DETERMINATION OF OPTIMUM CUTTING CONDITIONS IN TURNING STAINLESS STEEL AND CAST IRON WITH CEMENTED CARBIDE TOOL

A Project Thesis

by

MAHMOOD ALI

Submitted to the department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology, Dhaka in partial fulfilment of the requirements for the degree of MASTERS OF ENGINEERIRNG in Industrial and Production.

Department of Industrial and Production Engineering
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ABSTRACT

In metal cutting processes for economic machining, the selection of various cutting variables, tool geometry and cutting tools play an important role. The know how of selecting appropriate tool geometry and cutting conditions for various application is almost absent in the relevent industries of our country.The purpose of this work is therefore to raise the technical know how in this particular sphere.The present work attempts to present a method of selecting optimum metal cutting conditions for drawing rollers of stainless steel and cast iron.The experimental results may act as guide lines for selecting optimum cutting conditions for other combinations of work and tool materials.

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NOMENCLATURE

a	=	Thickness of metal removed
b	=	Thickness of chip
C_p	=	Total cost per piece
C_c	=	Machining cost per piece
C_I	=	Idle cost per piece
C_{tc}	=	Tool changing cost per piece
C_{tg}	=	Tool regrinding cost per piece
C_{td}	=	Tool depreciatin cost per piece
h_f	=	Flank wear of tool (mm)
h_c	=	Face wear of tool (mm)
h_{fc}	=	Intnesity of tool wear (mm/m)
k	=	Co-efficient of chip contraction
l	=	Shear plane length
L_c	=	Length of cut during turning
M	=	Total machine & operator rate (including overhead)
n	=	Taylor exponent
N_t	=	Number of tools used for a piece
N_b	=	Number of pieces machined by a tool after each grind
P_z	=	Cutting force (kg)
S	=	Feed (mm/rev.)
t	=	Depth of cut, (mm)
T, T_L	=	Tool life (mm)
t_i	=	Idle time per piece
t_m	=	Machining time per piece
t_{ct}	=	Tool changing time per piece
v_c	=	Critical cutting speed (m/min)
v	=	Cutting speed
v_{op}	=	Optimum cutting speed (m/min)
α	=	Relief angle of principal side cutting edge
α_1	=	Relief angle of auxiliary side cutting edge
Γ	=	Side rake angle
Γ_1	=	Back rake angle
β	=	Shear angle
ϕ	=	Principal cutting edge angle
ϕ_1	=	Auxiliary cutting edge angle
δ	=	Cutting angle.

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CHAPTER ONE

INTRODUCTION AND LITERATURE SURVEY

1.1 INTRODUCTION

The primary aim to manufacture a product is that it must be designed to satisfy all the desired purposes. Another important aim is to design a part for the most economical method of manufacturing. This may be accomplished by considering all feasible manufacturing methods and selecting the manufacturing method which appears to be most advantageous. It is not enough that inventors and engineers be able to develop new machineries and new products. After they have developed a new product, they must then be able to manufacture it at a sufficiently low cost. The design should be such that each component part should be manufactured at the constant possible cost. When a new product is assigned to the manufacturing department for production, it is necessary to select the manufacturing method which actually will be used for it. If the design is good enough, the manufacturing department should have little difficulty in selecting most suitable manufacturing method.

In our country, there are various types of production processes as well as huge amount of metal cutting processes in various sectors. They can meet a great portion of demand of our country. But shortage of technical knowledge is one of the main problems in these sectors. In most of our factories, the workers as well as many engineers use thumb rules. They don't think about accuracy, optimization and quality. This is due to the lack of their technical know-how and shortage of technical facilities.There is absence of adequate ideas about the influence of feed, depth of cut, tool geometry etc. on the cutting speed and also on cutting tool. In practice, the values of the metal cutting variables are determined aither by mere experience of the machine tool oparators or selected from the available out dated handbooks. It results in low production rate and high machining cost. This is not desirable for the factory. It is our concern to improve this situation. Economic machining is primarily based on the selection of different cutting variables and tool geometry. These are the governing factors in metal cutting process.

Cutting tools selection also play a vital role in metal cutting operations. For cutting cast iron, stainless steel, specially at high speeds, the cutting tool has to be heat and wear resistant.

The purpose of this report is therefore to give an idea how to overcome this undesirable situation by studying the metal cutting processes of different work materials with various cutting variables. Experiences gained over the years have led to the determination of the guidelines and empirical formulae for choosing the optimum cutting conditions for a given turning operation. This work attempts to present a simple method of selecting optimum metal cutting conditions during turning operation. It does not require special or costly equipments.

1.2 LITERATURE SURVEY

Metal cutting has a great importance, so many research works in this field has already been carried out. But most of the important fundamental theories have been developed only during the past three or four decades.

In 1873, H. Tresca[1], conducted research works on metal cutting. After that, A. Mallock[2] worked on the metal cutting processes. His contributions were made toward understanding the metal cutting process by determining cutting forces and the effects of tool geometry and cutting environments. The effect of temp. on tool life were developed by F.W. Taylor[3] by several experiments in 1907. This was published in his book "On the art of cutting metals". From 1907 to 1925, many empirical formula and data were developed.

In 1935 H.Ernst and M. Martellotti[4] in their work "The formation of built-up edge" confirmed the role of the built-up edge in metal cutting. They also 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. The effect of tool geometry, temperature, chip formation, surface finish, cutting thread on the metal cutting process was also explained by them. Actually fundamental researches on the metal cutting mechanism has been continued since 1930.

In metal cutting process accuracy, optimization has a vital role. This was not considered in the previous researches. Many of the processes were done by thumb-rule, rather than scientific method. The customary methods used in various metal cutting processes, using thumb rules must be replaced by scientific methods' - this realization had begun in 1950. Demand in metal cutting changes continuously better surface finish, higher rates of production, economic production had become under consideration. Since then extensive developments in metal cutting had been carried away. In the very near future, it is necessary to fulfil the requirements.

Many researches were done on the tool wear. Many reports have been presented by many researchers on the tool life test, testing method, wear process of the cutting tool, vibration etc. For cemented carbide tool, Merchant, Ernst and Krabacher[5] presented a scientific method of tool life, testing. T.N. Laladzee[6] of USSR presented a well recognized theory of chip formation during metal cutting process in 1952. Mechanical consideration during metal cutting also developed by Zorev[7] in the same year.

Optimum cutting condition with respect to minimum production cost was considered after the year 1950. Various development were done on the optimum machining variables. Here machining cost, tool cost which are the function of production cost, also considered. Relation of coefficient of chip shrinkage with cutting forces, also developed by Rozenberg. Eremin and Rozenberg[8] carried out experiments on basic metal cutting principles and established a relationship between metal cutting theory and machining variables. The role of tool wear in the optimization of metal cutting process were presented by Laladze. Clushin[9], a scientist of USSR in his research 'Metal cutting process' also confirmed the effect of tool wear for optimization process. For maximum production rate, basic turning operation to optimize the cutting variables, was performed by Brewer[10]. He developed that the production time depends on the machining time, idle time etc. Also Makarov[11] had carried out some investigations on tool wear and optimization of metal cutting process. Another economic analysis was done by Armerego and Russel[12] in 1966. They showed that tool cost and idle time influence the maximum profit. They used maximum profit rate as an objective function for optimizing machining variables.

In the research work "Development of the science of metal cutting" by Zorev, Gronovsky, Tritiakov and Larina[13], showed the mechanics of metal cutting. For optimum cutting condition, restrictions were also considered by Bekes[14]. In this method, the objective was only the production rate. This method was modified by Basu[15] in the same year. A mathematical model for calculating the cutting condition during turning operation was developed by Bjorke[16] in his paper "Mathematical Models for calculation of cutting Data in Rough Turning."

For cemented carbide tool the relationship between chip-tool contact process and tool wear in the metal cutting process was developed by Talantov[17] in 1969. The chip-tool contact process is an important factor in chip formation and it is one of the most significant factors for determining the process of tool wear. Later, several researches was done on it and the equation to determine critical cutting speed, was also developed by Nadai, resistance of metal during cutting also explained by I.A. Time. In 1978, in the research work "Influence of cutting speed on different characteristics of metal cutting process and tool wear" by Talantov, Cheriomoshnikov and Kurchenco[18] showed the relationship between cutting speed, metal cutting process and tool life. The fundamental theory for the optimization of metal cutting process also developed by Babrov[19].

All of these research works by many scientists and researchers had developed this field. By the series of experiments and analysis in these years, various factors which influence the metal cutting process had come under consideration on the basis of the earlier progress in optimizing the metal cutting process, this paper attempts to present a method of selecting optimum metal cutting conditions during turning operation. Works in this field for the development of the theory of metal cutting and their problems have been listed in this chapter. Thus the objectives of the present work are set on the basis earlier developments in this field and are discussed in the following section.

1.3 AIMS AND OBJECTIVES OF THE PROJECT WORK

The objectives of the research were set as follows:-

i) To determine the cutting speeds, at which intensity tool wear is minimum in turning stainless steel with cemented carbide tool.

ii) To determine the cutting speeds,at which intesity of tool wear is minimum in turning cast iron with cemented carbide tool.

iii) To determine influence of feed, depth of cut on the cutting speed corresponding to minimum tool wear.

iv) To conduct an economic analysis to select the cutting conditions for a particular work piece.

CHAPTER TWO

GENERAL THEORY

2.1 THEORY

From the manufacturing point of view, production costs, production rates and profit have the great importance during machining. But analysis of these three terms are not possible at a time for complexity. So, it is wise to use only one objective criterion, generally minimum cost criterion.

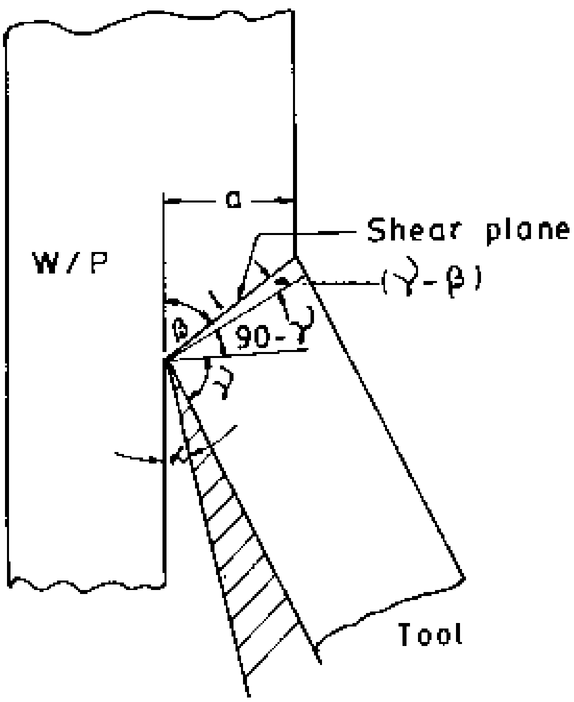
Therefore, economic cutting condition should be determined. For a given material and tool, the restrictions of feed, depth of cut, speed, cutting force (as function of power) and surface finish will be the restrictive criterion to determine the optimum cutting condition.

Before discussing the objective criterion, a brief description of tool material, and some properties which are essential to perform the experiment are discussed below.

2.2 Cutting Tool Material

To determine the optimum cutting condition, cemented carbide tool was used. Carbides are initially formed by powder metallurgy. The principal carbide is tungsten carbide, and this may be mixed with some tantalum carbide and titanium carbide. These carbide powders are mixed with a powder of cobalt or nickel, which serves as the binder. Carbide tool bits are extremely hard and somewhat brittle. To get more shock resistance, some hardness may be sacrificed. This may done by varying the composition, such as the amount of binder. This material is relatively high in cost, but tool bits made of it remain effective at exceptionally high cutting speeds. Thus they remove metal rapidly and produce excellent surface smoothness on the work. This tool bits remain effective longer. This tool bits can be sharpened by grinding with fine abrasive grains.

2.3 Coefficient of Chip Contraction



Here,

- β = Shear angle
- α = Relief angle
- Γ = Rake angle
- b = Thickness of chip
- a = Thickness of metal being removed
- l = Shear plane length

Fig.1 : Coefficient of chip contraction

Coefficient of chip contraction, k is a value and is expressed as,

$$k = \frac{\text{Thickness of chip}}{\text{Thickness of metal being removed}}$$

From the fig.,

$$k = \frac{b}{a} = \frac{l\cos(\gamma-\beta)}{l\sin\beta} = \frac{\cos(\gamma-\beta)}{\sin\beta}$$

The factors which effects on 'k' are as follows:

i) Tool geometry (mainly rake angle)

ii) Cutting variables, as feed, depth of cut and cutting speed

iii) Cutting fluid and

iv) Tool material and the metal being machined.

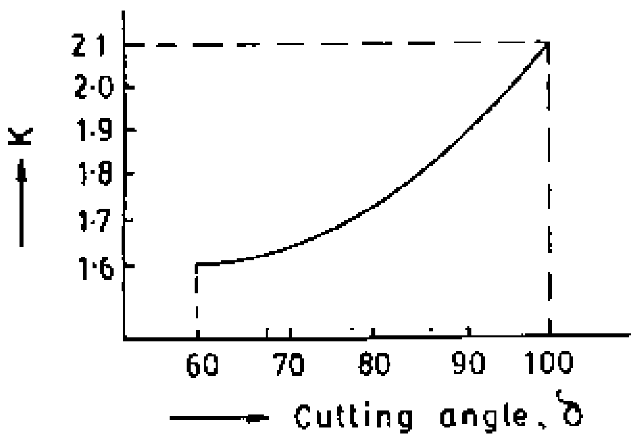


Fig.2(a) :
Effect of cutting angle on k
(Typical curve)

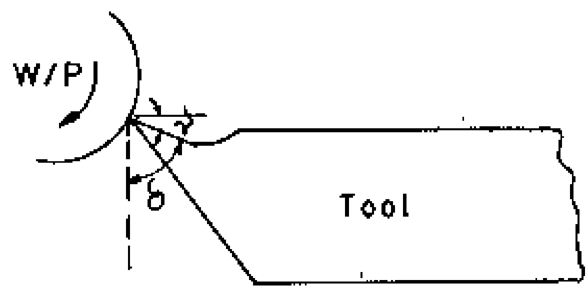


Fig.2(b) :
Cutting Angle

It is clear from Fig. 2(a) that coefficient of chip contration, k increases with cutting angle, δ, If δ increases then wear also increases.

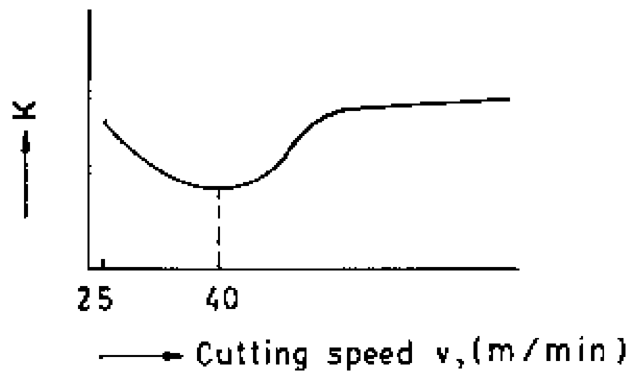


Fig. 3 :
Effect of cutting speed on, k

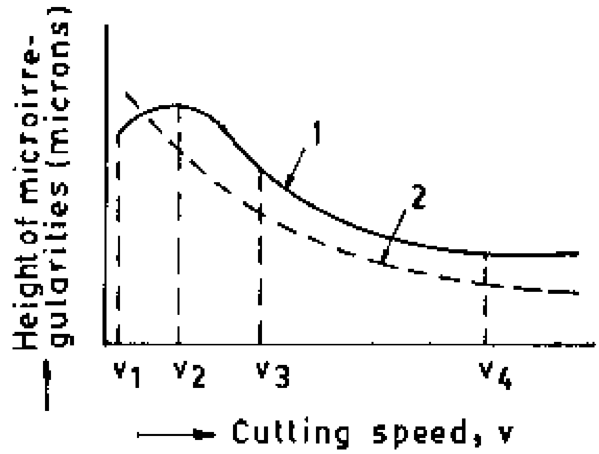


Fig. 4 :
Effect of cutting speed on micro irregulataries

From Fig.3, it is shown that the chip contraction, k decreases between 25-40 range and then increases and remains const in the case of medium carbon steel.

In Fig.4, the effect of the cutting speed on the surface roughness is shown. Curve 1 is shown for general case curve 2 for high alloy steels, nonferrous metals and brittle cast irons. In the range v_1 to v_2, where v_1 near to zero, the surface roughness increases. This is due to the beginning of built-up edge formation. It is maximum at speed, v_1. Beginning with speed v_2, the condition for BUE formation deteriorates due to rise in temperature, the height of the BUE is reduced, and at a certain speed, v_3 it disappears. Speed from v_3 to v_4 the surface roughness contunues to decrease due to the reduced friction between the tool flank and the machined surface. This is also to the general reduction in plaster deformation from speed, v_4, the height of the microirregularities remains practically const. Here the cutting process is stabilized. In curve 2 the roughness of the machined surface first drops sharply with an increase in the cutting speed and then becomes practically constant. This is due to complete absence of BUE formation.

2.4 Chip Tool Contact Process and Tool Life

During cutting, a portion of chip contact with the tool face due to high temperature, which is known as BUE. Generally hardness of tool is 1.8 times greater than the w/p, but hardness of BUE is 2-3 times greater than w/p. So it can cut metal. It reduces the tool wear. Cutting force also reduces by the formation of BUE due to increase in rake angle. It forms during low speed and during formation of continuous chip.

Chip-tool contact process mainly determines the tool wear during machining. Tool-wear is determined by various types of built-up edge, which exists in the cutting zone. The relationship between the contact process and the tool life was established by Talantov and is shown as follows in the Fig. 5.

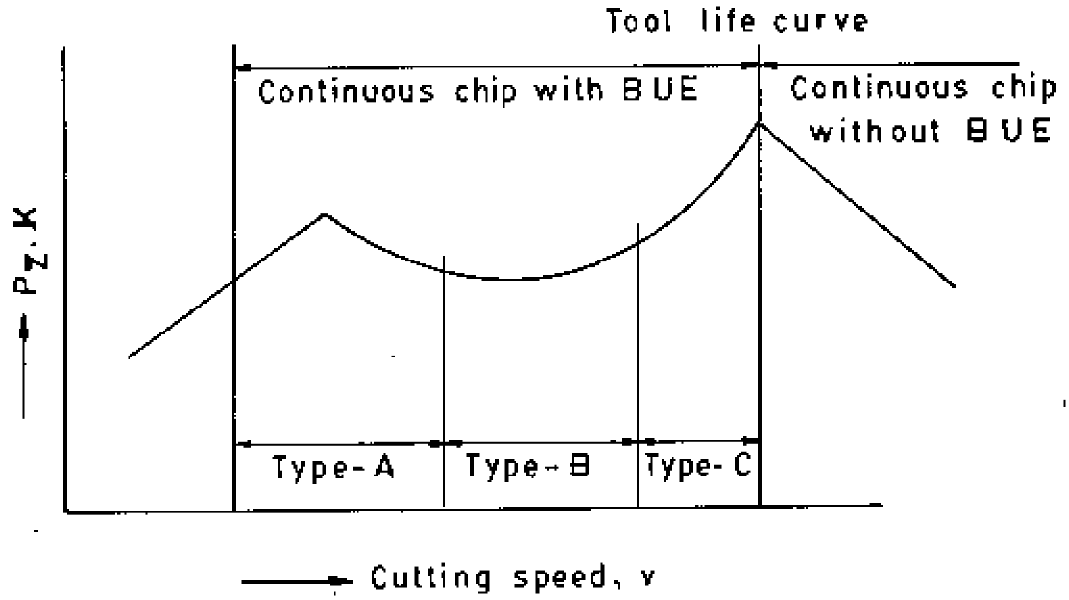


Fig. 5 : Typical relationship between contact process and tool life (By Talantov)

Tool life is maximum for type c BUE and minimum for type-B BUE. It is also experimentally showed by Talantov that in the contact process of type-C, though the BUE is unstable, but it protects the tool life from wear and reduces flank wear and also produce mirror-type surface finish. Here the value of flank wear, h_f for single carbide tool is also minimum.

2.5 Objective Criterion and Restrictions for Optimization

By a large number of researchers, it was developed that there are three types of objective criterion for optimization. These are (i) minimum cost criterion, when cost is the decisive factor, (ii) maximum production rate criterion, when production rate is the criterion and (iii) maximum profit rate when profit is the decisive factor. But here minimum cost criterion is used for the experiment.

The formula used for minimum cost criterion is,

$$C_p = C_i + C_c + C_{tc} + C_{tg} + C_{td}$$

Here,

C_p = Cost per piece

C_c = Machining cost

C_i = Idle cost

C_{tc} = Tool changing cost

$C_{tg} + C_{td}$ = Tool Cost

Restrictions for the objective criterion are considered as feed s, depth of cut t, and speed v. Because for optimum tool life cost is a function of speed, feed and depth of cut and should be minimum i.e.

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

Speed : The cutting speed should not exceed the upper limit for chip breaking and safety of the operator. The lower limit of speed should be maintained so that it should not be less than the limit. Because then built-up edge will form rapidly.

Feed : Combination of feed and depth of cut must be listed to keep the validity of the wear criterion.

Depth of Cut : Depending on the length of the main cutting edge, machining allowance, power of the machine, deflection of the workpiece, etc. the maximum depth of cut is restricted.

Power : During cutting process, the power should not exceed the capacity of the main drive.

2.6 Critical Cutting Speed

Critical cutting speed is that speed, where intensity tool wear is minimum. Typical diagram of Intensity of tool wear vs cutting speed is shown in Fig. 6.

Here, the value of h_{fc} first decreases with the increase of cutting speed. Then it increases to a maximum point by the increase of cutting speed. After that it decreases again. The critical cutting speed is that speed where the h_{fc} is minimum.

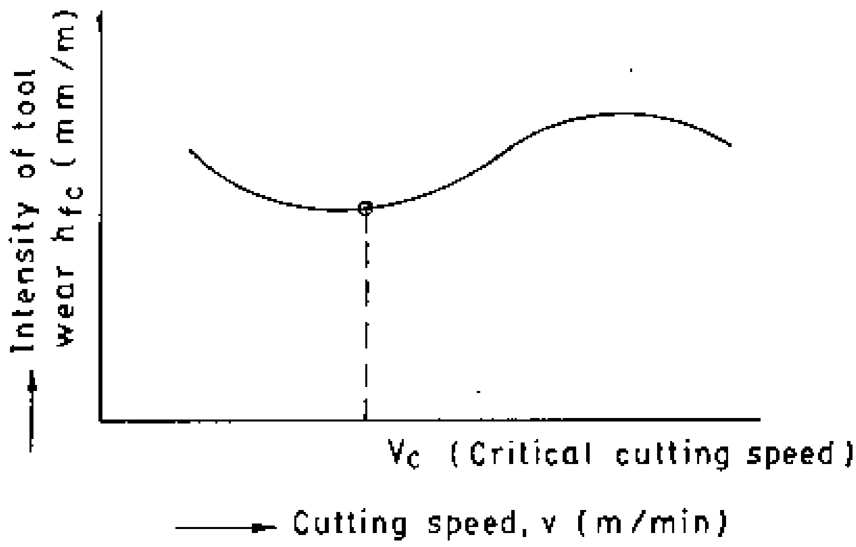


Fig.6 : Typical diagram for cutting speed vs. intensity of tool wear

From Tailors tool life equation, we know that,

$$vT^n = C,$$

where, value of 'n' and 'c' depends on the particular pair of tool and workpiece. For a particular cutting condition, where 's' and 't' are constant then,

Cutting force, $P_z = f(v)$

Tool life $T_z = f(v)$

and Flank wear, $h_f = f(v)$, also.

Effect of feed and depth of cut on tool life and cutting speed may be expressed by the following relationship,

$$v' = \frac{C}{T . S^{y} . t'}$$

The graphical relationship is shown in Fig. 7.

