector is at present capable of meeting a major portion of the country's demand in this field. One of the major problems which faced by the machine building industry is a shortage of Technical knowhow for proper and economic operation of the existing machine tools. This is hinderance to rapid Industrial Growth in the country. In factories, a small number of engineers and almost no worker are aware of optimum conditions of machining, without which achievement of economy in industrial production is almost impossible. In the factory, without using scientific method, the whole metal cutting operation is based on thumb-rules due to lack of proper technical knowledge in this field and equipment facilitiee. Thus, development of new economical, scientific process of metal cutting is beyond the scope of the factory. In practice, the values of the metal cutting variables are determined either by mere experience as usually done by machine-tool operators or selected from the available Engineering tables. None of methods takes the process constraints into consideration and merely depend on the personal experience of the employed personnel and hence lead to values which are too far away from the economic values. It results in low production rate and high machining cost which is undesirable for the factory. Therefore, any means of improving this situation is of direct concern to all.

To improve upon this condition, it is necessary to study the underlying principles of metal cutting and tool wear and to employ more effective methods of metal cutting. This will enable to raise productivity, to increase machining accuracy and to machine most econimically. The primary purpose of machining economically is to determine the machining parameters correspondinn to optimum conditions. The optimization is performed with respect to an objective function which may be (a) the machining cost, (b) production rate, (c) profit rate, or a suitable combination of these three functions. So, optimum results from metal cutting operations - interms of piece cost, productivity, and profit rate is of major importance to the factory.

The selection of cutting conditions has long been recognized ee a major factor governing the economics of metal cutting. Experiences gained over the years have led to the determination of certain emperical rules or guiding principles for choosing the optimum cutting conditions for a given machining operation. With a view to use the optimum conditions and the principles of metal cutting in the factory, this experimental study has been made. A turning operation has been chosen to develop a method which needs no special or costly equipments and adequate technical knowhow of the workers to reach the above mentioned goals.

1.2 Literature Review

Research in metal cutting had already been carried out by the French Scientist Tresca[19] as far back as 1873, although fundamental theories have been developed only during the past three or four decades. Beginning with Mallock[20] in 1881, and through 1900, several contributions were made toward understanding the metal cutting process by determining cutting forces and the effects of tool geometry and cutting environments.

In 1907, the classical work of Taylor[21], "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 developments led more toward producing emperical data than contributing to theoretical analysis.

Fundamental research on the metal cutting mechanism has been continued since 1930. And it has been influenced by similar researchers. In 1935 Ernst and Martellott[22] confirmed the role of the built-up edge in metal cutting and presented their theories on the mechanics of its formation and breaking off and its effect 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 Martellotti in 1935, Ernst[23] in 1938, and Ernst and Merchant[24] 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 extensive developments in metal cutting since the year 1950.

Regarding wear process of the cutting tool, tool life test, testing method, etc. many reports have been presented by many researchers. In 1952, Merchant, Ernst and Krabacher[12] presented a scientific method of tool life testing, specially, for cemented carbide tool. The mechanical aspect of metal cutting was investigated by Zorev[25] in 1952. In the same year, Laladzee[26], a leading scientist in USSR, presented a well recognized theory of chip formation during metal cutting process.

Considerable effort has been expended after the year 1950 on developing the optimum machining variables. In 1955, Ernst(1), Gilbert(2) optimized the cutting condition withrespect to minimum production cost. In this objective function, cost of production is a function of tool cost and machining cost.

In 1956, Rozenberg and Eremin(9) 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.

In 1958, Laladze(28) presented the role of tool wear for optimization in metal cutting process. This was confirmed by Clushin(27) in the same year after investigating the metal cutting process. Brewer(11) 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.

1966, Makarov(29) carried out investigations on tool wear and optimization of metal cutting process. In this year, Armerego and Russel(3) used maximum profit rate as an objective function for optimizing machining variables and have proved that maximum profit depends on both tool cost and idle time.

In 1967, Zorev, Gronovsky, Larina and Tritiakov[30] explained the mechanics of metal cutting. In this year, Bekes[5] 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[6] modified this method by developing a new approach for chosing optimum cutting variables. Boothroyed, Engle and Chisholm[14] determined the effect of tool flank wear on metal cutting process.

In 1968, Bjorke[4] developed a mathematical model for calculating the cutting condition during truning operation.

The nature of chip-tool contact process in an important factor in chip formation and it is one of the most significant factors determining the process of tool wear. In 1969, Talantov[8] presented a relationship between chip-tool contact process and tool wear for cemented carbide tools to improve metal cutting process. Nadai[31] 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[32] in 1969.

In 1970, Time[33] explained the resistance of metal during cutting operations. And in 1975, Bebrov[34] presented the fundamental theory of optimization of the metal cutting process.

In 1978, Talantov, Cheriomoshnikov and Kurchenco[18] presented the relationship between cutting speed, metal cutting process and tool life.

This work attempts to present a method of selecting optimum metal cutting conditions during turning operation on the basis of the earlier progress in optimizing the metal cutting process and in establishing relationship between tool wear and chip tool contactprocess. Attempts have been made in this article to present a comprehensive list of the works so far done in this direction overall development of the theory of metal cutting alongwith works which dealth with the problems, selected for study in the present work.

1.3 General Theory

The optimization is performed within the feasible region defined by the relevant constraints, and with regard to the expected value of the objective function.

1.3.1 Objective Criterion for Optimization:

Large number of research work were carried out by Ernest[1] Gilbert[2], Armarego & Russel[3] to determine this criterion. According to their decisions, the objective criteria are:

i) Minimum cost (cost as criterion):

$$C_P = C_I + C_c + C_{tc} + C_{tg} + C_{td} \quad \ldots \quad (1)$$

ii) Maximum production rate (production time as criterion):

$$T_P = T_1 + T_c + T_c\,(T_c/T_L) \qquad \ldots \quad (2)$$

iii) Maximum profit rate (profit rate as criterion):

$$P_R = \frac{I_P - C_P}{T_P} \qquad \ldots \quad (3)$$

1.3.2 Restrictions for optimization:

When the optimization of 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:

i) Power : Power absorbed by cutting process cannot exceed the power capacity of the main drive

ii) Torque : The torque absorbed by the cutting procees muet not exceed the torque capacity of either of the main drive, or of the work piece, or of clamping

iii) 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.

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

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

vi) Force & vibration : Forces and vibrations in tool and workpiece also restrict the cutting conditions.

vii) Machine feed & Speed steps : The restrictions in this case depend on the machine used.

1.3.3 Selection of Optimum Cutting Parameters under Various Restrictive Conditions:

i) With cost as objective criterion:

For optimum tool life, cost is a function of speed, feed, and depth of cut and should be a minimum.

$$C_P = f(v, s, t)$$

ii) With production rate as objective criterion:

The usual objective criterion is obtained from equation(2) in which time of production is minimized. According to Bekes[5], metal removal rate (v.s.t) should be maximum.

$$T_P = f(v, s, t) \text{ and}$$

$$v.s.t = \text{maximum}.$$

But, Basu[6] found that for this criterion -

$$T_L \quad T_L^*$$

$$V \quad V_{max}$$

$$t \quad t_{max}$$

iii) With maximum profit rate as objective creterion:

From equation(3), due to Armarego & Russel[3],

$$P_R = \frac{I_P - C_P}{T_P}$$

where, I_P = depends on market price,

$C_P = f(f, s, t)$

$T_P = f(v, s, t)$

It is true that, to a manufacturing concern, production costs, production rates and profit rates, all are of vital interest. But analysis of these three terms at a time is not possible for complexity. It is wise to use only one objective criterion, generally minimum cost criterion(7), as required to determine economical cutting conditions. According to the various authors, it should be noted that, for a given material and a tool, the restrictions of feed, speed, depth of cut, cutting force (as function of power), and surface finish will apply whatever criterion is used to determine "Optimum Cutting Conditions".

1.3.4 Cretical Cutting Speed

It is known that, cutting force, P_z is a function of cutting variables.

$$P_z = f(v, s, t).$$

– Expression of tool life, $T_L = \dfrac{C_v}{V^{1/n} \cdot S^{Y_v/n} \cdot t^{X_v/n}}$ ... (4)

For a particular cutting condition, where values of S & t are constant, P_z is a function of only cutting speed.

$$P_z = f(V) \quad \ldots \quad \ldots \quad (5)$$

and, similarly, $T_L = f(V)$ ... ... (6)

Since, the tool life, T_L is defined by flank-wear, h_f,

then, $h_f = f(V)$ ... ... (7)

From equation (4), the cutting speed, V can be expressed as follows taking tool life constant,

$$V = \frac{C_V}{S^{Y_V} \cdot t^{X_V}} \qquad \ldots \quad \ldots \quad (8)$$

when $s = 1$, $t = 1$, then $V = C_V$.

Generally, Y_v X_v, It means that feed has greater influence on cutting speed than depth of cut. This case is just opposite for cutting force, P_z on which depth of cut has greater influence than feed.

Large number of research works have been carried out in the "Volgograd Polytechnic Institute", USSR, to establish the relations described by equations 5, 6 & 7, for any cutting conditions with cemented carbide tool. According to the results, the relationship between P_z and V; h_f and V; T_L and V, can be represented graphically as in Figures - 1, 2 & 3 respectively. Fig. 1, shows that upto point C_I, the dependence of P_z on V is complex, for both the cases. After that, for single carbide tool material, curve takes a regular shape (P_z decreases with increase of V), but for double carbide tool material, the curve takes the shape as shown by dashed line which shows a second peak at C_2.

In Fig. 2, for single carbide tool, the value of h_f decreases first with increasing V, followed by an increase to maximum with further increase in V, then again h_f decreases upto a point, C_1 close to V_c. At the point V_c, h_f increases sharply and then

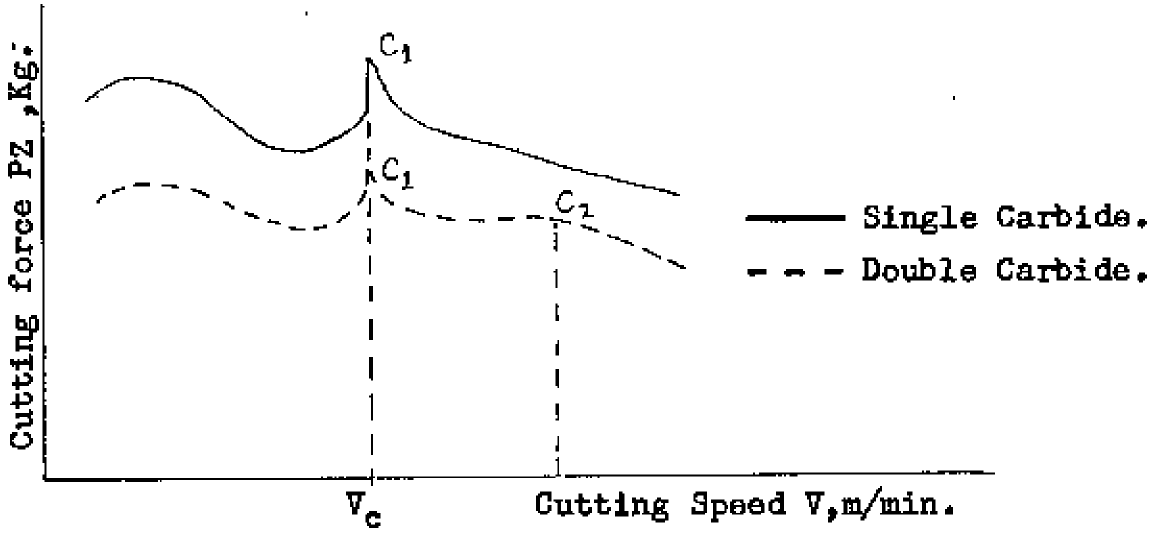


FIGURE - 1. Typical Curve, P_Z Vs V.

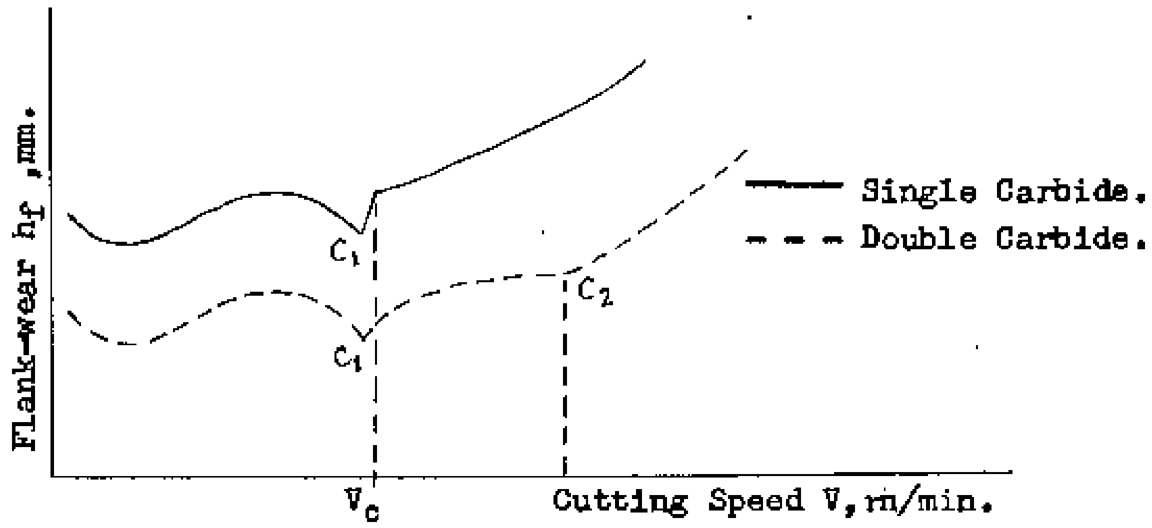


FIGURE - 2. Typical Curve, h_f Vs V.

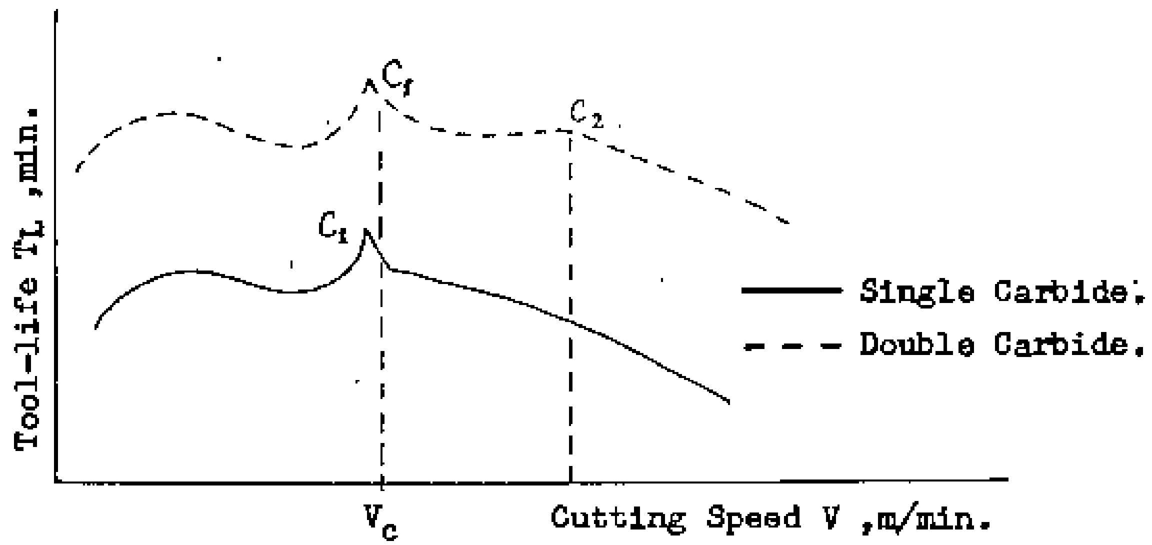


FIGURE - 3. Typical Curve, T_L Vs V.

the curve changes its shape indicating constant increase of h_f, with increase of V. But for double carbide tool, beyond the point V_c, with increase of V the value of h_f increases first and then decrease till point C_2, after that there is constant increase of h_f with further increase of V (within certain limits).

From Fig. 3, it is found that, for single carbide tool material, one peak at point C_1 which indicates maximum tool life at cutting speed corresponding to this point and then decreases with further increase of V. But, for double carbide tool material there are two peaks - one at point C_1 and other at point C_2 mean that tool life increases at first to a maximum value (point C_1) with increasing V, followed by a decrease with further increase of V. The relation reverses again upon further increase in V to another maximum value (point C_2) where upon tool life drops with continued increase in V. it seems apparently that, at point C_2, tool life is less than that of at point C_1. But considering tool life per piece of product, tool life at point C_2 is higher than that of at point C_1. Similar results were also obtained by other researchers[18] who worked in this field.

From the above figures, it is found that, the point V_c 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 "V_c". For single carbide tool material $V_{op} \leq V_c$, and for double carbide tool material, $V_{op_1} \leq V_c$, $V_{op_2} > V_c$.

1.3.5 Chip-tool Contact Process and Tool Life

During normal machining operation, tool-wear mainly depends on the "Chip-tool contact process". In the zone of cutting speed where built-up edge exist, the tool-wear is determined by the type of built-up edge. There are several types of built-up edge, whose typical views are shown in Figure 4.

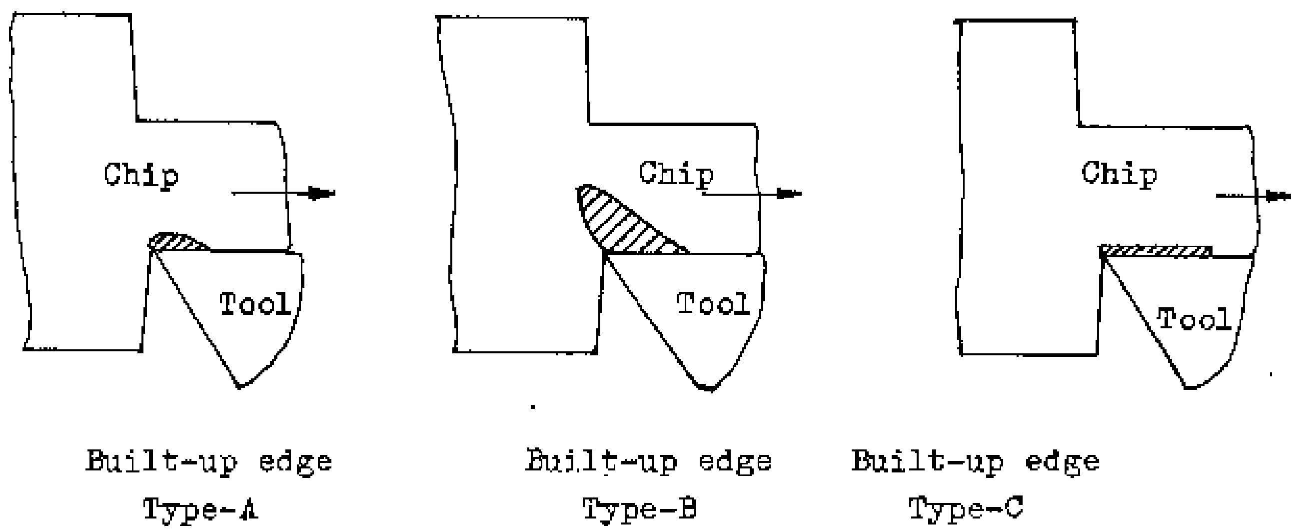


Figure 4: Typical view of built-up edge

Many researchers have worked on 'The effect of chip-tool contact process on tool wear'. And talantov[8] has been able to establish a relationship between the contact process and the tool life, which is shown in Figure 5.

