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A NEW METHOD FOR TESTING QUALITY OF CEMENTED CARBIDE
TOOLS AND A COMPARATIVE STUDY OF DIFFERENT CEMENTED
CARBIDE AND HIGH SPEED STEEL TOOLS AVAILABLE IN THE
LOCAL MARKET.

A PROJECT
BY
MD. RAFIQUUL ISLAM



DEPARTMENT OF INDUSTRIAL AND PRODUCTION ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA, BANGLADESH



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Submitted to the Department of Industrial and Production
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For the Degree of

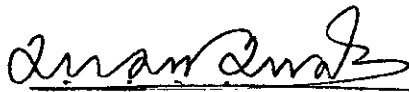
MASTER OF ENGINEERING (IP)

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Department of Industrial and Production Engineering
Bangladesh University of Engineering and Technology
Dhaka, Bangladesh

C E R T I F I C A T E

This is to certify that this thesis work was done
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Candidate

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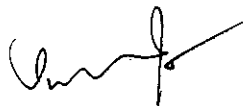
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ABSTRACT

Determination of tool-quality is a very important factor in metal cutting process. Because production rate, production cost, surface finish etc. depend on it. At present in Bangladesh, there is no testing facilities for cemented carbide tools which are most widely used in production. In the present research work, a new quality control method has been developed with which quality of the cemented carbide tool bits can be determined avoiding the lengthy method of tool wear test. Quality of high speed steel tool can also be tested using this method but for work-material apart from steel. A comparative analysis of economic effectiveness of cemented carbide and high speed steel tools have been made and it has been established that the cost of turning a lead screw of a lathe machine with the high speed steel tool is, on the average, two and a half times greater than that of carbide tipped tools at the cutting speed of 80 m/min. It has been further established by experiments that at higher cutting speeds like 100, 120, 150 mm/min., it is not possible to use a high speed steel tool at all for the same purpose.

N O M E N C L A T U R E

C_p	:	Total machining cost per piece
C_I	:	Idle cost per piece
C_c	:	Machining cost per piece
C_t	:	Tool cost per grind
C_{tc}	:	Tool changing cost per piece
C_{tg}	:	Tool regrinding cost per piece
C_{td}	:	Tool depreciation cost per piece
t_1	:	Idle time per piece including loading & unloading time
t_m	:	machining time per piece
t_{ct}	:	Tool changing time
T	:	Time
T_1	:	Time with respect to wear, h_{f1}
T_2	:	Time with respect to wear, h_{f2} after initial wear, h_{f1}
h_{f1}	:	Initial flank wear during the operation of time T_1
h_{f2}	:	Final flank wear during the operation of time T_2
h_f	:	Total flank wear ($h_{f1} + h_{f2}$)
h_{ft}	:	maximum allowable tool wear before regrinding
T_L	:	Tool life
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.
I	:	Intensity of tool wear, mm/m
α	:	Side clearance angle
γ	:	Rake angle
α_1	:	End clearance angle
ϕ	:	Principal cutting angle
n	:	Revolution per minute (r.p.m.)

CHAPTER-1

INTRODUCTION AND LITERATURE SURVEY

1.1 Introduction

The most important reason for embarking on a programme of industrialization including manufacturing of machine tools, cutting tools, agricultural and general purpose machines which involve a large amount of metal cutting and processing is that it may be a means to increase the national income of a country. As a focal point of development and major catalyst of economic growth, industrialization should be geared up for development activity, pulling with its other sectors of the economy.

A nation can not improve its own condition without the development of industrial sectors. For example, we can adduce the name of such countries like Japan, South Korea etc. For development of industries, there should exist a liaison between research works of universities and the works of factories. As a result, successful technical knowledge will be transferred into the various industries in order to utilize the modern technology properly. Otherwise local engineering products will not be comparable to that of the foreign products in the field of economy,

quality etc. But it is a matter of regret that metal cutting principles adopted by the machine building industry including BMTF (Bangladesh Machine Tools Factory), different engineering workshops are based on mere experience due to lack of proper technical knowhow which is not good 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 workers are aware of optimum conditions of machining without which achievement of economy in industrial production is impossible.

To improve upon this condition, it is important to study the tool wear, tool life and from which best tools should be selected and to employ more effective methods of metal cutting. This will enable to increase the productivity, machining accuracy and to machine most economically. It has been found that BMTF sells its tools, which are imported from different manufacturers of various countries without checking the tool quality, tool life etc. For this reason it is loosing its market, because sometimes worst quality tool bits are imported.

The optimum conditions of metal cutting is carried out 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. This is why, optimum results from metal cutting operations in terms of piece

cost, productivity and profit rate is of major importance to the factory.

The selection of cutting tools is an important factor governing the economics of metal cutting. Tool wear varies mainly with the cutting speed during machining operations. It has been found in Dholaikhal area of Dhaka that most of the engineering workshops including lathe machine manufacturing workshops use high speed steel (H.S.S.) as a cutting tool during the machining operation of steel which is uneconomical. Because at high cutting speeds like 100, 120, 150 m/min.; H.S.S. wears within a few seconds. So, in using H.S.S. tools, production rate falls, cost/piece increases because of grinding, loading and unloading time etc. Besides, surface finish is not good during turning with H.S.S. tools. But it is necessary to mention that high speed steel has good cutting properties at low or moderate cutting speeds and as such it is suitable for such operations as thread cutting, drilling, centering etc. However with a view to use carbide tools at higher cutting speeds, this experimental study has been performed. In addition to this, in this research work, a new method has been developed to check the quality of carbide tools with the help of milli-voltmeter. Since tool wear and tool life mainly depends on cutting speed, with the increasing cutting speed, temperature (at the surface of contact between tool and work and between tool and chip) increases i.e. milli-volt increases as well as wear increases. As a result, on the basis of this, a hypothesis has been proposed. Higher the emf, higher the

intensity of tool wear and lower the tool life and vice versa. For varification of this hypothesis, a simple jig-fixture has been designed and a turning operation has been preferred to develop this method which needs no special technical knowledge of the workers to reach the above mentioned goals.

1.2 Literature Survey

In 1924, Milton C. shaw⁽¹⁾ had shown the relationship between emf and temperature, between temperature and cutting speed, between tool life and cutting speed in machining steel with cemented carbide tools (Fig. 1.1-1.3). Eckersley and Trent⁽²⁾ illustrated manufacture, nature, properties and application of cemented carbides. They studied that the melting point of tungsten carbide is over 2500°C . They also tested the hardness of cemented carbides and showed the relationship between hardness and temperature.

Trent⁽³⁾ studied the main types of wear, factors affecting wear, including flank wear, the built-up edge, cratering, deformation, mechanical chipping and thermal cracking. He studied first four of these factors separately and their occurance over a wide range of conditions on a number of ferrous materials by a series of short time cutting tests. He also studied the flank wear occuring in short time cutting tests. The result suggest that the rate of wear is greatly influenced by the pattern of temperature distribution and flow of work material around the cutting edge.

Taylor⁽⁴⁾ studied the role of temperature of the tool on its life including the tool shape and size of cut in 1907.

Ernst and Martellotti⁽⁵⁾ confirmed the role of the built-up edge in metal cutting operation and illustrated the 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.