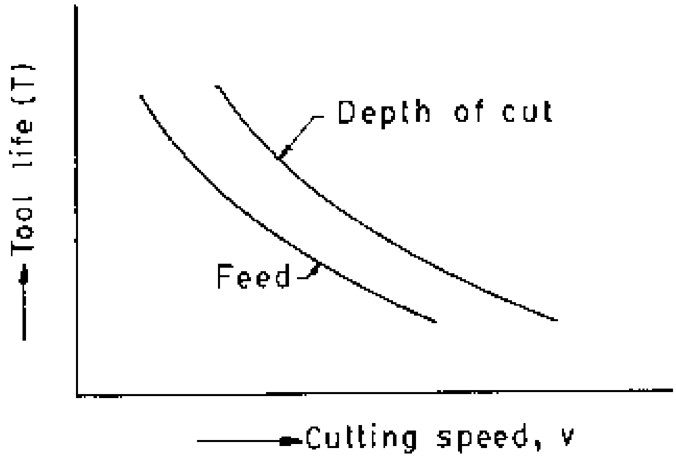


Fig.7 : Effect of 's' & 't' on tool life and speed

For, S=1, t=1 and taking tool life as const, then v'=C

For economic metal cutting, the critical cutting speed plays an important role. At critical cutting speed, the chip-tool contact processes changes sharply. For single carbide tool optimum cutting speed, v_{op} is less or equal to critical cutting speed, v_c, i.e. $v_{op} \le v_c$. Critical cutting speed point was denoted by many authors as 'critical point' or 'v-critical'. For single carbide tool, at the critical cutting speed, the tool life T is maximum. With further increase of the cutting speed tool life decreases. At the critical cutting speed, cutting force is maximum. These were derived by various researchers. In this work critical cutting speed was determined by measuring tool wear after turning operation and then optimum cutting condition was determined. Finally economic analysis was done.

CHAPTER THREE

DETERMINATION OF CRITICAL CUTTING SPEED AND OPTIMUM CUTTING CONDITION IN TURNING STAINLESS STEEL WITH CEMENTED CARBIDE TOOL

3.1 THEORY

Flank wear is a flat worn behind the cutting edge which eliminates some clearance or relief. Flank wear is limited ordinarily to a maximum of about 1/32 inch or 0.80 mm. The tool is considered to have reached the end of its useful life when this maximum has been reached. It must then be resharpened. The flank wear will be rapid if the temperature is too high during cutting process. If a cutting tool is allowed to wear too far, an excessive amount of tool material will have to be removed by grinding in order to recondition it. As cutting speed is increased, tool life decreases. A relationship between tool life and cutting speed may be shown by a typical graph as follows (Fig. 8).

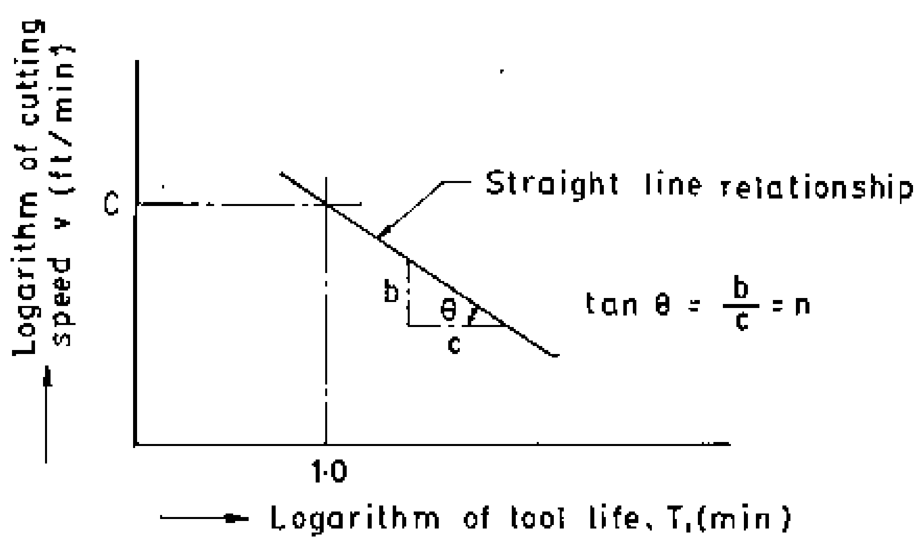


Fig.8 : Relationship between tool life and cutting speed shown plotted on log-log graph paper

This graph is drawn on a log-log graph paper-cutting speed as the ordinate and the tool life as the abscissa.

This line may be expressed by the slope-intercept type of equation for a straight line as,

$$v = \log c - n \log T$$

Taking antilogs

$$c = VT^n$$

where,

n = constant depending upon cutting condition

C = cutting speed for tool life of 1 min

T = Tool life, min.

For economic reasons, a relatively intricate cutting tool that is difficult to resharpen should be operated at a conservatively slow cutting speed.

Tool life may be observed by the following ways:-

i) The member of workpieces produce between tool sharpenings. This is the preferred method in manufacturing.

ii) Volume of material removed between tool sharpening.

iii) Cutting time in minutes between tool sharpenings. Cutting conditions must remain constant in this case.

The second method, that is the volume of the metal removed, is the most scientific method for measuring tool life and therefore preferred.

The flank wear is used to determine when a cutting tool has reached the end of its useful life. For large quantity production, tool life is very much important. The costs for the cutting tool sharpening and the down time of a large quantity production machine tool needed for the replacing of worn cutting tools with sharpened ones may account for the considerable portion of a machining operation cost. The forces required for the cutting increases when a tool cutting edge wears sufficiently or fails.

Tool wear, whether it is face or flank, is not uniform along the active cutting edge during actual machining operation. So it is difficult to measure. The effect of the wear of the carbide tool on the workpiece cannot be observed. So it is also difficult to determine the life of cemented carbide tool. It was determined 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 determined by mean of a Metallugrical Microscope.

Fig. 9 shows the flank wear:

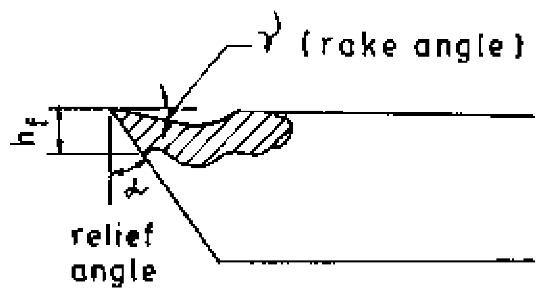
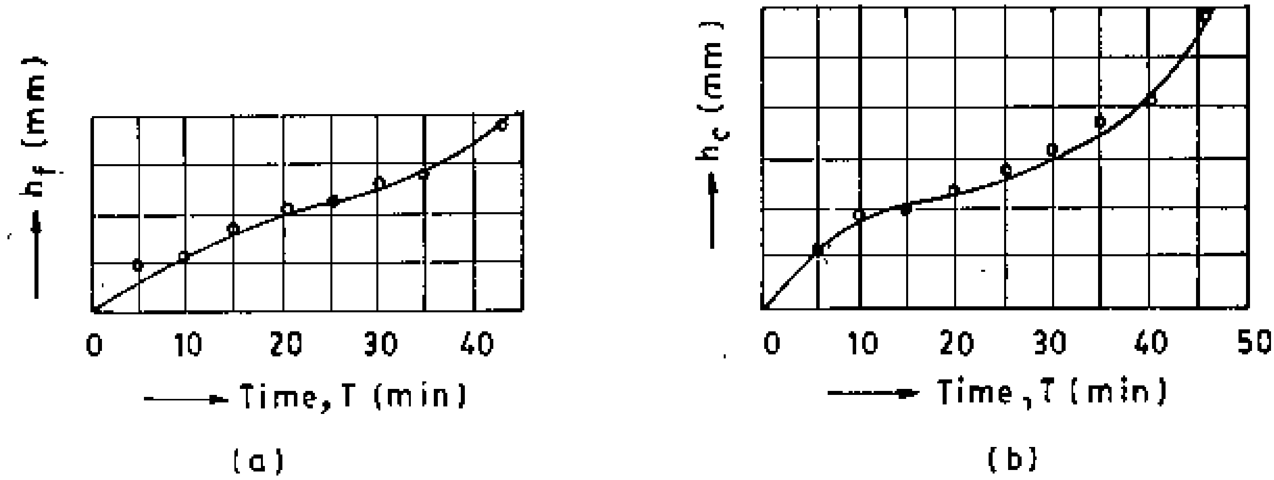


Fig.9 : Erratic width of the flank wear.

By Brearer[10] it was experimentally shown that the flank wear is the only the determining factor of the tool life of a carbide tool.

The dependence of wear on time and tool operation is expressed by the wear vs. time curve as shown in Fig.10.

In Fig. 10(a) it is for flank wear and 10(b) it is for face wear.



(a) (b)

Fig.10 : Relationship between wear and the time of operation (Typical curve)

The wear can be divided into three sections as follows : (Fig.11)

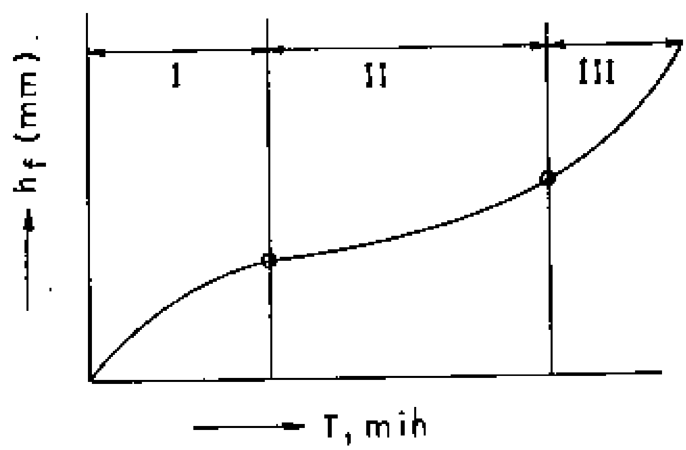


Fig. 11 : For a given work and tool material relationship between tool wear and time of operation

Section I : This is the wear-in period (initial wear) during which heavy abrasion of the most salient parts of the surface occurs. In flank wear this section is less pronounced.

Section II : This is the period of normal wear. With the operation time (abrasion time) increases it increases gradually.

Section III : This period begins after certain degree of wear has been reached and the friction condition changes.

3.2 DETAILED DESCRIPTION OF WORK MATERIAL AND TOOL MATERIAL

The total experiment was carried out in the machine shop of BUET. Two stainleess steel bar were used for this purpose. Both of them were about 90-94 mm of diameter and 950-1050 mm of length. The cemented carbide tip which used is Bk8 type. It contains 8% of Co and rest W_c. The tool was used during turning operation. It was resharpened with grinding after turning in a particular speed, feed and depth of cut.

The tool geometry was as follows:

α & $\alpha_1 = 10^0$

Γ & $\Gamma_1 = 0^0$

$\phi = 45^0$

$\phi_1 = 25^0$

The lathe machine used was Celtic-14 type provided with a 3.0 hp motor. Spindle speed of 60, 95, 118, 130, 185, 230, 260 r.p.m. were used.

The feed were 0.1, 0.20, 0.32 mm/rev. and the depth of cut were 0.5, 1.0 and 1.5 mm. All combinations of feed and deepth of cut were used to perform the experiment.

3.3 ASSUMPTIONS AND CONDITIONS OF THE EXPERIMENT

Some assumptions were considered during the experiment. They are as follows:

i) It was considered that the cutting region was more or less in steady state.

ii) Effect of temperature, pressure were not considered.

iii) The properties of work material and tool material do not vary during and after the operation

We know from the earlier theoretical investigations that to determine the optimum cutting condition, the factors which influence the process are speed, feed, depth of cut, cutting force, tool geometry, tool life, cutting fluid etc. In this experiment tool geometry was considered constant througout the experiment, thus omitting the effect of this factor. Cutting fluid was not used in the project work, since it has considerable effect in the cutting process. It was not used because coolant quickly shorters cutting edge and forms cracks for repeated quenching.

3.4 EXPERIMENTAL SET UP

In the experiment, it was noted that round solid bar was turned by cemented carbide tool. To determine the critical cutting speed, tool wear were measured in the metallurgical microscope. Initially two stainless steel bar were rough turned to 86 mm of dia from 90-94 mm of dia. This was performed to make ready the bars for the experiment. Cutting speed were selected near about 15, 25, 35 and 45 m/min. It was selected from the previous experimental knowledges.

First of all for a set of feed and depth of cut, a r.p.m. was selected to turn the bar with the existing diameter and with the selected speed. The traverse length was 10-11 mm. The time and the actual speed of the machine was also recorded by a stop watch and techometer respectively. Flank tool wears were measured under the microscope. This turning process at this combination of feed, depth of cut and r.p.m. was performed times and each time tool wear were measured. To rense this tool for another speed, it was grinded to the desired tool geometry which was used in this experiment. Critical cutting speed and optimum cutting conditions were determined from the measured cutting speed.

3.5 EXPERIMENTAL DETAILS AND DETERMINATION OF CRITICAL AND OPTIMUM CUTTING SPEED

To determine the critical cutting speed, predetermined speeds were selected from the previous experimental results, which were near about 15, 25, 35 and 45 m/min. They were selected without considering that whether they were critical or not. Three sets of feed and depth of cut were selected i.e. S=0.1, 0.2 and 0.32 mm/rev. and t = 0.5, 1.0 and 1.5 mm. The tool geometry explained in the previous article.

For the turning operation of S=0.1 mm/rev., t=0.5 mm, N=64.82 r.p.m. (actual) and V=16.7 m/min (actual), the stainless steel bar was cut four times, each had 10 cm traverse length (Sample data sheet-1). Here, after every turning operation, the tool was carefully observed under the microscope to determine the flank wear. The amount of wear was recorded each time (Sample data sheet - 1). It was observed that the wear increased with the increase of traverse length.

For these values of tool wear h_f and the corresponding values of length of cut L_c, a curve was plotted in fig.12. From the curve, it was shown that the curve is a straight line, having a slope. It means by increasing the cutting speed, the flank wear increases gradually. Here the feed value is the lowest and the r.p.m. is minimum (i.e. 64.82 r.p.m). This means from the Fig.5, that at low speed, it has medium tool life (type-A).

No. of Observation	Traverse Length (cm)	Diameter (mm)	Cutting Time (min)	RPM		Velocity (m/min)		Length of Cut (m)	Tool flank wear (mm)
				Selected m/c	Actual	Calculated	Actual		
1 2 3 4	10 20 30 40	82	16.13 16.17 16.22 16.13	60	64.82	15.457	16.70	257.61 515.22 772.83 1030.44	0.015 0.055 0.08 0.12
1 2 3 4	10 20 30 40	70	8.07 8.02 8.05 8.07	118	120.96	25.950	26.60	219.92 439.82 659.74 879.64	0.005 0.007 0.095 0.12
1 2 3 4	10 20 30 40	61	5.18 5.17 5.15 5.18	185	189.94	35.453	36.40	191.64 383.28 574.91 766.55	0.007 0.011 0.15 0.17
1 2 3 4	10 20 30 40	78	5.20 5.22 5.22 5.18	185	188.54	45.33	46.20	245.04 490.09 735.13 980.18	0.07 0.12 0.16 0.19

Sample data sheet-1 for turning stainless steel at S = 0.1 mm/rev, t = 0.5 mm

Feed S (mm/rev) depth of cut, t (mm)	Velocity (Actual) (m/min)	Intensity of tool wear h_{fc} (mm/m)	Feed S (mm/rev) and depth of cut, t (mm)	Velocity (Actual) (m/min)	Intensity of tool wear h_{fc} (mm/m)
S = 0.1 t = 0.5	16.70	0.136×10^{-3}	S = 0.32 t = 1.0	16.20	0.635×10^{-3}
	26.60	0.104×10^{-3}		26.50	0.477×10^{-3}
	36.40	0.188×10^{-3}		35.10	0.321×10^{-3}
	46.20	0.173×10^{-3}		44.70	0.765×10^{-3}
S = 0.2 t = 0.5	16.90	0.333×10^{-3}	S = 0.1 t = 1.5	15.60	0.139×10^{-3}
	25.60	0.222×10^{-3}		25.20	0.097×10^{-3}
	35.80	0.250×10^{-3}		35.20	0.161×10^{-3}
	46.00	0.300×10^{-3}		47.10	0.183×10^{-3}
S = 0.32 t = 0.5	16.70	0.476×10^{-3}	S = 0.2 t = 1.5	16.00	0.367×10^{-3}
	25.60	0.296×10^{-3}		25.50	0.225×10^{-3}
	35.80	0.667×10^{-3}		36.30	0.429×10^{-3}
	47.00	0.600×10^{-3}		45.10	0.313×10^{-3}
S = 0.1 t = 1.0	16.00	0.217×10^{-3}	S = 0.32 t = 1.5	15.80	0.516×10^{-3}
	26.60	0.132×10^{-3}		25.60	0.422×10^{-3}
	36.20	0.088×10^{-3}		35.20	0.750×10^{-3}
	46.50	0.250×10^{-3}		46.10	0.422×10^{-3}
S = 0.2 t = 1.0	15.50	0.360×10^{-3}			
	26.00	0.320×10^{-3}			
	36.10	0.208×10^{-3}			
	46.40	0.483×10^{-3}			

Table - 3 : Determined values of h_{fc} for various feeds and depth of cuts in turning stainless steel.

From the shape of this curve (Fig.12) intensity of tool wear, h_{fc} was determined by using the relation, $h_{fc} = \frac{h_f}{L_c}$. All of the values of h_{fc} were listed in table-1 for stainless steel.

Similarly, for the above set of feed and depth of cut i.e. S=0.1 mm/rev. and t=0.5 mm, tool wear were measured for the cutting speed of 26.6, 36.4 and 46.2 m/min (actual). In each case, h_f vs. L_c curve was drawn (Fig.12). From that graphs intensity of tool wear, h_{fc} were also calculated. It was mentioned above that all of the values of h_{fc} were listed in table-1.

The nine sets of feed and depth of cut used for various speeds were as follows:

S = 0.1 mm/rev. t = 0.5 mm	S = 0.2 mm/rev. t = 0.5 mm	S = 0.32mm/rev. t = 0.5 mm
S = 0.1 mm/rev. t = 1.0 mm	S = 0.2 mm/rev. t = 1.0 mm	S = 0.32 mm/rev. t = 1.0 mm
S = 0.1 mm/rev. t = 1.5 mm	S = 0.2 mm/rev. t = 1.5 mm	S = 0.32 mm/rev. t = 1.5 mm

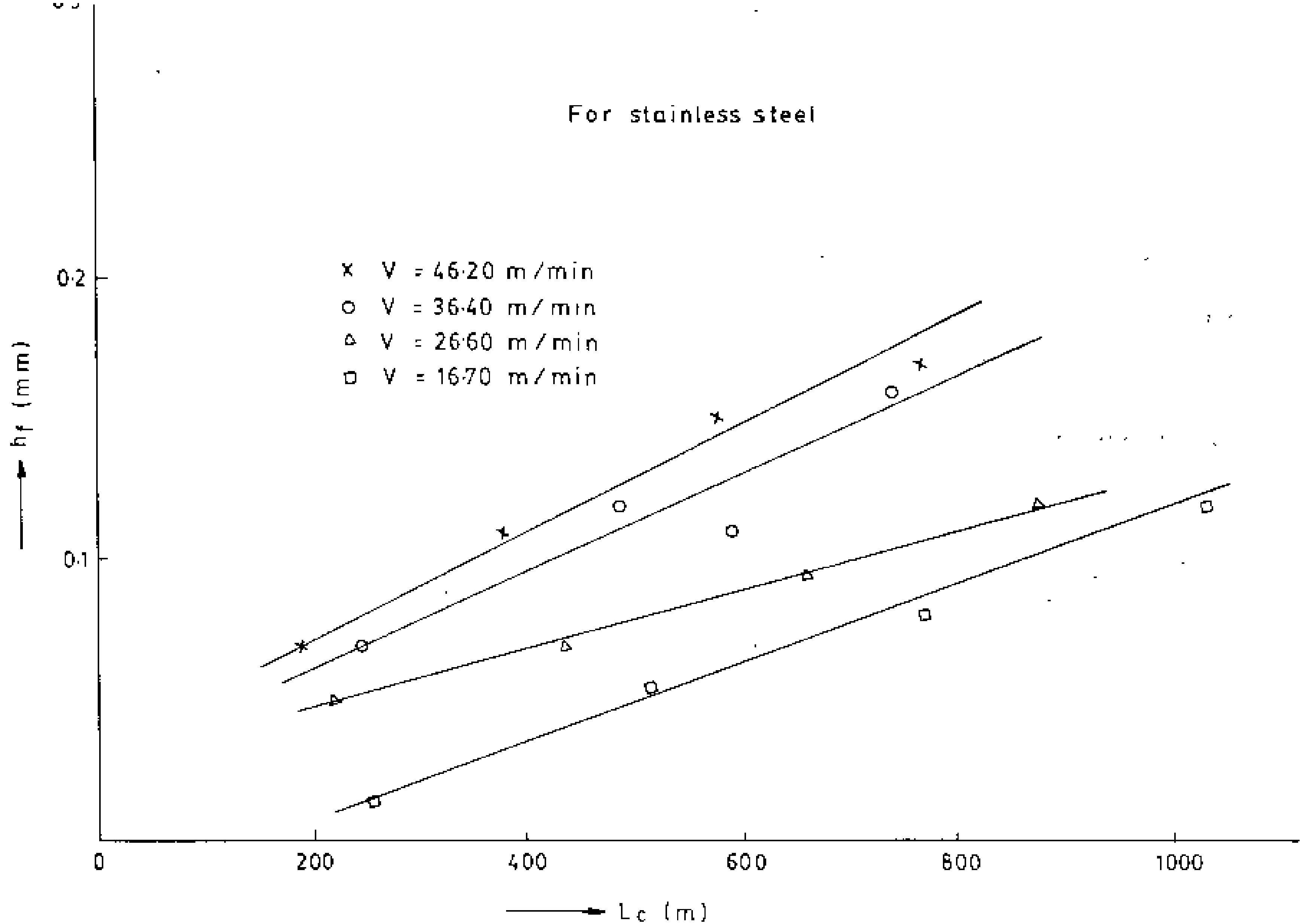


Fig. 12 Effect of cutting length on flank wear h_f for S = 0.1 mm/rev
t = 0.5 mm (éxperimental)

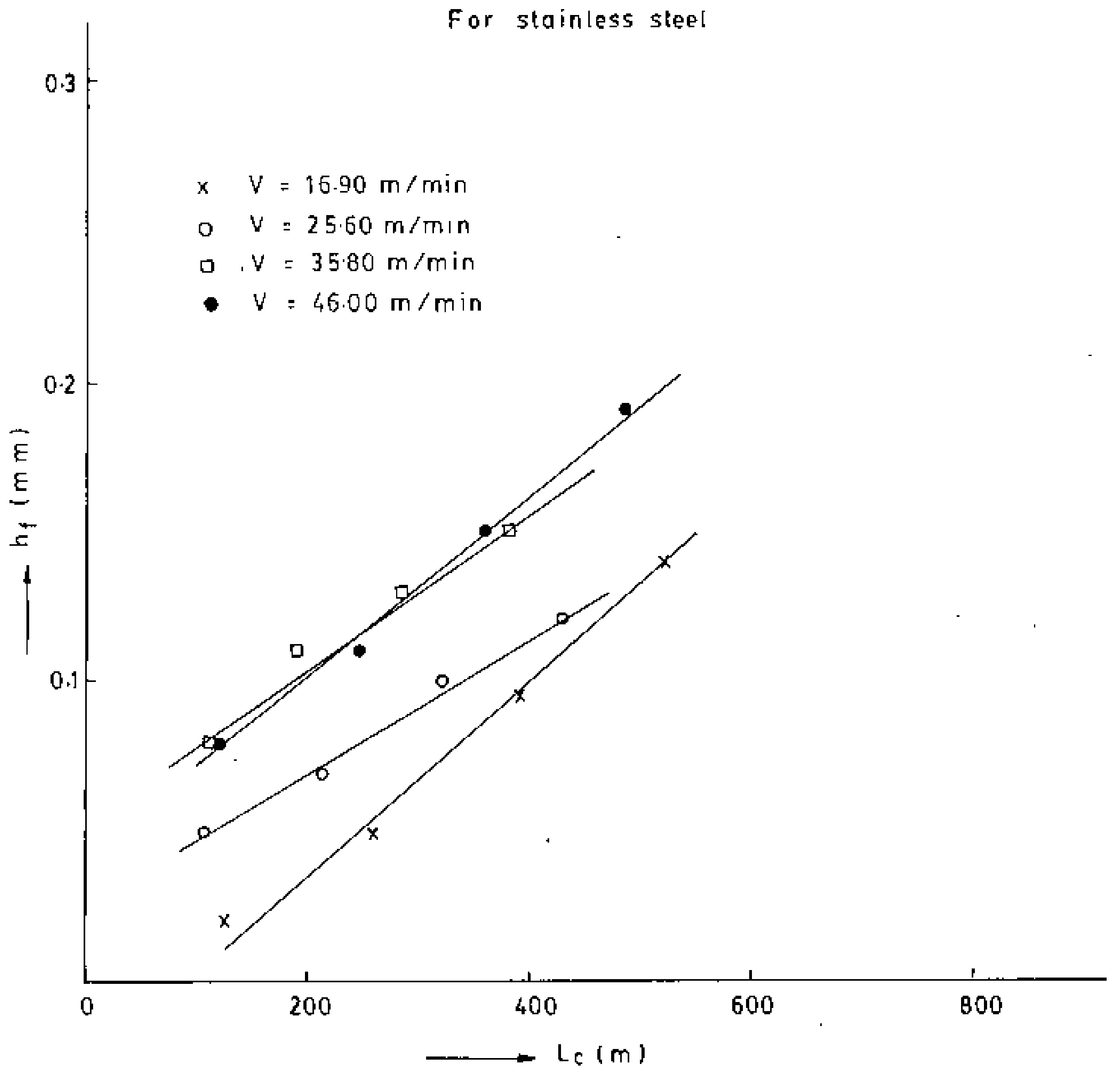


Fig. 13 Effect of cutting length on flank wear for S = 0.2 mm/rev
t = 0.5 mm (experimental)