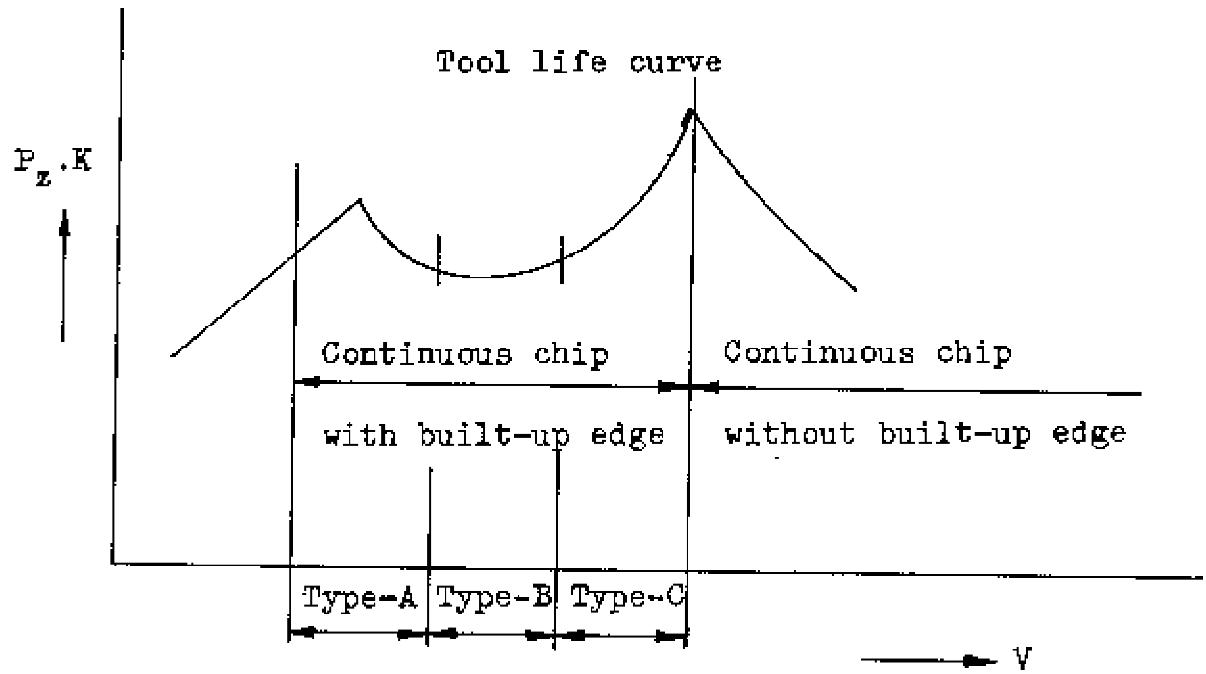


Figure 5: Typical relationship between contact process and tool life (after Talantov)

It is observed that at higher speed during type-C contact process, tool life is maximum and minimum tool life at type-B contact process. It is also experimentally proved by Talantov that type-C contact process, though unstable built-up edge but soft due to high temperature for higher speed, protects the tool life from wear and reduces flank-wear and also produce mirror type snrface finish. This is a special type of contact process and according to him it is called "Pulsation Coutact Process". It is also shown in Fig. 2, that in the range of cutting speed where this type of contact process is realised, the value of flank-wear, h_f is minimum for single Carbide tool material. By the recent research works of the same author, it has also been established that for double cemented carbide (titanium - tungstan) tool materials there exists a range of cutting speed just above V_c, where the tool is protected against wear by a permanent welded layer of work material formed on the tool-face. Approximate shape of the curve $T_L = f(V)$ is shown in Fig. 3.

1.4 Aims and Objectives:

i) To determine the critical cutting speed, V_c for different cutting conditions

ii) To determine the economic cutting condition with respect to tool life and to estahlish its relationship with critical cutting speed, V_c.

iii) To evaluate the economic benefit of the proposed methods over the existing one by cost analysis and to recommend the most economic method.

CHAPTER - 2

DETERMINATION OF CRITICAL CUTTING SPEED

2.1 Theory

The nature of variation of cutting force is intimately related with cutting speed. Rozenberg[9] established an expression of cutting force, P_z

$$P_z = \frac{\tau_s \cdot s \cdot t \cdot \dfrac{\cos \gamma_0}{\sin\beta \cdot \cos(\beta - \gamma_0)}}{1 - \dfrac{\sin\eta}{K \cdot \cos(\eta - \gamma_0)}} \text{ Kg.} \qquad \ldots \quad (9)$$

This indicates that P_z depends on the value of , K, S and t. K is the "chip-reduction co-efficient" or "chip shrinkage", where

$$K = \frac{\cos(\beta - \gamma_0)}{\sin\beta} = \frac{L_o}{L_c} = \frac{\text{length of uncut chip}}{\text{Actual length of the chip}}$$

The value of K is affected by:-

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

ii) Cutting environment and auxiliary variables

The behaviour 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 behaviour 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 otherhand, cutting force, P_z measurement is very troublesome and the instrument is also very costly. In Fig. 6, Rozenberg(9) has demonstrated that the behaviour of cutting forces with respect to cutting speed is identical with chip-shrinkage characteristics. So, to findout the critical cutting speed, V_c, chip-shrinkage, K is used instead of cutting force, P_z.

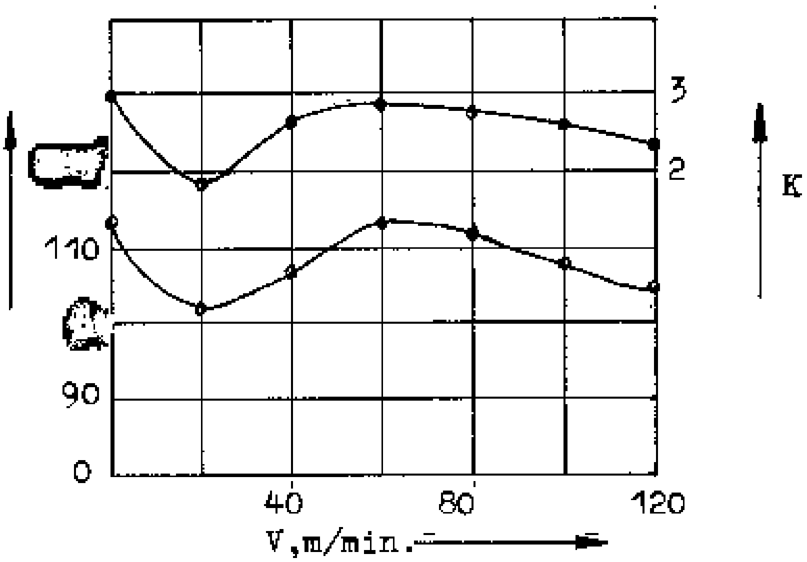


Fig. 6: The behaviour of cutting force, P_z and chip-shrinkage, K with respect to cutting speed, V. (after Rozenberg)

2.2 Place of Investigation

Bangladesh Machine Tools Factory Ltd. is the biggest factory in the country which involves huge amount of metal cutting and metal processing. It is evident that yearly metal cutting cost on machine-tools operated in BMTF is enormous. Thus savings can be realised by investigating and subsequently improving the existing metal cutting process. During the year

1980-81, 1981-82, BMTF incurred net loss of Tk.761.07 lacs and Tk.698.49 lacs respectively and factory production fulfils only 16% of the local demand(15). Existing metal cutting condition may be one of the causes of this situation as the assigned values of machining variables are determined on the basis of mere personal experience. This has emphasized the need for the determination of the machining condition. To show the efficiency and benefit of the proposed metal cutting process over the existing one, the field of research work was chosen in BMTF and the experimental study was done on one of its important product the "Drawing Roller" on which the main and primary operation is turning.

2.3 Details of Work and Tool Materials

The experiment was carried out in the machine shop of BUET. With a view to use all the facilities of BMTF and to maintain the existing working conditions (input variables) of BMTF, experiments were performed with identical work material, machime-tool, cutting-tool, etc. Nickel-Chromium steel of group 10NC6 (c = 0.12% Mn = 0.60 - 0.90%, Si = 0.10 - 0.40%, Ni = 1.2 - 1.6%, Cr = 0.85 - 1.15%, P(max) = 0.035%, & S(max) = 0.035%) as work-material and Cemented-Carbide of group P15 (15% TiC, 6% Co, 79% WC - Double Carbide) rectangular brazed type tool tip as cutting tool, were used is the experiment and both of them were supplied from the office of BMTF. Size of the tool-shank was 25mm x 25mm x 140mm.

Tool geometry was as follows: $\gamma = 6^\circ$, $\varphi_1 = 5^\circ$, α & $\alpha_1 = 8^\circ$, $\varphi = 91^\circ$, Diameter of the drawing roller was 73 - 74mm and length was 954 - 1207 mm. Machine used was a 'MTM No.7' engine lathe provided with a 10 h.p. motor, Spindle speed: 83, 109, ..., 141, 182, 242, 316, 410 & 528 r.p.m. and Feed: 0.20, 0.25, 0.30, 0.35, 0.40 mm/rev. close to those available in the production 'OERLIKON' engine lathe used in the HMTF for this very operation.

2.4 Condition and Assumptions of the Experiment

The aims of all the experimental setups were to findout the critical values of the factors influencing the optimum cutting condition. From the earlier theoretical investigation, it was proved that the influencing factors were, cutting force, speed, feed, depth of cut, tool-life, etc. Influence of tool geometry was neglected for constant tool geometry through out the investigation. Although cutting fluid has considerable influence on cutting conditions yet it was not used, since coolant quickly shatters cutting edge and forms crack for repeated quenching. To investigate the above mentioned factors carefully and systematically, experiment was conducted in several stepa and the assumptions were stated below:

i) The properties of the work-material do not vary during and after the operations

ii) Instanteneous conditions of temperature, pressure, and chip-formation in the region of cutting correspond to the appropriate steady-state conditions.

2.5 Experimental Setup

Conventional method was applied for to determine critical cutting speed. It was noted that for this experiment a round solid bar was turned with cemented carbide tool. Shallow axial slots were cut on the bar surface before turning operation, because chips of 25mm to 100mm in length can be measured without difficulty. But longer chips are usually unhandy while shorter chips donot permit sufficient accuracy. So to determine the value of chip-shrinkage, K from turning operations, it is feasible and also recognized to interrupt the cut by a groove inorder to have a measure of the uncut length of the material which later is removed as a chip. A small groove parallel to the centre-line of the workpiece leaves marks at the edge of the chip at a distance equal to one revolution of the work. The chip-shrinkage, K is found by measuring the distance of the mark on chip and dividing the circumstance of the work piece by the measured length. The length of the chip is measured preferably on the smooth surface, chip-tool contact processes were estimated by viewing the scratch patterns on the rake face of chip and by studing the photomicrographs of the chip.

2.6 Experimental Details

To determine the existing factory (EMTF) condition, which is S = 0.20mm/rev., t = 2.5mm, V = 52m/min, N = 225 rpm., whether critical or not, cutting operations were carried out with previously said lathe speeds taking S = 0.20 mm/rev., and t = 2.5 mm. The chips were collected separately for each cut whose duration was a few seconds and the value of chip-shrinkage, K was calculated after measuring the chip length carefully and accurately and also chip-tool contact type was marked and noted for every case. With these values of K and corresponding values of V, a curve K = f(V) was plotted in Fig. 7. This curve is similar to that of previously established test results. 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 a reduction in cutting force and also with an increase in temperature and vice-versa[14]. Thus at maximum K P_z is also maximum and for minimum K value of P_z is minimum. After analyzing the curve and chip-tool contact process, critical cutting speed was determined which was V_c = 75 m/min and corresponding N = 346 r.p.m.. This indicates that factory cutting speed, V = 52 m/min, N = 225 r.p.m. was not critical as it was too low in comparison with the experimental value of V_c for the given values of S and t.

Similarly, keeping feed constant, S = 0.20 mm/rev, varying only depth of cut, t and taking its value equal to 3.0, 3.5, 4.0 4.5 and 5.0 mm cutting tests were performed. For each condition, chip were collected seperately and value of chip-shrinkage, K was calculate. Chip-tool contact process was also noted. Finally after plotting curves K = f(V) in Fig. 7, the value of V_c was

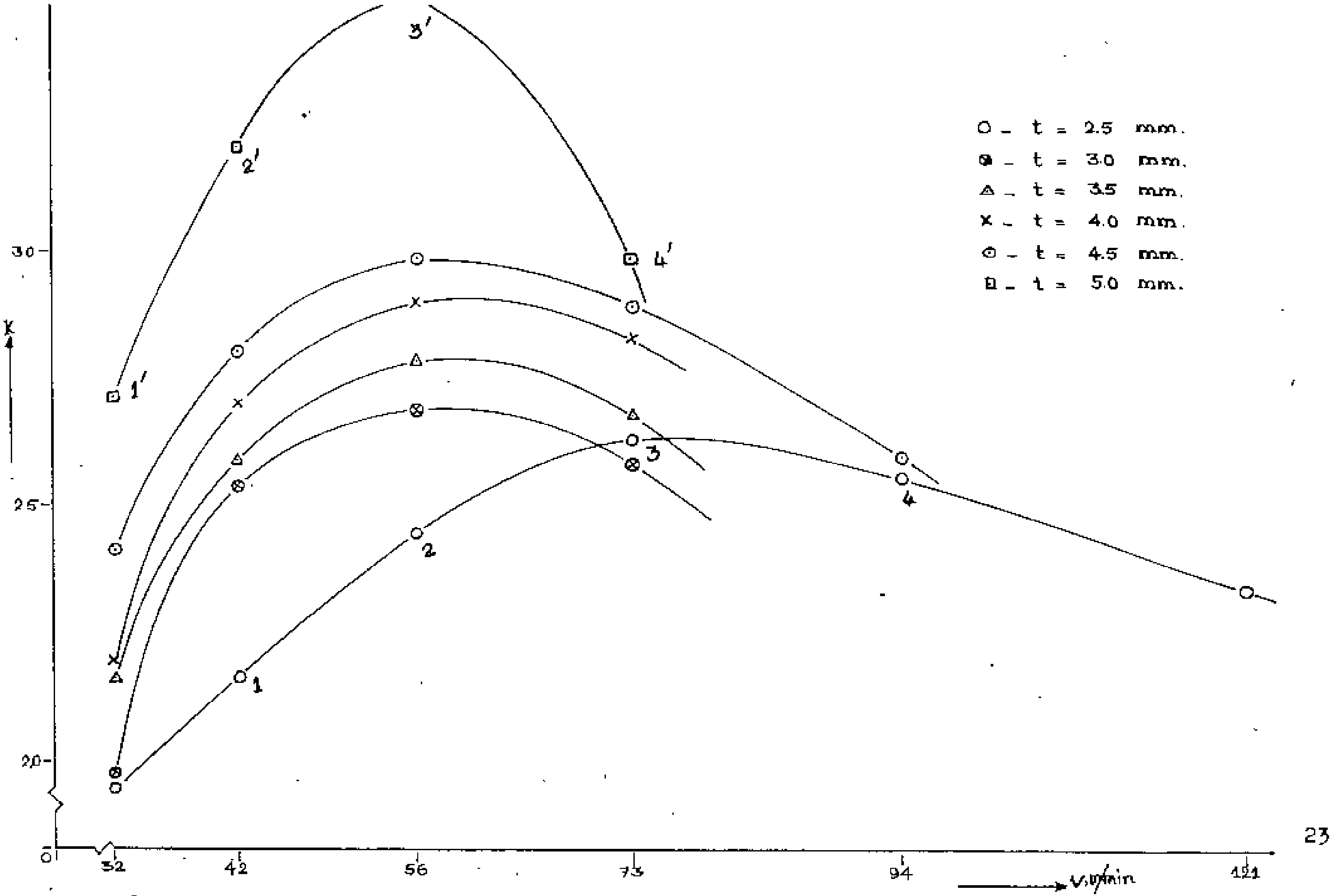


FIGURE - 7. Effect of cutting speed on chip-shrinkage at S = 0.20 mm/rev. (From experimental data).

determined for each condition. Similarly, for each of the following values of S of 0.20, 0.25, 0.35 and 0.40 mm/rev, cutting tests were conducted with the six above mentioned values of t (t = 2.5, 3.0, 3.5, 4.0, 4.5 & 5.0 mm) for various values of cutting speed, V. In every case, types of chip-tool contacts were marked carefully and values of K were calculated. With these values, curves K = f(V) were plotted as shown in Figures 8, 9, 10 & 11. Photomicrographs of the chips for the points marked on the curves in Figures 7, 8, 9, 10 & 11 are shown in Figures 12, 13, 14, 15, 16 & 17 respectively. Photographs of Fig. 12 represent the points, such as 1, 2, 3 & 4, marked on the curve (t = 2.5 mm, S = 0.20 mm/rev.) in Fig. 7. It is observed that at point 1, chip is discontinuous type and there are prominant fracture marks on chip. At point 2, chip-tool contact process is continuous type with traces of builtup edge; while at point 3, the chip is continuous with unstable builtup edge and traces of this type of builtup edge can be observed on the rake face of chip, as well as on the cutting surface. At point 4, continuous chip almost without builtup edge which vanishes after a few seconds of cut (as in Fig. 29).

Due to similar shape of all curves in Fig. 7, it is argued that the similar point on any curve behaves similarly i.e. they should correspond to identical chip-tool contact process. To establish this statement, photomicrographs of the points 1', 2', 3' & 4'

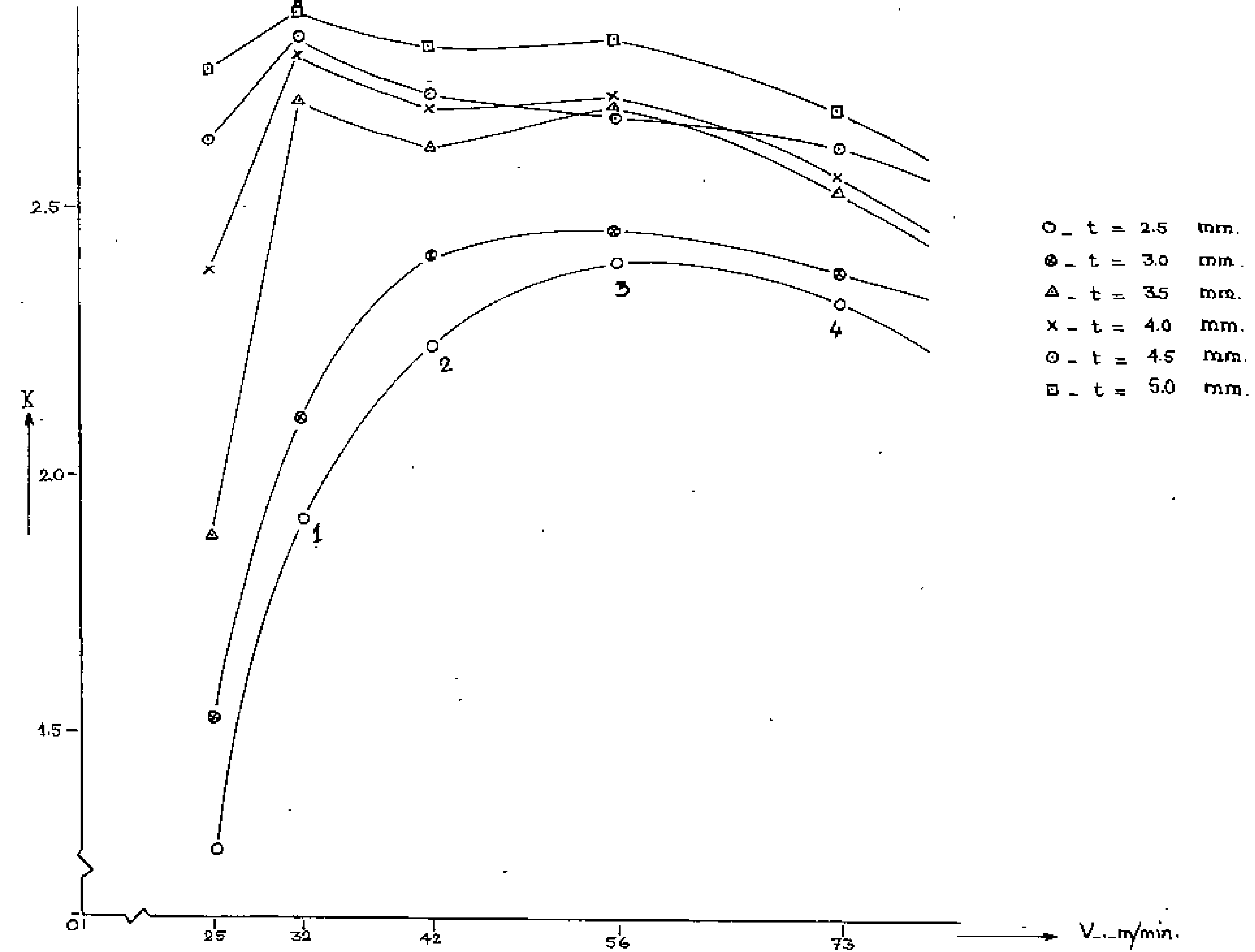


FIGURE - 8. Effect of cutting speed on chip-shrinkage at $S = 0.26$ mm/rev. (From experimental data).