In 1938 Ernst⁽⁶⁾ and in 1940 Ernst and Merchant⁽⁷⁾ explained the mechanics of metal cutting and the interrelated effect of tool geometry, tool temperature, chip formation, cutting fluid and surface finish.

Ernst⁽⁸⁾, Gilbert⁽⁹⁾ studied the cutting condition with respect to minimum production cost. In this objective function, cost of production is a function of tool cost and machining cost.

Loladze⁽¹⁰⁾ in 1958, explained the role of tool wear for optimization in metal cutting process.

Brewer⁽¹¹⁾ 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.

In 1966, Markov⁽¹²⁾ performed various tests on tool wear and optimization of metal cutting process. In the same year, Armerego and Russel⁽¹³⁾ used maximum profit rate as an objective function for optimizing machining variables and proved that maximum profit depends upon both tool cost and idle time.

Boothroyd, Engle and Chisholm⁽¹⁴⁾ carried out investigations on the effect of flank wear of the tool on metal cutting process.

Talantov, Cheriomoshnikov and Kurchenko⁽¹⁵⁾ illustrated the relationship between cutting speed, metal cutting process and tool life.

In 1920, Herbert⁽¹⁶⁾ Rosenhain and Sturtevant⁽¹⁷⁾ were the first men to use the term "machinability" which referred specifically to the speed-life relationship and not to criteria like surface finish, chip disposal etc. However, the presence of the tool chip interface temperature was considered at this period.

Hanifa⁽¹⁸⁾ studied the effect of cutting speed on chip-tool contact process and tool wear for steel of unknown composition.

Sankar⁽¹⁹⁾ determined the optimum cutting conditions in turning low alloyed steel with cemented carbide tool.

Archinov⁽²¹⁾ showed the relationship between tool wear and cutting time that can be divided into three sections (Fig. 1.4). Section I is the wear in-period (Initial wear) during which heavy abrasion of the most salient parts of the surface occurs. The smoother the friction surfaces, the lower the rate of wear. Section II is the period of normal wear. It is characterized by gradual wear with the operation time (abrasion time).

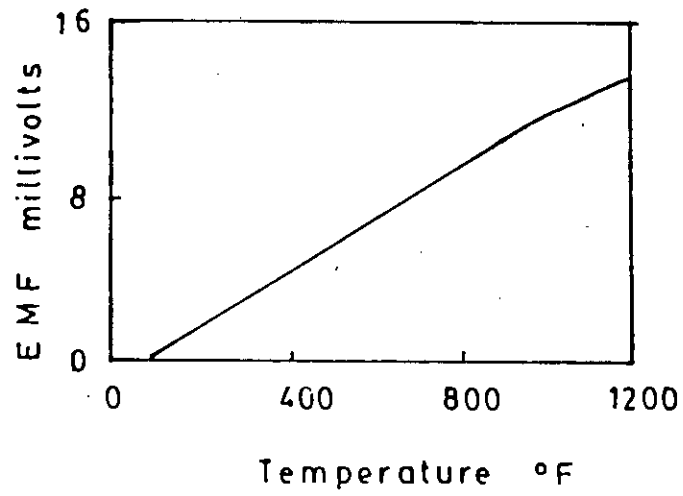


Fig.1-1: Effect of temperature on e m f (After Milton)

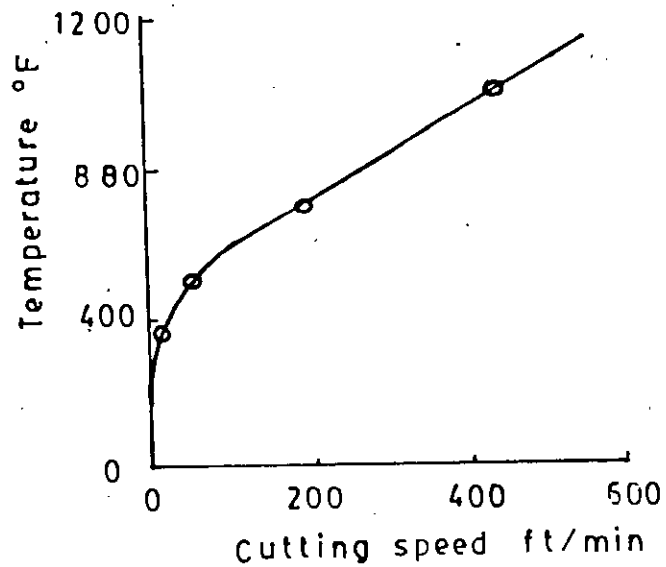


Fig.1-2: Effect of cutting speed on temperature (After Milton)

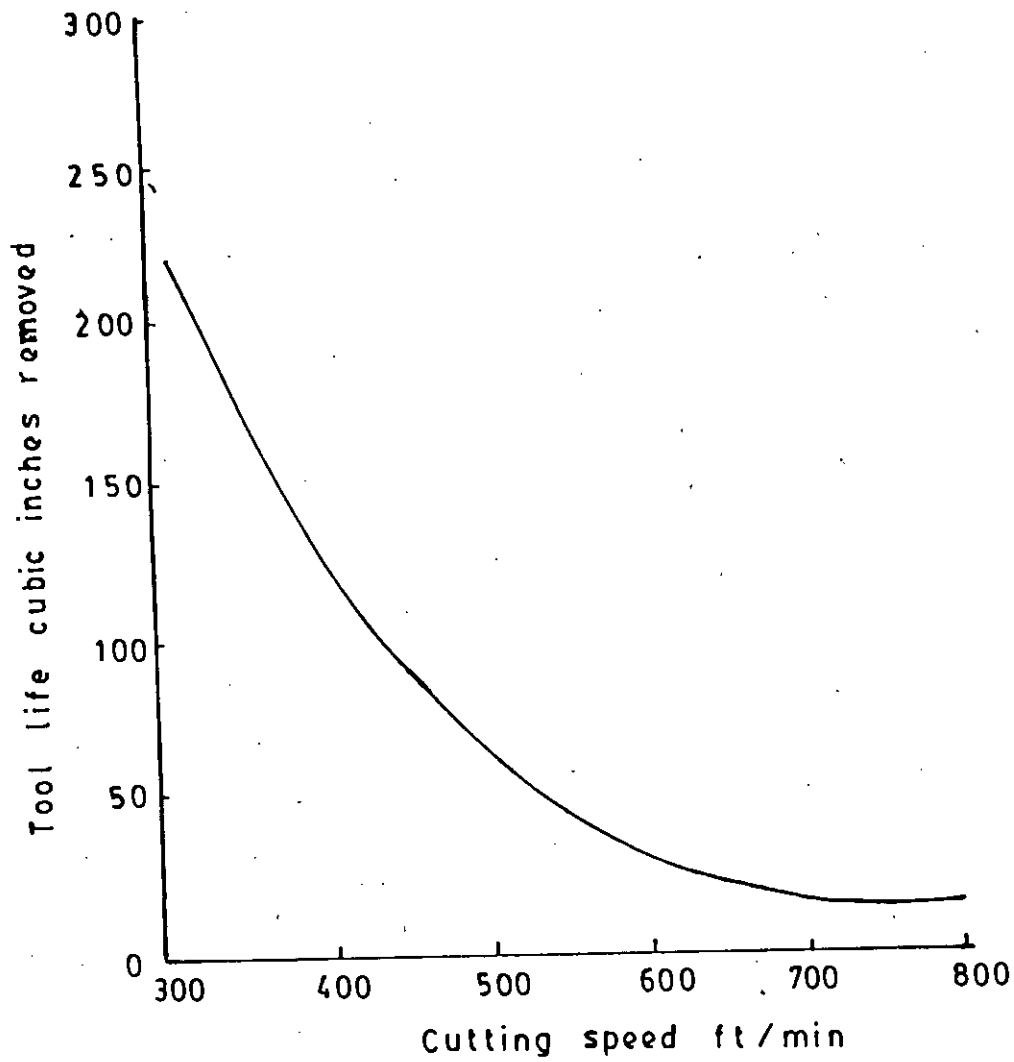


Fig-1.3:Effect of cutting speed on tool life (After Milton)