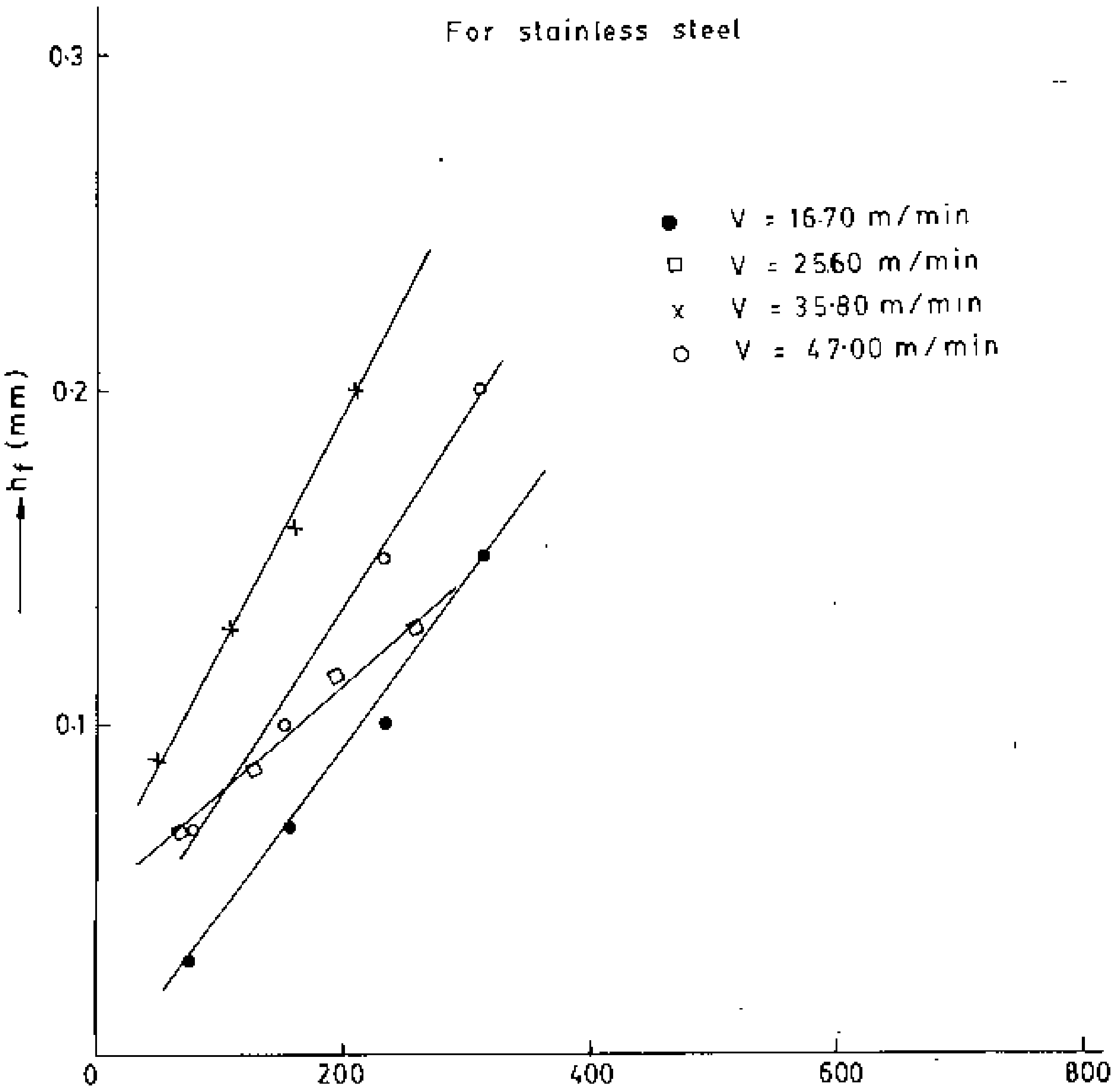


Fig.14 Effect of cutting length on flank wear for S = 0·32 mm/rev. t = 0·5 mm (experimental)

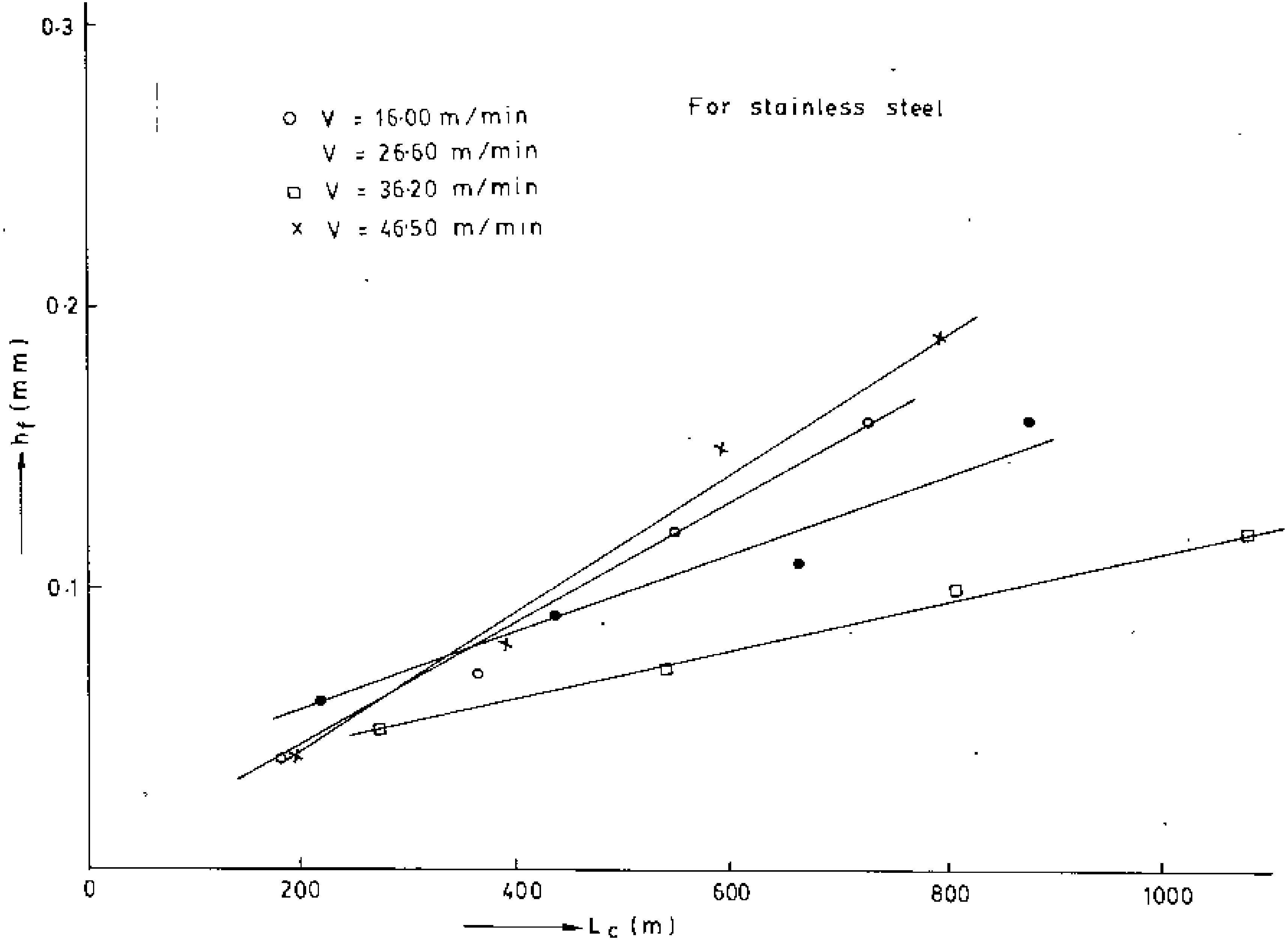


Fig.15 Effect of cutting length on flank wear for S = 0·1 mm/rev and t = 1·0 mm (experimental)

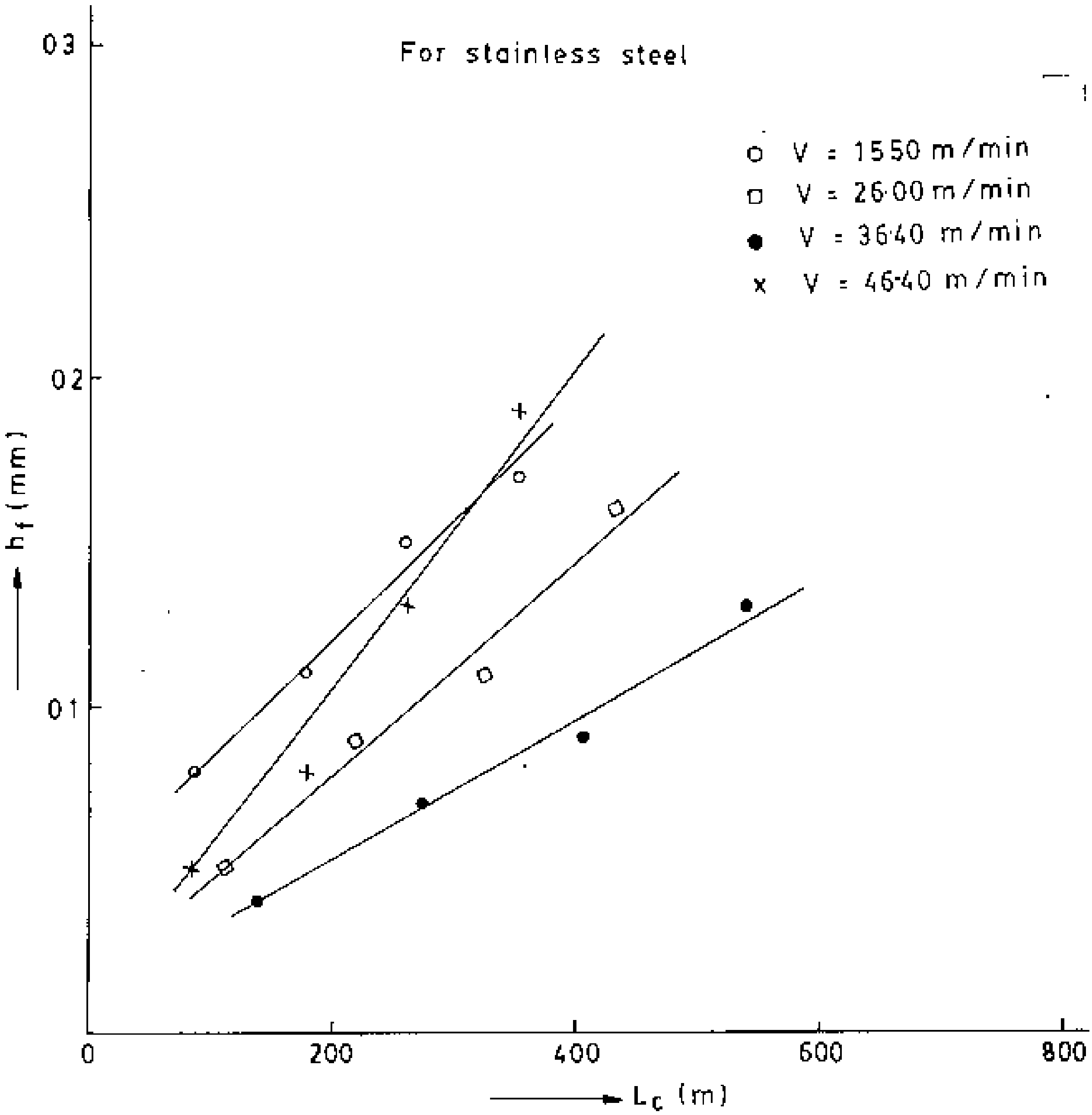


Fig.16 Effect of cutting length on flank wear for $S = 0{\cdot}2$ mm/rev and $t = 1{\cdot}0$ mm (experimental)

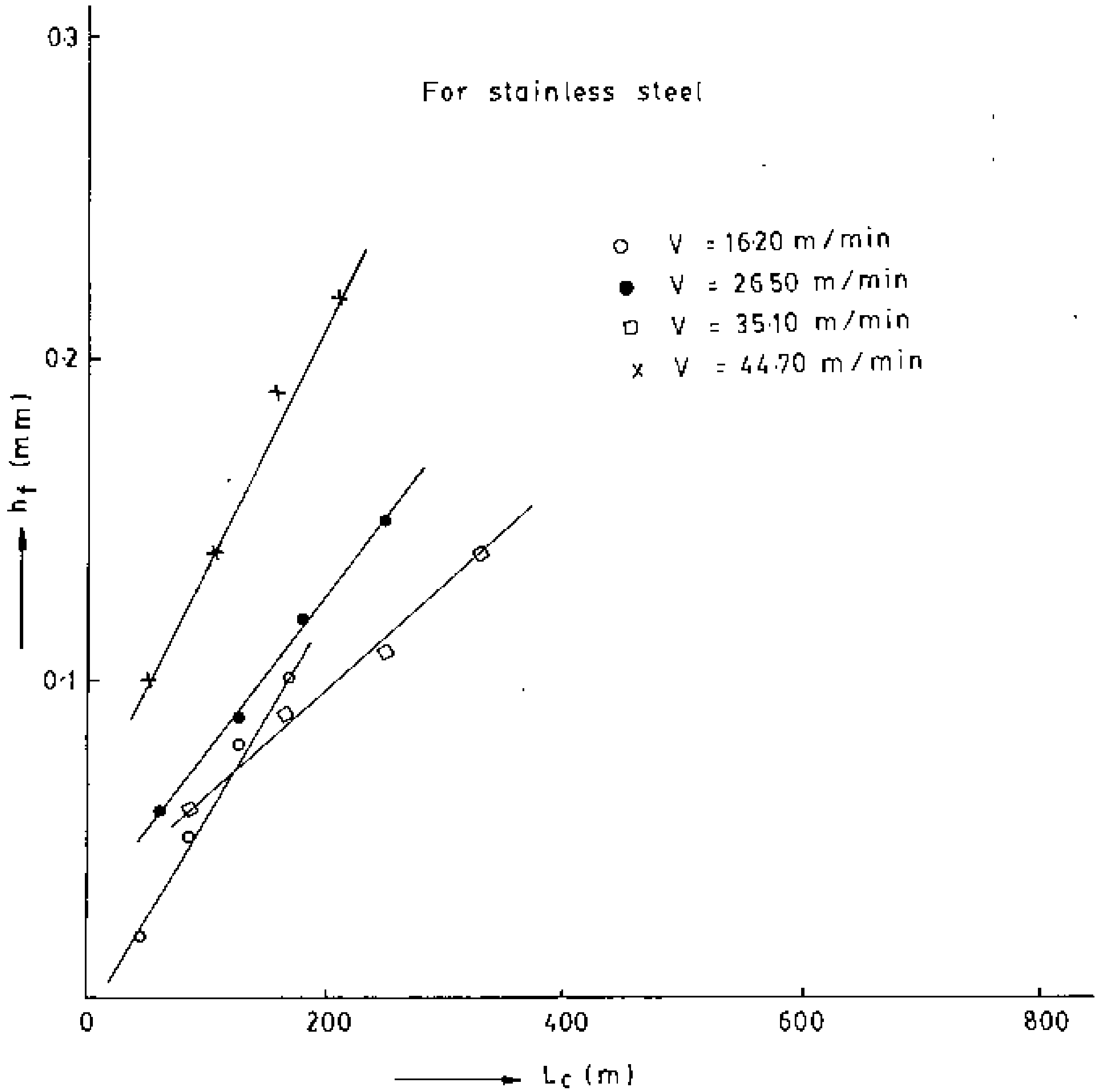


Fig.17 Effect of cutting length on flank wear for S = 0.32 mm/rev t = 1.0 mm (experimental)

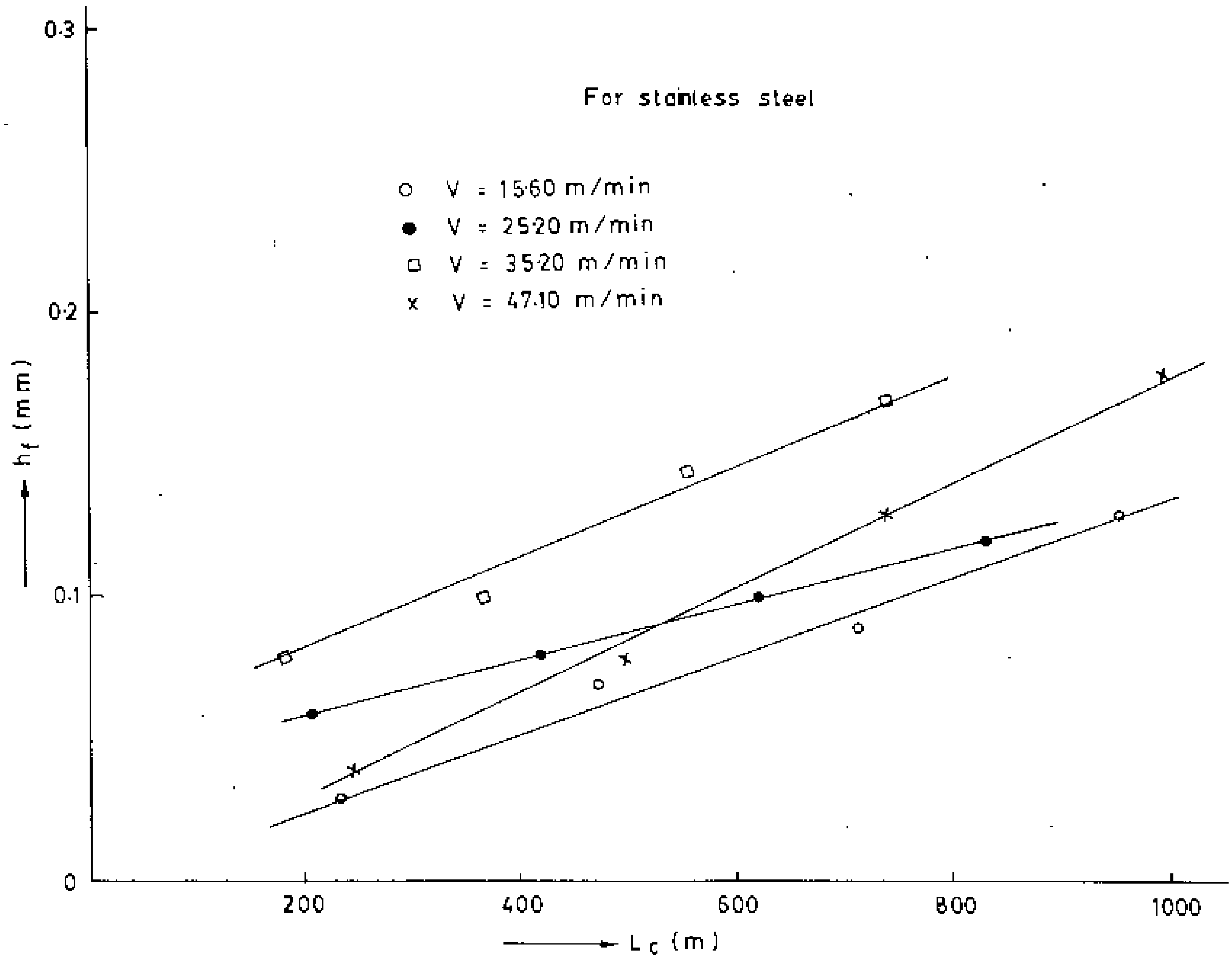


Fig.18 Effect of cutting length on flank wear for S = 0·1 mm/rev
t = 1·5 mm (experimental)

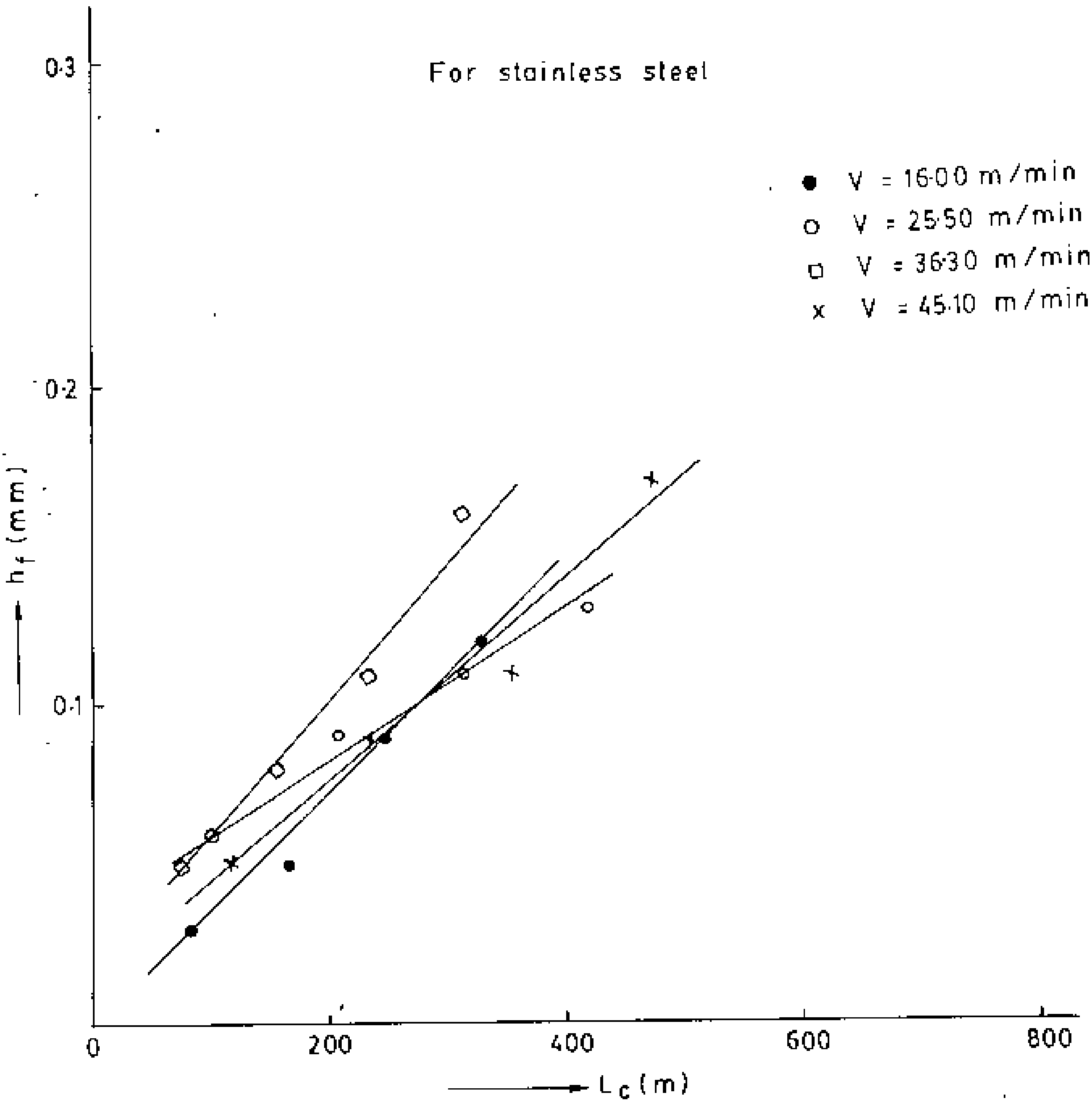


Fig.19 Effect of cutting length on flank wear for S = 0·2 mm/rev t = 1·5 mm (experimental)