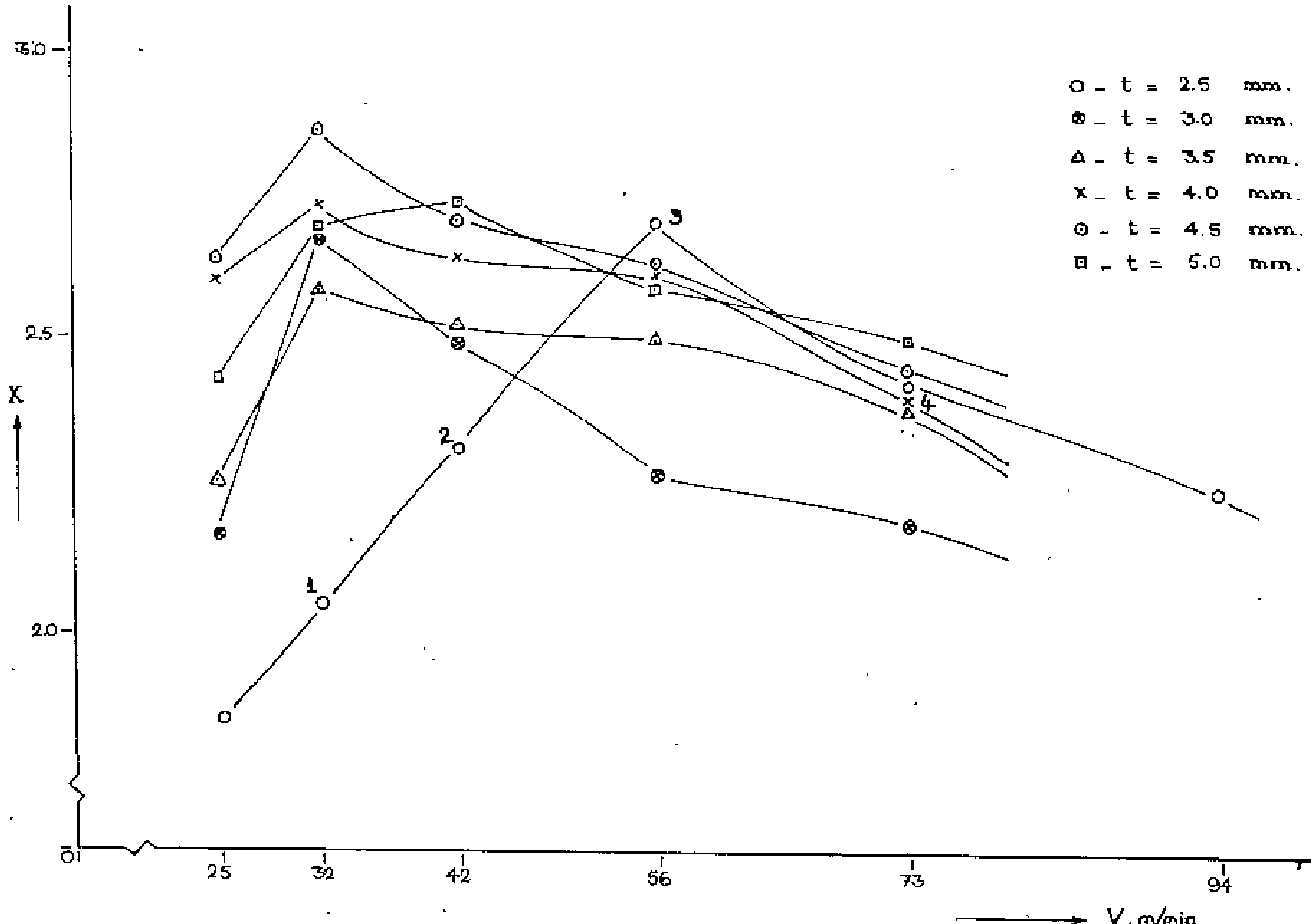


FIGURE - 9. Effect of cutting speed on chip - shrinkage at S = 0.30 mm/rev. (From experimental data).

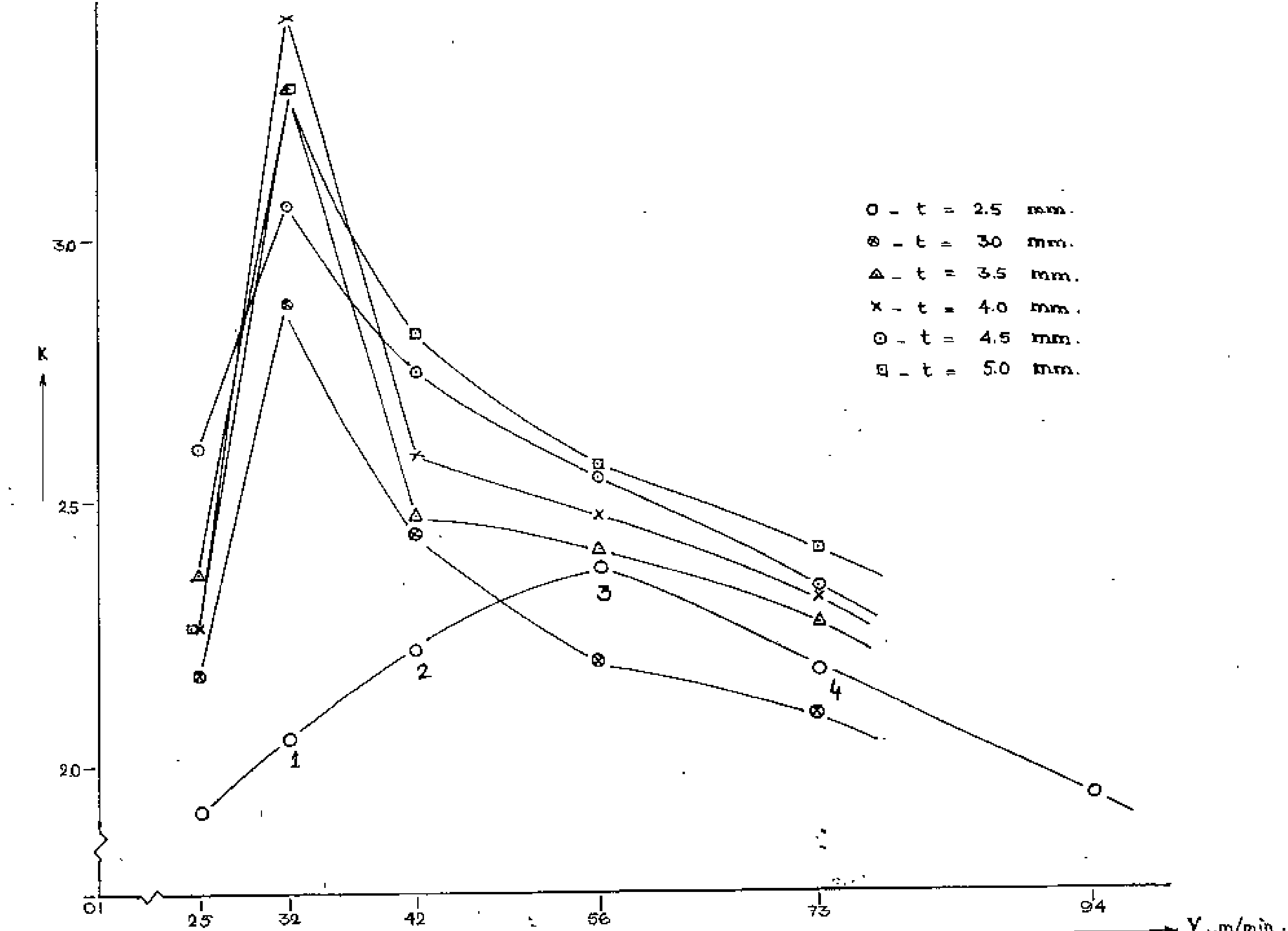


FIGURE – 10. Effect of cutting speed on chip - shrinkage at $\delta = 0.35$ mm/rev. (From experimental data).

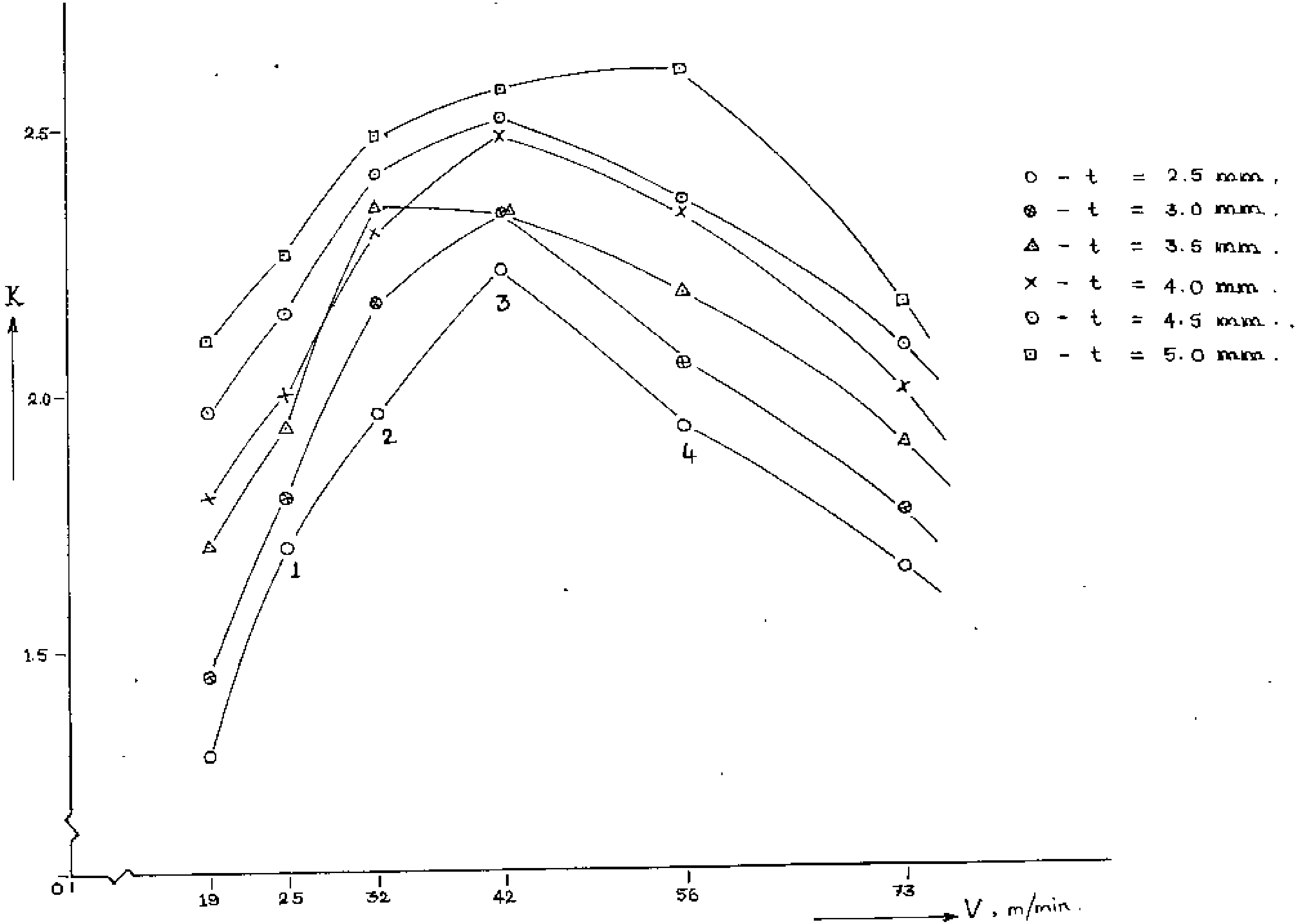


FIGURE - 11. Effect of cutting speed on chip - shrinkage at S = 0.40 mm/rev. (From experimental data).

V = 42 m/min, t = 2.5 mm., S = 2.0 mm/rev.

V= 56 m/min, t = 2.5 mm., S = 2.0 mm/rev.

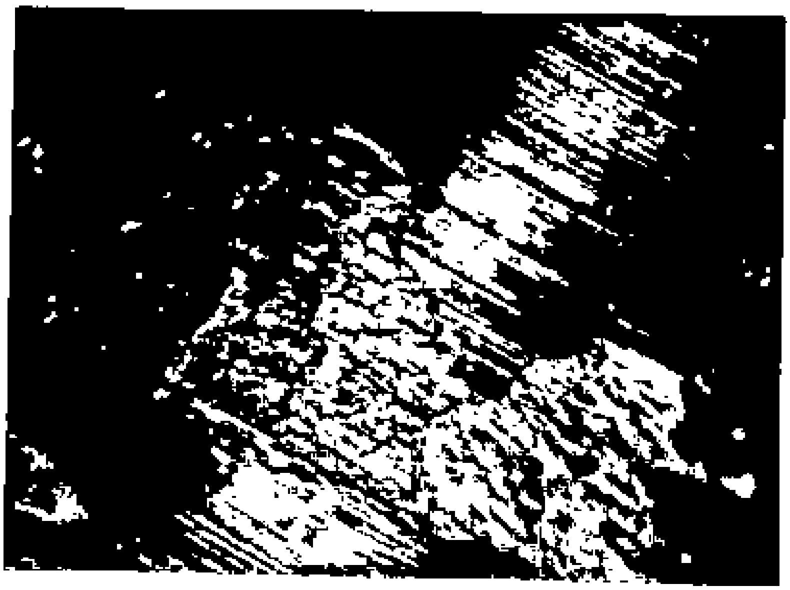
Fig. 12: Photomicrographs of chip at S = 0.20 mm/rev., t = 2.5 mm. magnification = 100.

V = 73 m/min, t = 2.5 mm., S = 0.20 mm/rev.

V = 94 m/min, t = 2.5 mm., S = 0.20 mm/rev.

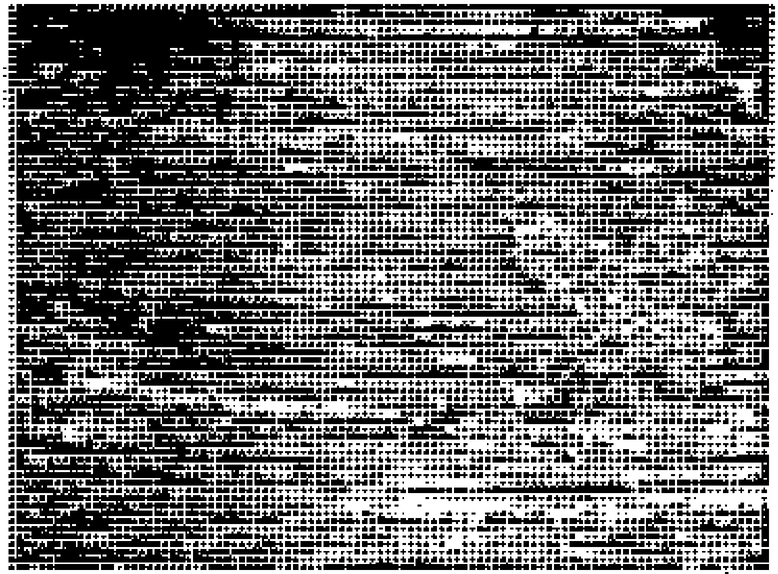
Fig. 12: Photomicrographs of chip at S = 0.20 mm/rev., t = 2.5 mm., Magnification = 100

V = 32 m/min, t = 5.0 mm., S = 0.20 mm/rev.



V = 42 m/min, t = 5.0 mm., S = 0.20 mm/rev.

Fig. 13: Photomicrographs of chip at S = 0.20 mm/rev., t = 5.0 mm. Magnification = 100



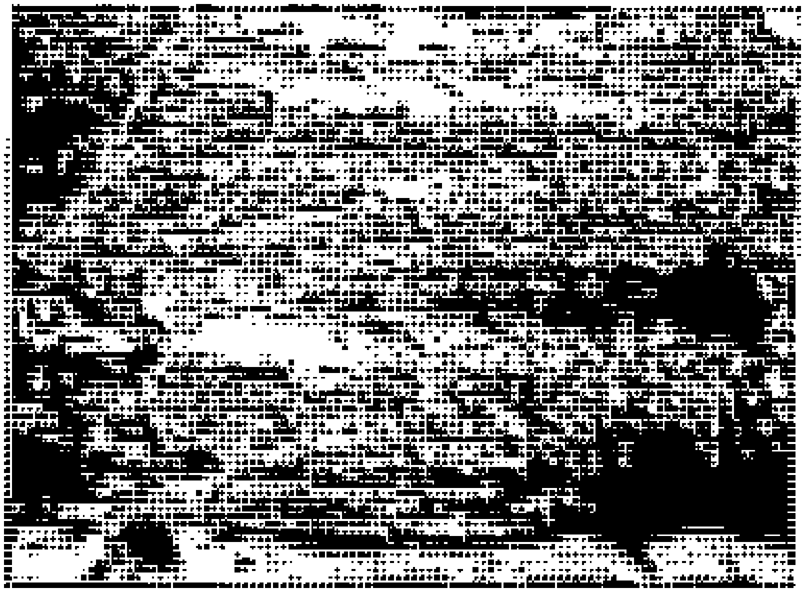
V = 56 m/min, t = 5.0 mm, S = 0.20 mm/rev.

V = 73 m/min, t = 5.0 mm., S = 0.20 mm/rev.

Fig. 13: Photomicrographs of chip at S = 0.20 mm/rev
t = 5.0 mm. Magnification = 100

marked on the curve (t = 5.0 mm, S = 0.20 mm/rev) in Fig. 7, which were similar to the points 1, 2, 3 & 4 respectively, are shown in Fig. 13. It is observed from the photographs that at point 1, chip is discontinuous type and there are prominant fracture marks on chip. At point 2', chip-tool contact process is continuous type with traces of builtup edge; while at point 3' the chip is continuous with unstable builtup edge and traces of this type of builtup edge can be observed on the rake side of the chip as well as on the cutting surface. At point 4', continuous chip without builtup edge is observed.

Figure 14, shows the nature of chip and chip-tool contact process for the points 1, 2, 3 & 4 marked on the curve (t = 2.5 mm S = 0.25 mm/rev) in Fig. 8. From the photographs it is found that at point 1, chip is discontinuous type and there are prominant fracture marks on chip. At point 2, chip-tool contact process is continuous type with traces of built up edge; whi;e at point 3, the chip is continuous with unstable builtup edge and traces of this type of builtup edge can be observed on the rake side of chip as well as on the cutting surface. At point 4, continuous



V = 32 m/min, t = 2.5mm., S = 0.25 mm/rev.

V = 42 m/min, t = 2.5 mm., S = 0.25 mm/rev.

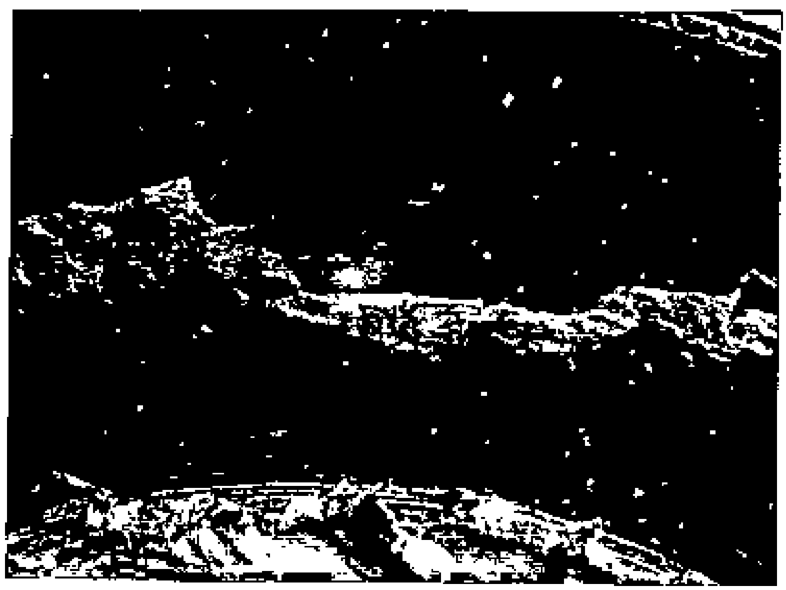
Figure 14: Photomicrographs of chip at S = 0.25 mm/rev. t = 2.5 mm. Magnification = 100

V = 56 m/min, t = 2.5 mm, S = 0.25 mm/rev.