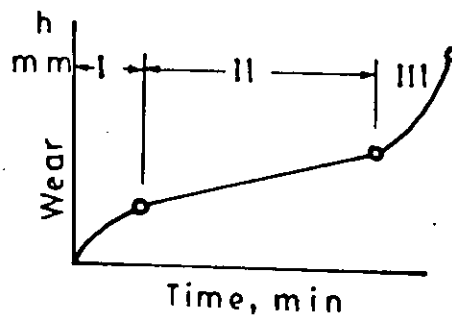


Fig.1.4:Relationship between tool wear and time of operation (After Archinov)

When a certain degree of wear has been reached, the friction conditions change (mainly due to the sharp rise in cutting temperature) and period III begins. This can be called the period of rapid (Catastrophic) wear. Because of the high hardness of cemented carbides and very slight reduction in this hardness at high temperatures, almost no period of rapid wear is observed with carbide tipped tools.

This work attempts to present a method of selecting a tool with the millivoltmeter during turning operation in metal cutting. This type of work for selecting the tool bits is entirely a new method and still now it has been performed nowhere in the world as far my knowledge goes. This study determines the relationship between emf and cutting speed, intensity of tool wear and cutting speed and also between tool life and cutting speed. This work also attempts to present the difference in using the cemented carbide tool bits and H.S.S. tool in turning operation of steel specially at high cutting speeds with respect to production cost, production rate, surface finish etc.

1.3 Aims and Objectives

- i. To develop a new set-up for checking the quality of carbide tipped tools.
- ii. To measure the emf developed during turning with different carbide tips at various cutting speeds.

- iii. To find a correlation between emf developed during turning and intensity of tool wear, if there is any.
- iv. To make an economic analysis to compare carbide tipped tools with H.S.S. tool.

CHAPTER-2

EXPERIMENTAL SET-UP AND PROCEDURE

2.1 Description of Set-up and Procedure For Measurement of emf (Electro-motive Force)

The following method has been applied to determine the emf (electro-motive force) from milli-voltmeter. The experimental set up is shown in Fig. 2.1. For this experiment, a round steel shaft of 90 mm was turned with cemented carbide tools of different manufacturers of various countries.

To perform this experiment, the tool bit was mechanically clamped in its position of tool bit holder by the clamping plate fixed with washer and standard $\frac{1}{4}$ " BSW bolt. During turning operation to take milli-voltmeter reading, the tool bit holder was kept completely insulated from the tool post of lathe machine. (Lathe machine of size 4 feet bed length and maximum machinable job diameter 150 mm). From the end of the tool bit, one probe was connected to the milli-voltmeter and another probe of milli-voltmeter was connected to the bolt ($\frac{5}{16}$ " size) of the fixture body which, in turn was connected to the graphite rod of $\frac{1}{4}$ " size (Fig. 2.2). This graphite rod was also connected to a steel disc which was placed in the hole of the lathe machine spindle. When the lathe was started, the spindle as well as disc rotated. When the turning operation was going on, a voltage difference was generated.

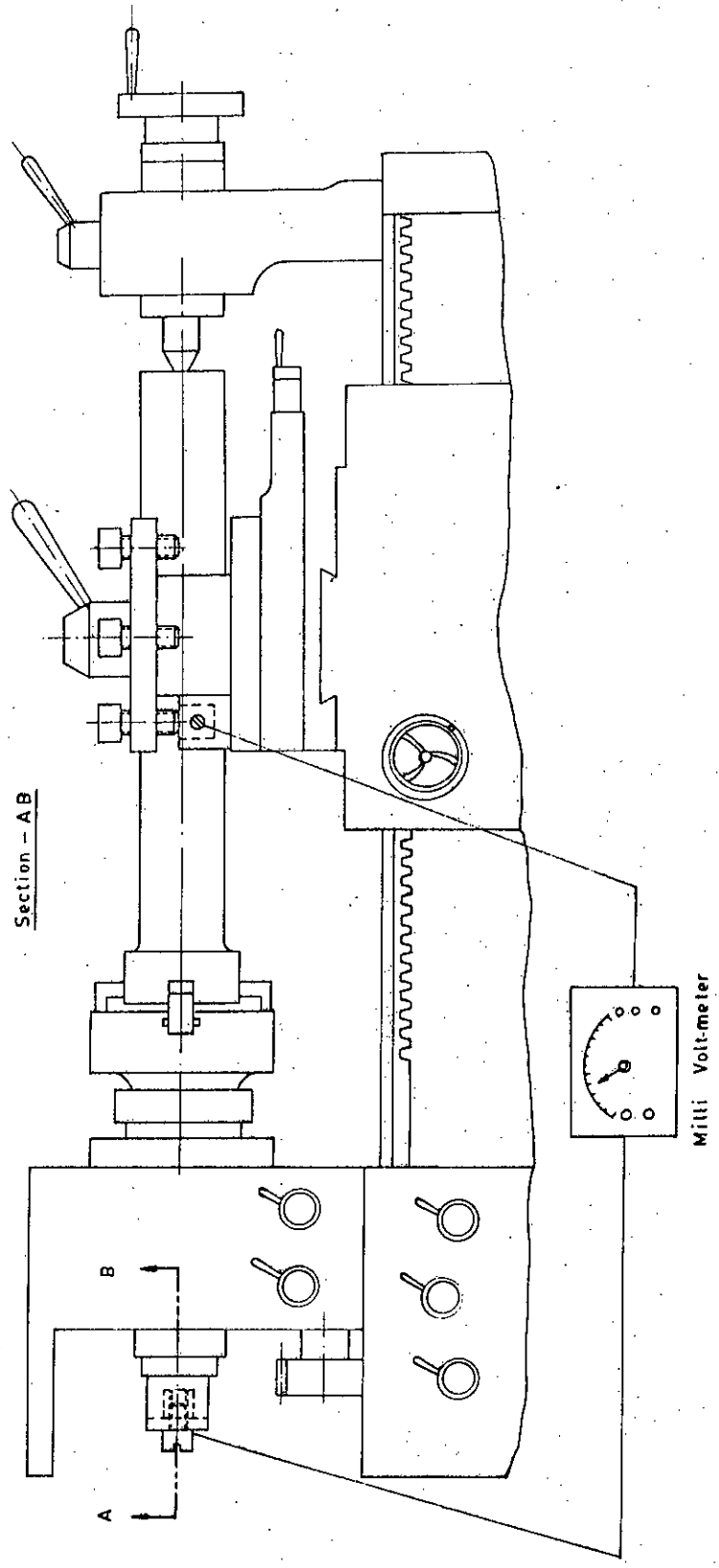
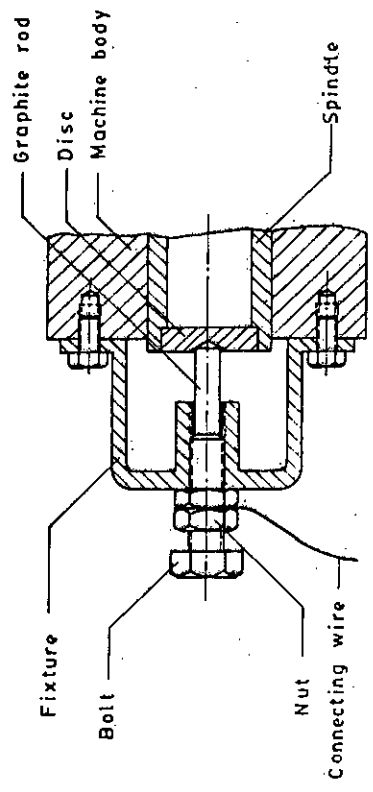
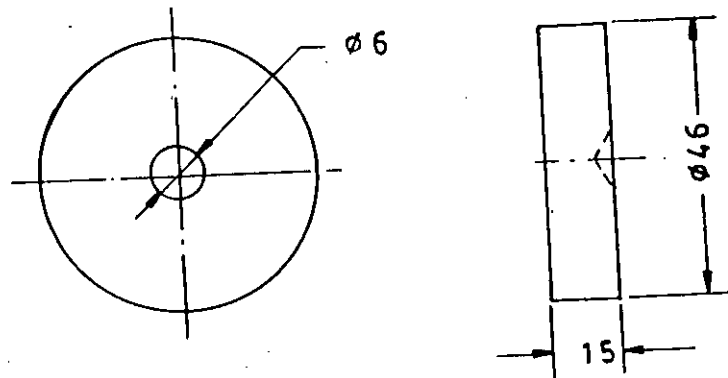
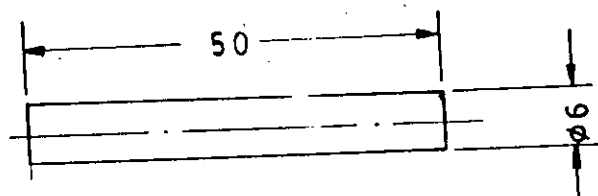