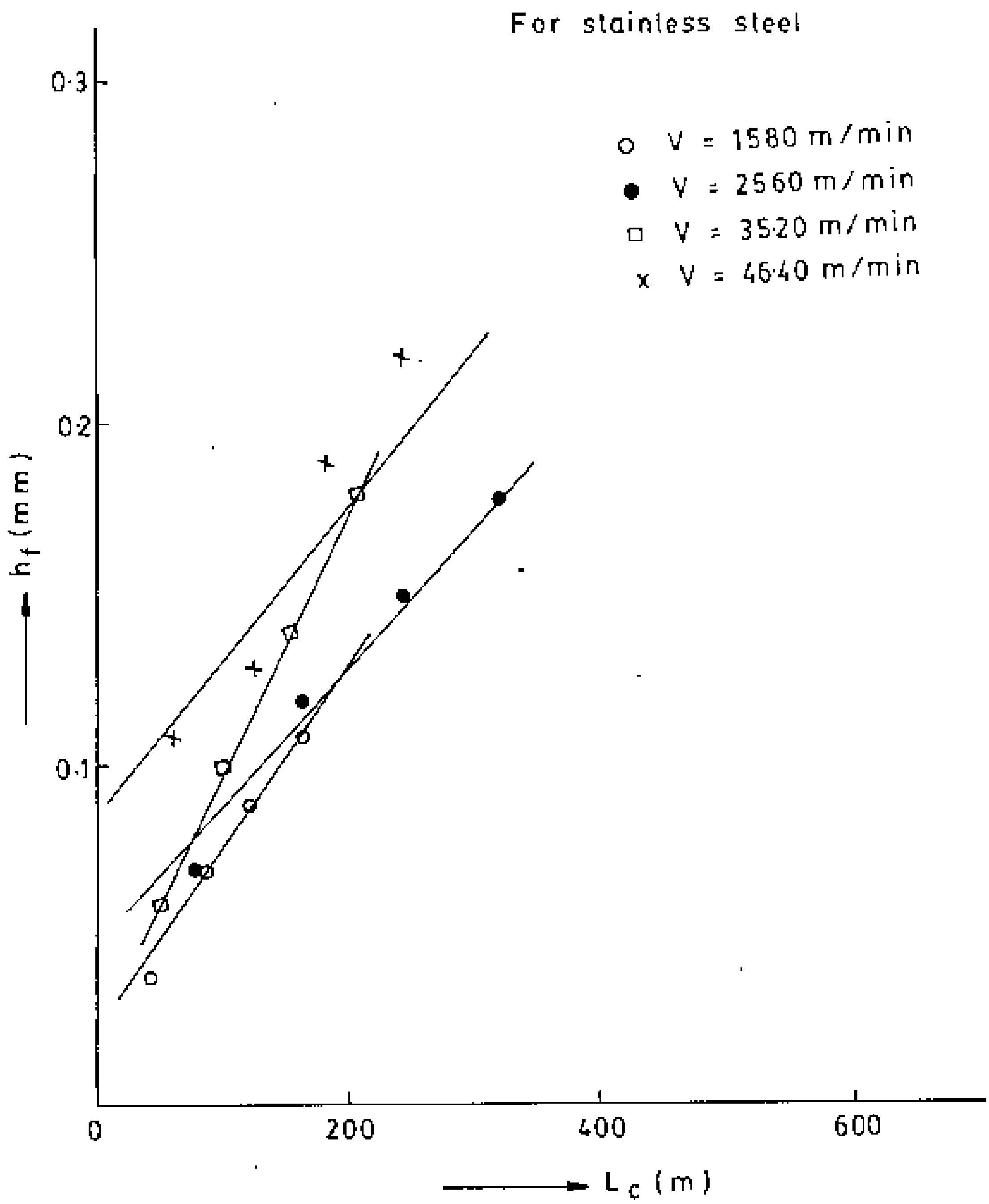


Fig 20 Effect of cutting length on flank wear for
S = 0.32 mm/rev t = 1.5 mm (experimental)

For each set, the h_f vs. v_c graph was plotted in Fig.12, 13, 14, 15, 16, 17, 18, 19 and 20.

It should be noted here that after the turning operation for a particular speed, it was carefully grinded to the original shape (the tool geometry used in this experiment). Actual r.p.m. and cutting time were also measured during the turning operation. Chips were also collected for microscopic analysis and to determine the optimum cutting condition.

For a set of feed and depth of cut there are four values of h_{fc} and v. Critical cutting speed, v_c was determined for each set of feed and depth of cut. The optimum cutting conditions were determined from the graph intensity of tool wear vs.speed. For the different cutting conditions,the optimum cutting speed were determined. Values of the critical and optimum cutting speeds are listed in table:2 & 3 showing influence of depth of cut and feed. Figure 21, 22 & 23 respectively show the influence of feed and figure 24, 25 & 26 respectively show the influence of depth of cut in determining the optimum cutting speed.

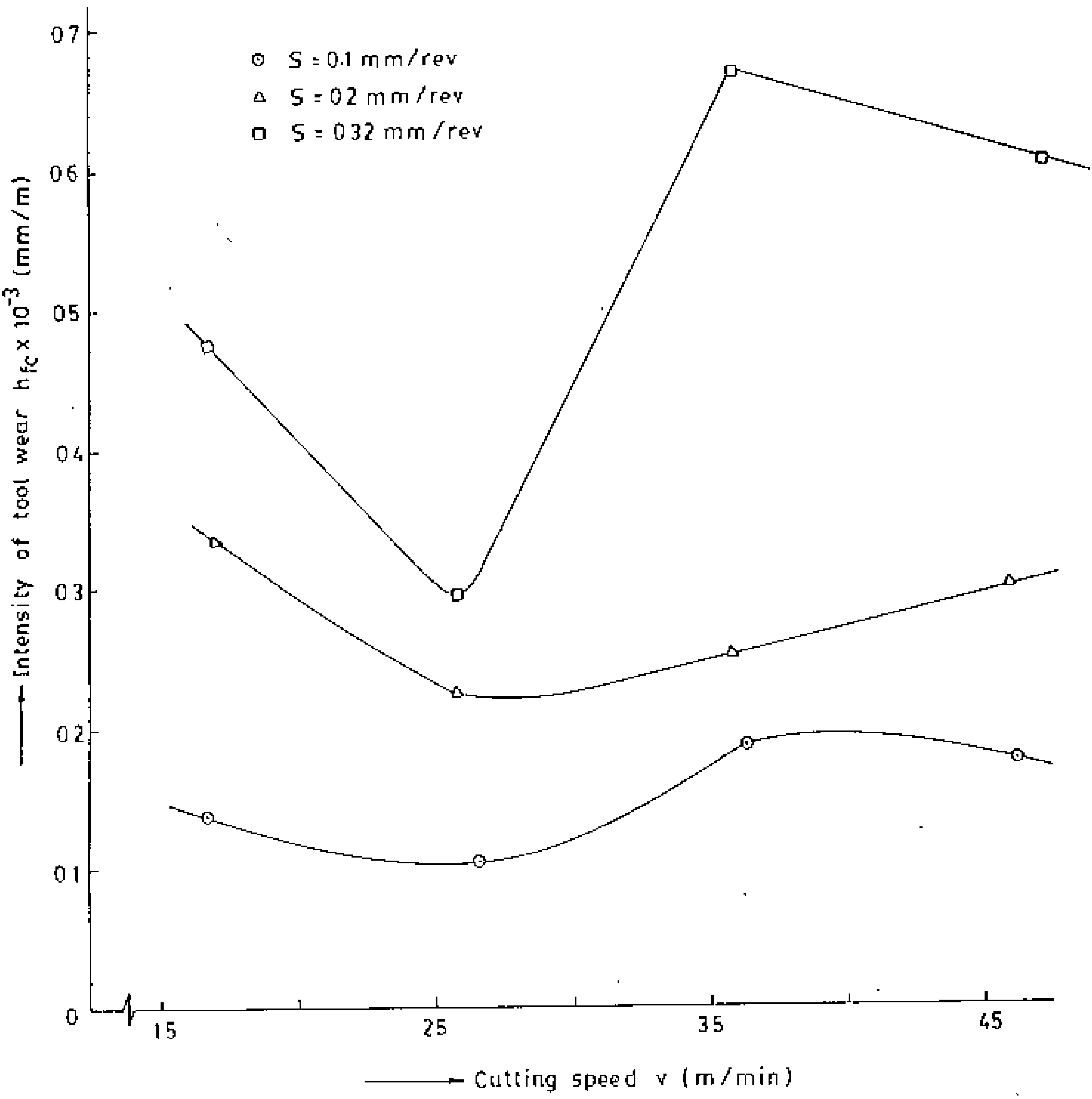


Fig 21 Determination of optimum cutting speed of stainless steel keeping depth of cut constant at t = 0.5 mm (Experimental)

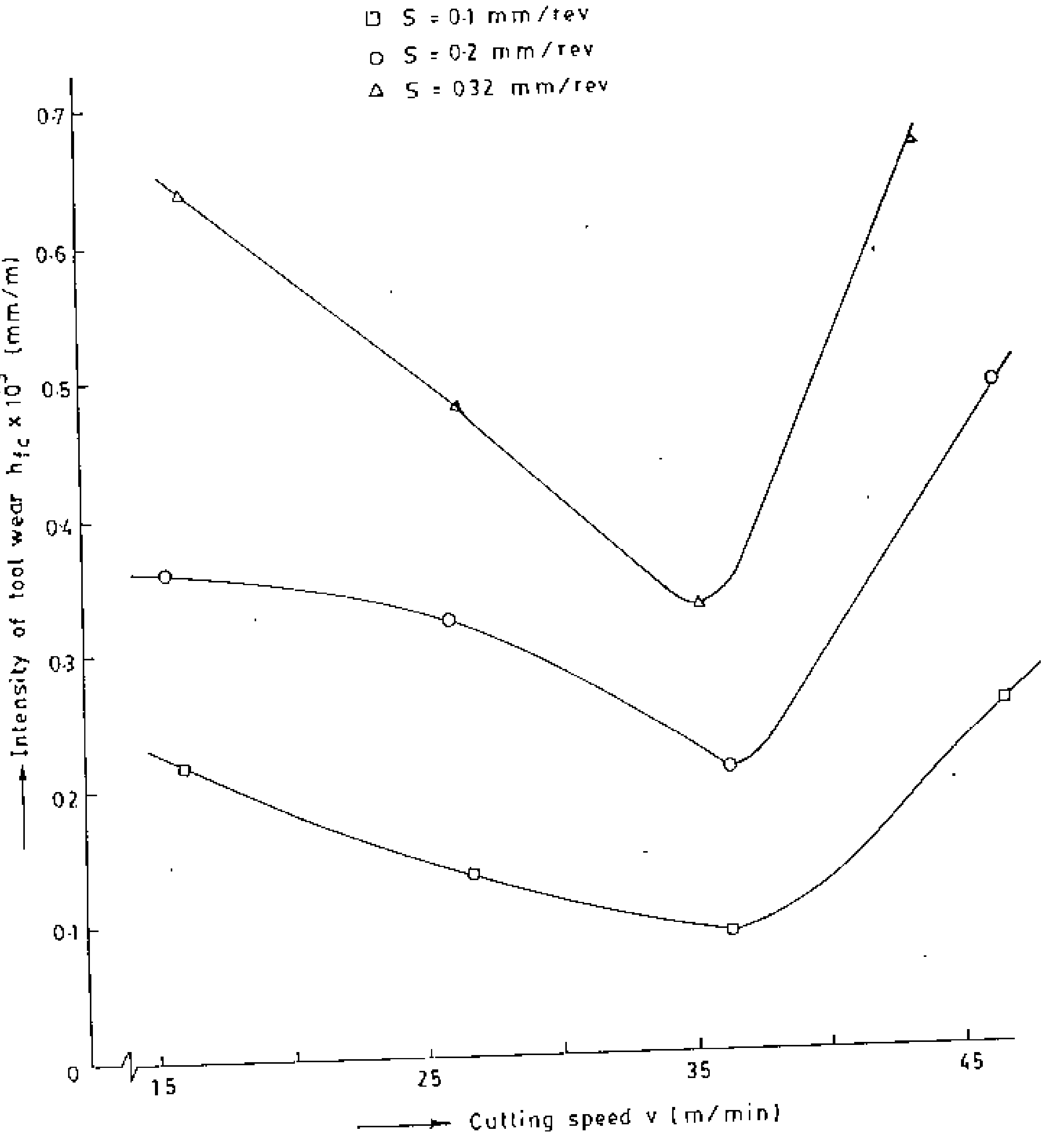


Fig. 22 Determination of optimum cutting speed of stainless steel keeping depth of cut constant at t = 1·0 mm (Experimental)

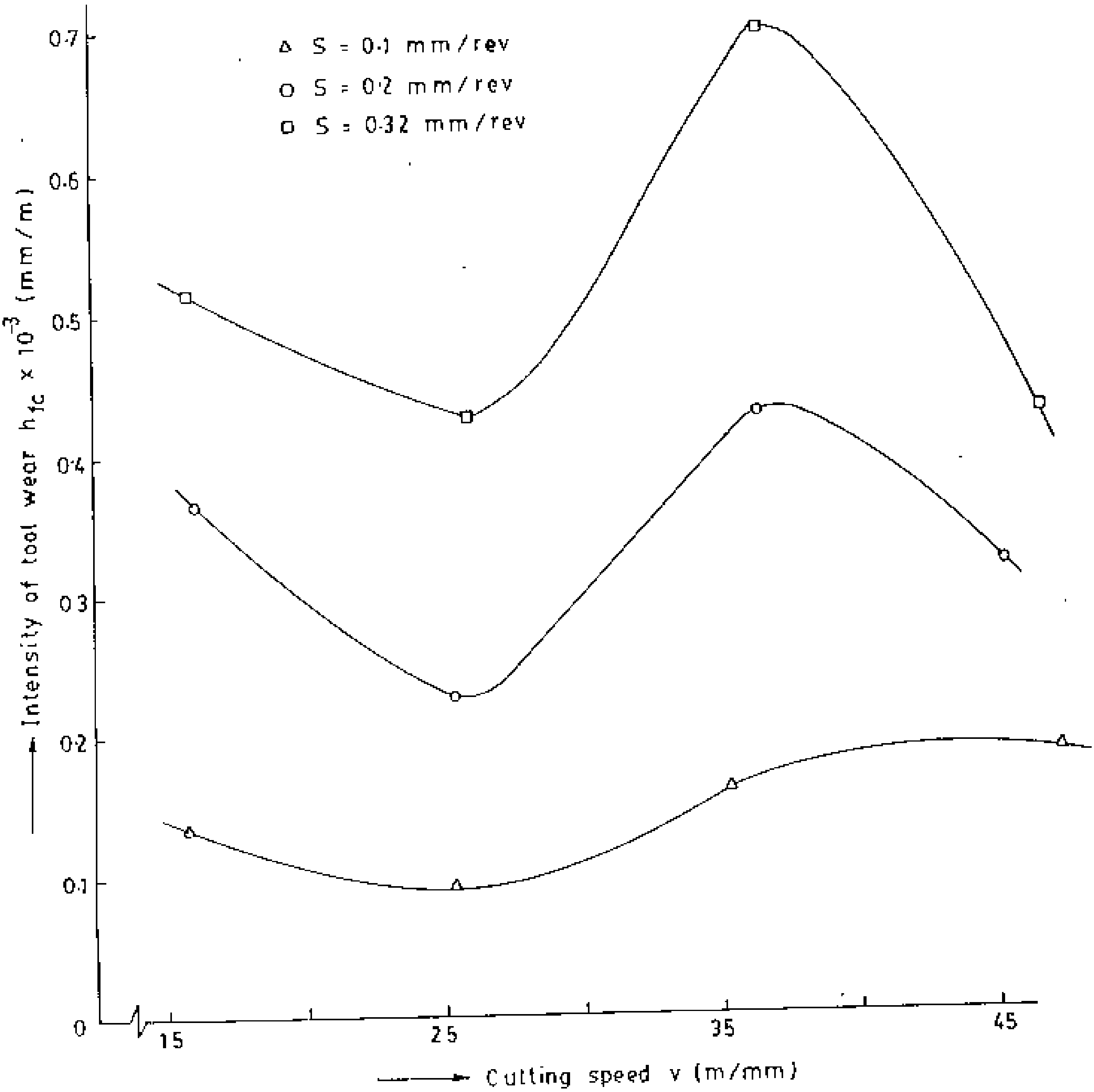


Fig. 23 Determination of optimum cutting speed of stainless steel keeping depth of cut constant at t = 1·5 mm (experimental)

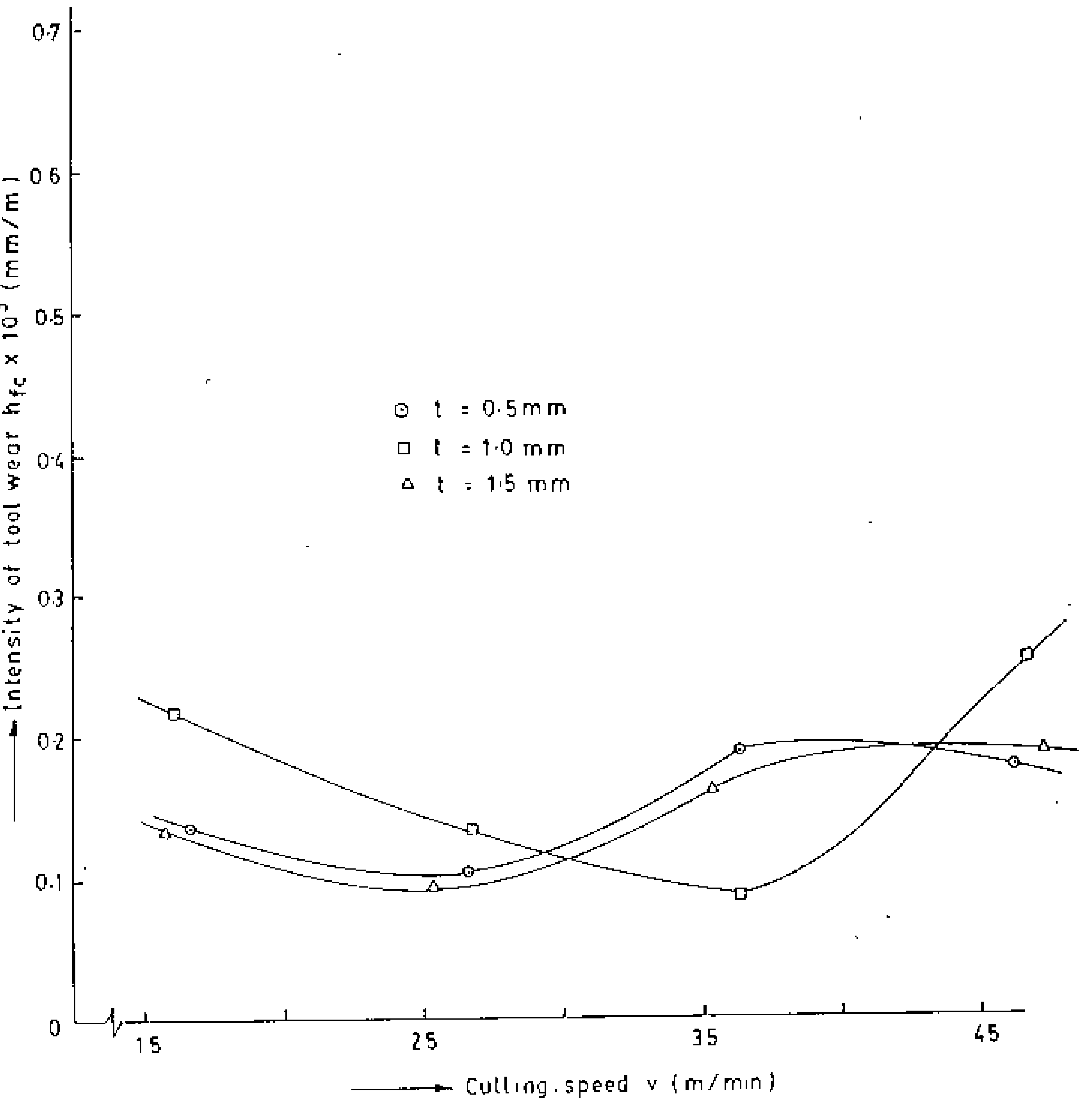


Fig 24 Determination of optimum cutting speed of stainless steel keeping feed constant at S = 0.1 mm/rev (experimental)

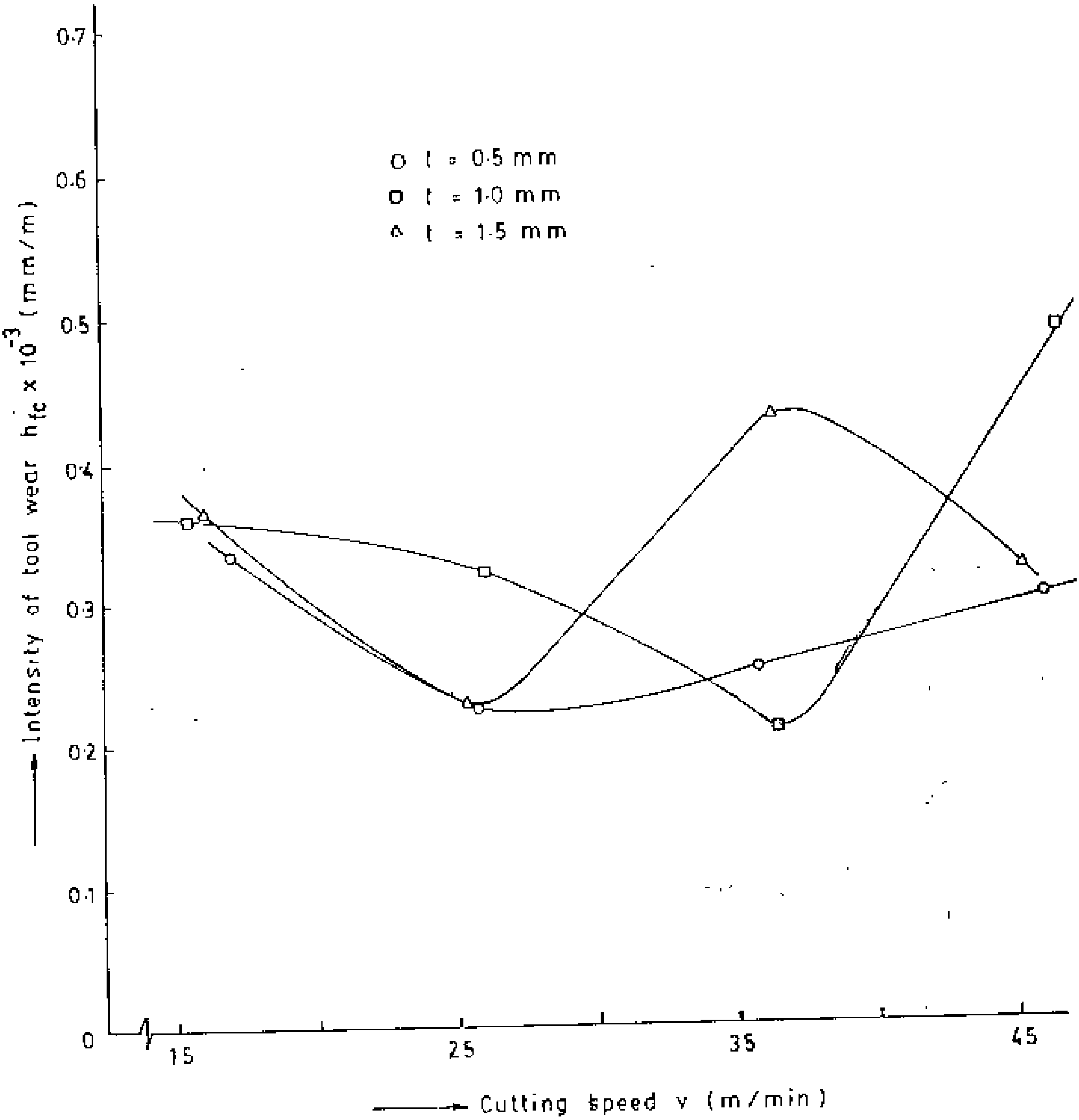


Fig 25 Determination of optimum cutting speed of stainless steel keeping feed constant at S = 0.2 mm/rev (experimental)