V = 73 m/min, t = 2.5 mm, S = 0.25 mm/rev.

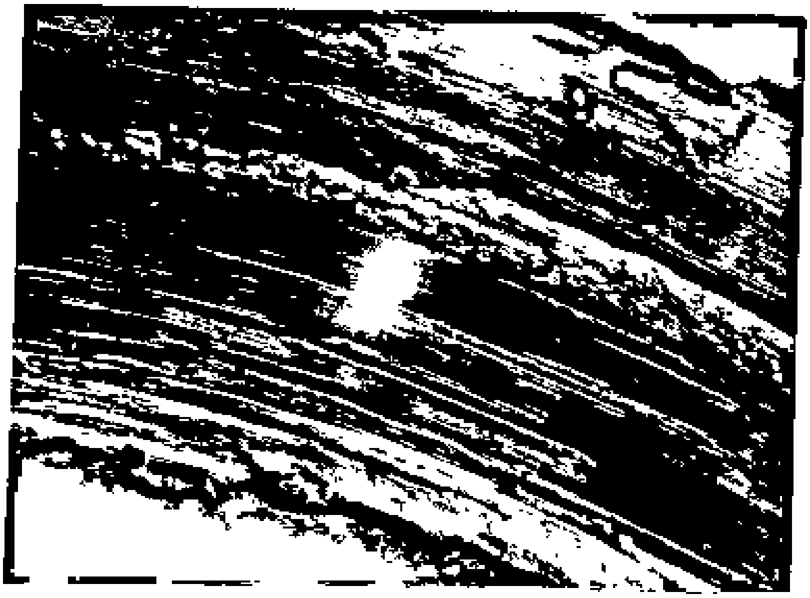
Figure 14: Photographs of chip at S = 0.25 mm/rev.
t = 2.5 mm. Magnification = 100

V = 32 m/min, t = 2.5 mm, S = 0.30 mm/rev.

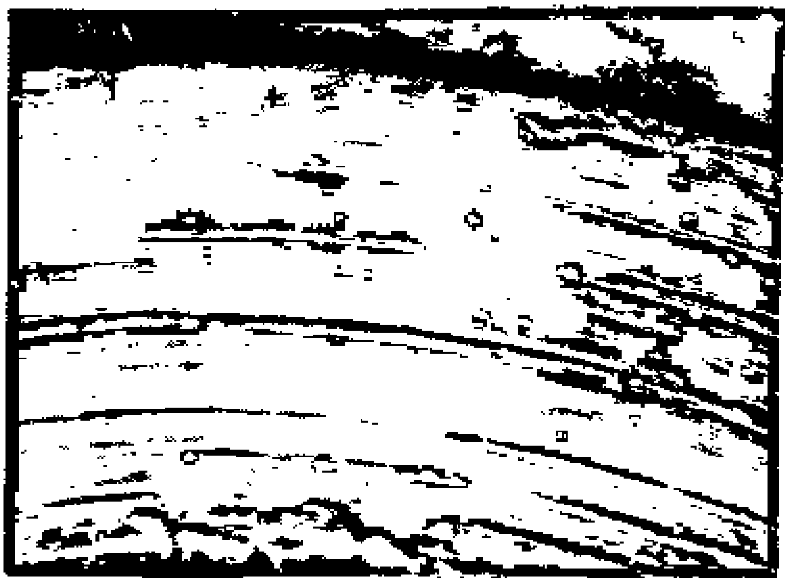


V = 42 m/min, t = 2.5 mm, S = 0.30 mm/rev.

Figure 15: Photomicrographs of chip at S = 0.30 mm/rev. t = 2.5 mm. Magnification = 100



V = 56 m/min, t = 2.5mm, S = 0.30 mm/rev.



V = 73 m/min, t = 2.5 mm, S = 0.30 mm/rev.

Figure 15: Photomicrographs of chip at S = 0.30 mm/rev. t = 2.5 mm. Magnification = 100

chip without built-up edge is found. For similar nature of all curves in Fig. 8, the chip-tool contact process and chip-type will behave similarly for similar point on any curve as shown in Fig. 14.

Photographs of Fig. 15, for the points 1, 2, 3 & 4 respectively marked on the curve (t = 2.5 mm, S = 0.30 mm/rev.) in Fig. 9, show that at point 1, chip is discontinuous type and there are prominant fracture marks on chip. At point 2, chip tool contact process is continuous type with traces of built-up edge; while at point 3, the chip is continuous with unstable built-up edge and traces of this type of built-up edge can be observed on the rake side of chip as well as on the cutting surface. At point 4, chip is continuous without built-up edge. Due to similar nature of all curves in Fig. 9, the behaviour of the similar points on each curve will be same as shown in Fig. 15.

Photographs of Fig. 16 represent the point 1, 2, 3, 4 respectively marked on the curve (t = 2.5 mm, S = 0.35 mm/rev.) in Fig. 10. It is observed that at point 1, chip is discontinuous type and there are prominant fracture marks on chip. At point 2, chip-tool contact process is continuous type with traces of

V = 32 m/min, t = 2.5mm, S = 0.35 mm/rev.

V = 42 m/min, t = 2.5 mm., S = 0.35 mm/rev.

Fig. 16: Photomicrographs of chip at S = 0.35 mm/rev. t = 2.5 mm. Magnification = 100

V = 56 m/min, t = 2.5 mm, S = 0.35 mm/rev.

V = 73 m/min, t = 2.5 mm, S = 0.35 mm/rev.

Fig. 16: Photomicrographs of chip at S = 0.35 mm/rev. t = 2.5 mm. Magnification = 100

built-up edge; while at point 3, the chip is continuous with unstable built-up edge and traces of this type of built-up edge can be observed on the rake face of the chip as well as on the cutting surface. At point 4, chip is continuous without any built-up edge. The similar points on the all other curves, as similar in shape, in Fig. 10 will behave similarly like that of photographs in Fig. 16.

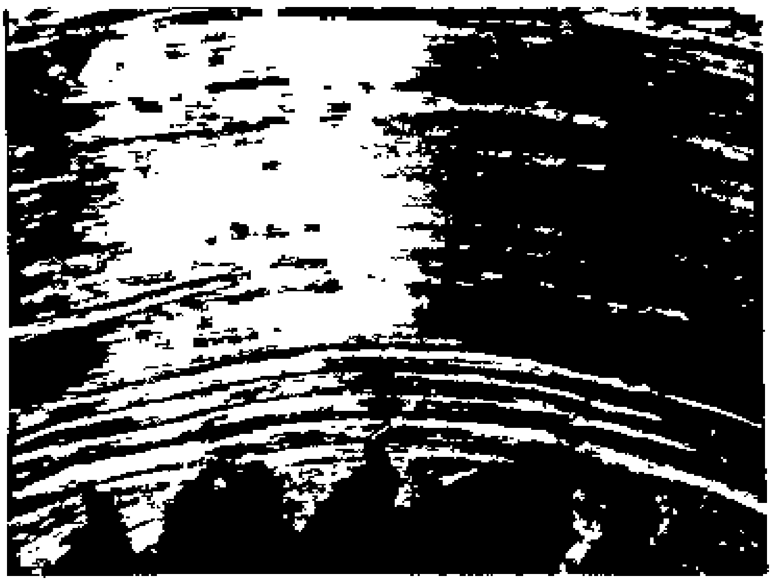
Photographs of Fig. 17, show the nature of chip and chip-tool contact process for the points 1, 2, 3, 4 respectively marked on the curve (t = 2.5 mm, S).40 mm/rev.) in Fig. 11. From the photographs, it is observed that at point 1, chip is discontinuous type and there are prominant fracture marks on the chip. At point 2, chip-tool contact process is continuous type with traces of built-up edge; while at point 3, the chip is continuous with unstable built-up edge and traces of this type of built-up edge can be observed on the rake side of chip as well as on the cutting surface. At point 4, chip is continuous without built-up edge. Since the shape of all curves in Fig. 11 are similar in nature, the similar point on any other curve will behave similarly as observed in Fig. 17.

V = 25 m/min, t = 2.5 mm, S = 0.40 mm/rev.

V = 32 m/min, t = 2.5 mm, S = 0.40 mm/rev.

Fig. 17: Photomicrographs of chip at S = 0.40 mm/rev. t = 2.5 mm. Magnification = 100

V = 42 m/min, t = 2.5 mm, S = 0.40 mm/rev.



V = 56 m/min, t = 2.5 mm, S = 0.40 mm/rev.

Figure 17: Photomicrographs of chip at S = 0.40 mm/rev. t = 2.5 mm. Magnification = 100

2.7 Experimental Results

From the above figures and conclusions, it is justified to say that the critical cutting speed, V_c must lie somewhere in between the two points 2 and 4 or in between two similar points on the other curves. The critical cutting speed, V_c is considered to the cutting speed at which few traces of unstable built-up edge appear on or just disappear from the rake side of the chip, as it protects the tool from excessive wear. So, after investigating and comparing carefully the rake face of chip-formed at the three points 2, 3 and 4 on each curve, the critical cutting speed, V_c was determined for each cutting condition, which is shown in Table 1. It is found that some values of V_c are mentioned by range, not by a particular value. The actual value of V_c lies somewhere within the above mentioned range, because of the fact that the speed of the given machine-tool could be varied infinitely during the operation.

In the next chapter it will be shown that tool life has certain relationship with the shape of the curve $K = f(V)$. It will be also shown that knowing the shape of the above mentioned curve it is possible to predict at which particular cutting speed or its range, the value of tool wear will be minimum.

Table - 1

Values of critical cutting speeds for different cutting conditions

Feed S, mm/rev.	Depth of cut t, mm	Critical cutting speed, V_c mm/min	Corresponding spindle Speed N, r.p.m.
	2.5	73	316
	3.0	56	242
	3.5	56	242
0.20	4.0	42 - 56	182 - 242
	4.5	42 - 56	182 - 242
	5.0	42 - 56	182 - 242
	2.5	56	242
	3.0	42 - 56	182 - 242
0.25	3.5	32 - 42	141 - 182
	4.0	32 - 42	141 - 181
	4.5	32 - 42	141 - 182
	5.0	42	182
	2.5	56	242
	3.0	32	141
0.30	3.5	32 - 42	141 - 182
	4.0	32 - 42	141 - 182
	4.5	32 - 42	141 - 182
	5.0	32 - 42	141 - 182
	2.5	56	242
	3.0	32 - 42	141 - 182
0.35	3.5	32	141
	4.0	32	141
	4.5	32	141
	5.0	32	141
	2.5	42	182
	3.0	32 - 42	141 - 182
	3.5	25	109
0.40	4.0	25 - 32	109 - 141
	4.5	25 - 32	109 - 141
	5.0	32 - 42	141 - 182

CHAPTER - 3

DETERMINATION OF OPTIMUM CUTTING CONDITION WITH RESPECT TO TOOL LIFE AND ITS RELATION WITH CRITICAL CUTTING SPEED

3.1 Theory

The most important mechanical factor influencing machining costs, is normally tool-life. But it has several interpretations. It can either be the useful life of a cutting tool expressed in minutes between grinds or the total time which a tool can withstand before complete destruction. For cemented Carbides, tool-life is frequently designated as the time to produce a specified amount of flank-wear, e.g. 0.80 mm. While tool-life expressed in time alone may have merit in computing machining cost, it may not be a fair index of a tool's effectiveness to remove metal by chip formation, since the cuts can be deep or shallow, the feeds heavy or light, and the speeds fast or slow. Kronenberg[10], in his study concluded that only the volume of metal removed from the workpiece can definitely be coordinated with tool-wear. Hence, in grest majority of the tests, tool-life is expressed in terms of the volume of metal removed.

The tool-life enters machining costs in three ways:

i) in down time for tool changing

ii) in labour and overhead involved in tool regrinding and repair, and

iii) in replacement of wornout tool.

Thus any means of improving tool-life results in a lower cost per piece and a higher production rate. In order to form a basis for such improvement much effort has been made to understand the nature of tool wear and other forms of tool failure. The life of a cutting tool can be brought to an end in various ways, but these ways may be seperated into two main groups:

i) The gradual or progressive wearing away of certain regions of the face (crater wear) and flank (flank wear) of the tool

ii) Failures brinding the life of tool to a premature end.

Before the advent of Carbide tool, it was considerably easier to determine tool-life because the failure of the tool could readily be seen from the appearance of a burnished ring on the workpiece when the tool was dull. But the burnished ring usually cannot be observed on the work piece when machined with carbide tools. So it is a bit troublesome to determine the life of cemented carbide tool. In practical machining operations, the wear of the face and flank of the cutting tool is not uniform along the active cutting edge and hence measurement of wear is also difficult. It is proved(7) that the wear of the carbide tool progresses at the tool flank and the width of the wear-land at the flank is usually taken as a measure of the amount of wear and can be determiued by means of a Metallugrical Microscope. Figures 18 & 19, show the typical wear at the tool flank[10].

From previous experimental results[11], it is true that, under all circumstances the wear at the tool flank is the sole gage in prescribing the useful life of a carbide tool. It is also true[7] that when tools are used under economical conditions, the flank wear is usually the controlling factors.

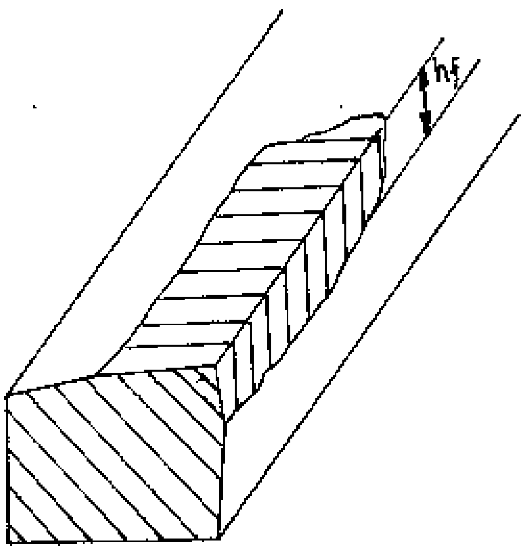


Figure 18: Wear land on the tool flank, h_f.

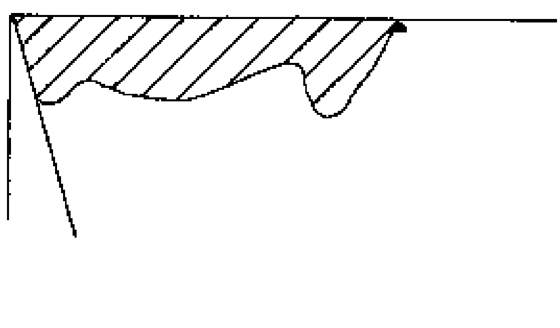


Figure 19: Erratic width of wear land.

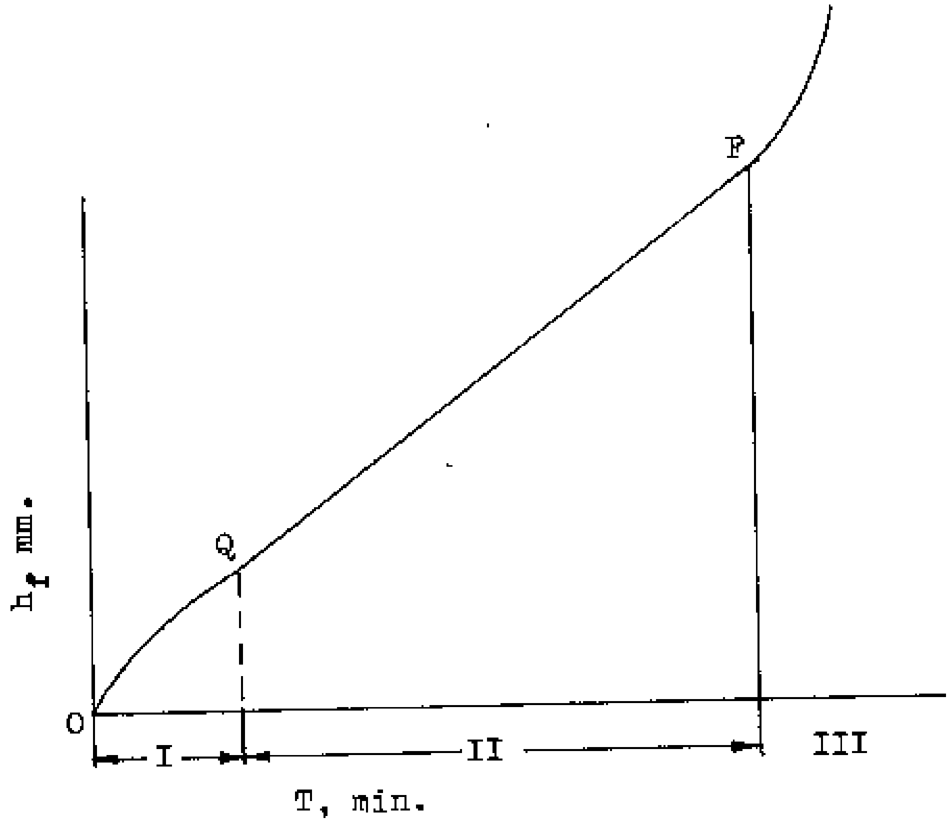


Figure 20: Growth of wear land with respect to time at a constant cutting speed and for a given pair of work and tool material (Theoretical)

Figure 20 shows the growth of flank wear with respect to time[13].

The characteristic features of this figure are:

i) the zone I, upto point Q, denotes the zone of initial "break-in" which repidly breaks down.

ii) the zone II, QF, is the mechanical wear region.

iii) the zone III, beyond F, the rapid growth of wear process and tool fails very soon. Point F is known as critical flank wear. This point shifts with increase or decrease of cutting speed.

3.2 Experimental Setup

There are several methods of tool-life testing, such as Radio-active method and Conventional method[12]. In radio-active method, radio-active tool is used in operation and the wear particles that travel with chip or the cutting fluid are counted with "Geiger - Counter". On the other hand, the conventional one consists of machining with a cutting tool, either until complete failure occurs or to a predetermined amount of wear, as measured with a Metallurgical microscope.

Conventional method, for its simplicity, was applied here which consists of machining with carbide tool to a predetermined length (time of cut) and the flank-wear, h_f was measured with a Metallurgical Microscope. Test-experiment was not based on tool failure rather on the rate of tool-wear, so that wear can be determined by measurements after short period of time (i.e. small amount of metal removal).

Cutting tests were carried out on the same machine-tool, as was used for previous series of experiments using same tool-geometry. The rate of wear of carbide tool, when machining under normal conditions, is so slow that measurement required a long period of time of the same order of magnitude as the life of tool. But due to limitation of cutting material (stock of solid bar) and to get the mechanical wear region of Fig. 20 (i.e. the straight-lined portion of the theoretical curve), a predetermined flank-wear, h_{f_o} had been deliberately and accurately imposed on the tool-flank before starting the cutting operation. This was done during grinding operation of the tool.