Fig.2.1 Experimental setup

Material - M.S.

Disc

Graphite rod

Fig. 2.2: Detail drawing of disc and graphite rod

This experiment was carried-out in above-mentioned lathe machine taking feed, $S = 0.20$ mm/rev. and depth of cut, $t = 1$ mm. The three bits of each manufacturer was tested during a few seconds and each time, the emf was recorded directly from millivoltmeter during turning operation over a range of cutting speeds.

2.2 Description of Set-up and Procedure For Measurement of Tool Wear

There are several methods of tool-wear testing such as radio-active method, conventional method etc. Radio-active method is used for the rapid measurement of tool life where a radioactive tool is used. This method measures wear on the cutting face as well as on the clearance face. This method is well-suited to the rapid evaluation of tool-wear with different fluids or work materials. But in this experiment, conventional method has been used for measurement of tool wear. 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. Test experiment was not based on tool failure rather on the rate of tool wear, so that tool-wear can be determined by the measurements after turning for a short period of time.

Cutting tests were performed on the same machine tool, as was used for previous series of experiments using same tool-bit holder, tool geometry, depth of cut ($t = 1$ mm), and feed ($S = 0.20$ mm/rev.) but varying the cutting speed.

The solid bar of diameter 102 mm and length approx. 630 mm was turned at different cutting speeds, $v = 80, 100, 120$ and 150 m/min. cutting tests were interrupted at regular intervals (after cutting a predetermined length) and flank wear was measured after each interval. For every cutting speed, there were four interruptions and consequently four values of tool wear (h_f).

2.3 Design and Fabrication Procedure of Fixture and Tool Bit Holder

Design of fixture and tool bit holder depends mainly on the type and size of the machine on which it will be used. In this study, the apparatus was designed and fabricated for a lathe machine (Lathe machine of size 4 feet bed length and maximum machinable job diameter 150 mm), having a square turret. Tool fixing space in the turret and the distance from the base of the turret to the center line of the lathe (s) has been shown in Figure 2.3. In order to fabricate, easy detailed drawing as well as master operation sheet for each of the parts has been shown in the following figures.

2.4 Details of Workpiece and Tool Bits

These experimental tests were carried out in the machine tools laboratory of BUET (Bangladesh University of Engineering and Technology). Work material was of steel shaft of diameter 90 mm (for emf measurement) and 102 mm (for tool wear