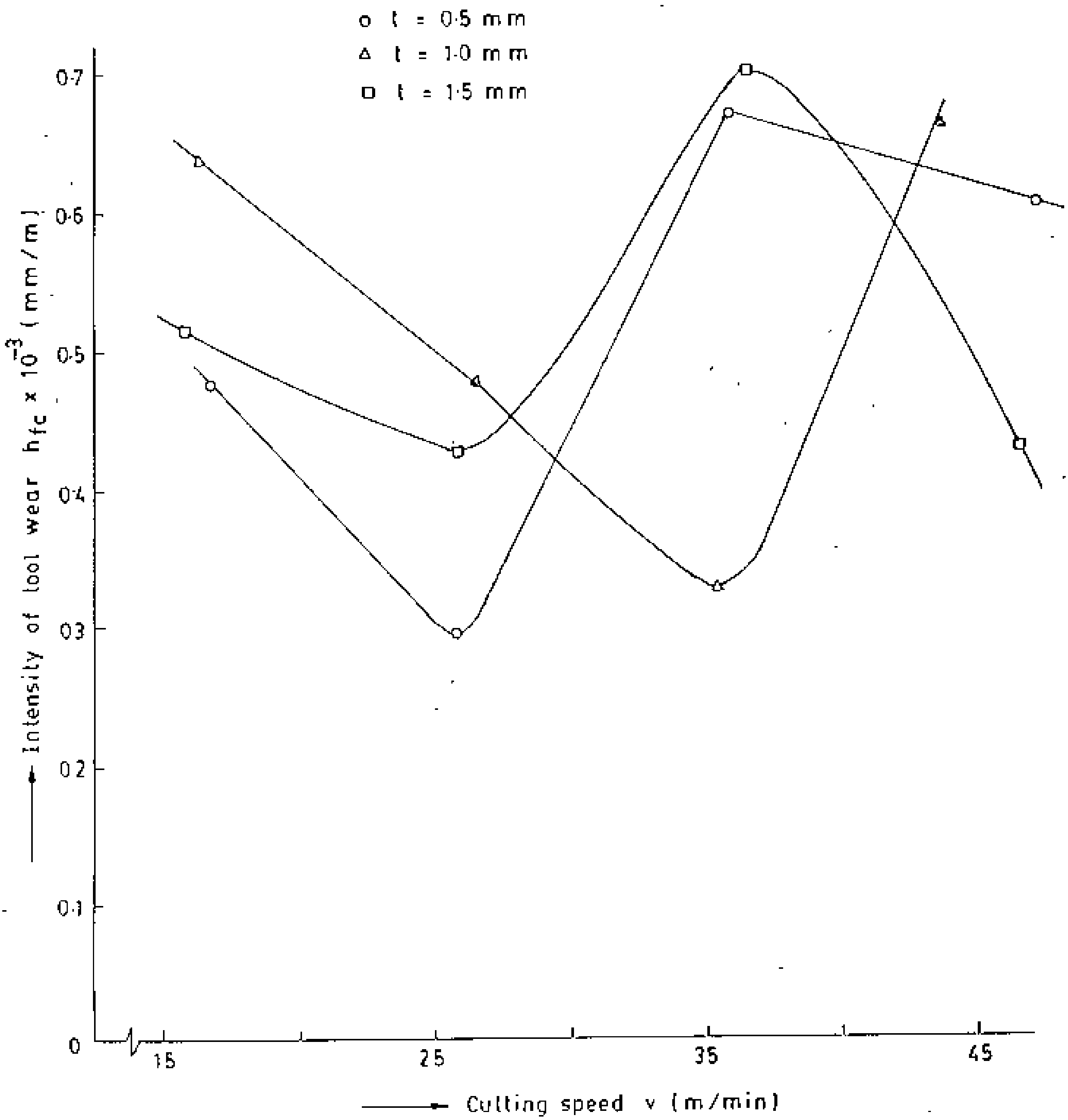


Fig 26 Determination of optimum cutting speed of stainless steel keeping feed constant at S = 0·32mm/rev (experimental)

Depth of cut, t (mm)	Feed, S (mm/rev)	Critical cutting speed, v_c (m/min)	Optimum cutting speed, v_{op} (m/min)	Diameter (mm)	Corres-ponding rpm
0.5	0.1	35	25.0	84.0	95
	0.2	25-35	25.5	85.5	95
	0.32	25-35	25.5	85.5	95
1.0	0.1	35-45	36.0	62.0	185
	0.2	35-45	36.0	62.0	185
	0.32	25	35.0	60.0	185
1.5	0.1	35	25.5	85.5	95
	0.2	25-35	25.0	84.0	95
	0.32	25	25.0	84.0	95

Table- 2 : Values of different critical & optimum cutting speeds of stainless steel showing influence of feed.

Feed, S (mm/rev)	Depth of cut, t (mm)	Critical cutting speed, v_c (m/min)	Optimum cutting speed, v_{op} (m/min)	Diameter (mm)	Corresponding rpm
0.1	0.5	35	25.0	84.0	95
	1.0	35-45	36.0	62.0	185
	1.5	35	25.5	85.5	95
0.2	0.5	25-35	25.5	85.5	95
	1.0	35-45	36.0	62.0	185
	1.5	25	25.0	84.0	95
0.32	0.5	25-35	25.5	85.5	95
	1.0	25-35	35.0	60.0	185
	1.5	25	25.0	84.0	95

Table-3 : Values of critical and optimum cutting speed of stainless steel showing influence of depth of cut

3.6 EXPERIMENTAL RESULTS & CONCLUSION

The critical cutting speeds of stainless steel at S=0.1, 0.2 & 0.32 mm/rev. and at constant depth of cut, t=0.5 mm were found to be 35, 25-35 and 25-35 m/min. respectively. For the above set of feed but depth of cut at t=1.0 mm, the critical cutting speeds were found to be 35-45, 35-45 and 25 m/min. respectively. And at depth of cut t=1.5 mm, the critical cutting speeds were 35,25-35,and 25

From the above results it can be concluded that critical cutting speeds decreases with the increase of feed at constant depth of cut.

The optimum cutting speeds of stainless steel at feed S=0.1, 0.2 and 0.32 mm/rev. and at constant depth of cut, t=0.5 mm are 25.0, 25.5, 25.5 m/min. respectively. For the same set of feed values and depth of cut, t=1.0 mm, the optimum cutting speeds were found to be 36.0, 36.0 & 35.0 m/min respectively, and at depth of cut t=1.5 mm, the values are 25.5, 25.0 and 25.0 m/min respectively, which shows that effect of feed on optimum cutting speed is negligible.

It can be justified that for single carbide tool, optimum cutting speed is less or equal to critical cutting speed, i.e. $V_{op} \leq V_c$.

The above results can be rearranged so that at depth of cut, t=0.5, 1.0 and 1.5 mm and constant feed, S=0.1 mm/rev., the critical cutting speeds are 35, 35-45 and 35 m/min respectively. These values at S=0.2 mm/rev. are 25-35, 35-45 and 25 m/min and at S=0.32 mm/rev. are 25-35, 25-35 and 25 m/min. respectively. These results shows that by increasing the depth of cut at constant feed the values of the critical cutting speeds decreases. But the effect of depth of cut is smaller than that of feed on critical cutting speed.

The optimum cutting speeds, at depth of cut, t=0.5, 1.0 and 1.5 mm and constant feed, S=0.1 mm/rev. are 25.0, 36.0 and

25.5 m/min respectively. The values at S=0.2 mm/rev. are 25.5, 36.0 and 35.0 m/min and at S=0.32/rev. are 25.5, 35.0 and 25.0 m/min. From these results it is seen that there is an effect of depth of cut on optimum cutting speed.

Though a wide range of velocity was not used in the experiment, so some values of critical cutting speeds were determined in range.

CHAPTER FOUR

DETERMINATION OF CRITICAL CUTTING SPEED AND OPTIMUM CUTTING CONDITION IN TURNING CAST IRON WITH CEMENTED CARBIDE TOOL

4.1 DETAILED DESCRIPTION OF WORK AND TOOL MATERIALS

This experiment was also performed in the laboratory of BUET. Two solid bars of cast iron were used for this purpose. The lathe machine is used was Celtic-14 type provided with a 3 hp motor. The two bars were initially about 98 mm and 86 mm dia. And the length were 900-1000 mm. The tool used was the type of Bk8, which contains 8% of Co. and rest w_r. The tool geometry was as follows:

$$\alpha,\ \alpha_1 = 10^0$$

$$\Gamma,\ \Gamma_1 = 0^0$$

$$\phi = 45^0$$

$$\phi_1 = 25^0$$

The feed were 0.1, 0.2 and 0.32 mm/rev. and depth of cut were, 0.5, 1.0 and 1.5 mm.

4.2 EXPERIMENTAL DETAILS AND DETERMINATION OF CRITICAL AND OPTIMUM CUTTING CONDITION OF CAST IRON

To determine the critical cutting speed some pre-determined speeds were selected, whether they are critical or not. Total nine cutting conditions at this four cutting speeds, were

No. of Observation	Traverse Length (cm)	Diameter (mm)	Cutting Time (min)	RPM		Velocity (m/min)		Length of Cut (m)	Tool flank wear (mm)
				Selected m/c	Actual	Calculated	Actual		
1 2 3 4	8 16 24 32	50	2.42 2.42 2.40 2.42	95	97.40	14.923	15.30	39.27 78.54 117.81 157.08	0.07 0.01 0.13 0.15
1 2 3 4	8 16 24 32	82	2.43 2.45 2.43 2.45	95	96.27	24.473	24.80	64.40 128.80 193.20 257.60	0.07 0.09 0.11 0.13
1 2 3 4	8 16 24 32	92	1.88 1.87 1.87 1.88	118	121.79	34.105	35.20	72.26 114.52 216.78 289.04	0.06 0.08 0.11 0.13
1 2 3 4	8 16 24 32	76	1.22 1.23 1.22 1.20	185	187.63	44.171	44.80	59.69 119.38 179.07 238.76	0.08 0.12 0.15 0.17

Sample data sheet-2 for turning Cast Iron at S = 0.32 mm/rev, t = 1.5 mm

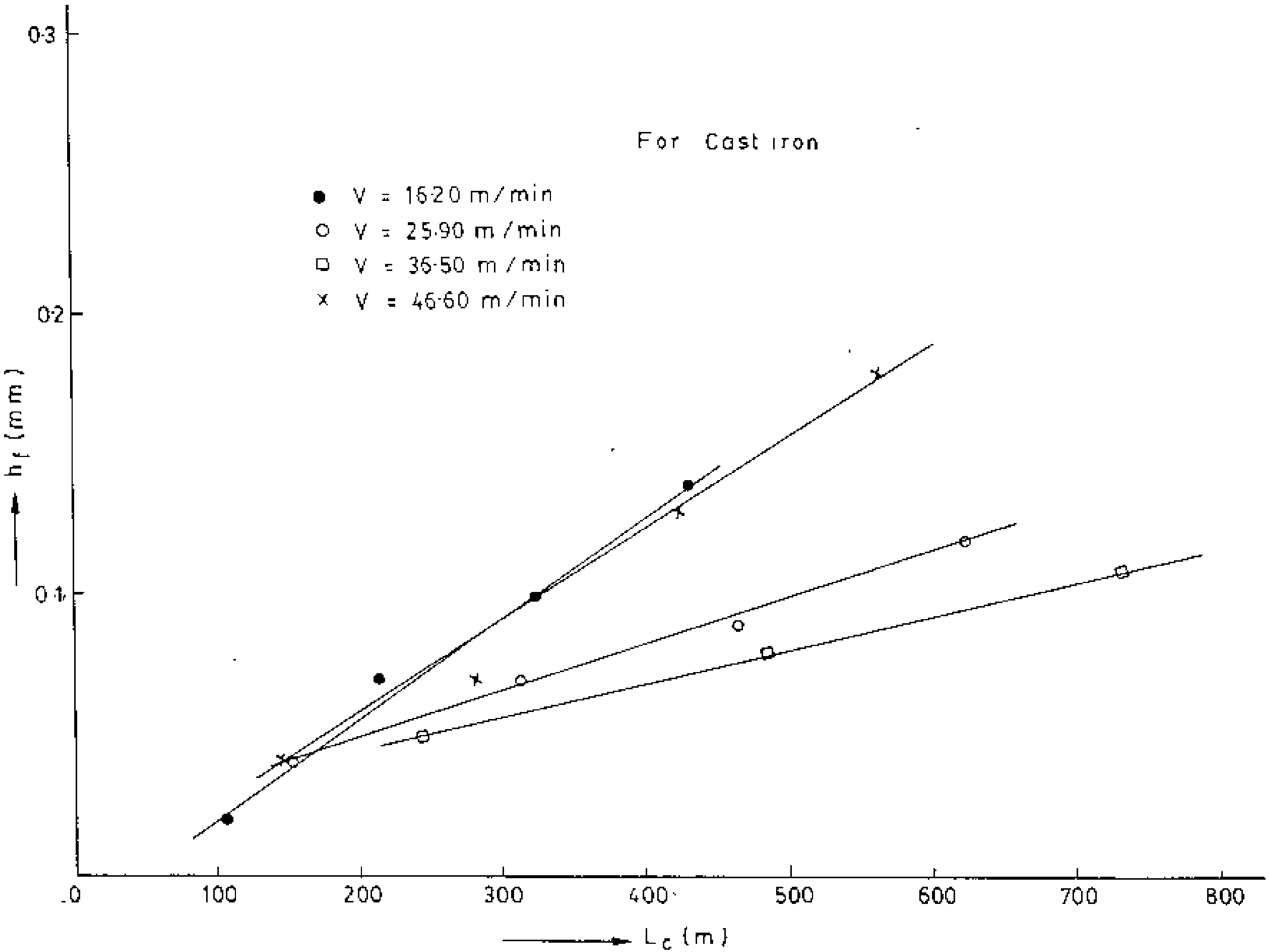


Fig. 27 Relationship between flank wear and length of cut at S = 0·1 mm/rev
t = 0·5 mm (experimental)

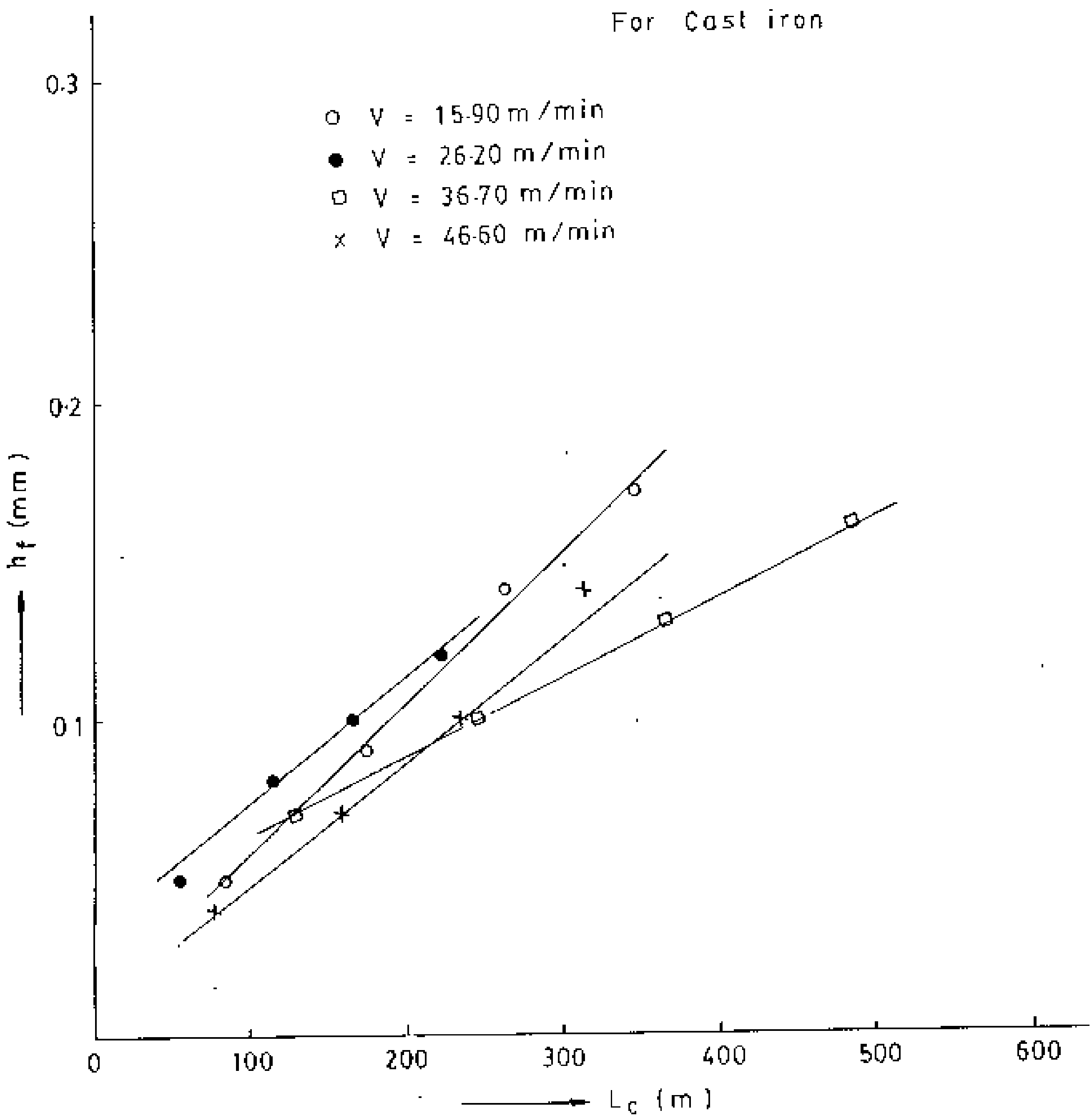


Fig. 28 Relationship between flank wear and length of cut at S = 0·2 mm/rev t = 0·5 mm (experimental)

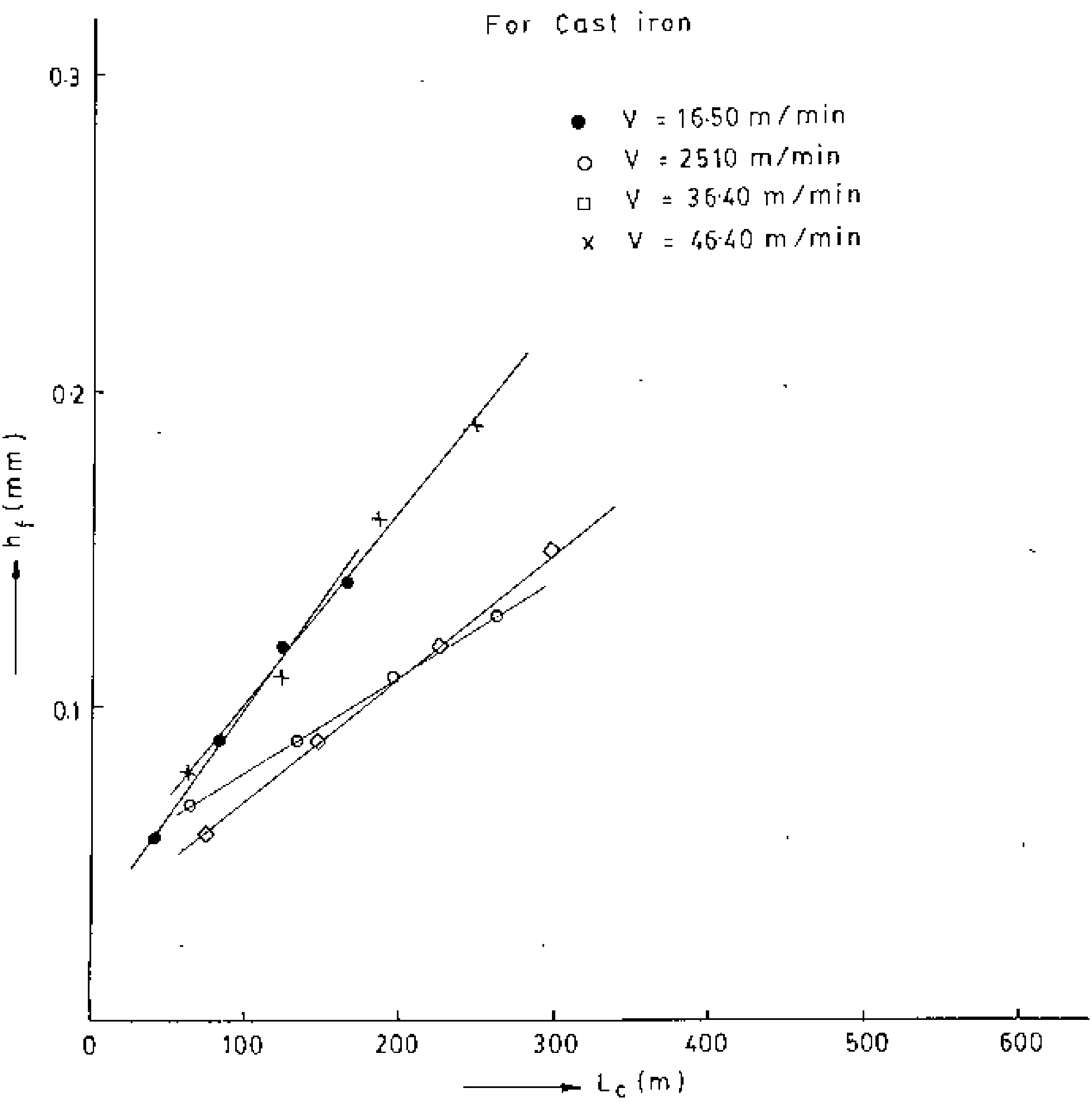


Fig.29 Relationship between flank wear and length of cut at S = 032 mm/rev t = 0 5 mm (experimental)

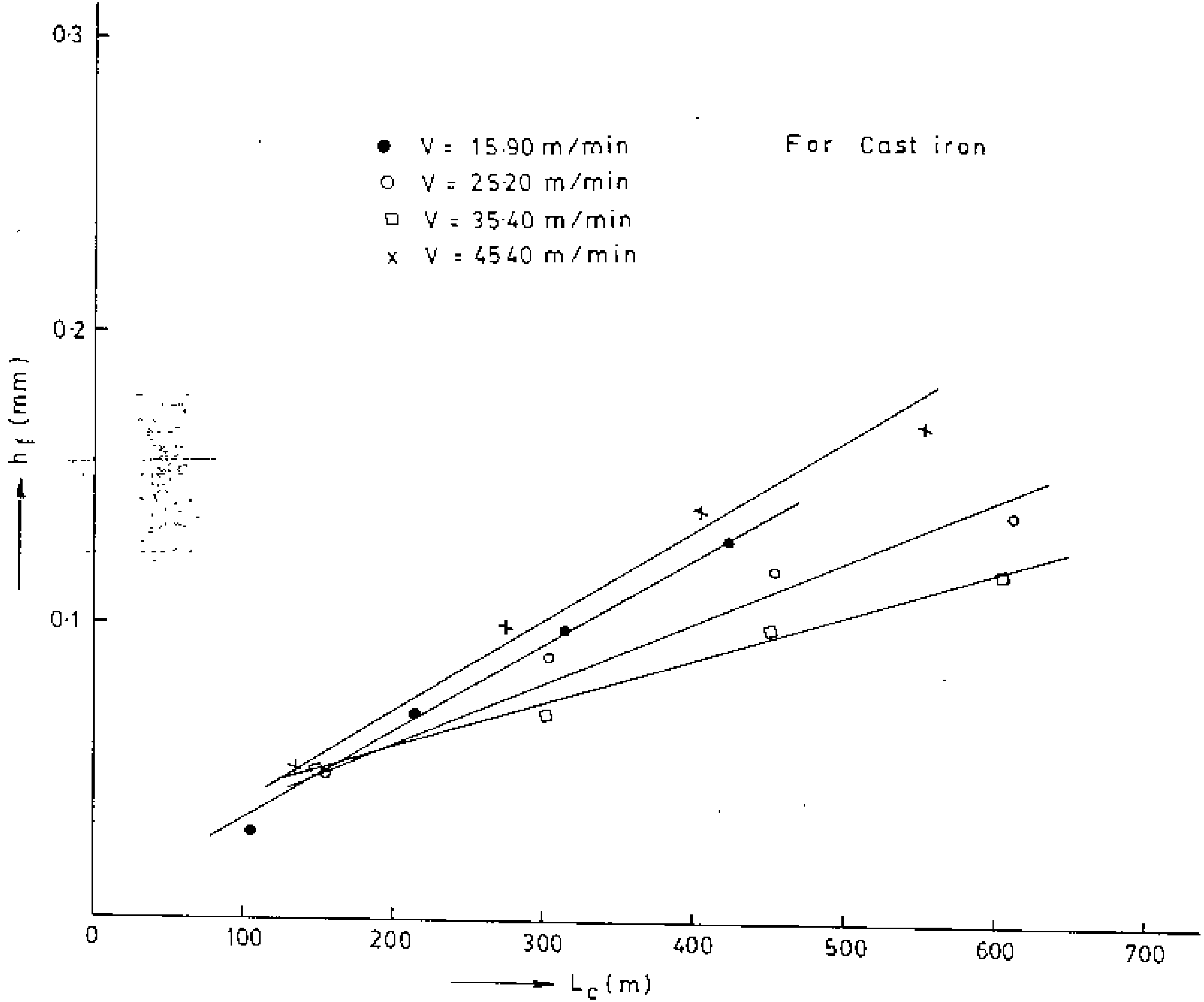


Fig. 30 Relationship between flank wear and length of cut at
S = 0·1 mm/rev t = 1·0 mm (experimental)