3.3 Experimental Details

The solid bar of the material, dimensions as mentioned earlier was cut at different speeds, N = 182, 242, 316 & 410 rpm. with feed, S = 0.20 mm/rev, and depth of cut, t = 2.5 mm. This experiment was started with the lower value of feed, as because it is known that feed has greater influence on tool-life. It is shown in Fig. 5, that at Pulsation contact process (zone C), tool wear is minimum i.e. maximum tool life and at contact process of type-B, tool wear is maximum i.e. minimum tool life. It is also observed from Fig. 5 that at contact process without built up edge tool life decreases continuously with increase of cutting speed. So, for maximum tool life, cutting speed must be in the range of pulsation contact process zone. This speed can only be determined by measuring and comparing the tool wear at different speeds close to that contact zone (zone C). So, to determine that speed by comparing the tool-wear, the speed ranges were so selected during the experiment that they were below and above the critical cutting speed, V_c as determined in chapter-2. Cutting tests were interupted at regular intervals (after cutting a predetermined length) and the flank wear, h_f was measured after each

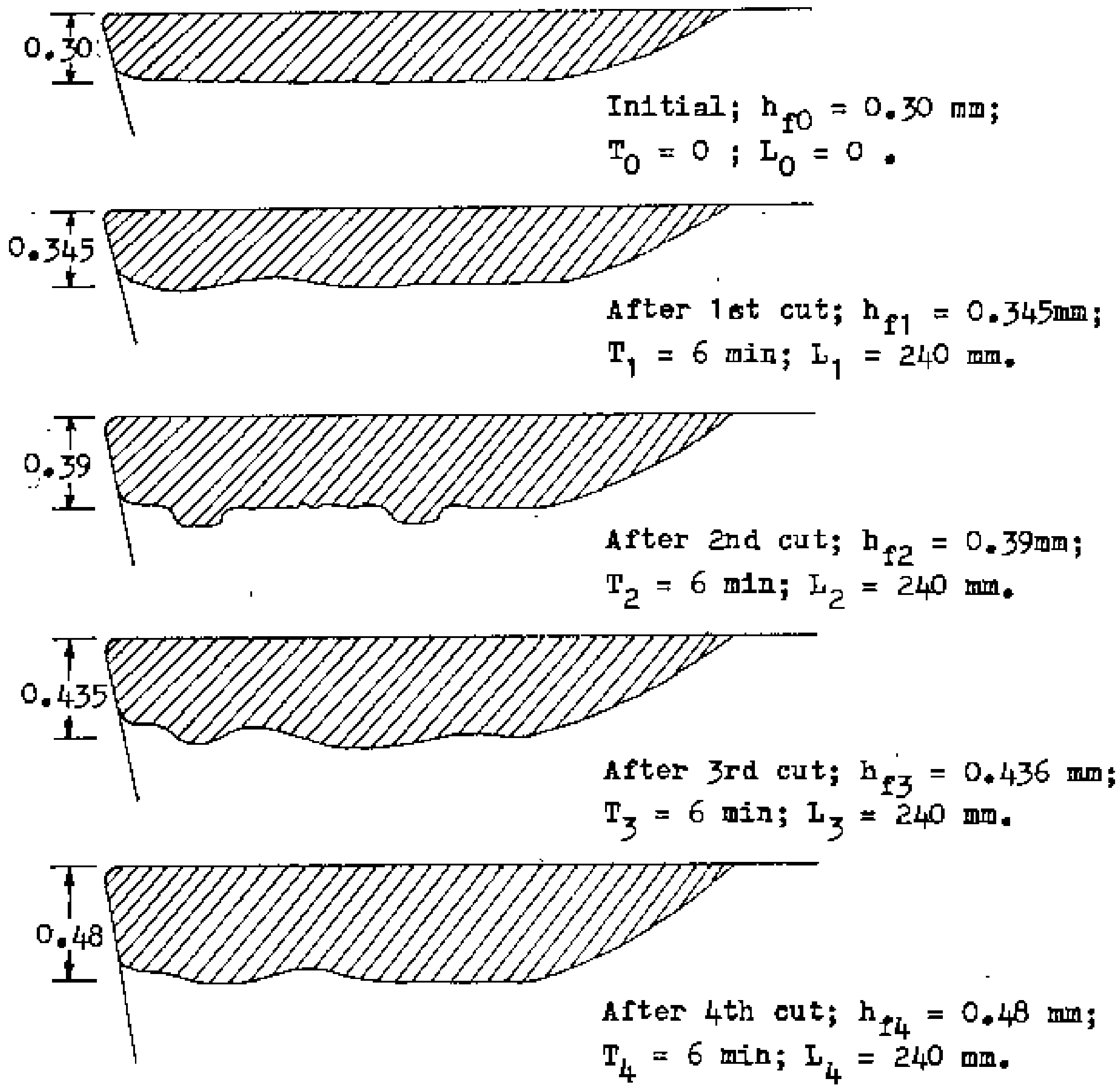
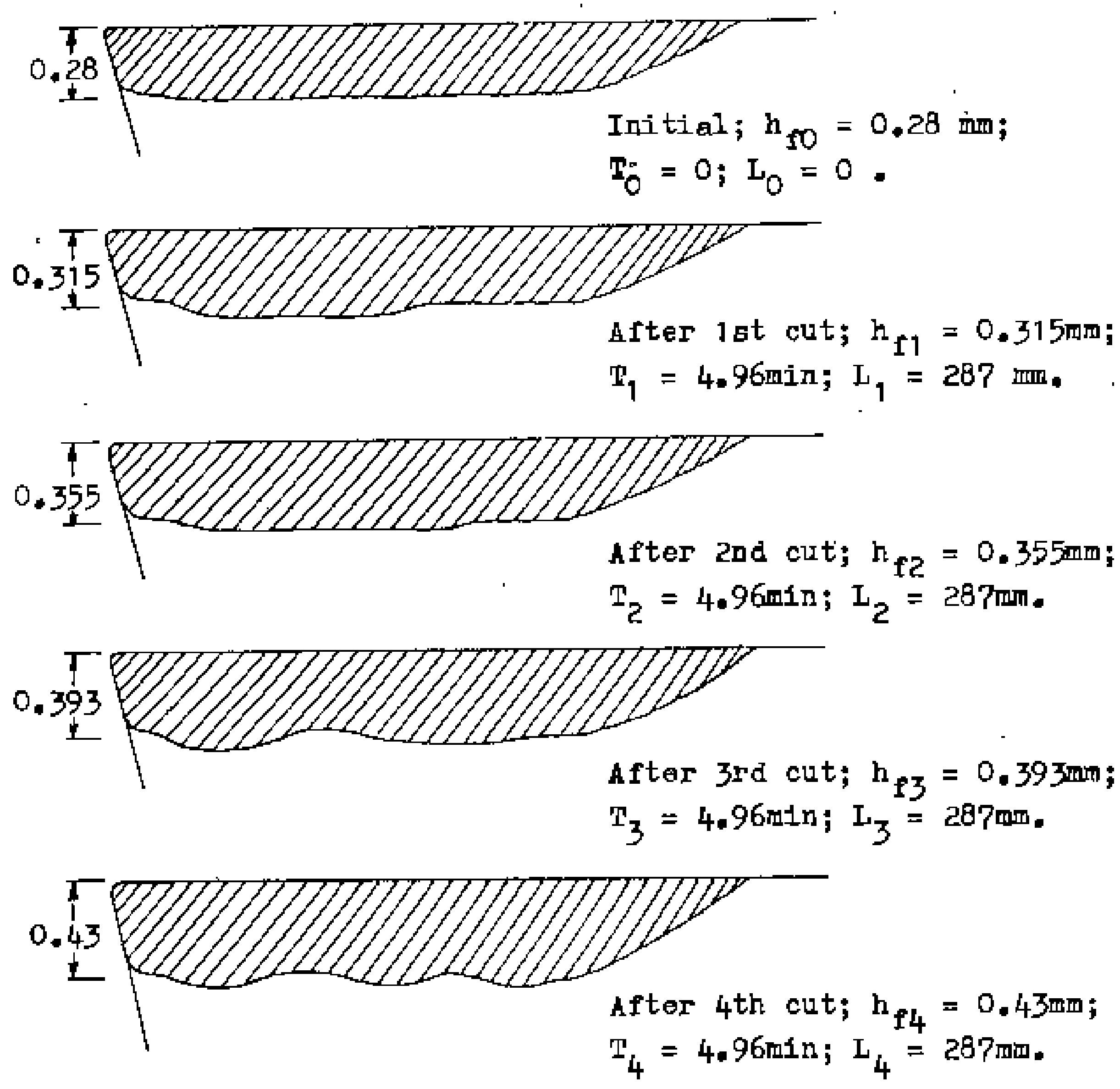


FIGURE - 21. Typical view of flank wear land (cumulative)

N = 182 r.p.m., S = 0.20mm/rev., t = 2.5mm.

(Experimental).



<u>FIGURE - 22.</u> Typical view of flank wear land (cumulative)

$N = 242$ r.p.m., $S = 0.20$mm/rev., $t = 2.5$mm.

(Experimental).

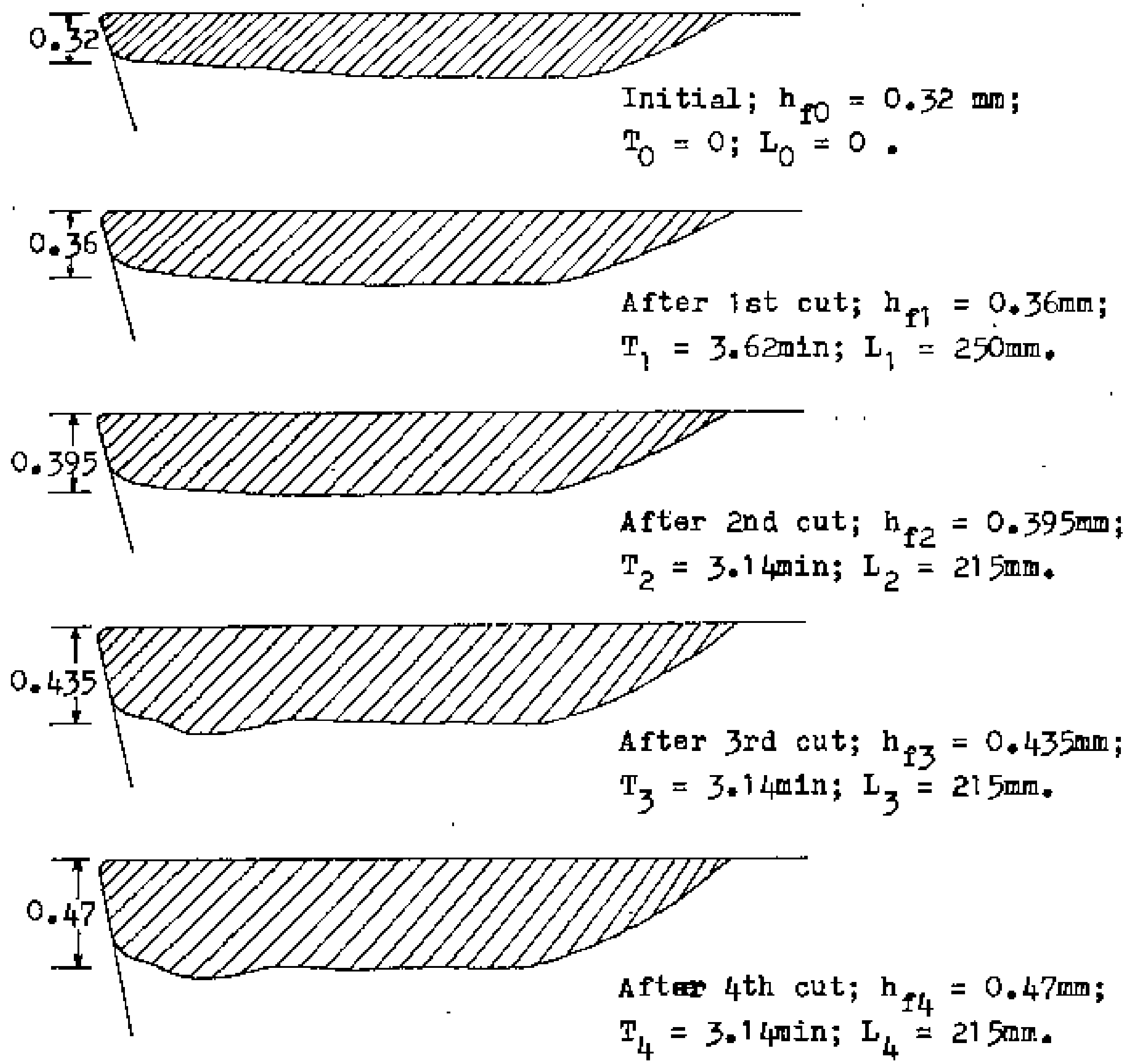
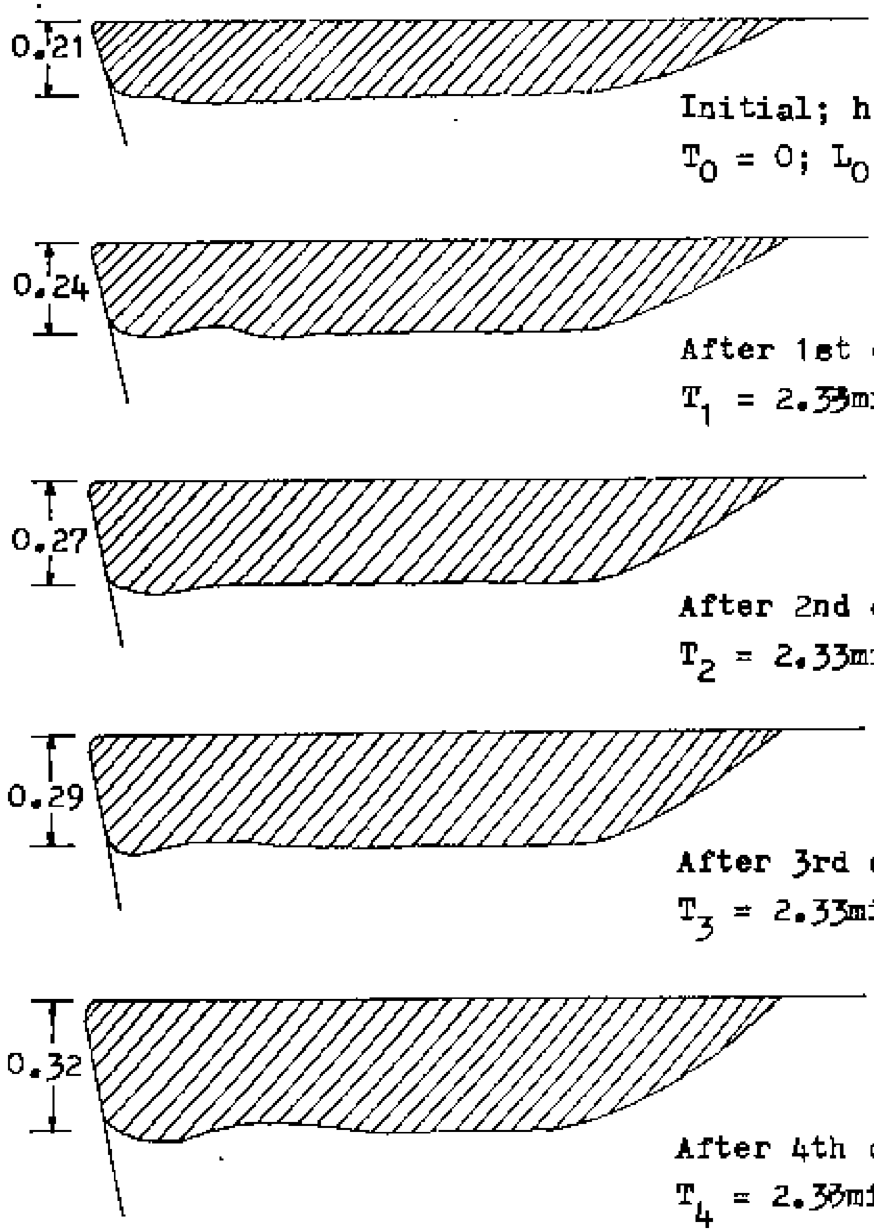


FIGURE - 23. Typical view of flank wear land (cumulative)

N = 316 r.p.m., S = 0.20mm/rev., t = 2.5mm.

(Experimental).



Initial; h_{f0} = 0.21 mm;
T_0 = 0; L_0 = 0 .

After 1st cut; h_{f1} = 0.24mm;
T_1 = 2.33min; L_1 = 200mm.

After 2nd cut; h_{f2} = 0.27mm;
T_2 = 2.33min; L_2 = 200mm.

After 3rd cut; h_{f3} = 0.29mm;
T_3 = 2.33min; L_3 = 200mm.

After 4th cut; h_{f4} = 0.32mm;
T_4 = 2.33min; L_4 = 200mm.

FIGURE - 24. Typical view of flank wear land (cumulative)

N = 410 r.p.m., S = 0.20mm/rev., t = 2.5mm.

(Experimental).

interval using a Mettalurgical Microscope (model no. ZEISS 35196, CARL, Germany with 50 times magnification). For every cutting speed, there were four interruptions and consequently four values of h_f. Since the wear-land is not of uniform-width but rather erratic, as in Fig. 19, the average width of wear land was taken. The flank wear-land before and after operation at different speeds are sketched in Figures 21, 22, 23, 24 respectively. With the experimental data curves $h_f = f(T)$ were plotted on Fig. 25.

To compare the tool wear for different speeds, (N = 182, [illegible] 242, 316 & 410 r.p.m.) at same feed and depth of cut, (S = 0.20 mm/rev. & t = 2.5 mm), total metal removal during cutting operation for each speed was determined and finally intensity of wear was calculated as shown in Table – 2. From these experimental and calculated values different curves were plotted as shown in figures listed below:

i) $h_f = f(Z_w)$ (flank wear versue metal removal rate) in Fig. 26

ii) $h_f = f(L)$ (flank wear versue total length of cut) in Fig. 27

iii) $= f(V)$ (intensity of wear versue cutting speed) in Fig. 28

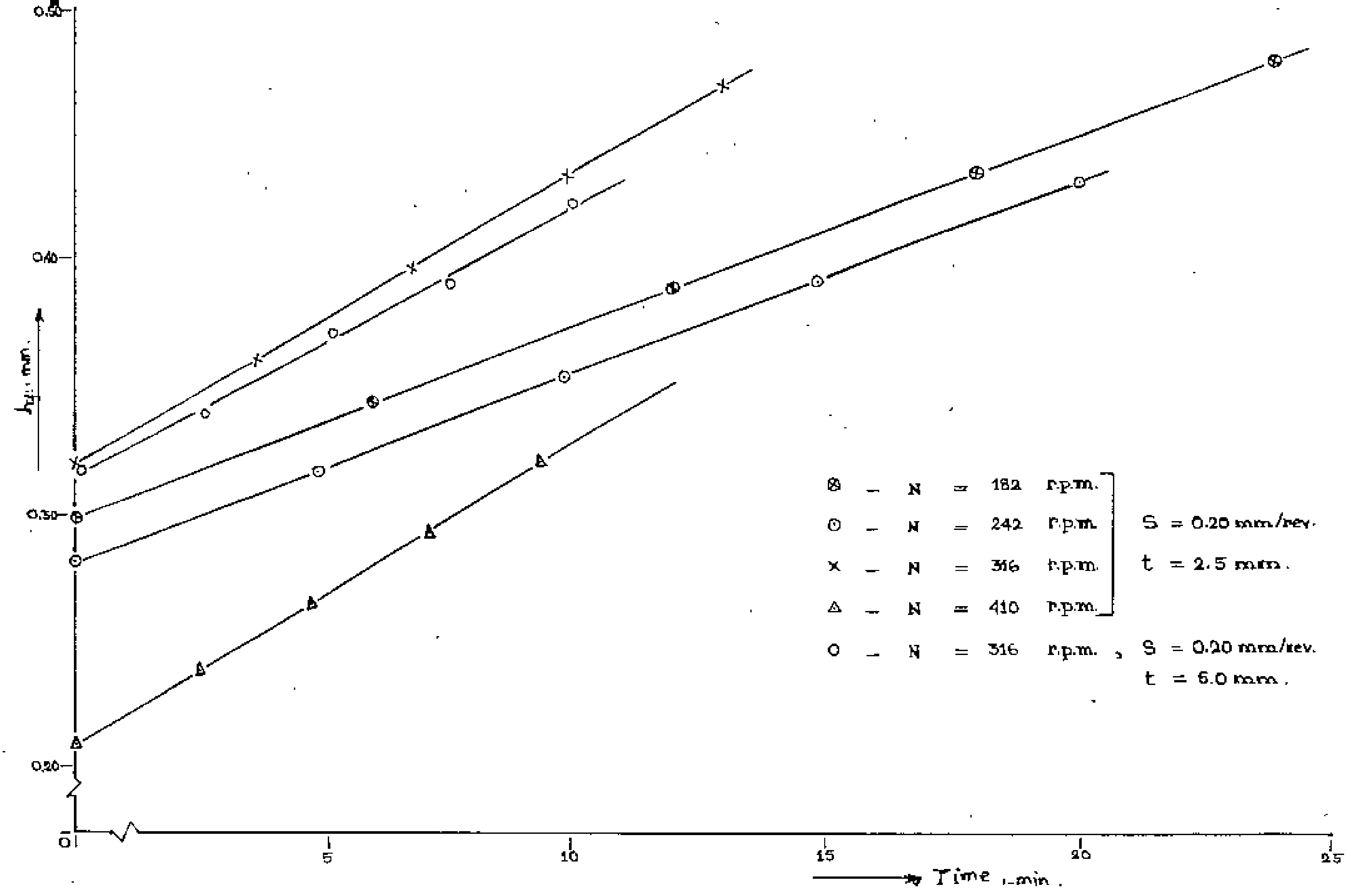


FIGURE - 25. Effect of cutting time on flank - wear (From experimental data) .