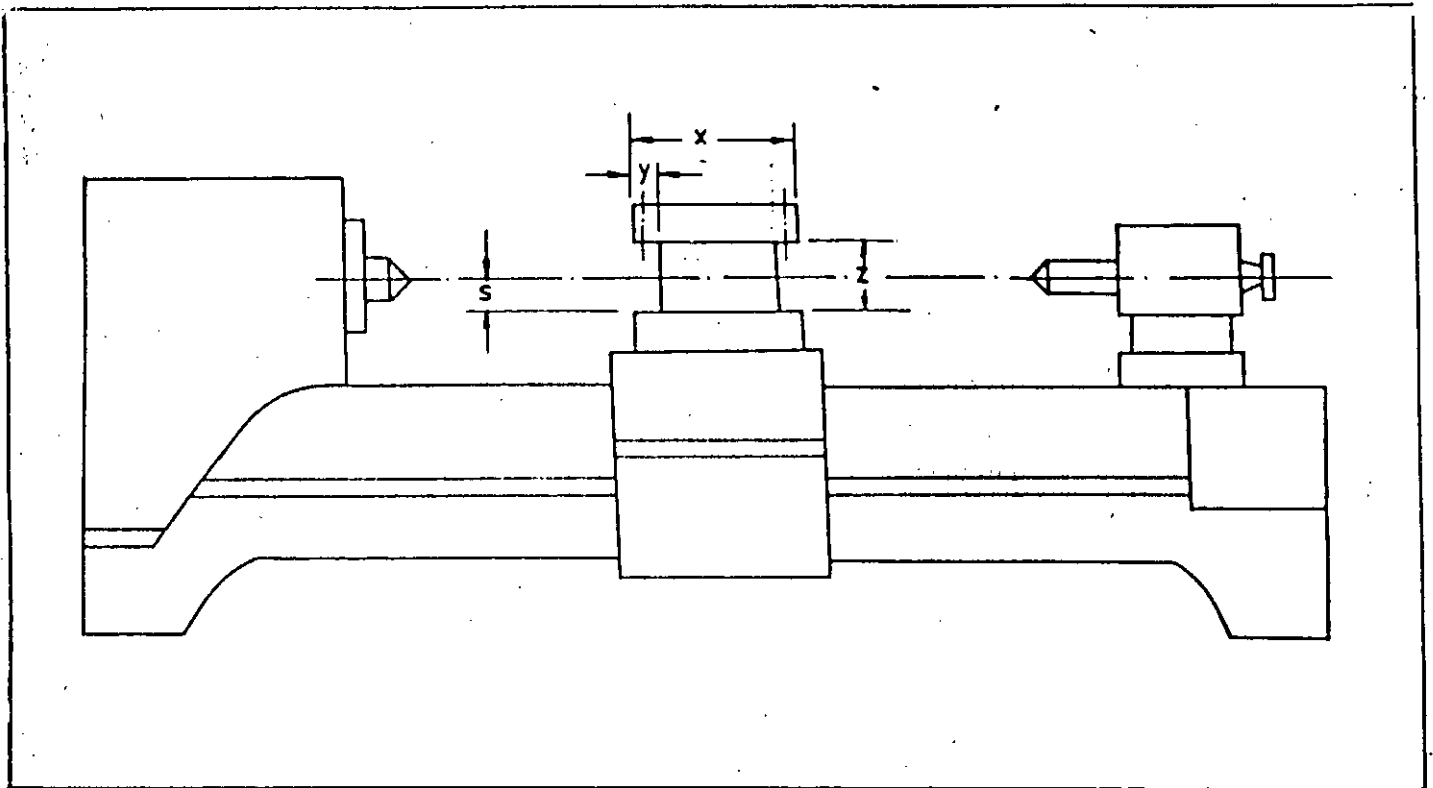


Figure -2.3 Sketch of lathe

Material - Medium carbon steel

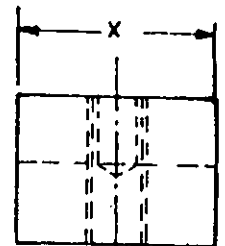
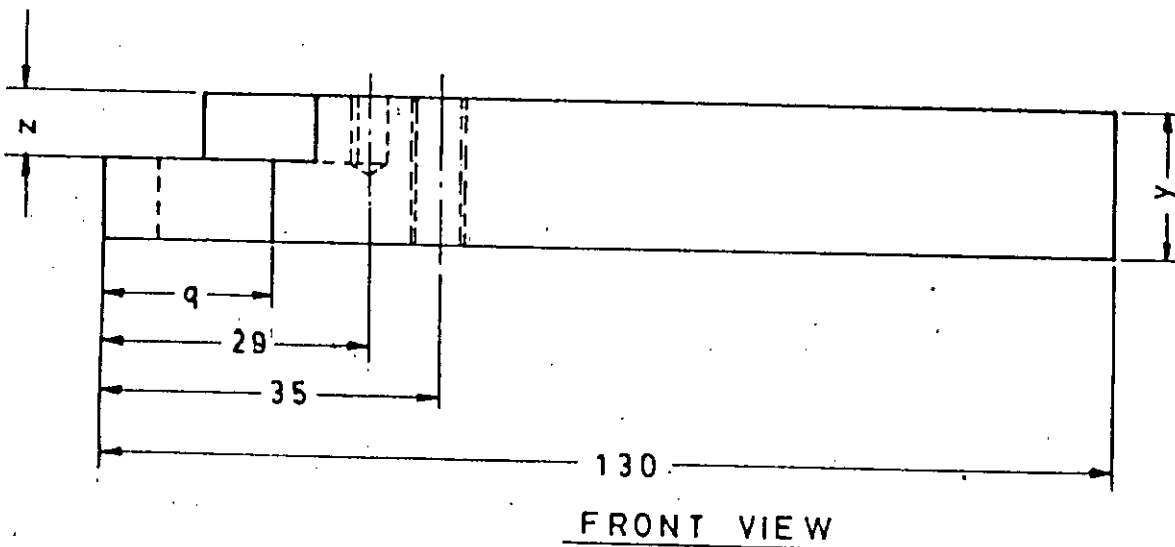
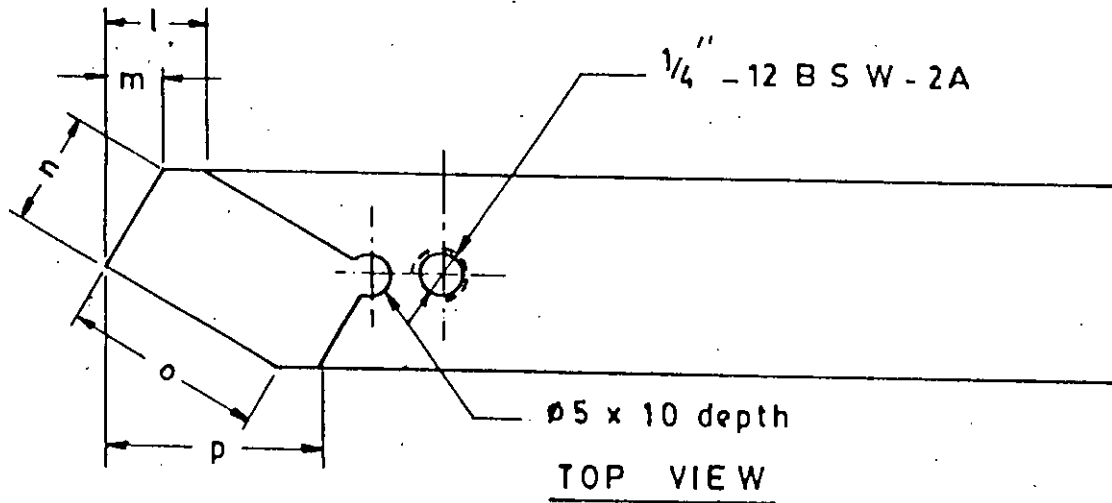
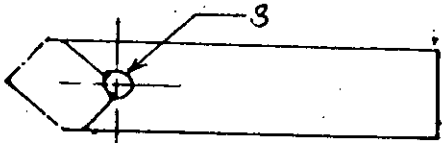
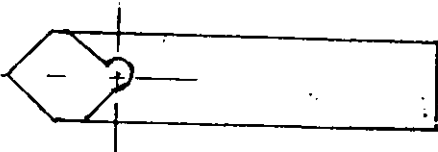
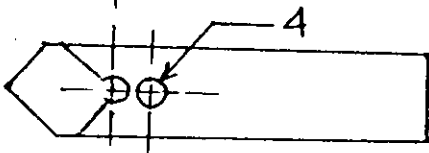


Fig.2.4: Detail drawing of tool bit holder

Cross-section of tool holder, mm ²	l	m	n	o	p	q	x	y	z
18x18	8.5	5	12	11	25	10	18	18	8
	8.0	5	10	11	25	10	18	18	8
	7.5	5	9.5	11	25	10	18	18	8
	7.5	5	9.5	7	12	6	18	18	4

Master Operation Sheet:

Operation No.	Description	Sketches	Machine, fixture tool and gauge
1.	Cutting of the blank		Power hacksaw, Machine Vice, scale.
2.	Machining all the faces		Shaper, Machine Vice, scale
3.	Machining face 1 & 2		Do
4.	Drilling hole 3 for Milling corner of tool bit housing		Drill machine, Drill bit, Machine vise, centre punch, hammer, scale.
5.	Milling for tool bit housing		Milling machine, Machine vise, scriber
6.	Drilling hole 4		Drill Machine, Drill bit, Machine Vice, centre punch, hammer, scale
7.	Cutting of thread in hole-4		Tap, vise
8.	Cleaning and Chamfering		Brush and Files.