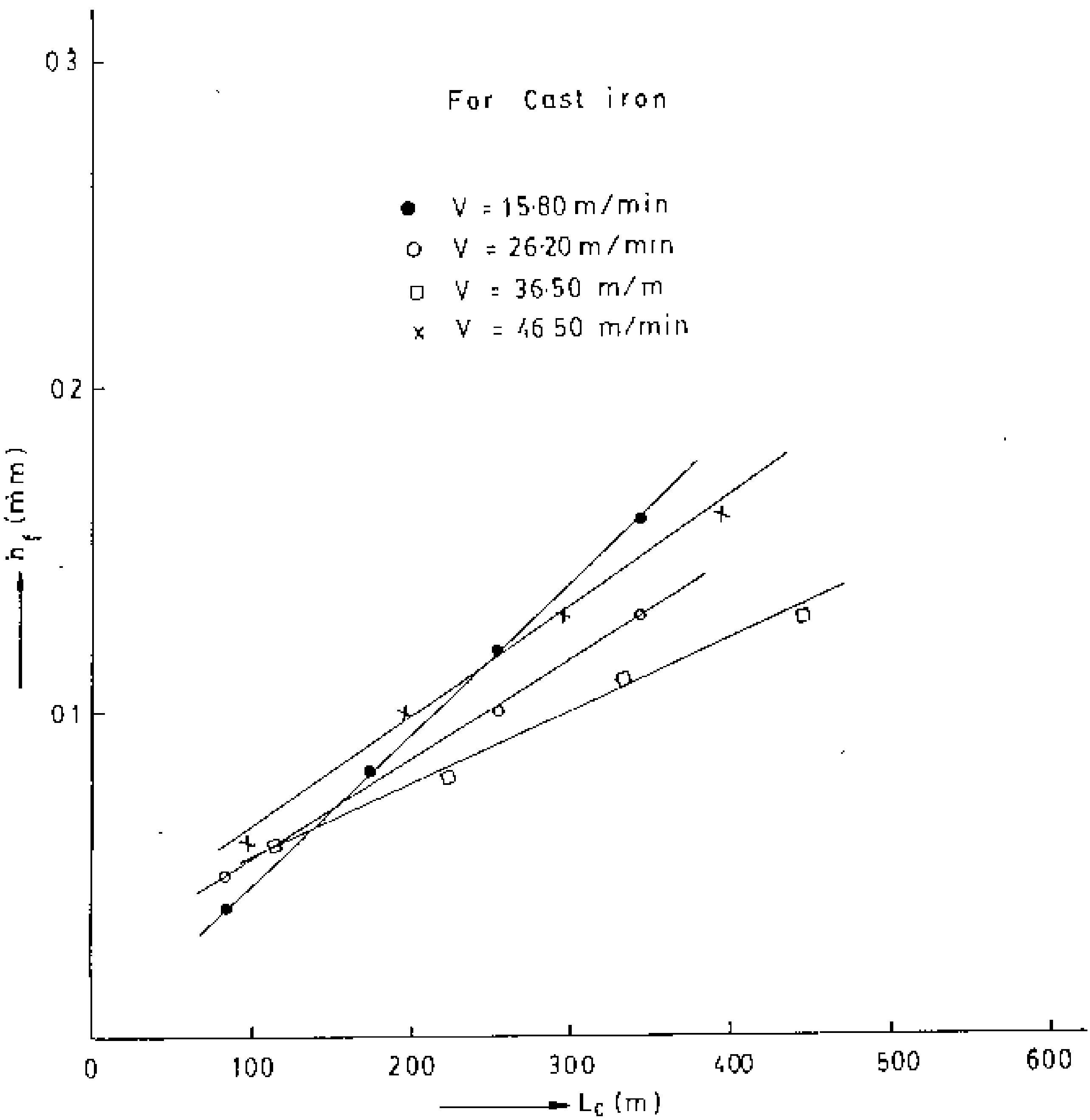


Fig. 31 Relationship between flank wear and length of cut at S = 0·2 mm/rev t = 1·0 mm (experimental)

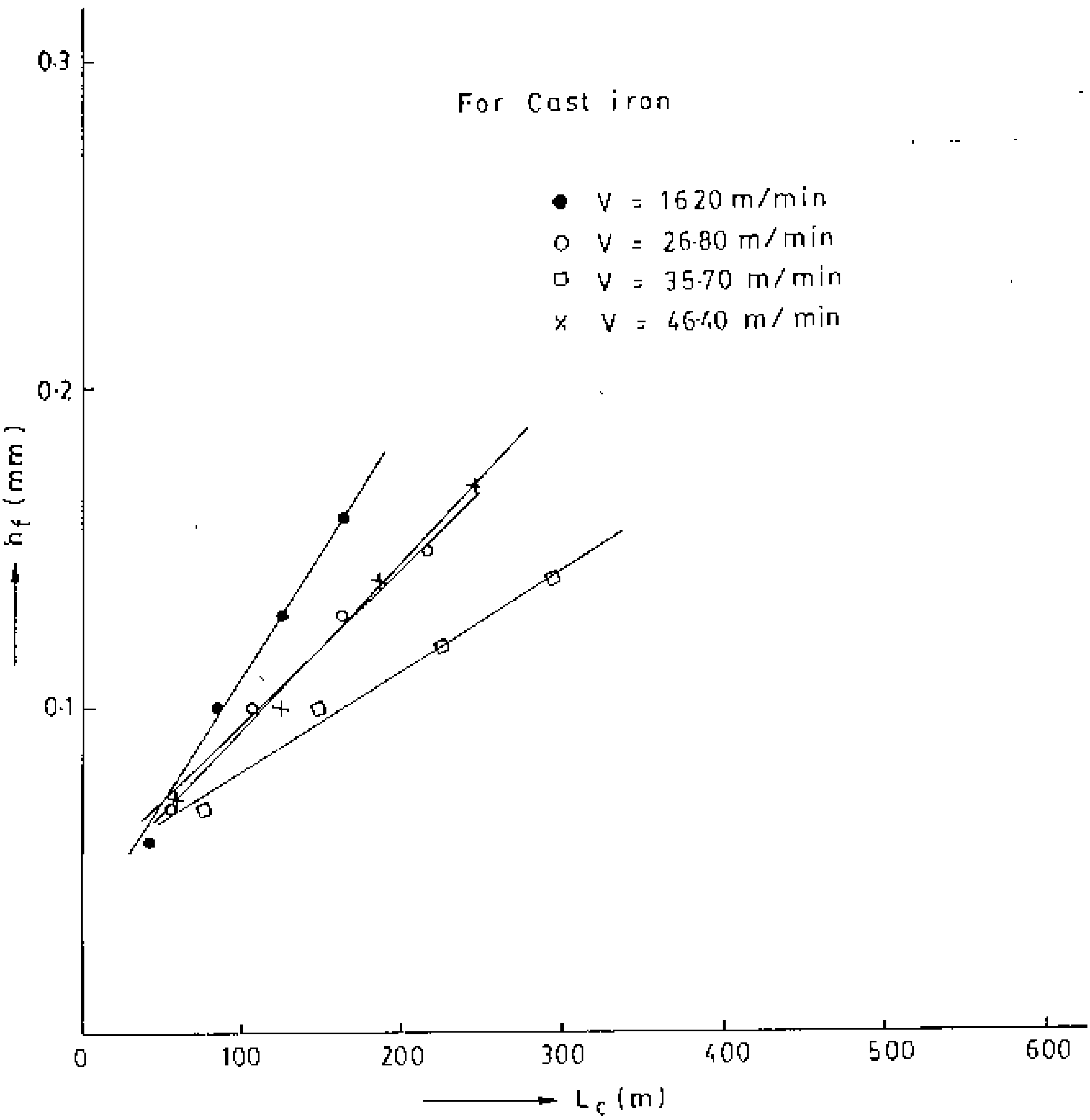
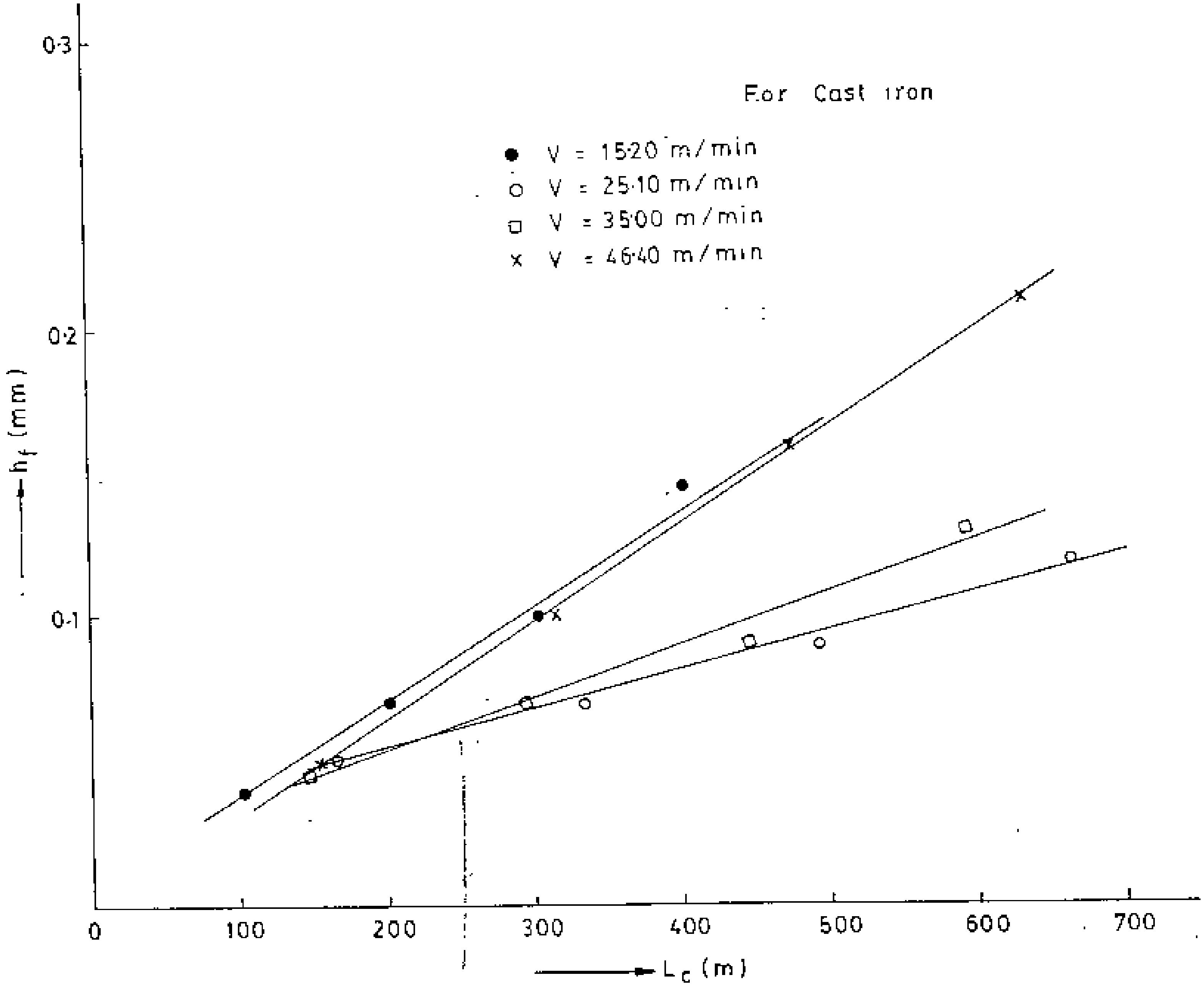


Fig.32 Relationship between flank wear and length of cut at S = 0.32 mm/rev t = 1.0 mm (experimental)



Fig·33 Relationship between flank wear and length of cut at
S = 0·1 mm/rev t = 1·5 mm (experimental)

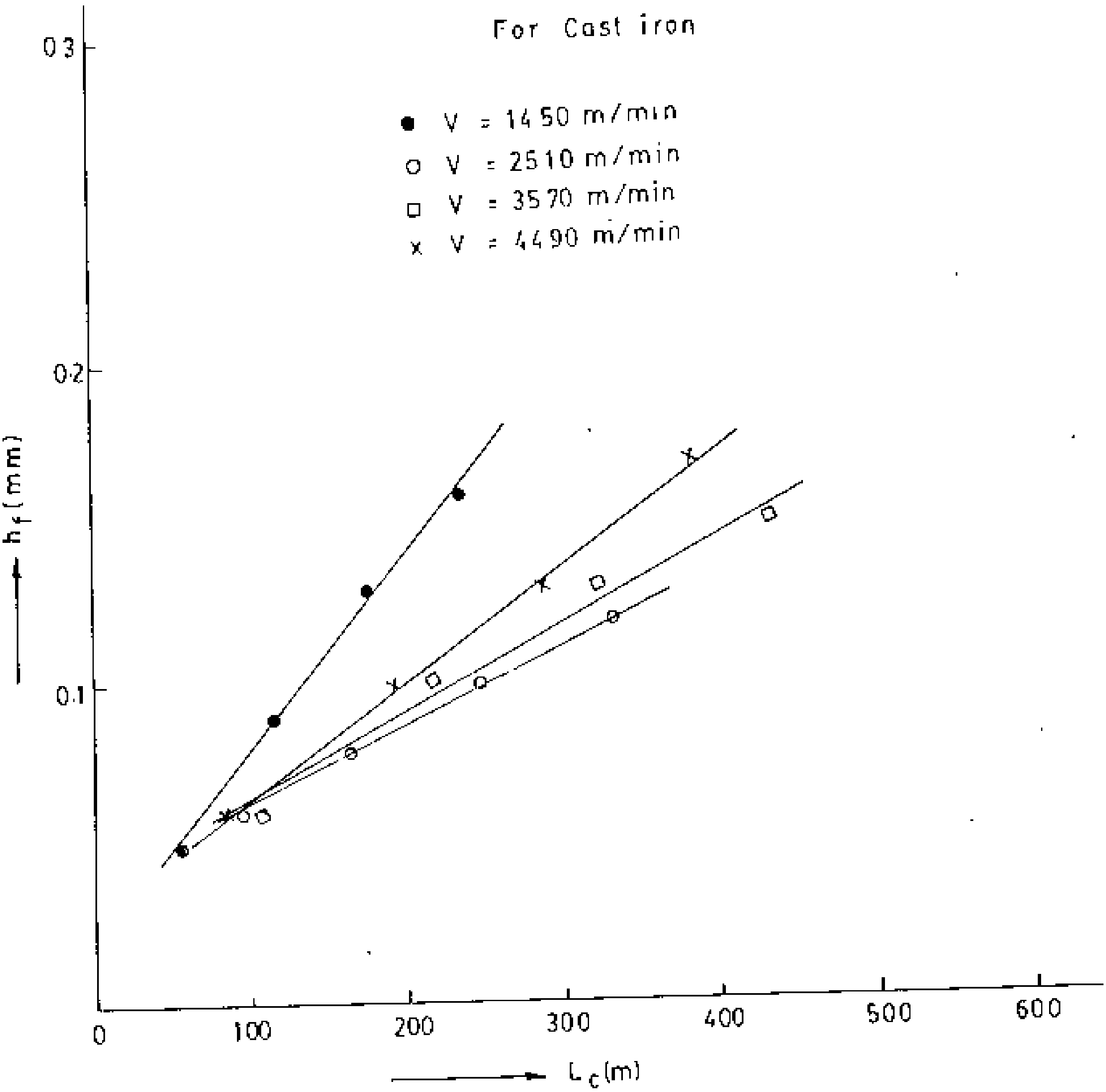


Fig. 34 Relationship between flank wear and length of cut at
S = 0.2 mm/rev t = 1.5 mm (experimental)

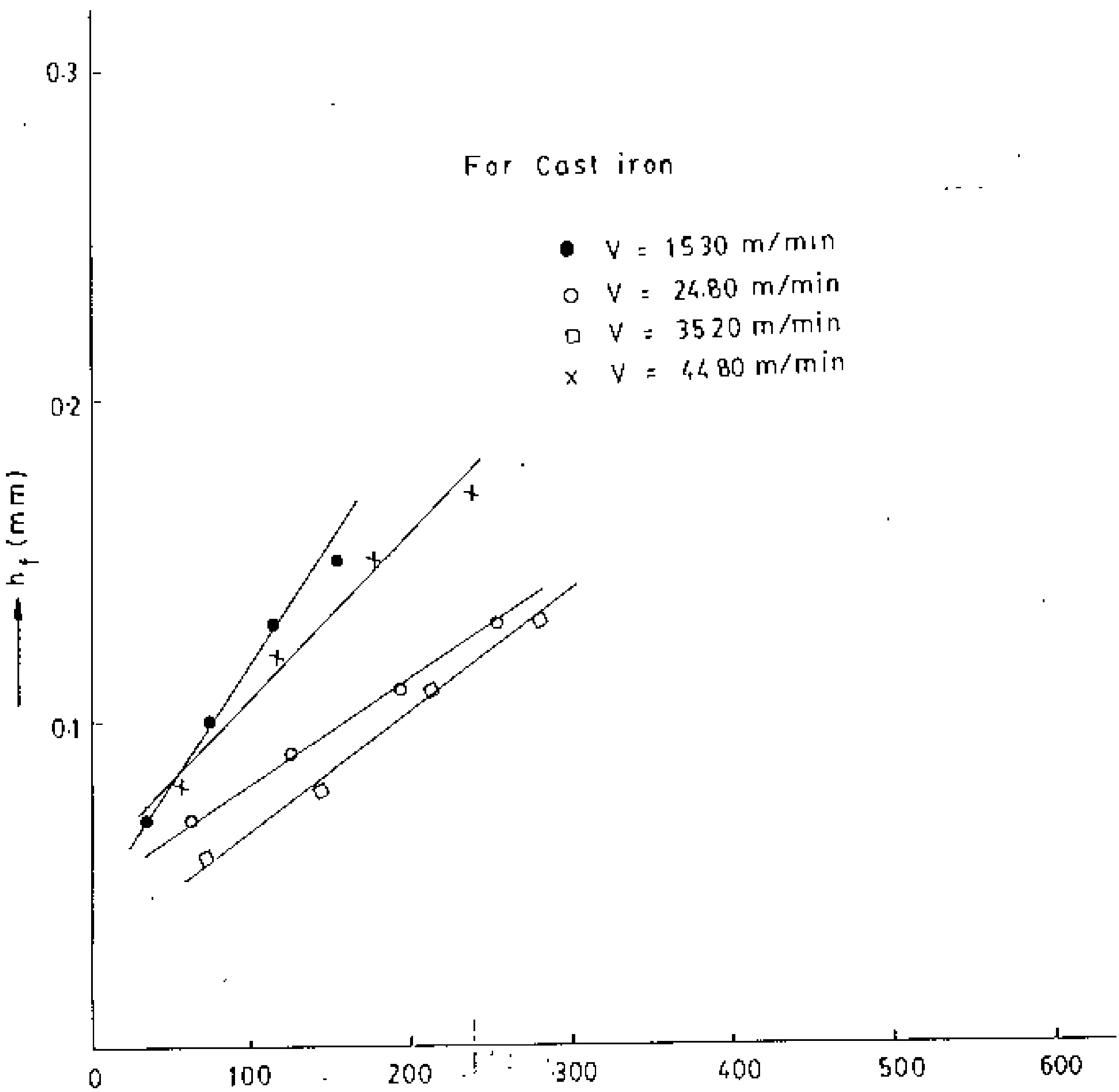


Fig 35 Relationship between flank wear and length of cut at $S = 0.32$ mm/rev $t = 1.5$ mm (experimental)

performed by turning operation in the lathe. After every turning operation, the tool and the chip were carefully observed under the microscope.

In this experiment the procedure applied for stainless steel, was same. So there is no need for detail description (sample data sheet-2). The selected speed were near about 15, 25, 35 and 45 m/min. After carefully observe the chips under the microscope, the critical cutting speeds were determined. Here the chips were not continuous, they were brittle.

The tool after every turning operation were observed under the microscope to determine its flank wear. After measuring it, flank wear vs. cutting length curves were plotted in Fig. 27, 28, 29, 30, 31, 32, 33, 34 & 35. From these graphs intensity of tool wear, h_{fc} were calculated. All of the values of h_{fc} are listed in Table-4.

In Fig.36, 37, 38, 39, 40 & 41 graphs were plotted for h_{fc} vs. cutting speed for different sets of cutting conditions showing influence of feed and depth of cut. From that curves the optimum cutting speeds were determined. In the optimum cutting speed, intensity of tool wear is minimum. The values of the critical and optimum cutting speeds are listed in Table-5 & 6 showing influence of feed and depth of cut respectively.