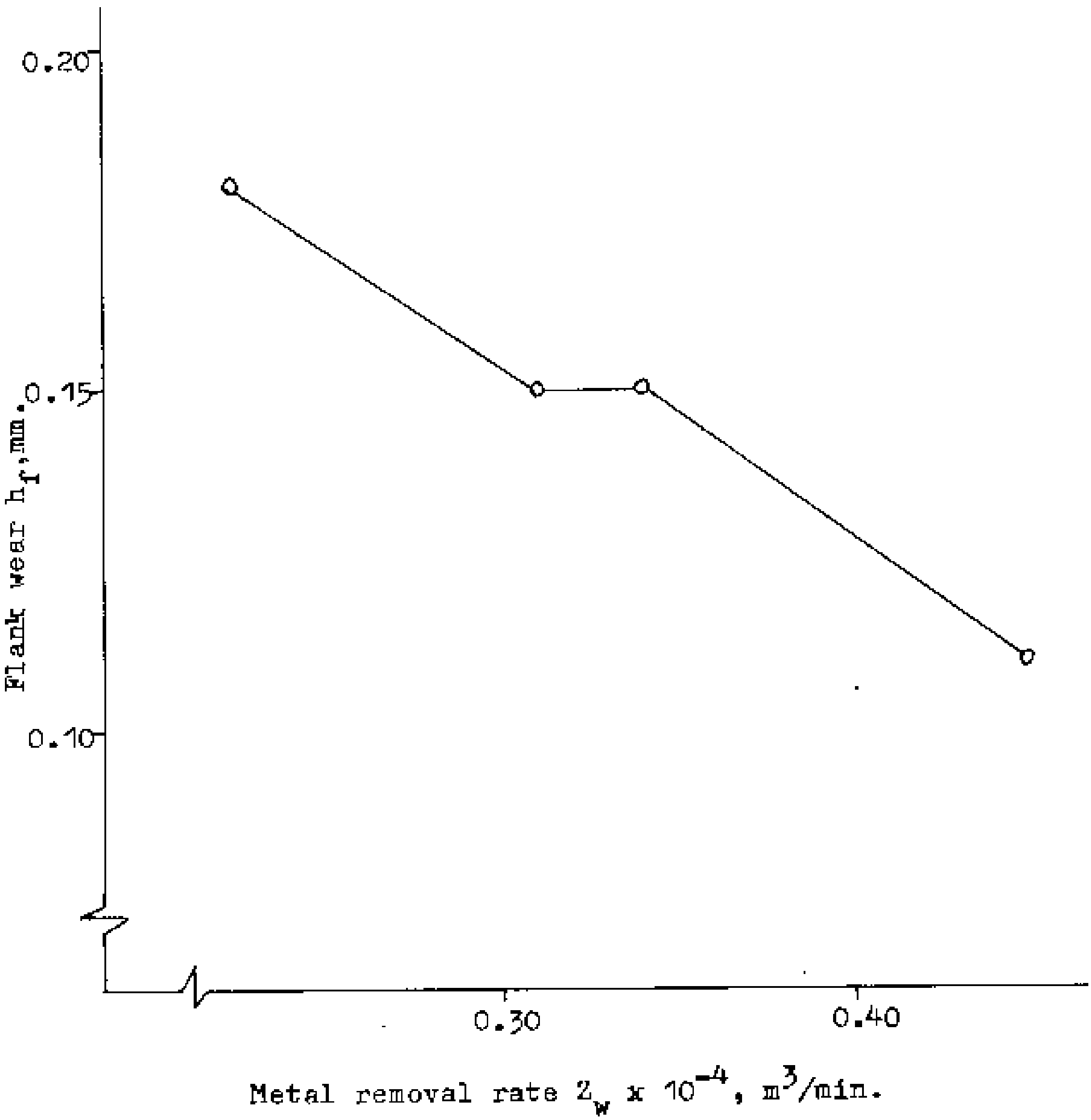


Figure 26: Effect of metal removal rate Z_w = v.s.t. on flank wear. (Evaluated from test data given in table-2, S = 0.20 mm/rev.,t=2.5 mm)

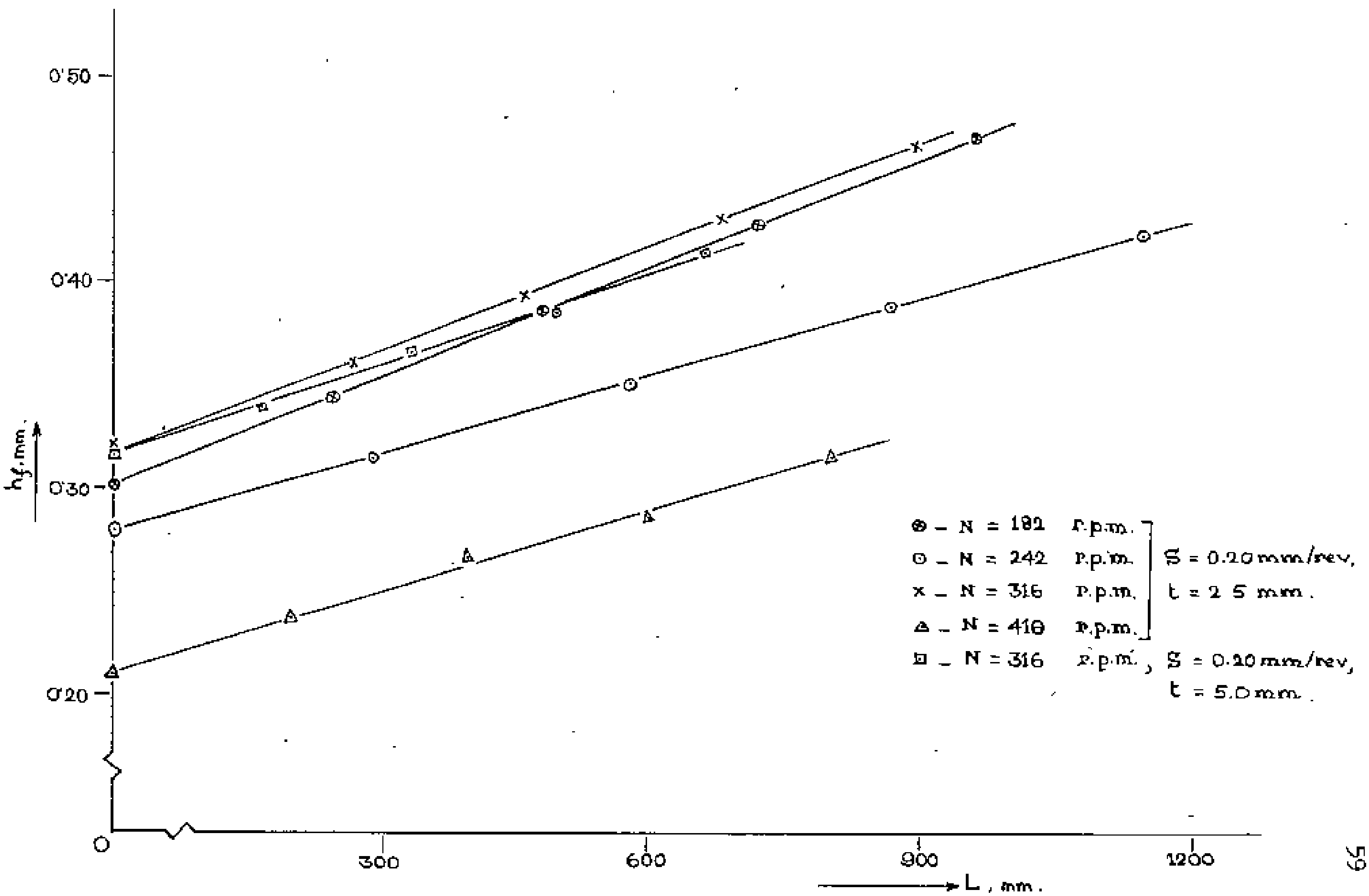


FIGURE - 27. Effect of length of cut on flank - wear (Evaluated from test data).

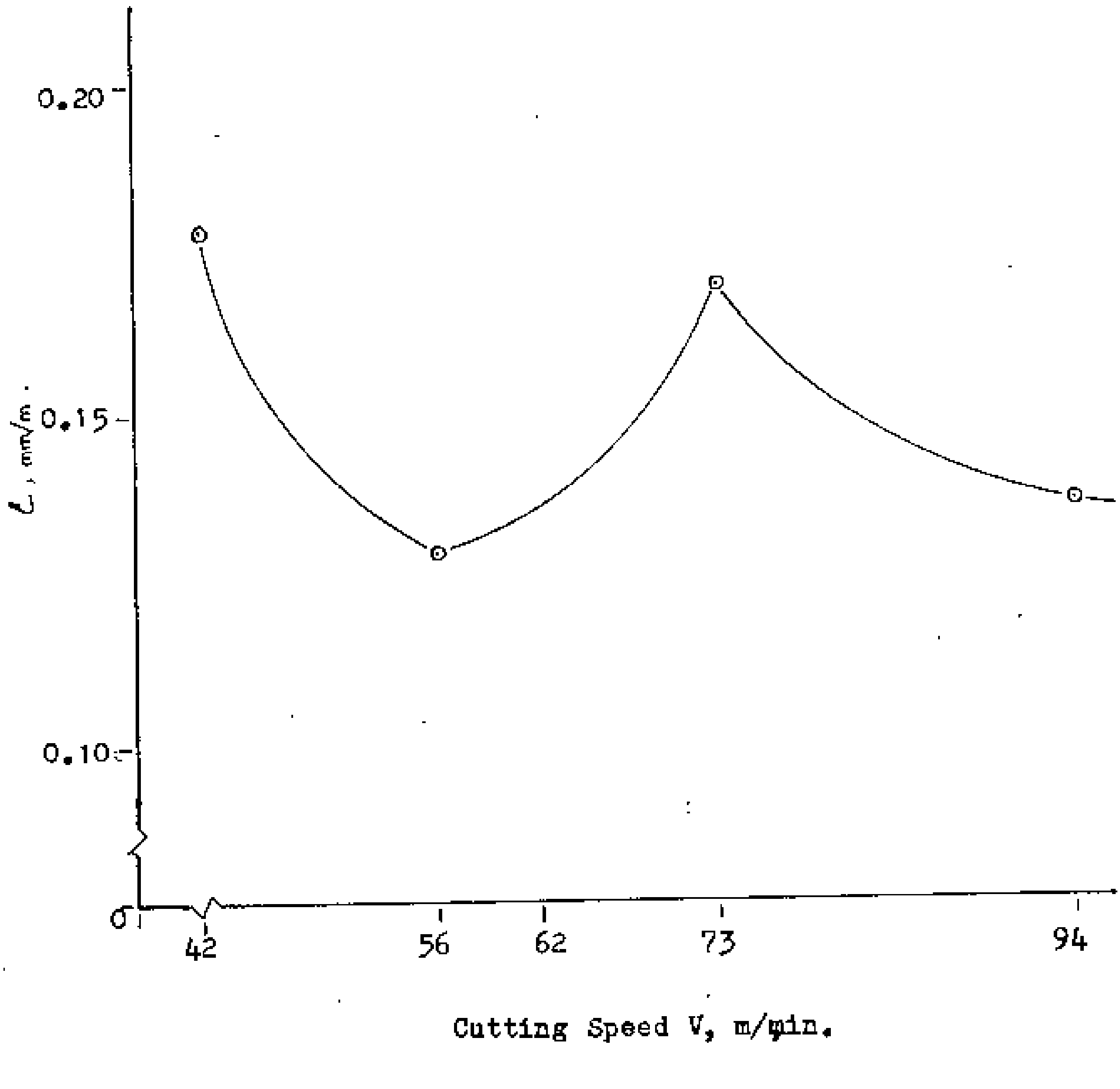


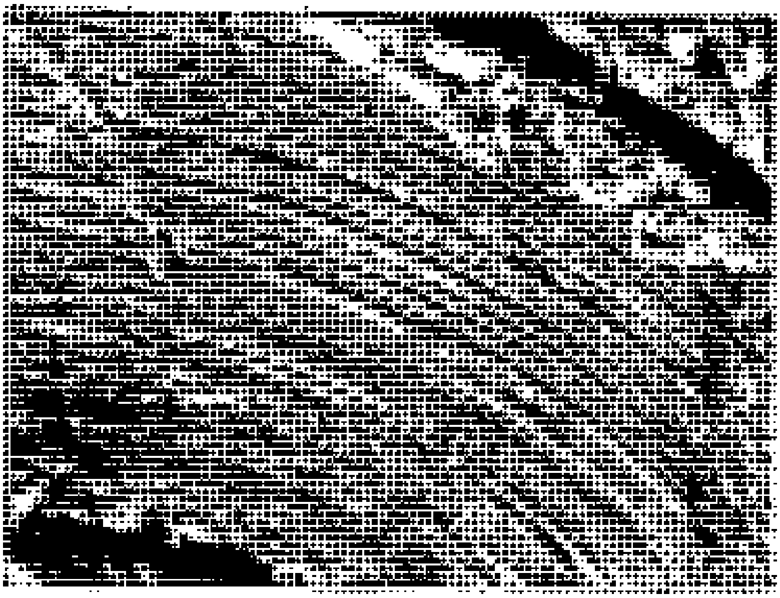
FIGURE - 28 Effect of Cutting Speed on Intensity of wear at S = 0.20 mm/rev., t = 2.5 mm.

(Evaluated from test data)

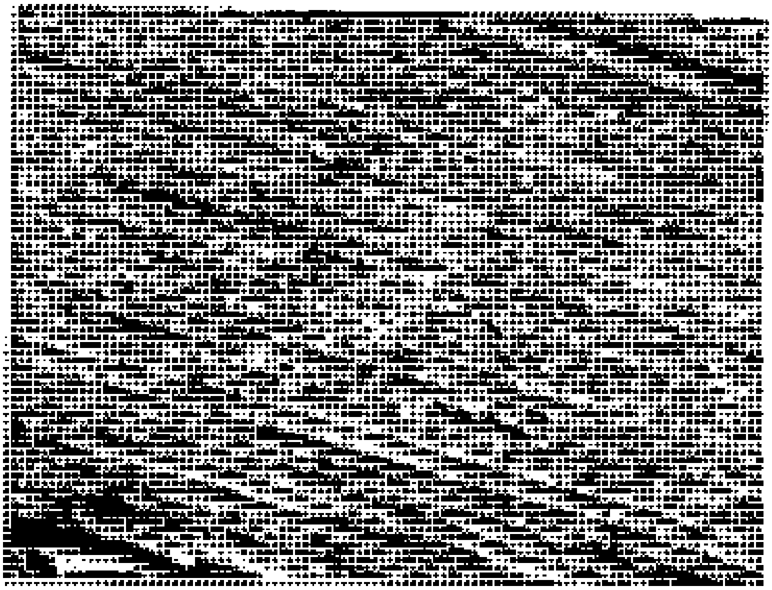
Figure 28 shows that wear intensity increases to a maximum value with increasing cutting speed, followed by a decrease with further increase in the cutting speed, the relation reverses again upon further increase in speed to another maximum value where upon wear intensity drops with increase in cutting speed. Photomicrographs of the chip at cutting speeds

N = 182, 242, 316 & 410 r.p.m. are shown in Fig. 29.

After carefully studying the above sigures and the values of Table-2, it was found that at N = 242 & 410 r.p.m. wear intensity per unit length is more or less equal. This indicates that there are two similar zones of minimum wear intensity at two different cutting speeds - one is before the critical cutting speed, V_c and other is after V_c. This condition occurs only for double carbide tool material. But for single carbide tool material, there must be one such zone before V_c. During the metal cutting operation with double carbide tool at higher speed beyond V_c, a thin layer of work material welded on the tool face, becomes a part of tool and maximum temperature zone is shifted from the tool face to the upper portion of the welded layer over which the chip flow. This layer protects the tool face from wear and this type of chip-tool contact is called as "stagnant Contact Process". At higher cutting speed beyond this contact process,

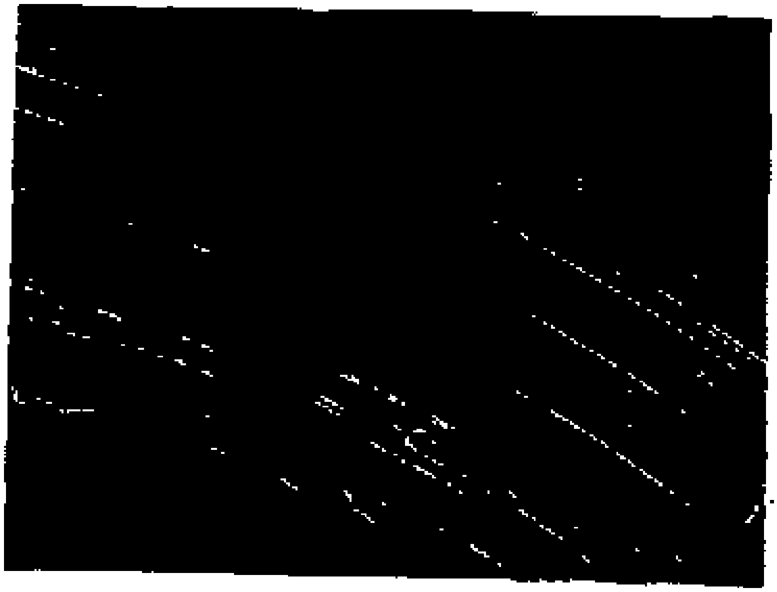


V = 42 m/min, t = 2.5 mm, S = 0.20 mm/rev.,

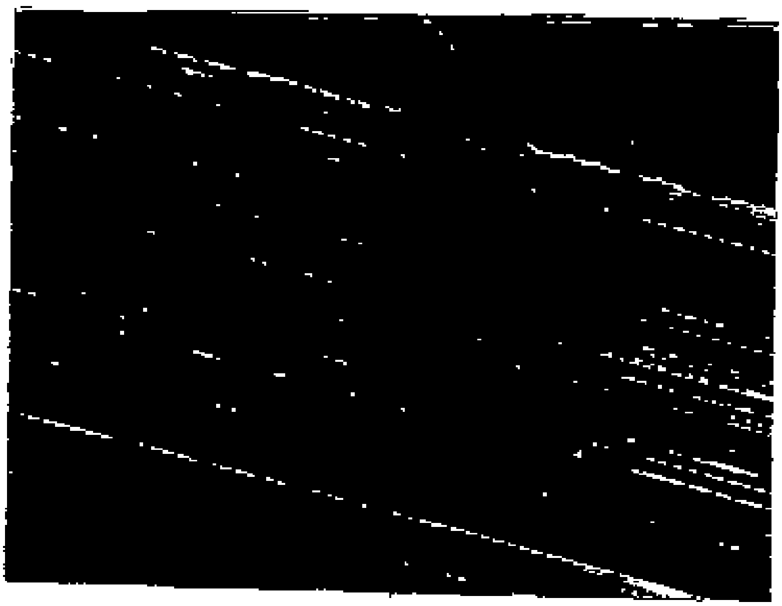


V = 56 m/min., t = 2.5., S = 0.20 mm/rev.

Figure 29: Photomicrographs of chip at S = 0.20 mm/rev.
t = 2.5 mm. (after continuous cut)
Magnification = 100



V = 73 m/min., t = 2.5 mm., S = 0.20 mm/rev.



V = 94 m/min., t = 2.5., S = 0.20 mm/rev.