Material - Medium carbon steel

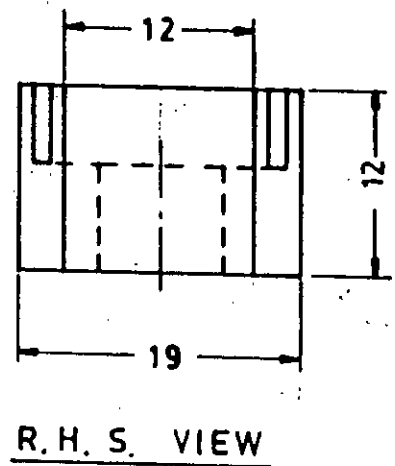
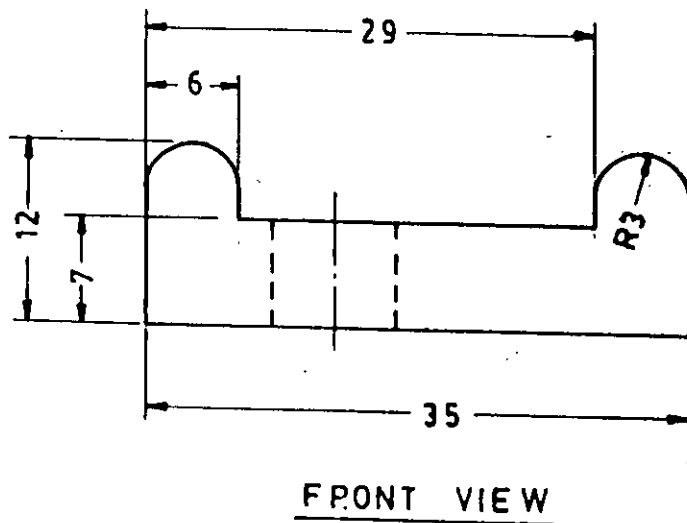
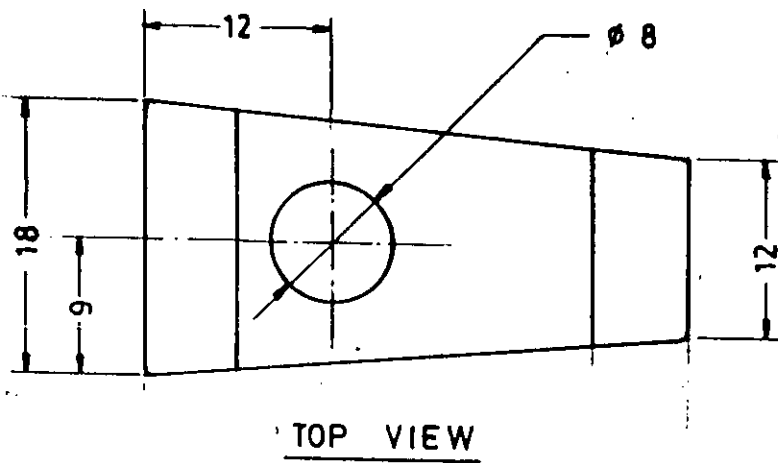
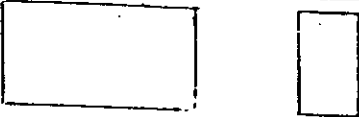
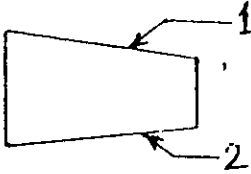
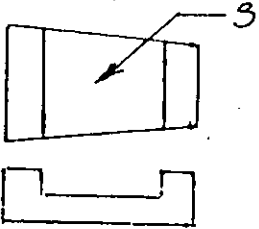
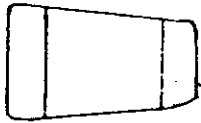
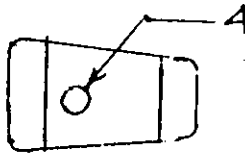
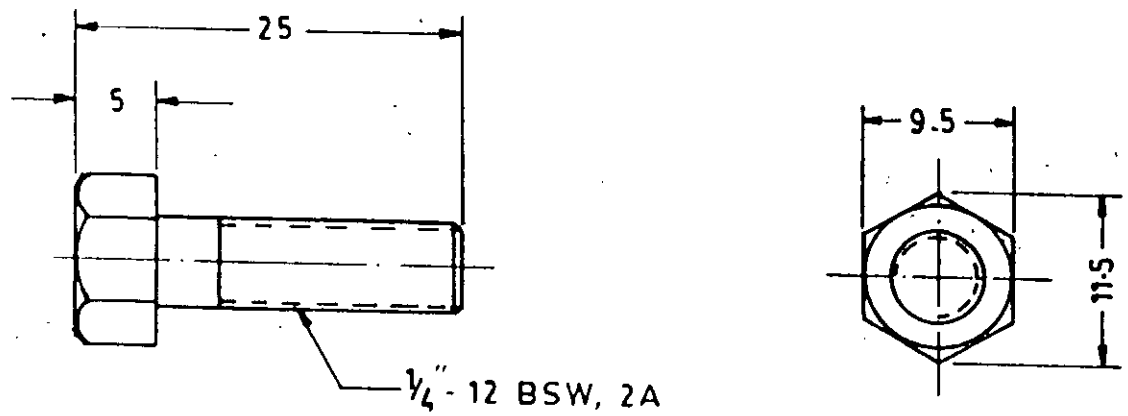


Fig.-2.5 Detail drawing of clamping plate

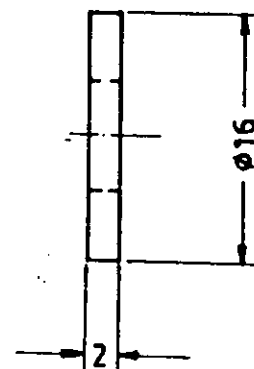
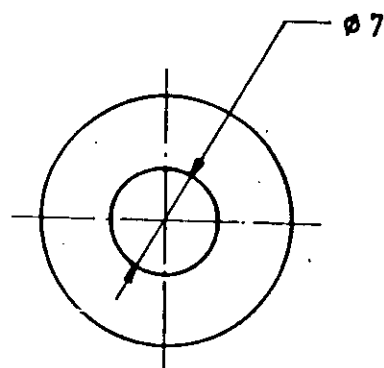
Master Operation Sheet :

Operation no.	Description	Sketches	Machine, Fixture Tools & Gauges
1.	Cutting off the blank		Power and Machine vice, scale.
2.	Machining faces 1 & 2		Shaper, Machine Vice, scriber, scale.
3.	Machining Surface		Do
4.	Grinding all the corners		Grinding Machine
5.	Drilling hole 4		Drilling Machine, Drill bit, Machine Vice, centre Punch, Hammer.
6.	Cleaning and Chamfering		Brush and File.