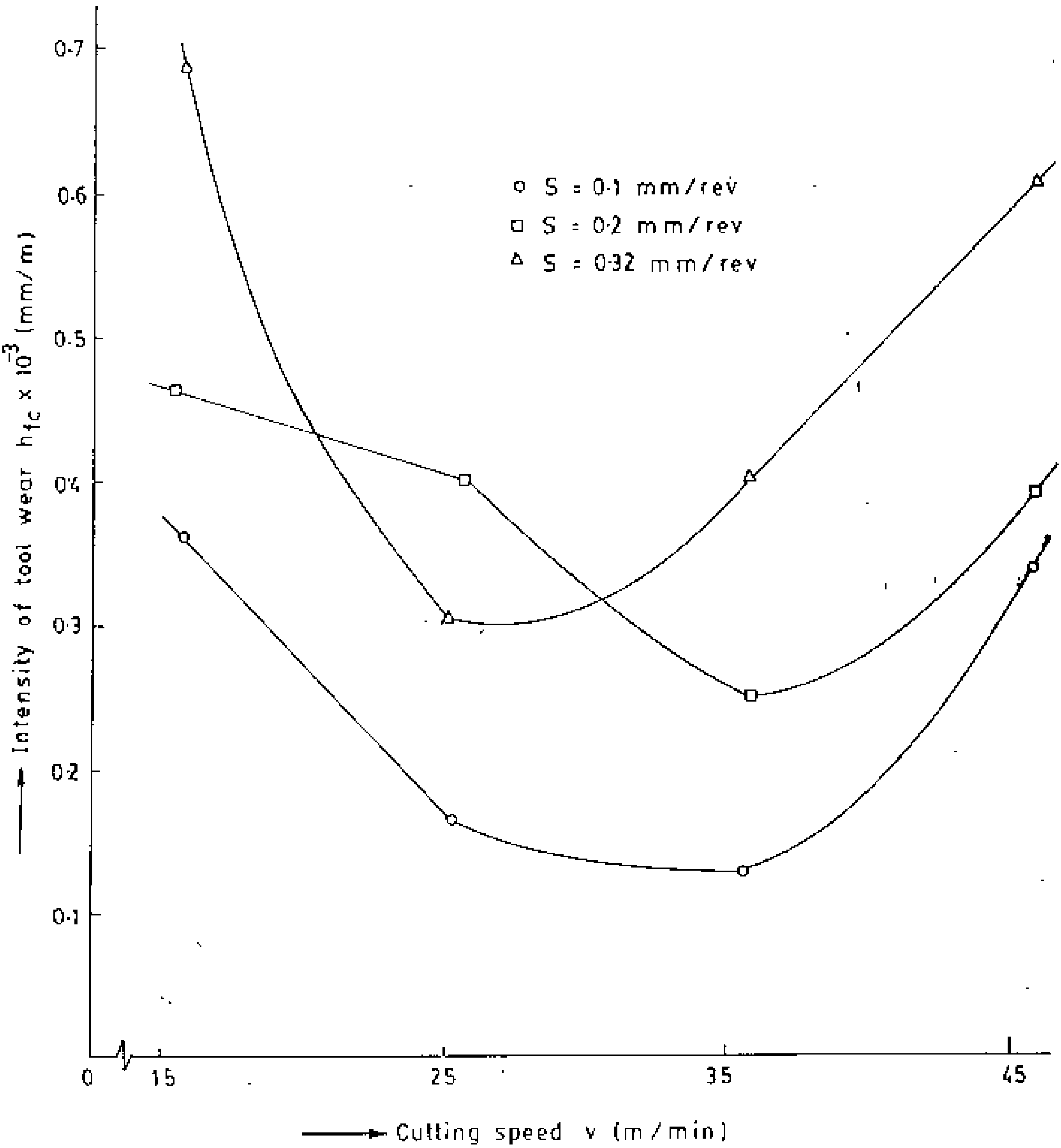


Fig. 36 Determination of optimum cutting speed of cast iron keeping depth of cut constant at t = 0·5 mm (experimental)

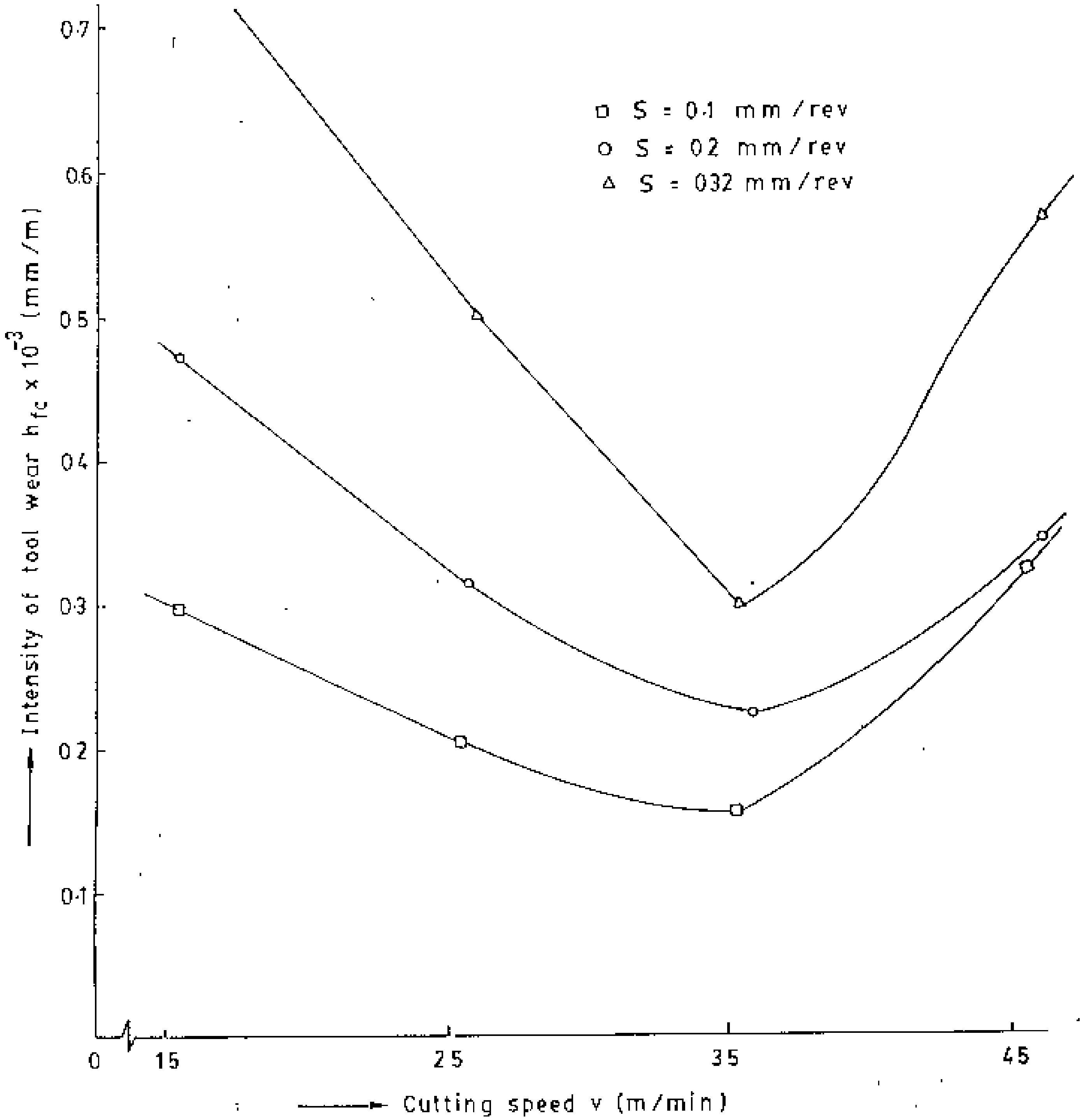


Fig 37 Determination of optimum cutting speed of cast iron keeping depth of cut constant at t =1.0 mm (experimental)

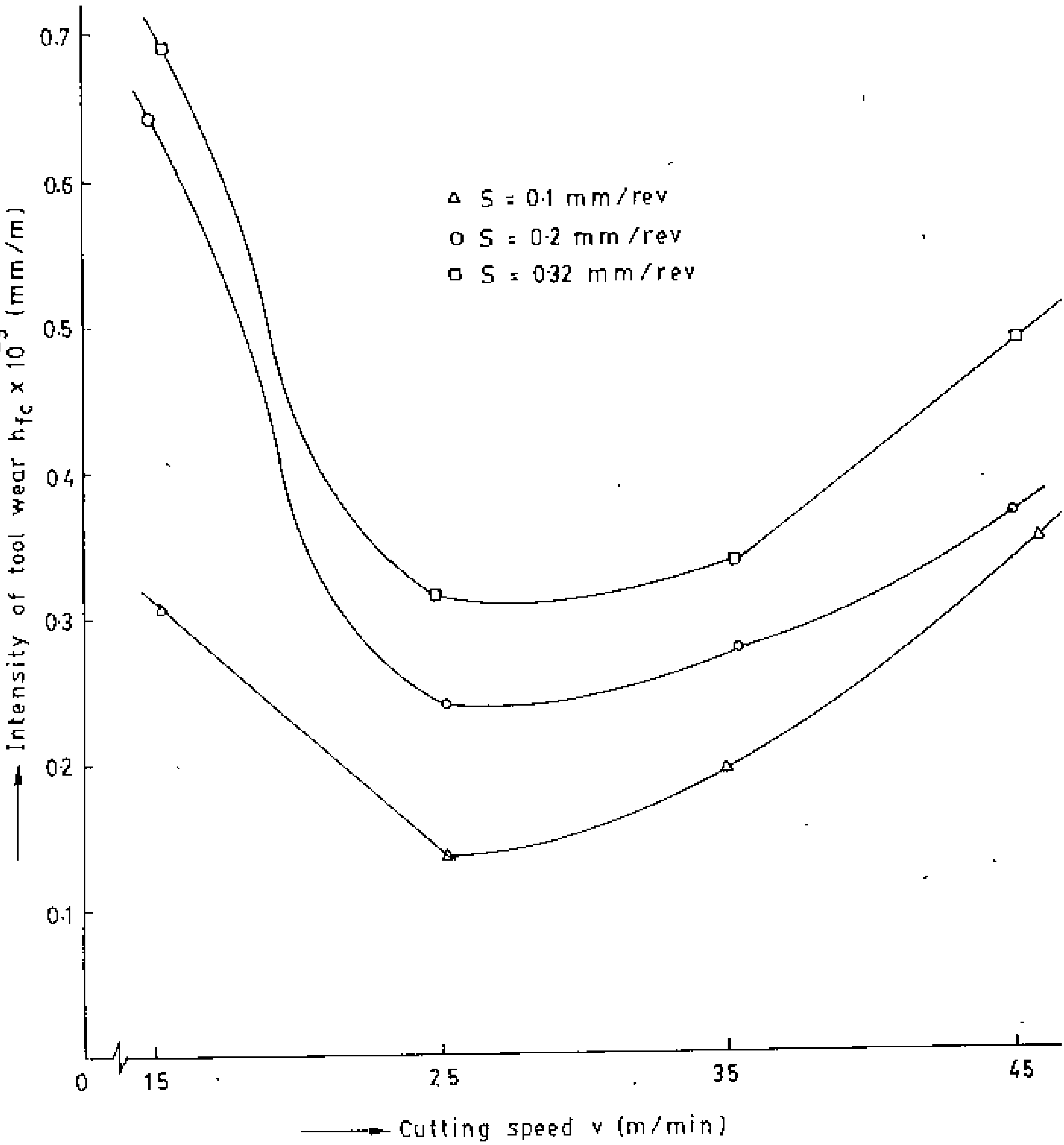


Fig. 38 Determination of optimum cutting speed of cast iron keeping depth of cut constant at t = 1·5 mm (experimental)

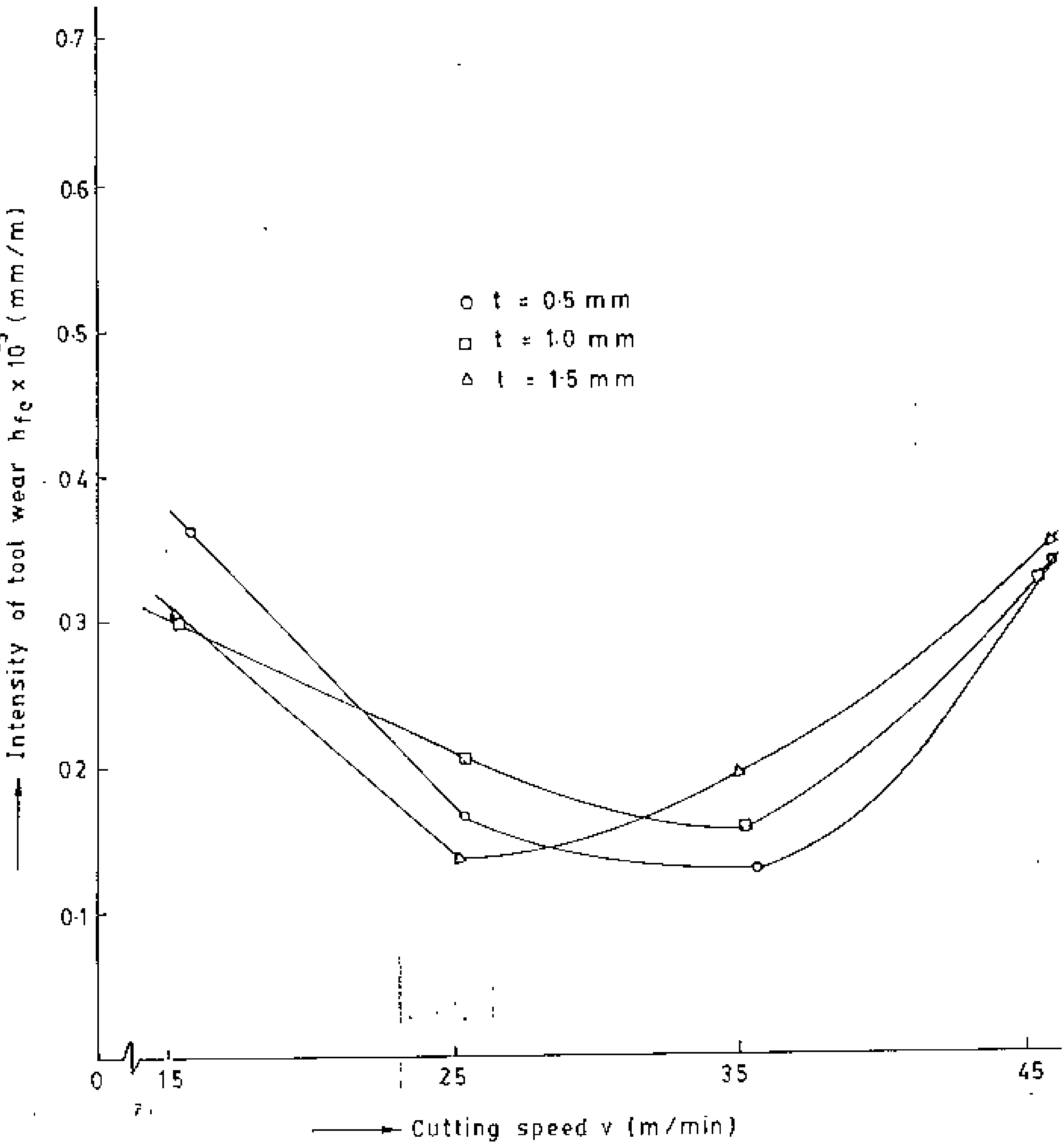


Fig 39 Determination of optimum cutting speed of cast iron keeping feed constant at S = 0.1 mm/rev (experimental)

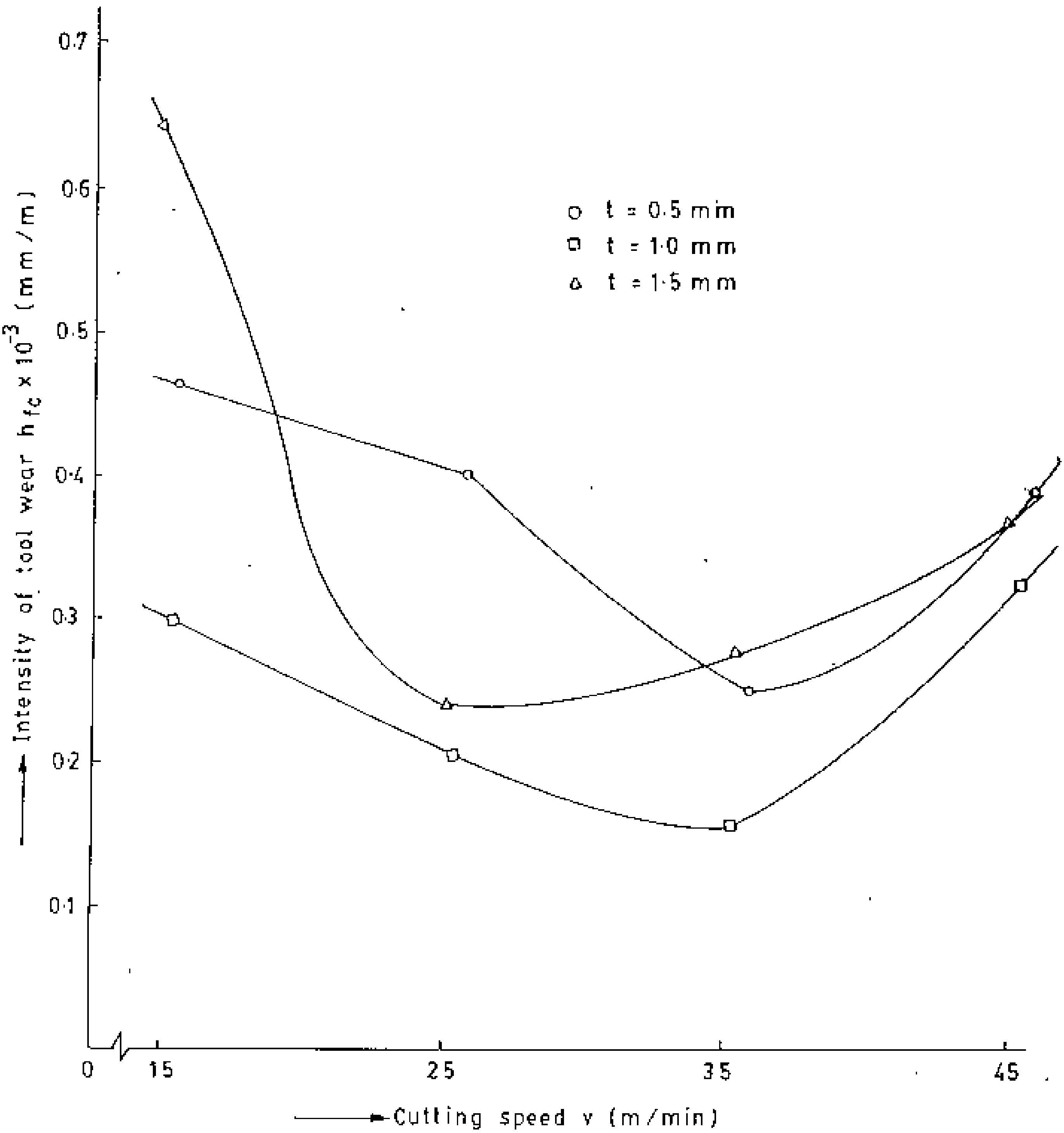


Fig. 40 Determination of optimum cutting speed of cast iron keeping feed constant at S = 0.2 mm/rev (experimental)

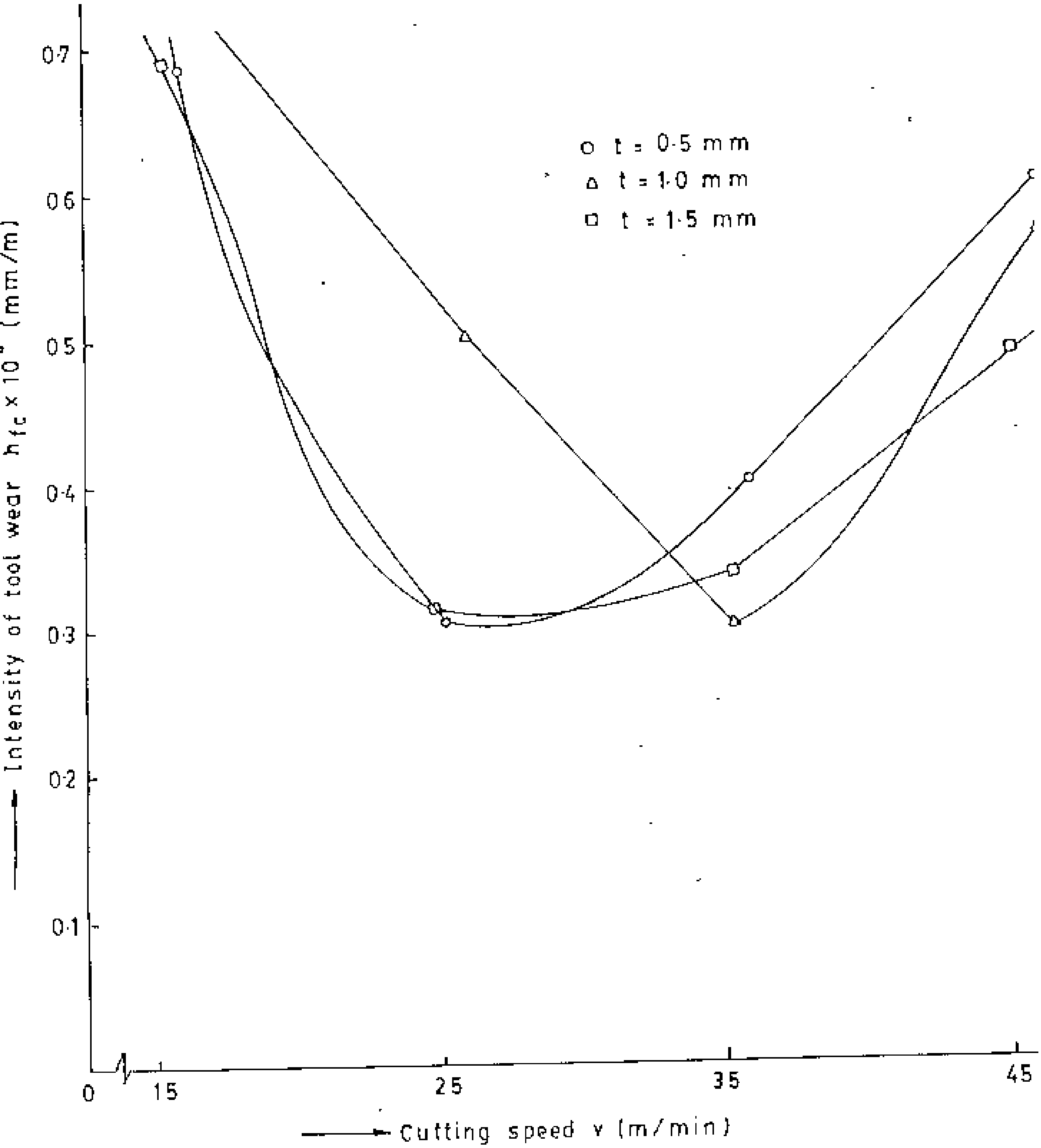


Fig 41 Determination of optimum cutting speed of cast iron keeping feed constant at S = 0·32 mm/rev (experimental)

Feed S (mm/rev) depth of cut, t (mm)	Velocity (Actual) (m\min)	Intensity of tool wear h_{fc} (mm/m)	Feed S (mm/rev) and depth of cut, t (mm)	Velocity (Actual) (m\min)	Intensity of tool wear h_{fc} (mm/m)
S = 0.1 t = 0.5	16.20	0.364×10^{-3}	S = 0.32 t = 1.0	16.20	0.778×10^{-3}
	25.90	0.670×10^{-3}		26.80	0.500×10^{-3}
	36.50	0.125×10^{-3}		35.70	0.300×10^{-3}
	46.60	0.333×10^{-3}		46.40	0.563×10^{-3}
S = 0.2 t = 0.5	15.90	0.469×10^{-3}	S = 0.1 t = 1.5	15.20	0.318×10^{-3}
	26.20	0.400×10^{-3}		25.10	0.136×10^{-3}
	36.70	0.250×10^{-3}		35.00	0.192×10^{-3}
	46.60	0.385×10^{-3}		46.40	0.333×10^{-3}
S = 0.32 t = 0.5	16.30	0.688×10^{-3}	S = 0.2 t = 1.5	14.50	0.643×10^{-3}
	25.10	0.308×10^{-3}		25.10	0.238×10^{-3}
	36.40	0.106×10^{-3}		35.70	0.273×10^{-3}
	46.60	0.600×10^{-3}		14.90	0.364×10^{-3}
S = 0.1 t = 1.0	15.90	0.300×10^{-3}	S = 0.32 t = 1.5	15.30	0.692×10^{-3}
	25.20	0.208×10^{-3}		24.80	0.313×10^{-3}
	35.40	0.156×10^{-3}		35.80	0.333×10^{-3}
	45.10	0.321×10^{-3}		44.80	0.484×10^{-3}
S = 0.2 t = 1.0	15.80	0.471×10^{-3}			
	26.20	0.313×10^{-3}			
	36.50	0.222×10^{-3}			
	46.50	0.333×10^{-3}			

Table - 4 : Determined values of h_{fc} for various feeds and depth of cuts in turning Cast Iron.

Depth of cut, t (mm)	Feed, S (mm/rev)	Critical cutting speed, v_c (m/min)	Optimum cutting speed, v_{op} (m/min)	Diameter (mm)	Corres-ponding rpm
0.5	0.1	35-45	36.0	62.0	185
	0.2	35-45	36.5	62.5	185
	0.32	35	25.5	85.5	95
1.0	0.1	35-45	35.0	60.0	185
	0.2	35	35.0	60.0	185
	0.32	25-35	35.0	60.0	185
1.5	0.1	35	26.0	87.0	95
	0.2	25-35	25.0	84.0	95
	0.32	25	25.0	84.0	95

Table- 5 : Values of different critical & optimum cutting speeds of Cast Iron showing influence of feed.