Figure 29: Photomicrographs of chip at S = 0.20 mm/rev.
t = 2.5 mm (after continuous cut)
Magnification = 100

Table – 2

Test Results

Theoretical N (rpm)	Theoretical V (m/min)	Actual Measured value N (rpm)	Actual Measured value V (m/min)	Feed S (mm/rev)	Depth of cut t (mm)	Total time of cut T (min)	Total length of cut L (mm)	Initial flank wear h_{f_0} (mm)	Final flank wear h_{f_1} (mm)	Total flank wear $h_f = h_{f_1} - h_{f_0}$ (mm)	Total metal removal Z (m^3)	Metal removal rate Z_w (m^3/min)	Intensity of wear (mm/m)	Wear per unit of metal removal I (mm/m^3)
182	42	200	46	0.20	2.5	24	960	0.30	0.48	0.18	5.162×10^{-4}	0.22×10^{-4}	0.19	348.70
242	56	289	66	0.20	2.5	19.48	1148	0.28	0.43	0.15	6.121×10^{-4}	0.31×10^{-4}	0.13	245.10
316	73	342	73	0.20	2.5	13.04	895	0.32	0.47	0.15	4.414×10^{-4}	0.34×10^{-4}	0.17	339.80
410	94	434	94	0.20	2.5	9.26	800	0.21	0.32	0.11	4.126×10^{-4}	0.45×10^{-4}	0.1375	266.60
316	73	323	75	0.20	5.0	10.23	655	0.32	0.42	0.10	6.640×10^{-4}	0.65×10^{-4}	0.1526	150.60

the thin layer mentioned above vanished and result is vigorus wear of tool-face. So, the cutting speed, N = 410 r.p.m., lies in the stagnant contact zone. From the above observations it was argued that, on the basis of maximum tool life, there were two optimum values - one was N = 242 r.p.m. and other was N = 410 r.p.m. But from the experiment in chapter - 2, for this condition, the selected critical speed was, V_c = 73 m/min, & N = 316 r.p.m. The results of experiments are given below:

V_c = 75 m/min, N = 316 r.p.m.

V_{op_1} = 56 m/min, N = 242 r.p.m.

V_{op_2} = 94 m/min, N = 410 r.p.m.

The above results also justify the previous statement in chapter 1 that $V_{op_1} \leq V_c$ and $V_{op_2} > V_c$ for double carbide tool material. But considering the value of metal removal rate, Z_w, N = 410 r.p.m. is more advantageous than N = 242 r.p.m. And also with respect to quality of surface finish, it was experimentally proved that N = 410 r.p.m was the best of all other values (i.e. N = 182 , 242, 316 r.p.m.). Now combining the above three considerations together (tool life, metal removal rate, and surface finish), it was concluded that for this cutting condition i.e. S = 0.20 mm/rev. t= 2.5 mm, the optimum cutting speed is V_{op} = 94 m/min, & N = 410 r.p.m.

With this experimental results and decision, it may be also argued that the optimum cutting speed will be the next higher value of the V_c, determined from experiment in chapter 2, for every cutting condition. The optimum value for different cutting conditions are shown in Table-3 and the curves $V_{op} = f(t)$ and $V_{op} = f(s)$ were plotted in the figures 30 & 31 respectively. It is true to say that any change of the values of S, t & V will affect the magnitudes of h_f, Z_w, V_c, etc. throughout the experiment, but the general shape of all the curves, plotted for only one cutting condition and chip-tool contact process as shown in photomicrographs will not be affected. In this light of analysis, it may be also concluded that N = 316 rpm at S = 0.20 mm/rev., t = 5.0 mm will be the similar point to N = 410 rpm at S = 0.20 mm/rev., t = 2.5 mm. To know the exact value, tool-life testing was also done for this condition, N = 316 r.p.m. S = 0.20 mm/rev., t = 5.0 mm, and intensity of flank wear was calculated as shown in Table 2 and photomicrograph of chip is shown in Fig. 32 to compare the chip-tool contact process with that of at N = 410 r.p.m. S = 0.20 mm/rev., t = 2.5 mm. From this test, tool-wear land was sketched on Fig. 33 and curves $h_f = f(T)$ and $h_f = f(L)$ were also plotted in Figures 25 & 27 respectively. It was observed that, in this cutting condition metal removal rate is very high, wear intensity is low and surface finish is moderate.

Table - 3

Critical and Optimum values for different Cutting Conditions

Feed S,mm/rev	Depth of cut	Critical N rpm	Value V m/min	Optimum N rpm	Value V m/min
0.20	2.5	316	73	410	94
	3.0	242	56	316	73
	3.5	242	56	316	73
	4.0	182 - 242	42 - 56	316	73
	4.5	182 - 242	42 - 56	316	73
	5.0	182 - 242	42 - 56	316	73
0.25	2.5	242	56	316	73
	3.0	182 - 242	42 - 56	316	73
	3.5	141 - 182	32 - 42	242	56
	4.0	141 - 182	32 - 42	242	56
	4.5	141 - 182	32 - 42	242	56
	5.0	182	42	242	56
0.30	2.5	242	56	316	73
	3.0	141	32	182	42
	3.5	141 - 182	32 - 42	242	56
	4.0	141 - 182	32 - 42	242	56
	4.5	141 - 182	32 - 42	242	56
	5.0	141 - 182	32 - 42	242	56
0.35	2.5	242	56	316	73
	3.0	141 - 182	32 - 42	182	42
	3.5	141	32	182	42
	4.0	141	32	182	42
	4.5	141	32	182	42
	5.0	141	32	182	42
0.40	2.5	141 - 182	32 - 42	242	56
	3.0	141	32	182	42
	3.5	109 - 141	25 - 32	141	32
	4.0	109 - 141	25 - 32	182	42
	4.5	109 - 141	25 - 32	182	42
	5.0	141 - 182	32 - 42	182	42

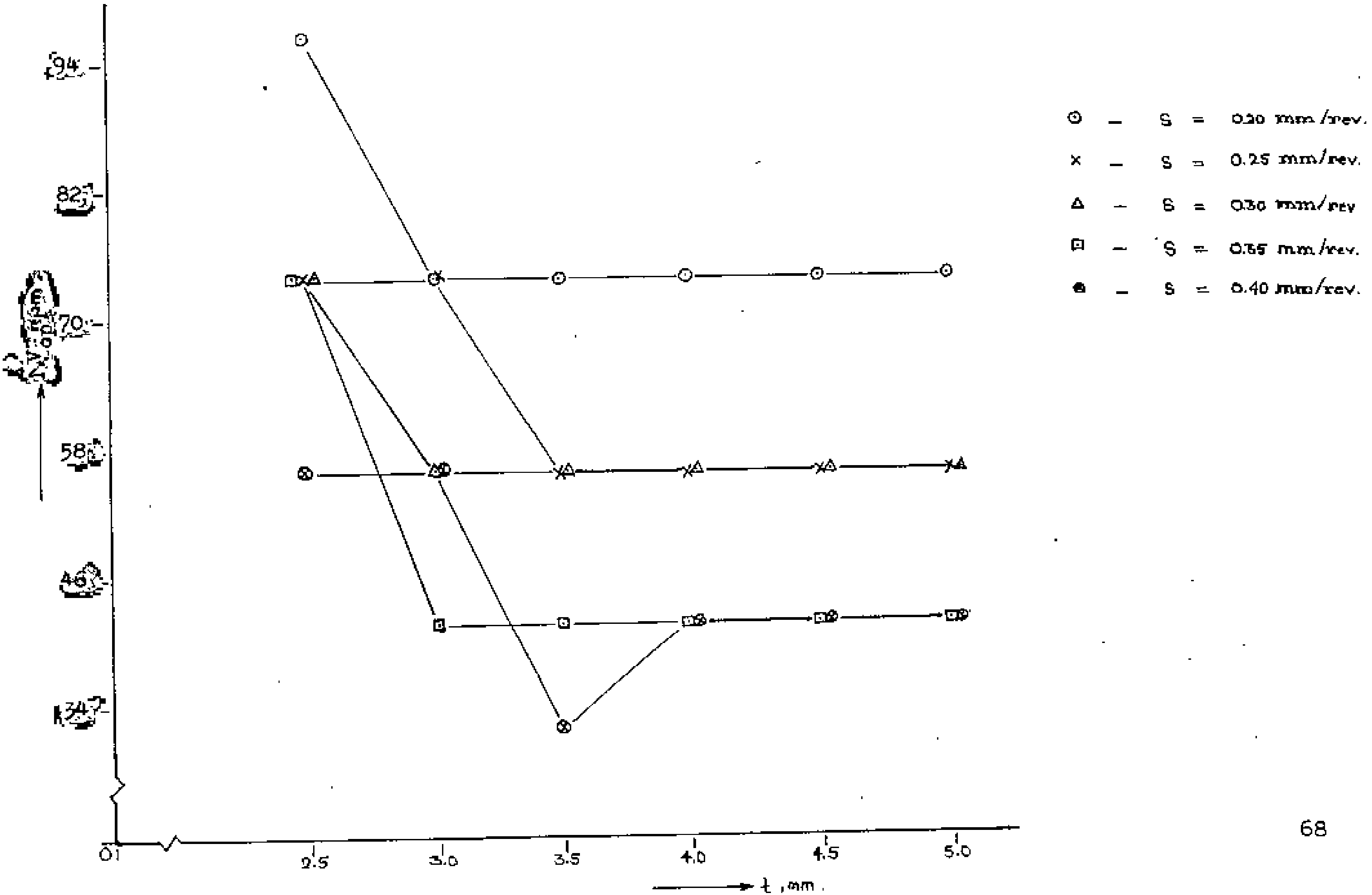


FIGURE - 30. Effect of depth of cut on Optimum cutting speed (From experimental data).

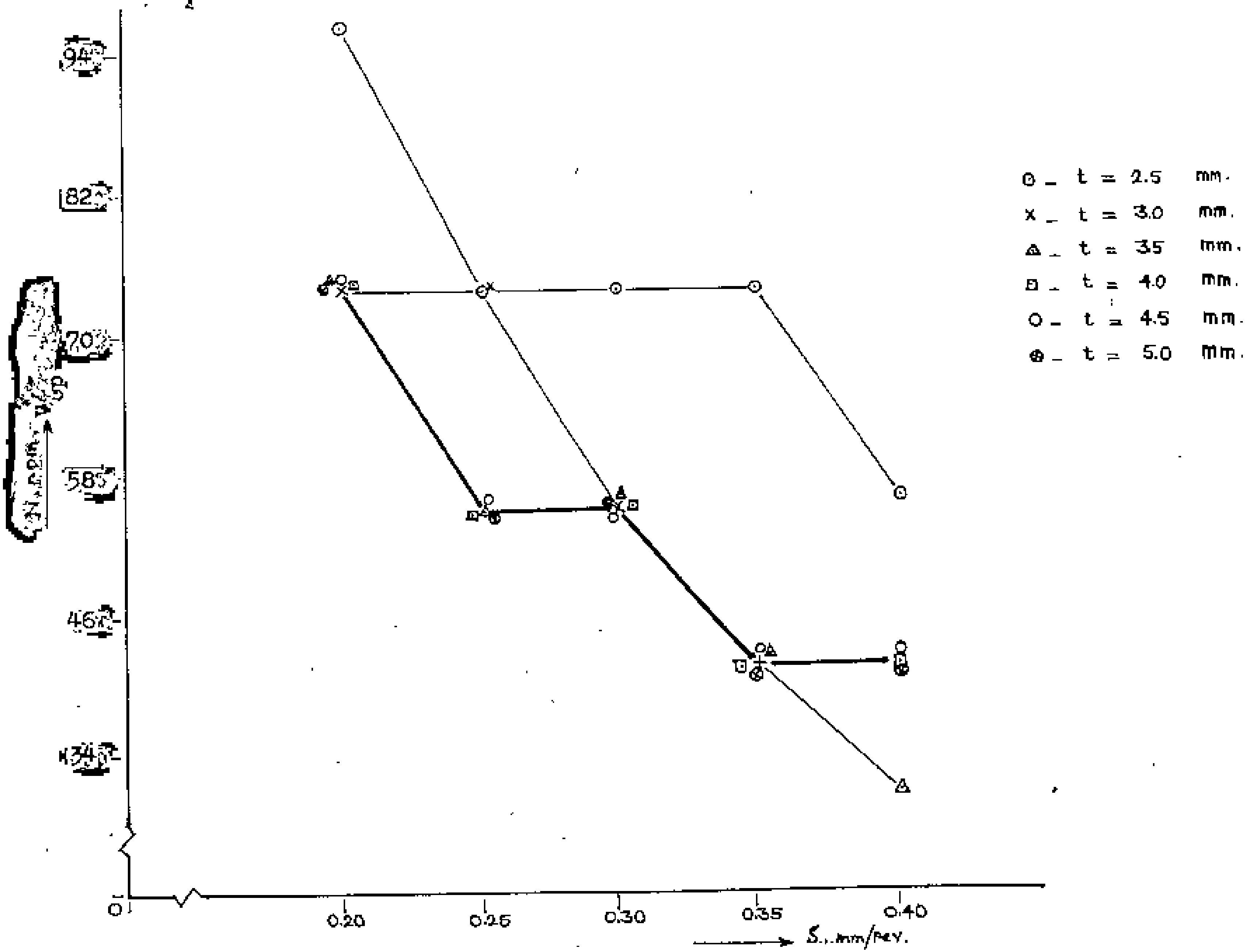
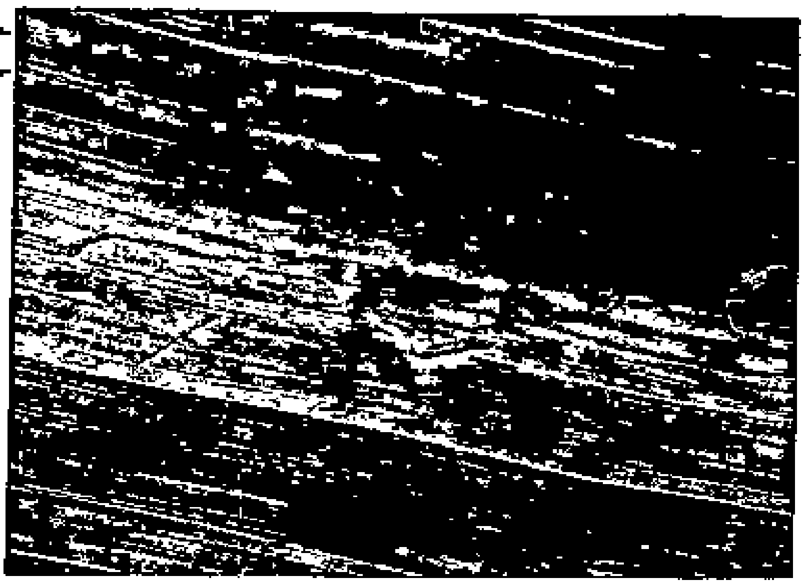


FIGURE - 31. Effect of feed on Optimum cutting speed (From experimental data).

Further changing of the cutting conditions towards higher values, continuation of these tests were not possible with this brazed tip type cutting tool, because of the development of very high temperature at cutting edges which leads to the crack of brazed type carbide tips due to appreciable uneven linear-expansion of steel and carbide. From the above mentioned, experimental findings, it can be concluded that optimum cutting speed, V_{op}, for S = 0.20 mm/rev, t = 2.5 mm, is 94 m/min, and for S = 0.20 mm/rev, to = 5.0 mm. is 73 m/min.



V = 73 m/min, t = 5.0 mm, S = 0.20 mm/rev.

Figure 32: Photomicrograph of chip at S = 0.20 mm/rev.
t = 5.0 mm (continuous cut)
Magnification = 100

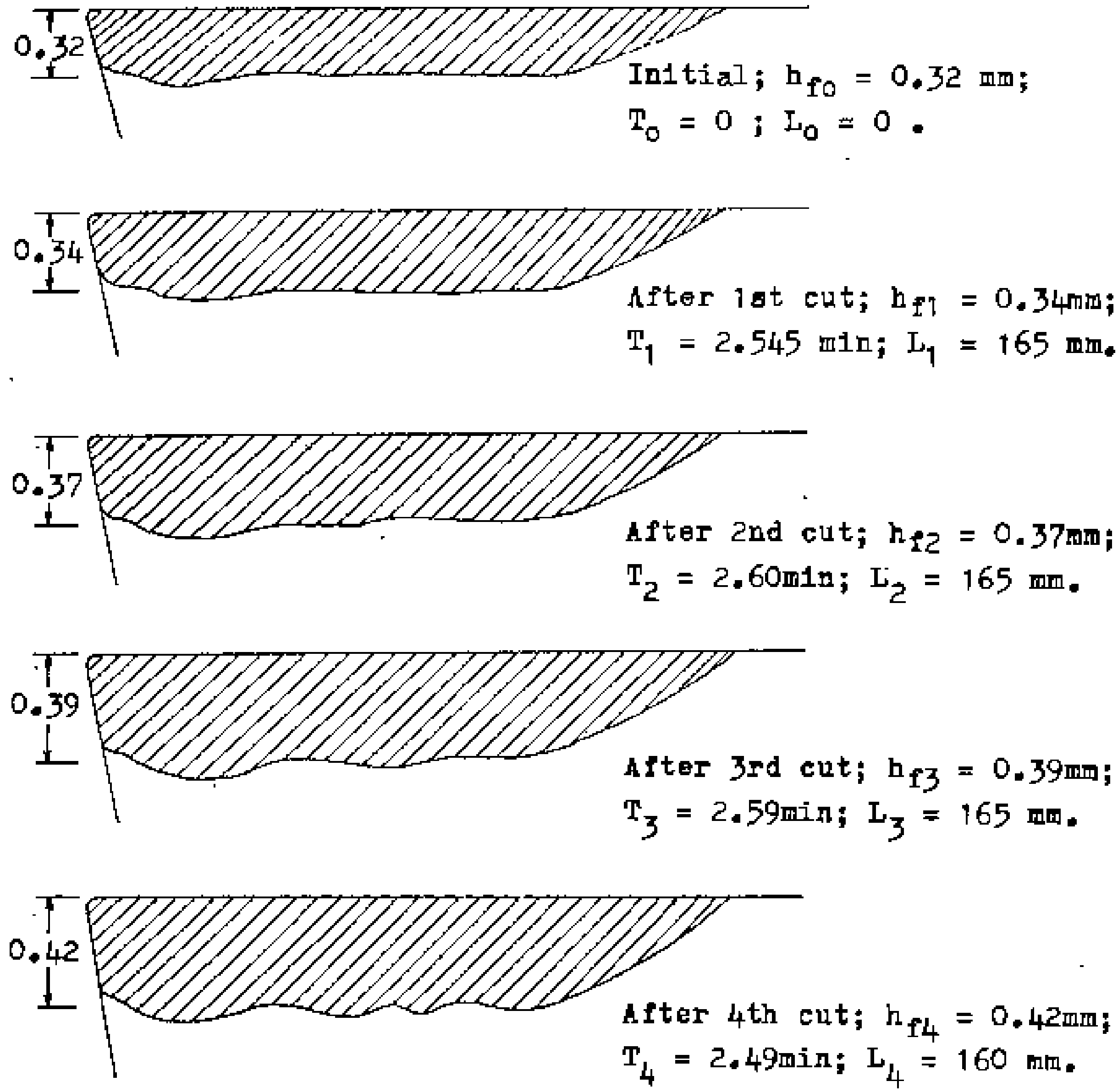


FIGURE - 33. Typical view of flank wear land (cumulative)

$N = 316$ r.p.m., $S = 0.20$mm/rev; $t = 5.0$ mm.

(Experimental).

3.4 Experimental Result

Machining allowance on the job i.e. solid-bar, in the turning operation can be calculated from the diameters of the job before and after the cut which are 74 and 59 mm respectively. So, maximum depth of cut is 7.5 mm. There are two possible ways of turning the solid bar within the specified dimension by using the above cutting conditions, such as:

i) turning by 2 passes (cuts), - (variant-1):
initial cut with N = 316 rpm, S = 0.20 mm/rev, t=5.0mm
final cut with N = 410 rpm, S = 0.20 mm/rev, t=2.5mm

ii) turning by three passes (cuts), - (variant-2):
each cut with N = 410 rpm, S=0.20 mm/rev., t=2.5 mm.