Material:- Medium carbon steel



BOLT



WASHER

Fig-2.6 Detail drawing of standard fasteners

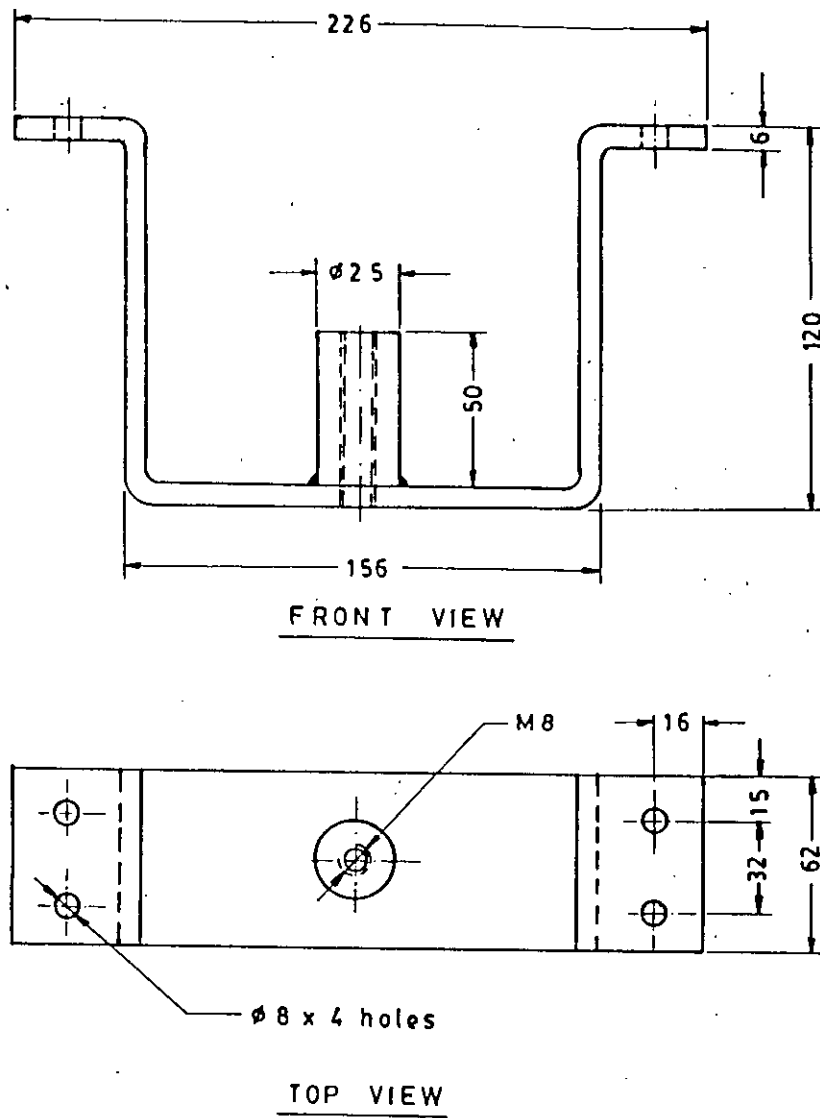


Fig.2.7Detail drawing of fixture

measurement). The tool materials were of cemented carbide and high speed steel. Tool geometry was as follows:

Rake angle	$\gamma = 0^\circ$
Side clearance angle	$\alpha = 13^\circ$
End clearance angle	$\alpha_1 = 4\frac{1}{2}^\circ$
Principal cutting angle	$\phi = 55^\circ$

For the success of the method of testing used here, the tool geometry was maintained constant within very close limits throughout the whole experiments.

Composition of tool materials of the different USSR groups are given below:

- 1st group (BK8) : (92% wc and 8% Co)
- 2nd group (T5K10) : (85% wc, 5% TiC and 10% Co)
- 3rd group (T15K5) : (80% wc, 15% TiC and 5% Co)

Composition of the remaining (Chinese, Polish and Indian) bits were not available.

2.5 Condition and Assumptions of the Experiments

From the earlier investigations of Trent⁽³⁾, it was demonstrated that tool wear as well as tool life largely depends on cutting speed, depth of cut, feed, tool geometry, cutting fluid, material to be machined etc. According to Milton C. Shaw⁽¹⁾, mf also depends on cutting speed and other cutting variables. Here influence of tool geometry was avoided by using

constant tool geometry throughout the whole experiment. Although cutting fluid has some effect on cutting conditions, yet it was not used, since coolant quickly shatters cutting edge and forms crack for repeated quenching. In this study, feed and depth of cut was also kept constant throughout the whole investigation. To carryout these experiments, the following assumptions were made:

- i. The properties of the work material do not vary during and after the turning operations;
- ii. Instantaneous conditions of temperature, pressure and chip-formation in the region of cutting operations correspond to the appropriate steady-state condition.

CHAPTER-3

MEASUREMENT OF emf (ELECTROMOTIVE FORCE)
DURING TURNING WITH DIFFERENT CUTTING TOOLS3.1 Theory

There is a wide variety of methods which have been used to estimate the chip-tool interface temperature including complicated radiation pyrometers, embeded thermocouples, temperature sensitive paints, the development of temper colours and indirect calorimetric techniques, but all of these methods suffer from a slow speed of response⁽¹⁾. The most successful approach to this problem has been the tool-work thermocouple, apparently first used by shore in 1924. In this respect, it is necessary to mention that since tool life is mainly dependent on the temperature reached at the tool-chip interface, the quality of a tool can be assessed by the millivolts obtained directly from milli-voltmeter. However, in this method, the tool work contact area serves as the hot junction in a thermo-electric circuit and the emf generated is proportional to its temperature.

The laws of thermo-electric circuits that are applicable may be summarized as follows:

- i. The emf in a thermoelectric circuit which depends only on the difference in temperature between the hot and cold junctions and is independent of the gradient in the parts making up the system.

- ii. The emf generated is independent of the size and resistance of the conductors.
- iii. If the junction of two metals is at uniform temperature, the emf generated is not affected if a third metal, which is at the same temperature is used to make the junction between the first two.

Tool temperature measurement offers not only a more rational approach to tool life, but one that can save a great deal of time in rating machinability of materials when a correlation exists between tool life and temperature. There had been made a long series of experiments designed to relate tool life (M) and temperature (θ in $^{\circ}\text{F}$) and was found that

$$\theta \cdot M^{1/n} = C$$

where C and n are constants for a given tool material.

The cutting speed also affects the cutting temperature. This relationship can be expressed by the following equation.

$$T = C_1 v^Z$$

where T = cutting temperature in $^{\circ}\text{C}$ or $^{\circ}\text{F}$

v = cutting speed in m/min. or ft/min.

C_1 = coefficient depending upon the machining conditions (metal being machined, depth of cut, rate of feed, tool geometry, cutting fluid etc.).

z = exponent characterizing the intensity of temperature growth with increased cutting speed.

Experimental data show that the exponent $z < 1$ ($z = 0.26$ to 0.72)

3.2 Experimental Results

This experiment was performed by taking three carbide tips from each manufacturer of each country. The work material was turned for few seconds with each of the tool bits and the millivoltmeter reading of these three was recorded. The average millivoltmeter reading (i.e. emf) of these three has been plotted against the cutting speed. From the Figure 3.1 (emf vs. cutting speed), it is seen that at lower cutting speed, the emf is less but with the increase of cutting speed, emf increases. From the same Figure, it is also found that emf of carbide bit of china is higher and emf of carbide bit of poland is lower at the high cutting speed e.g., 100, 120 m/min. The average milli-voltmeter reading has been given in Table-1.