Feed, S (mm/rev)	Depth of cut, t (mm)	Critical cutting speed, V_c (m/min)	Optimum cutting speed, V_{op} (m/min)	Diameter (mm)	Corres-ponding rpm
0.1	0.5	35-45	36.0	62.0	185
	1.0	35-45	35.0	60.0	185
	1.5	35	26.0	87.0	95
0.2	0.5	35-45	36.0	62.0	185
	1.0	35	35.0	60.0	185
	1.5	25-35	25.0	84.0	95
0.32	0.5	35	25.5	85.5	95
	1.0	25-35	35.0	60.0	185
	1.5	25	25.0	84.0	95

Table-6 : Values of critical and optimum cutting speed of Cast Iron showing influence of depth of cut

4.3 EXPERIMENTAL RESULTS AND CONCLUSION

At S=0.1, 0.2, 0.32 mm/rev. and at constant depth of cut, t=0.5 mm, the critical cutting speeds of cast iron were found 35-45, 35-45 and 35 m/min. The same values at t=1.0 mm are 35-45, 35, 25-35 m/min and at t=1.5 mm are 35, 25-35 and 25 m/min. It is clear from the above results that there is a effect of feed in critical cutting speed. It decreases with the increase of feed.

The above results can be explained in the way that at depth of cut, t=0.5, 1.0 and 1.5 mm, the critical cutting speeds at S=0.1 mm/rev. are 35-45, 35-15 and 35 m/min. The same at S=0.2 mm/rev. are 35-45, 35, 25-35 and at S=0.32 mm/rev. are 35, 25-35 and 25 m/min. The effect of depth of cut in critical cutting speed is clear from the above results. It decrease by the increase of depth of cut.

The optimum cutting speeds of cast iron at S=0.1, 0.2 and 0.32 mm/rev. and at depth of cut, t=0.5 mm are 36.0, 36.0 and 25.5 m/min. These values at t=1.0 mm are 35.0, 35.0, and 35.0 m/min respectively and at t=1.5 mm are 26.0, 25.0 and 25.0 m/min. respectively. It can be concluded from the above results that effect of feed is smaller than that of depth of cut on optimum cutting speed. The value of optimum cutting speeds at t=0.5, 1.0 and 1.5 mm and at S=0.1 mm/rev. are 36.0, 35.0 and 26.0 m/min. These values at 0.2 mm/rev. are 36.0, 35.0, 25.0 and at S=0.32 mm/rev. are 25.5, 35.0 and 25.0 m/min. respectively. It shows that there is an effect of depth of cut in optimum cutting speed.

From the above result it can also be concluded that for single carbide tool, optimum cutting speed is less or equal to critical cutting speed.

CHAPTER FIVE

ECONOMIC ANALYSIS OF TURNING STAINLESS STEEL AND CAST IRON

5.1 THEORY

Economic analysis of turning stainless steel and cast iron were performed in three cutting conditions. Though, there are several machining operations for drawing roller, here in this experiment, turning operation was used. We know from previous investigations and analysis that cost per piece depends on cutting speed, feed and depth of cut and flank wear. Depth of cut influence the machining time. The flank wear influence tool grinding time, because maximum permissible wear is 0.8 mm. But in this experiment, tool was regrinded before 0.22 mm (maximum) of wear. Tool changing time, cutting time also influence the production cost per piece.

The most commonly used formula used here for economic analysis, is,

$$C_p = C_m + C_I + C_{tc} + C_{tg} + C_{td}$$

Here, C_p = Total cost per piece

C_m = Machining cost

C_I = Idle cost

C_{tc} = Tool changing cost

$C_{tg} + C_{td}$ = Tool cost per piece.

The above terms can be illustrated as follows:

Machining cost,

$C_m = M.\ T_m$ — M = Machine & operator rate

T_m = Machining time

Idle cost,

$C_I = M.T_I$ — T_I = Idle time

Tool changing cost,

$C_{tC} = M.N_t/N_b\ .\ t_{ct}$

N_t = No. of tool

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}}$$

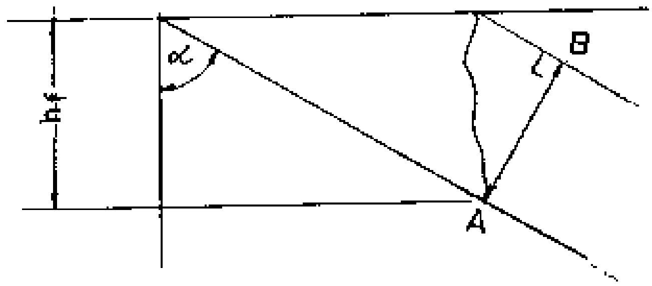
t_{ct} = Tool changing and resetting time

Tool cost per piece,

$C_{tg} + C_{td} = N_t/N_b.C_t$ — C_t = tool cost per grind.

It was assumed that the bars were stached near the machine ready to be grasped by the operator.

For to determine tool grinding cost, the number of grinds possible must be determined. This can be done as follows:



The fig. shows the portion of a tool with flank wear of amount h_f. Considering a small portion Δ to be ground off together with $h_f \sin\alpha$ and 'Q' be the limiting amount of portion which can be ground-off before a tool is useless for its present purpose, the regrinds possible is

$$G = \frac{Q}{h_f \sin\alpha + \Delta} = \frac{9.5 - 2.5}{0.8 \times \sin 10^\circ + 0.075} \quad (let)$$

... ... [From table 7]

≈ 33 *times*

The value of 33 times of regrinding is for stainless steel. and for cast iron it is

$$G = \frac{7.5 - 2.5}{0.8 \sin 10^\circ + 0.075} \approx 23 \text{ times}$$ ... [From table 7]

5.2 COST OF GRINDING

Cost of grinding a tool is (From table 7).

= Machining cost + Direct labour cost + Indirect labour cost

= Tk.42.96 x 7/60 + Tk.10.00 x 7/60 + Tk.56 x 7/60

= Tk.12.712

Tool depreciation per grind (For stainless steel)

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

$$= Tk.\ \frac{120}{33} = Tk.\ 3.63$$

Tool depreciation (For cast iron)

$$= Tk.\ \frac{130}{23} = Tk.\ 5.22$$

Therefore Total tool cost per grinding is (C_t)

<u>For stainless steel</u>

C_t = grinding cost + Depreciation cost

= Tk.12.71 + Tk.3.63

= Tk.16.34

For cast iron

C_t = Tk.12.71 + Tk.5.22

= Tk.17.93

For both cases,

Machine and operator rate

M = Machine cost + Direct labour cost + indirect labor cost

= Tk.42.96/hr. + Tk.10.00/hr. + 56.00/hr.

= Tk.108.96

Some data of BMTF were reused in this experiment (Table-7). These data were used by Mr. Sankar Roy in his M.Sc. thesis work.

5.3 COST ANALYSIS FOR STAINLESS STEEL

Turning of depth of cut of 1.5 mm can be performed by the following three ways:

i) By turning in 1 pass (cut)

Turning at, V = 25.5 m/min

S = 0.1 mm/rev.

t = 1.5 mm.

ii) By turning in 2 passes (cuts)

1st turning at

V = 35.0 m/min

S = 0.32 mm/rev.

t = 1.0 mm.

and then at

$V = 25.5$ m/min

$S = 0.2$ mm/rev.

$t = 0.5$ mm.

iii) By turning in 3 passes (cuts)

Each of which are at

$V = 25.5$ m/min

$S = 0.2$ mm/rev.

$t = 0.5$ mm.

5.3.1 Cost for Cutting according to Condition-1

Actual turning time = $\frac{L}{s.N}$

$= \frac{900}{0.1 \times 95}$ [*From table-2, N = 95 rpm*]

$= 94.74$ min.

Idle time, $t_I = 40$ mins.

Tool wear

$\frac{0.14 \times 94.74}{25.65} = 0.52$ *mm.*

[$h_f = 0.14$ mm after turning, 25.65 min.]

$$\text{Tool life} = \frac{0.8 \times 25.65}{0.14} = 146.57 \text{ min.}$$

Each tool will produce before regrind.

Now, $N_b = \frac{0.8}{0.52} = 1.54$ *pieces.*

& $\frac{N_t}{N_b} = \frac{1}{1.54} = 0.65$

Now,

$C_I = Mt_I$ = Tk.108.96 x 40/60 = Tk.72.64

$C_m = M.t_m$ = Tk.108.96 x 94.74/60 = Tk.172.05

$C_{tc} = M.N_t/N_b.t_{ct}$ = Tk.108.96 x 0.65 x 3/60

= Tk.3.54

$C_{tg} + C_{td} = N_t/N_b.C_t$ = Tk.0.65 x 16.34

= Tk. 10.621

Therefore Total cost per piece

$C_p = C_I + C_m + C_{tc} + C_{tg} + C_{td}$

= Tk.72.64 + Tk.172.05 + Tk.3.54 + Tk.10.62

= Tk.258.85

Therefore total cost for turning of 500 pieces of drawing rollers

$= C_p \times 500$

$=$ Tk.258.85 x 500

$=$ Tk.1,29,425.

5.3.2 Cost for cutting according to cutting condition-2

Actual turning time,

For rough cut $= \frac{L}{s.N} = \frac{900}{0.32 \times 185}$

$= 15.2$ min [*From table-2,* $N = 185$ *rpm*]

For finish cut, time $= \frac{L}{s.N} = \frac{900}{0.2 \times 95}$

$= 47.37$ min [*From table-2,* $N = 95$ *rpm*]

Total actual turning time = (15.20 + 47.37) min. = 62.57 min.

Since, 2-passes were used, so auxiliary cutting time = 2 min.

Therefore total Machining time, t_t = (62.57 + 2) min.

= 64.57 min.

Idle time, t_I = 40 mins.

Tool wear during rough cut $= \frac{0.22 \times 15.20}{9.1}$ mm = 0.37 mm.

[Tool wear = 0.22 mm after turning 9.1 min.]

During finish cut $= \frac{0.09 \times 47.37}{18.5}$ mm = 0.23 mm.

[Tool wear = 0.09 mm after turning 18.5 min]

Total tool wear = (0.37 + 0.23) mm

= 0.60 mm

Tool life for rough cut = $\frac{0.8 \times 9.1}{0.22}$ = 33.09 min.

Tool life for finish cut = $\frac{0.8 \times 18.5}{0.09}$ = 164.44 min.

Therefore, $N_b = \frac{0.80}{0.60} = 1.33$ *pieces*

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.33} = 0.75$

Now, C_T = Tk.108.96 × $\frac{40}{60}$ = Tk.72.64

$$C_m = Tk.108.96 \times \frac{64.57}{60} = Tk.117.26$$

$$C_{tc} = Tk.108.96 \times 0.75 \times \frac{5}{60} = Tk.4.086$$

$$C_{tg} + C_{td} = 0.75 \times 16.34 = Tk.12.26$$

$$\therefore C_p = Tk.72.64 + Tk.117.26 + Tk.4.086 + Tk.12.26$$

$$= Tk.206.70$$

Total cost for turning of 500 pieces

= $C_p \times 500$ = Tk.206.70 x 500

= Tk.1,03,352

5.3.3 Cost Calculation for Cutting Condition-3

Here, 3-passes were used, so taking auxiliary cutting time = 3 mins.

Actual turning time = $\frac{900}{0.2 \times 95} \times 3$ min. = 142.11 min.

[From table-2, N = 95 rpm]

Total turning (machining) time = 142.11 + 3 = 145.11 min.

Tool wear during operation = $\frac{0.12 \times 145.11}{16.1}$ mm = 1.08 mm.

[Tool wear = 0.12 mm after turning 16.1 min].

$N_b = \frac{0.8}{1.08} = 0.74$ *pieces*

$N_t/N_b = \frac{1}{0.74} = 1.35$

Now, $C_I = M.t_I$ = Tk.108.96 x 40/60 = Tk.72.64

$C_m = M.t_m$ = Tk.108.96 x 145.11/60 = Tk.263.52

$C_{tc} = M.N_t/N_b.t_{ct}$ = Tk.108.96 x 1.35 x 3/60 = Tk.7.35

$C_{tg}+C_{td} = N_t/N_b.C_t$ = Tk.1.35 x 16.34 = Tk.22.06

Therefore, $C_p = C_I + C_m + C_{tc} + C_{tg} + C_{td}$

= Tk.72.64 + Tk.263.52 + Tk.7.35 + Tk.22.06

= Tk.365.57

Therefore, cost of turning of 500 pieces of drawing roller is,

= C_p x 500

= Tk.365.57 x 500

= Tk.1,82,785

5.4 COST ANALYSIS FOR CAST IRON

For cost analysis of cast iron three turning of depth of cut of 1.5 mm can be performed by the following three ways:

i) By turning in 1 pass (cuts)

Here the cutting condition and r.p.m. are:

V = 25.0 m/min

S = 0.2 mm/rev.

t = 1.5 mm

ii) By turning in 2 passes

1st,	V = 35.0 m/min	2nd V = 36.5 m/min
	S = 0.32 mm/rev.	S = 0.2 mm/rev.
	t = 1.0 mm.	t = 0.5 mm.

iii) By turning in 3 passes

Each cut will be at,

V = 25.5 m/min

S = 0.32 mm/rev.

t = 0.5 mm.

5.4.1 Determination of cost according to condition-1

Here 1 pass was used

So, Actual turning time = $\frac{L}{S.N}$

$\frac{900}{0.2 \times 95}$ min = 47.37min. [From table-5, N = 95 rpm]

Idle time, t_I = 40 mins. (Table-7)

Tool changing time according to Table-7 is, t_{ct} = 3 mins.

During turning, tool wear = $\frac{0.16 \times 47.37}{16.5}$ = 0.46 *mm.*

(From experiment, h_f = 0.16 mm after turning 16.5 min)

Tool life = $\frac{0.8 \times 16.5}{0.16}$ = 82.5 *mins.*

Now N_b = $\frac{0.8}{0.46}$ = 1.74 *pieces*

$\therefore \frac{N_t}{N_b} = \frac{1}{1.74}$ = 0.575, *since one tool is used so* $N_t = 1$

Now,

C_I = Idle cost = $M.t_I$ = tk.108.96 x 40/60 = Tk.72.64

C_M = Machining cost = $M.t_M$ = Tk.108.96 x 47.37/60 = Tk.86.02

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

= Tk. 108.96 x 0.575 x 3/60

= Tk.3.13

$C_{tg}+C_{td} = N_t/N_b \times C_t$ = 0.575 x 17.93 = Tk.10.31

Therefore, Total cost per piece

C_p = $C_I + C_m + C_{tc} + C_{tg} + C_{td}$

= Tk.72.64 + Tk.86.02 + Tk.3.13 + Tk.10.31

= Tk.172.10

For drawing 500 pieces of cast iron bar,

cost is needed

= C_p x 500

= Tk.172.10 x 500

= Tk.86,050

5.4.2 Cost calculation for cutting condition-2

Here 2-passes were used. So auxiliary cutting time is taken 2 mins.

Actual turning time,

For rough cut

$= \frac{L}{s.N} = \frac{900}{0.32 \times 185} = 15.21$ min. [From table-5, N = 185 rpm]

For finish cut = $\frac{L}{s.N} = \frac{900}{0.2 \times 185} = 24.32$ min. [From table-5,

N = 185 rpm]

Therefore, Total turning time = (15.21 + 24.32) mins.

= 39.53 mins.

Total actual turning (machining time)

= (39.53 + 2) mins = 41.53 mins.

Tool wear :

During rough cut, = $\frac{0.28 \times 15.21}{5.60} = 0.76$ mm.

[h_f = 0.28 mm after turning 5.60 min]

During finish cut, = $\frac{0.16 \times 24.32}{8.30} = 0.47$ mm.

[h_f = 0.16 mm after turning 8.30 min]

Therefore Total tool wear = (0.76 + 0.47) mm = 1.23 mm.

Tool life for rough cut $= \dfrac{0.8 \times 5.60}{0.28} = 16.00$ min.

Tool life for finish cut $= \dfrac{0.8 \times 8.30}{0.16} = 41.5$ min.

Now, $N_b = 0.8/1.23 = 0.65$ pieces

and $N_t/N_b = 1/0.65 = 1.54$ (since, $N_t = 1$)

Now,

C_I = Idle cost = $M.t_I$ = Tk.108.96 x 40/60

= 72.64

C_m = Machining cost = $M.t_m$ = Tk.108.96 x 41.53/60

= Tk.75.42

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

= Tk.108.96 x 1.54 x 3/60

= 8.39

$C_{tg} + C_{td}$ = Tool cost per piece = $N_t/N_b \times C_t$

= 1.54 x Tk.17.93

= Tk.27.61

Therefore, total cost per piece,

$C_p = C_I + C_m + C_{tc} + C_{tg} + C_{td}$

= Tk.72.64 + Tk.75.42 + Tk.8.39 + Tk.27.61 = Tk.184.06

For drawing 500 pieces total cost

= Tk.184.06 x 500

= Tk.92,030.00

5.4.3 Determination of cost according condition-3

Here 3 cuts were used, and therefore auxiliary cutting time was 3 min

Actual turning time

$$= \frac{L}{S.N} \times 3 = \frac{900}{0.32 \times 95} \times 3 \; mins. \quad \text{[From table-5, N = 95 rpm]}$$

= 88.82 mins.

Total turning (machining) time = (88.82 + 3) mins.

= 91.82 mins.

Table - 7

Some Records of Work Material, Tool Material, Working Conditions and some data of B.M.T.F.

i)	Length of bar (stainless steel & cast iron) drawn	=	900 mm
ii)	Job loading & unloading time (centering, tool approach & engage time also included) idle time	=	40 mins.
iii)	Tool changing & resetting time, = t_{ct}	=	3 mins.
iv)	Tool grinding time	=	7 mins.
v)	Auxiliary cutting time/cut	=	1 min.
vi)	Carbide tip size	=	9.5mm x 24 mm
	This tip was reased for cast iron Then the size was	=	7.5mm x 20 mm

From BMTF Data (Previous thesis by Sankar Roy)

Machine rate & overhead	=	Tk.42.96/hr.
Direct labour rate & overhead	=	Tk.10.00/hr.
Administrative overhead (Indirect labour)	=	Tk.56.00/hr.

Idle time = 40 mins. (Table-7)

Tool changing time, t_{ct} = 3 mins.

Tool wear during operation = $\frac{0.14 \times 88.82}{9.67}$ mm = 1.29 mm.

[h_f = 0.14 mm after turning 9.67 min]

Tool life, T_L = $\frac{0.8 \times 9.67}{0.14}$ min. = 55.26 min.

Now N_b = 0.8/1.29 = 0.62 pieces

Therefore, N_t/N_b = 1/0.62= 1.61, since no. of tool = 1.

To determine the value of cost per piece, the cost components are calculated as follows:-

C_I = Idle cost = $M.t_I$ = Tk.108.96 x 40/60

= Tk.72.64

C_m = Machining cost = $M.t_m$ = Tk.108.96 x 91.82/60

= Tk.166.75

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

= Tk.108.96 x 1.61 x 3/60

= Tk.8.77

$C_{tg} + C_{td}$ = Tool cost per piece = $N_t/N_b \times C_t$

= 1.61 x Tk.17.93 = Tk.28.87

Therefore, total cost per piece,

$$C_p = C_I + C_m + C_{tc} + C_{tg} + C_{td}$$

= Tk.72.64 + Tk.166.75 + Tk.8.77 + Tk.28.87

= Tk.277.03

Therefore, Total cost for turning of 500 pieces of drawing roller,

= $C_p \times 500$

= Tk.277.03 x 500

= Tk.1,38,515.00

5.5 RESULTS & RECOMMENDATION

From the previous cost calculation of both stainless steel & cast iron for the three condition a comparative study can be done as follows:

5.5.1 For Stainless Steel

For production of 500 pieces, of drawing roller

At condition-1	Total cost	=	Tk.1,29,425.00
At condition-2	Total cost	=	Tk.1,03,352.00
At condition-3	Total cost	=	Tk.1,82,785.00

It is clear from the above three figures, that the cost for drawing 500 stainless steel rollers is minimum for condition-2.

From condition-1, it is less

= Tk.1,29,425 - Tk.1,03,352.00

= Tk.26,073

From condition-2, it is less

= Tk.1,82,785 - Tk.1,03,352.00

= Tk.79,433.00

Therefore condition-2, is the economically advantageous from the other two conditions. So it is recommended for turning operation of the solid bar.

So, the recommended cutting condition is,

a) For rough cut, V = 35 m/min

S = 0.32 mm/rev.

t = 1.0 mm.

b) For final cut, V = 25.5 m/min

S = 0.2 mm/rev.

t = 0.5 mm

5.5.2 For cast iron

For drawing roller (turning operatin) of 500 pieces of cast iron,

At condition-1 Total cost = Tk.86,050.00

At condition-2 Total cost = Tk.92,030.00

At condition-3 Total cost = Tk.1,38,515.00

It is clear from the above three figures that the cost at condition-1 is minimum than the other two cases.

It is less,

from condition-2	=	Tk.92,030.00 - Tk.86,050.00
	=	Tk.5,980.00
from condition-3	=	Tk.1,38,515.00 - Tk.86,050.00
	=	Tk.52,465.00

Therefore, condition-1 is recommended and is economically advantageous from the other two cases.

So the recommended cutting condition is,

V = 25.0 m/min

S = 0.2 mm/rev.

t = 1.5 mm.

CHAPTER – SIX

DISCUSSION, CONCLUSION & FUTURE RECOMMENDATION

6.1 DISCUSSION

By determining the optimum cutting speed and then by economic analysis, the most economic cutting conditions for drawing rollers of stainless steel and cast iron have been determined. This method enable us to select the most economic cutting condition.

This experiment may act as a guide line for large no. of production at various cutting conditions with no. of tools and work material. Here in this experiment only one tool is used and two workpieces were used. This method can be applied to many small and large industries where metal cutting is involved. Because the method to determine the optimum cutting conditions and cost analysis is not so complex, that adequate technical knowledges and expensive instruments is needed. Rather, it is necessary to use this technique or other techniques to fulfil the objective. Because, metal cutting process and other machining processes by thumb-rules or by previous technical data can decrease the quality of work as well as effect the cost. The test results and experimental work will encourage the industrial sector for the development of future planning.

Due to various limitations of experimental facilities, there may be some variations during the application of the process in the practical field. Within its various limitations, it is hoped that the experimental investigation has analyzed some aspects of optimum cutting condition.

Stainless steel and cast iron are always used in small and large industries for metal cutting purpose. So selection of these two metals are justified. Similar method can also be applied to other metals.

6.2 CONCLUSION

From the experimental results and analysis, it can be concluded that -

a) For single carbide tool(used in this experiment) optimum cutting speed, V_{op} is less or equal to critical cutting speed, V_c

b) Critical cutting is that speed, where, few traces of unstable BUE appear on or just disappear from the rake side of the chip.

c) For single carbide tool, the V_{op} is explained by pulsation type of chip-tool contact process in the range of cutting speed just before V_c.

d) Increase of feed and depth of cut decreases the critical cutting speeds of both stainless steel and cast iron.

e) For drawing roller of stainless steel bar the most economic cutting condition is,

For rough cut	For finish cut
V = 35.0 m/min	V = 25.5 m/min
S = 0.32 mm/rev.	S = 0.2 mm/rev.
t = 1.0 mm	t = 0.5 mm.

and for cast iron, the most economic cutting condition is

V = 25.0 m/min

S = 0.2 mm/rev

t = 1.5 mm.

6.3 FUTURE RECOMMENDATIONS

This experiment was performed by cemented carbide tool of type BK8 which contains Co.8% and rest Wc. This is a single carbide tool. Though only one type of tool is used, so there is no scope to compare the process with other type of tips. Performing the experiment with various grades of tools, will give a more clear idea.

Here nickel chromium steel was used. Although the results confirms the theoretical values, though there remains scope of further study by changing the composition of work material.

The tool geometry used were const. for the two work material throughout the experiment. This was done to avoid complexity. Because nine sets of feeds and depth of cuts were selected & also four speeds were selected from previous experimental investigation. Changing tool geometry with this cutting condition could lengthen the procedure and make it complex. So, there remains a scope of further study by changing the values of the tool geometry.

Cutting fluid was avoided during the experiment. It has considerable effect on turning operation. So, there is a chance to use cutting fluid, to observe, that how the values vary from the experimental results.

The pattern of the graphs in varying situations will be more or less same. Further investigations in this field will be helpful to compare these results with those obtained in the real production situation.

The values of depth of cut were selected low. This and the values of feed can be changed to perform the experiment.

Further researches and experiments in this field by varying various cutting conditions, work material, tool material, will enable to find a more economic cutting condition.

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