The existing factory variant, - (variant - 3) is as follows:
turning by 3 passes (cuts) and each cut with N = 225 rpm
S = 0.20 mm/rev, t = 2.5 mm.

It apparently seems that turning by 3 passes - (variant-2) is more advantageous than turning by 2 passes-(variant-1) and also than the existing Factory variant-(variant-3). But it has been proved by economic analysis in chapter-4, variant-1 is most economic amongst the above mentioned 3 (three) variants. Economic advantage of the variant-1, in machining 1000 pieces, over variant-2 is approximately Tk. 26,140.00 and over variant-3 for the same lot is approx. Tk. 95,120.00.

A comparative study of the above three conditions of cut is shown in Table-5, (chapter-4). Therefore, variant-1 i.e. turning by 2 passes (cuts) can be recommended for the turning operation of the solid bar. The initial and final cuts can be termed as rough cut and finish cut respectively.

Thus, the recommended cutting conditions are as follows:

i) For rough cut, N = 316 rpm, S = 0.20 mm/rev, t=5.0 mm.

ii) For finish cut, N = 410 rpm, S = 0.20 mm/rev, t=2.5mm.

CHAPTER - 4

ECONOMIC ANALYSIS

4.1 Theory

The production of Drawing Roller involves several machining operations using a variety of Machime-tools. But only turning operation was considered throughout this experimental investigation.

$$\text{Cost per piece, } C_P = C_I + C_c + C_{tc} + C_{tg} + C_{td}$$

After analysis the each cost term of the above equation, Brewer[11], concluded that the cost/piece is a function of four variable, viz, v, s, t and h_f. It is true that for optimum values of v and s a maximum amount of wear, $h_f \approx 0.8$ mm in permitted before regrinding the tool. Machining time is directly influenced by depth of cut. In practical purpose, only rough & finish cuts are used. So, cutting time, tool grinding time, and tool changing time are the major influencing factors of total production cost per piece, as the other factors remain constant for any cutting conditions. The method of calculating these costs varies from factory to factory but the mostly used method is applied here. From equation(1), the cost terms may be written in the following form:

$C_I = M.t_1$, which is constant for particular operation

$C_c = M.t_2$, which is reduced as cutting speed and depth of cut are increased at constant feed

$C_{tc} = M. \frac{Nt}{N_b} . t_{ct}$ and,

$C_{tg} + C_{td} = \frac{Nt}{N_b} . C_t$.

To avoid material handling cost, it is assumed that the solid bars are stacked near the machine ready to be grasped by the operator and that the operator will stack the machined piece conveniently near the machine. According to the 3 - variants mentioned in Chapter - 3, the cutting conditions are as follows:

i) Cutting condition according to variant-1:

a. Rough cut with, N = 316 rpm, S = 0.20 mm/rev t = 5.0 mm

b. Finish cut with, N = 410 rpm, S = 02.0 mm/rev t = 2.5 mm.

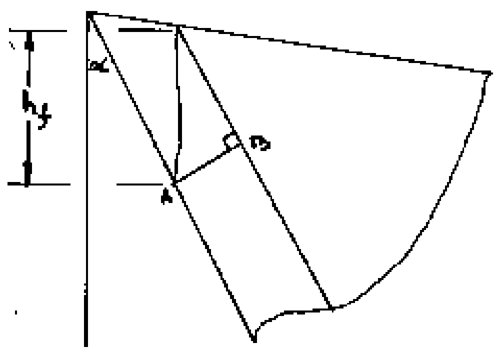
ii) Cutting condition according to variant - 2:

Each cut with, N = 410 rpm, S = 0.20 mm/rev, t=2.5 mm

iii) Existing Factory cutting variant, (variant - 3):

Each cut with, N = 225 rpm., S = 0.20 mm/rev. t = 2.5 mm.

4.2 Determination of Number of Regrind Possible for the Tool:



The figure shown above indicates the profile of a tool with flank wear of amount, h_f. Theoretically, the amount to be ground-off inorder to produce a satisfactory flank is, $AB = h_f \cdot \sin\alpha$. But in practice, an amount $(h_f \cdot \sin \; + \Delta)$ must be ground-off as the worn face is not a well defined line. Let, tool is reground 'R' times before it is of no use for the operation and 'Q' be then limiting amount which can be ground-off before a tool is useless for its present purpose. The tool is ground after its maximum flank wear, i.e. $h_f = 0.80$ mm. Hence,

$\alpha = 8^\circ$, $\Delta = 0.075$ mm (Let),

$Q = 10.5 - 3 = 7.5$ mm. (Table 4)

$\therefore$ Number of grinds possible,

$$R = \frac{Q}{h_f \cdot \sin\alpha + \Delta} = \frac{7.5}{0.8 \times \sin 8^\circ + 0.075}$$

$= 40$ times.

4.3 Determination of Cost of Grinding

There are certain costs associated with regrinding which are independent of the amount of wear. Generally, these are handling costs associated with removal of tool, inspection, lapping where necessary, machine depreciation, overhead, etc.

Cost of grinding a tool is, (data from table-4)

$= \text{Machine Cost} + \text{Direct labour cost} + \text{Indirect labour cost}$

$= \text{Tk.}42.96 \times \frac{10}{60} + \text{Tk.}10 \times \frac{10}{60} + \text{Tk.}56 \times \frac{10}{60}$

$= \text{Tk.}18.16$

Tool depreciation per grind is,

$$D = \frac{\text{Tool cost}}{\text{Total no. of regrinds}}$$

$$= \text{Tk.}\ \frac{165}{40} = \text{Tk.}4.13$$

Total tool cost per grind is,

$C_t = \text{Cost of grinding} + \text{tool depreciation}$

$= \text{Tk.}18.16 + \text{Tk.}4.13$

$= \text{Tk.}22.29$

Information for cost calculation has been recorded in table-4.

Machine and operator rate,

M = Machine cost + Direct labour cost + Indirect labour cost

= Tk. 42.96 + Tk. 10 + Tk. 56

= Tk. 108.96 per hour.

Table - 4

Records from BMTF regarding Drawing Roller, Carbide tool and Factory rates:

Length of the solid bar to be turned,	L	=	1207 mm
Initial diameter of the bar ,	D_w	=	74 mm
Final diameter of the bar ,	D_m	=	59 mm
Machine rate including overhead		=	Tk. 42.96/hr.
Labour rate including overhead (direct labour rates)		=	Tk. 10.00/hr.
Administrative overhead (indirect labour rate)		=	Tk. 56.00/hr.
Job loading & unloading time, including centering, tool approach & engage time (idle time)	t_1	=	40 mins.
Tool changing and resetting time,	t_{ct}	=	3 mins.
Tool grinding time i/c loading & unloading		=	10 mins.
Auxiliary cutting time per cut		=	1 min.
Carbide tip size		=	10.5 mm x 18 mm
Initial tool cost (306R, P15, RH)		=	3 mm.

Machine and operator rate:

M = Machine cost + Direct labour cost + Indirect labour cost

= Tk. 42.96 + Tk. 10.00 + Tk. 56.00 = Tk. 108.96/hour

Tool cost per grind:

C_t = Tk. 22.29

4.4 Cost Analysis for 3-variants

4.4.1 Cost for cutting condition according to variant-1:

Auxiliary cutting time is 2 min, since two passes are used in this variant

Actual turning time:

for rough cut, $= \frac{L}{S.N} = \frac{1207}{0.2 \times 316} = 19.1$ mins.

for finish cut, $= \frac{L}{S.N_5} = \frac{1207}{0.2 \times 410} = 14.72$ mins.

Total actual turning time = 19.1 + 14.72 = 33.82 mins.

and total turning (machining) time, t_m = 33.82+2=35.82 mins.

Idle time, t_1 = 40 mins.

Tool wear:

during rough cut $= \frac{0.10 \times 19.1}{10.23} = 0.19$ mm.

(since from table-2, h_f = 0.10 mm, after turning 10.23 mins)

during finish cut $= \frac{0.11 \times 14.72}{9.26} = 0.175$ mm.

(from table-2, h_f = 0.11 mm, after turning 9.26 mins)

Total tool wear = 0.19 + 0.175 = 0.365 mm.

Tool life for rough cut $= \frac{0.8 \times 10.23}{0.10} = 81.84$ mins.

Tool life for finish cut $= \frac{0.8 \times 9.26}{0.11} = 67.35$ mins.

Each tool will produce before regrind,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Total wear after operation}} = \frac{0.8}{0.365} = 2.19 \text{ pieces.}$$

$$N_t/N_b = \frac{1}{2.19} = 0.46, \text{ since Number of tool, } N_t = 1.$$

Now, inorder to calculate cost per piece, C_P according to equation(1), the values of its components are calculated as follows:

$$\text{Idle cost, } C_I = M.t_1 = \text{Tk. } 108.96 \times \frac{40}{60} = \text{Tk. } 72.64$$

$$\text{Machining cost, } C_c = M.t_m = \text{Tk. } 108.96 \times \frac{35.82}{60} = \text{Tk.}65.05$$

$$\text{Total changing cost, } C_{tc} = M.\frac{N_t}{N_b}\, t_{ct} = \text{Tk. } 108.96 \times 0.46 \times \frac{3}{60} = \text{Tk. } 2.51$$

Tool cost per piece,

$$C_{tg} + C_{td} = \frac{N_t}{N_b} .C_t = 0.46 \times 22.29 = \text{Tk. } 10.25$$

(from table-4, C_t = Tk. 22.29)

∴ Total cost per piece,

$$C_P = C_I + C_c + C_{tc} + C_{tg} + C_{td}$$

$$= \text{Tk.}72.64 + \text{Tk. } 64.05 + \text{Tk. } 2.51 + \text{Tk. } 10.25$$

$$= \text{Tk. } 150.45$$

Total cost for turning of 1,000 pieces of Drawing Roller is, $= C_P \times 1000 = 150.45 \times 1000$

= Tk. 150,450.00

4.4.2 Cost for cutting condition according to Variant-2:

Auxiliary cutting time is 3 mins, since three passes are used in this variant.

$$\text{Actual turning time} = \frac{L}{S.N} \times 3 = \frac{1207}{0.2 \times 410} \times 3$$

$$= 44.16 \text{ mins.}$$

Total turning (machining) time, $t_m = 44.16 + 3 = 47.16$ mins

Idle time, $t_1 = 40$ mins, from table-4

Tool changing time, $t_{ct} = 3$ mins., from table 4.

$$\text{Tool wear during operation,} = \frac{0.11 \times 44.16}{9.26} = 0.525 \text{ mm.}$$

(since from table-2, $h_f = 0.11$ mm, after turning 9.26 mins)

$$\text{Tool life, } T_L = \frac{0.8 \times 9.26}{0.11} = 67.35 \text{ mins.}$$

Each tool will produce before regrind,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Total wear after operation}} = \frac{0.8}{0.525} = 1.52 \text{ pcs.}$$

$\therefore$ $N_t/N_b = 1/1.52 = 0.66$, since number of tool,

$N_t = 1$.

Inorder to calculate cost per piece, C_p according to equation(1), the values of its components are calculated as follows:

Idle cost, $C_I = M.t_1 = Tk.\ 108.96 \times \frac{40}{60} = Tk.72.64$

Machining cost $C_c = M.t_m = Tk.\ 108.96 \times \frac{47.16}{60}$

$= Tk.\ 85.64$

Tool changing cost, $C_{tc} = M.\frac{N_t}{N_b}.t_{ct} = Tk.\ 108.96 \times 0.66 \times$

$\times \frac{3}{60} = Tk.\ 3.60$

Tool cost per piece,

$$C_{tg} + C_{td} = \frac{N_t}{N_b}.C_t = Tk.\ 0.66 \times 22.29 = Tk.\ 14.71$$

(from table-4, C_t = Tk. 22.29)

∴ Total cost per piece,

$$C_P = C_I + C_c + C_{tc} + C_{tg} + C_{td}$$

$= Tk.\ 72.64 + Tk.\ 85.64 + Tk.\ 3.60 + Tk.\ 14.71$

$= Tk.\ 176.59$

Total cost for turning of 1000 pieces of Drawing Roller is,

$= C_P \times 1000$

$= Tk.\ 176.59 \times 1000$

$= Tk.\ 176,590.00$

4.4.3 Cost for existing factory cutting variant (variant-3):

Auxiliary cutting time is 3 mins, since three passes are used in this variant.

Actual truning time = $\frac{L}{S.N} \times 3 = \frac{1207 \times 3}{0.2 \times 225}$

= 80.47 mins.

Total turning (machining) time, t_m = 80.47 + 3

= 83.47 mins.

From table - 2, for V = 46 m/min, which is close to factory speed, V = 52 m/min & N = 225 rpm.

h_f = 0.18 mm after turning 24 mins.

Tool life, $T_L = \frac{0.8 \times 24}{0.18}$ = 106.67 mins.

Total tool wear after operation = $\frac{0.18 \times 80.47}{24}$

= 0.604 mm.

Each tool will produce before regrind,

$$N_n = \frac{\text{Maximum wear for tool life}}{\text{Total tool wear after operation}} = \frac{0.8}{0.604} = 1.30 \text{ pcs.}$$

$\therefore N_t/N_b$ = 1/1.30 = 0.77, since number of tool, N_t = 1

Now, in order to calculate cost per piece, C_p according to equation (1), the values of its components are calculated as follows:

Idle cost, $C_I = M.t_1$ = Tk. 108.96 x $\frac{40}{60}$ = Tk. 72.64

Machining cost, $C_c = M.t_m$ = Tk. 108.96 x $\frac{83.47}{60}$

= Tk. 151.58

Tool changing cost, $C_{tc} = M.\frac{N_t}{N_b}.t_{ct}$

= Tk. 108.96 x 0.77 x $\frac{3}{60}$

= Tk. 4.19

Tool cost per piece,

$C_{tc} + C_{td} = \frac{N_t}{N_b}.C_t$ = 0.77 x 22.29 = Tk. 17.16

(from table-4, C_t = Tk. 22.29)

Total cost per piece,

$C_P = C_I + C_c + C_{tc} + T_{tg} + C_{td}$

= Tk. 72.64 + 151.58 + 4.19 + 17.16

= Tk. 245.57

Total cost for turning of 1000 pieces of Drawing Roller is,

C_P x 1000

245.57 x 1000 = Tk. 245,570.00

4.5 Results and Recommendation

From the above mentioned cost calculation for three variants, it can be concluded that the total cost for turning of 1000 pieces of Drawing Roller is as follows:

For variant-1, total cost is Tk. 150,450.00
For variant-2, total cost is Tk. 176,590.00
For variant-3, total cost is Tk. 245,570.00

Now, the benefit of Variant - 1 over Variant-2 is,

= Tk. 176,590 - Tk. 150,450

= 26,140.00

And also, benefit of Variant-1 over Variant-3 is,

= Tk. 245,570 - Tk. 150,450

= Tk. 95,120.00

It is clear from the above mentioned that Variant-1 is the most economic Variant amongst the three Variants. Economic advantage of the Variant-1, in machining 1000 pieces of Solid bar (Drawing Roller), over variant-2 is approximately Tk.26,140 and over Variant-3 for the same lot is Tk. 95,120. Therefore, the Variant-1, can be recommended for the turning operation of the solid bar (Drawing Roller).

So, finally the recommended cutting conditions are as follows:

i) Rough cut: N = 316 rpm, S = 0.20 mm/rev., t = 5.0 mm.

ii) Finish cut: N = 410 rpm., S = 0.20 mm/rev., t = 2.5 mm.

Table - 5

A Comparative study of the 3 (three) Variants:

	Name of Items	Variant - 1	Variant - 2	Variant - 3
i)	Idle time, t_1	40 min.	40 min.	40 min.
ii)	Tool changing time, t_{ct}	3 min	3 min.	3 min.
iii)	Auxiliary turning time	2 min.	3 min.	3 min.
iv)	Actual turning time/piece	Rough cut = 19.1 min. Finish cut= 14.72 min 33.82 min.	44.16 min.	80.47 min.
v)	Total turning(machining) time/piece	35.82 min.		
vi)	Total tool wear/piece	Rough cut = 0.19 mm Finish cut= 0.175 mm 0.365 mm	0.525 mm	0.604 mm
vii)	Tool life	Rough cut = 81.84 min. Finish cut= 67.35 min	67.29 min	106.67 min.
viii)	No. of pieces produce before regrind	2.19 pieces	1.52 pieces	1.3 pieces
ix)	Idle cost, C_I	Tk. 72.64	Tk. 72.64	Tk. 72.64
x)	Machining cost, C_c	Tk. 65.05	Tk. 85.64	Tk. 151.58
xi)	Tool changing cost, C_{tc}	Tk. 2.51	Tk. 3.60	Tk. 4.19
xii)	Tool grinding cost	Tk. 10.25	Tk. 14.71	Tk. 17.16
xiii)	Total cost/piece, C_P	Tk. 150.45	Tk. 176.59	Tk. 245.57
xiv)	Total cost for 1000 pieces	Tk. 150,450	Tk. 176,590	Tk. 245,570
xv)	Cost reduction over variant-3	39%	28%	-

CHAPTER - 5

DISCUSSION AND CONCLUSION

5.1 Discussion

Experimental results show that the most economic method i.e. optimum condition of metal cutting reduces approximately 39% of the existing machining cost. The technique of finding the optimum cutting condition is so simple that it needs no adequate technical knowledge and expensive as well as special instrument. After giving a thorough idea about this technique, a semiskill also can predict the optimum condition with only a simple scale using this method. So, a simple scale can save 39% production cost. It is no doubt a break through over factory's present method of metal cutting and it will also speed up the Industrial growth in the country. This method can be applied everywhere irrespective of small and large enterprises where metal cutting is involved. It is a moral obligation of all to improve and increase production by optimization and to do this, the proposed method may be applied for selecting optimum cutting condition. The test results and the experimental work will encourage the Industrial Sector for planning future development & improvement of metal cutting methods.

Though the investigation was performed with only one pair of tool and work material using only the facilities of BMTF and limited test data, this experimental result will act as a guide line and also will encourage every one to determine the optimum condition for any other pair of 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 hinderances, the experimental study was carried out carefully.

It is hoped that the experimental investigation has analyzed some aspects of optimum cutting condition within its limitations and finally has enabled the establishment of a method of predicting the optimum cutting condition in machining steel with carbide tipped tools.

5.2 Conclusions

From the results of the experimental investigations the following conclusions can be drawn:

1. There exists certain relationship between coefficient of chip-shrinkage, K and critical cutting speed, V_c. The maximum value of K correspond to critical cutting speed, V_c.

2. There also exists definite relationship between V_c and V_{op}. For single carbide tool material, V_{op} V_c (at maximum value of K); but for double carbide tool material, V_{op} V_c and V_{op} V_c.

3. Existance of V_{op} for single carbide tool material is explained by a pulsation type of chip-tool contact process in the range of cutting speed just before V_c. For double carbide tool material the existance of two optimum cutting speeds is explained as follows: the first optimum cuttint speed, V_{op_1} exists due to the presence of pulsation type chip-tool contact process as in the case of single carbides, where as the presence of V_{op_2} is explained by the presence of Stagnant contact zone on the tool face which saves the tool free intensive wear at that speed range.

5.3 Future Recommendation

The following shortcomings might have been observed in the work:

The recommended method was developed on the basis of experiments on only nickel chromium steel as work material. Although these results confirmed the theoretical values, there remains scope of further study by changing the composition of work material to prove the validity of the proposed method for any other grade of steel.

In the experiment the value of tool geometry was selected from the engineering Handbook and throughout the experiment these values not were changed. 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 to confirm the experimental results for any other tool geometry.

Throughouth the experiment only double carbide tool was used due to time and tool limitations. Although the test results coincide with the theoretical one for this material there remains a scope for further study with other carbide tool materials to justify the validity of the method of chosing optimum value developed in this work.

The research work was conducted without using cutting fluid. Though cutting fluid has negligible effect as lubricant during high speed turning, there is a scope of study to correct the experimental results quantitatively.

The experiment was conducted completely in the "laboratory condition" and the proposed method was developed on the basis of only these experimental results. Any change in "experimental condition" may change the exact values of optimum conditions. Though, in our opinion, the general pattern of the curves developed from the test data will remain the same, further investigation may be made to correlate the test results with actual one.

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