3.3 Discussion

From the Figure 3.1 (emf vs. cutting speed), it is found that with the increase of cutting speed, emf increases. It is due to the cause that at the increasing cutting speed, temperature (at the surface of contact between tool and work and between tool and chip) increases, because there exists a relationship

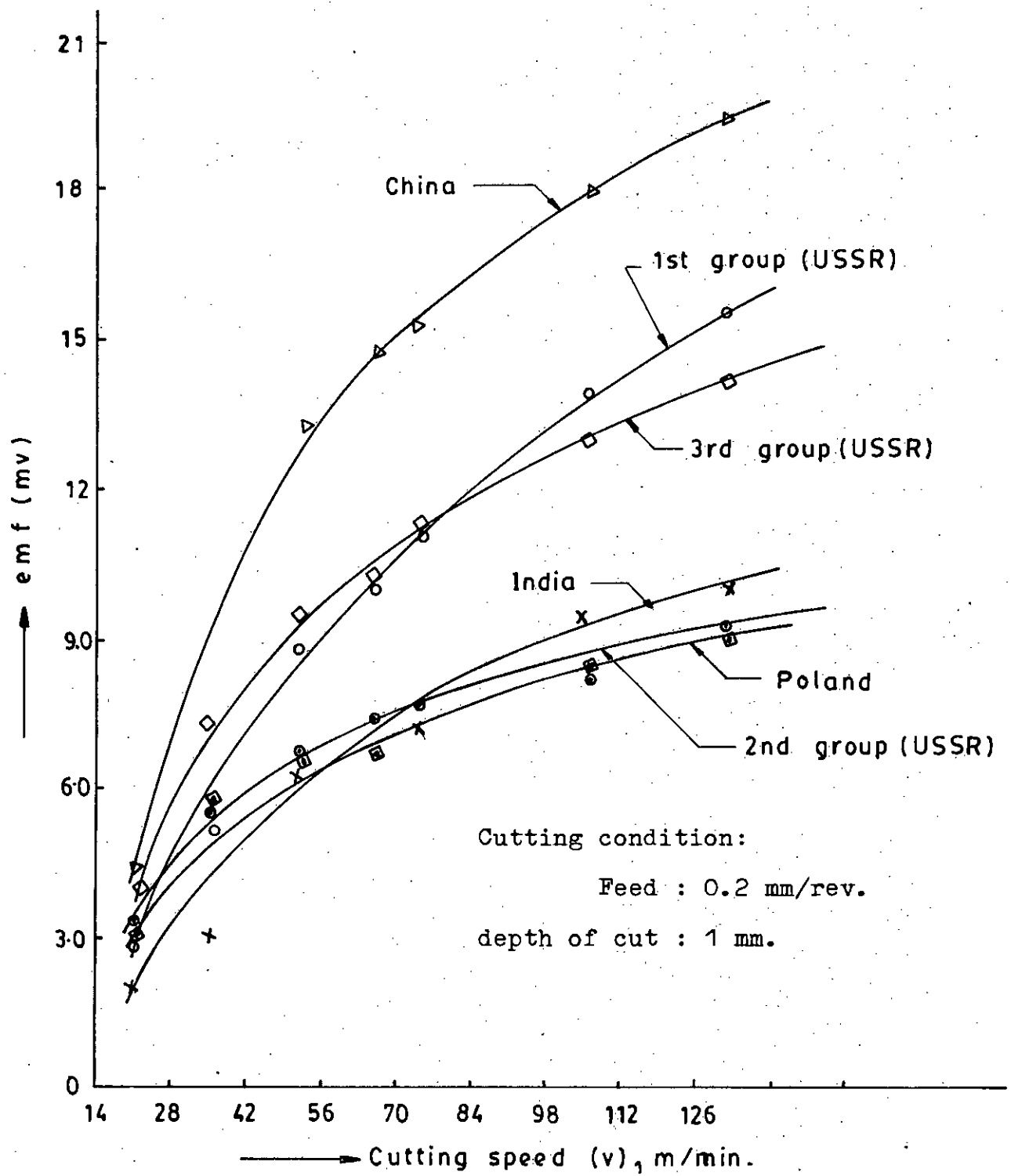


Fig.3.1 Effect of cutting speed on emf

(approximately linear relationship) between temperature and emf (which has been shown in Chapter-1, after Milton C; Shaw⁽¹⁾.) Milton C. Shaw also showed the relationship between temperature and cutting speed. So, from this, it can be demonstrated that there is a relationship between emf and cutting speed. Since linear relationship exists between emf and temperature, shape of curves of temperature vs. cutting speed will be of same nature with respect to emf vs. cutting speed. In this study, nature of curves of temperature vs. cutting speed has a similarity with the nature of curves of emf vs. cutting speed. It is necessary to remember that when test was carried out with H.S.S. tool (China), no emf was generated. It may be due to the cause that work material and tool was of the same material i.e. steel. That was why, it was not possible to take reading in case of high speed steel tool. From the same Figure, it is seen that at higher cutting speed around 130 m/min, bit of Poland is the best tool for cutting a work material of steel and bit of China is the worst bit. Between these two, there are bit of USSR 2nd group, India, USSR 3rd group and USSR 1st group respectively. At a cutting speed around 100 m/min., bit of Poland and USSR 2nd group is good and then bit of India, USSR 3rd group, USSR 1st group, China respectively. At lower cutting speed around 60 m/min., bit of India is very good. Though it is found that bit of India is very good at this cutting speed, yet the economic analysis will give the actual perception about the tool bits.

In the next Chapter, it will be shown that intensity of tool wear has certain similarity with the emf with respect to cutting speed in the case of the shape of curve. It will be also shown that knowing the shape of the above mentioned curves, it will be possible to predict at which particular cutting speed or its range, the value of tool wear will be minimum or which tool bit is best.

TABLE-1Average Millivoltmeter Reading of Different Carbide Tips

Actual r.p.m.	Actual Linear speed	Millivoltmeter reading of carbide tool bits of different manufacturer					
		Poland	India	USSR 1st group	USSR 2nd group	USSR 3rd group	China
r.p.m.	m/min.	mv.	mv.	mv.	mv.	mv.	mv.
72	20.36	3	1.916	2.916	3.33	4.083	4.33
130	36.8	5.75	3.0	5.17	5.58	7.25	6.83
185	52.3	6.67	6.25	8.83	6.75	9.33	13.167
230	65.03	6.83	6.917	10.33	7.41	10.17	14.66
260	73.5	7.17	7.10	11.33	7.67	11.3	15.17
375	106.02	8.5	8.9	13.83	8.08	12.9	17.917
455	128.65	9.17	10	15.58	9.33	14.17	19.17

CHAPTER-4DETERMINATION OF INTENSITY OF TOOL WEAR AND
TOOL LIFE AT VARIOUS CUTTING SPEEDS4.1 Theory

There are several factors such as feed, depth of cut, cutting speed, tool geometry, cutting fluid etc. which affect the tool wear as well as tool life - the machining time of tool operation between grinds (from one sharpening to the next or upto a definite amount of wear). Again tool life influences the machining as well as the production costs. However, tool life has several explanations. It can either be the useful life of a cutting tool expressed in minutes between two grinds or the total time upto which a tool can withstand before completely worn out. Tool life is frequently designated as the time to produce a specified amount of flank wear. In this study, the limiting amount of flank wear which has been adopted, is 0.50 mm. After this, the tool has been regrounded. When tool life is expressed in time alone, it becomes easier to compute the machining cost. Kronenberg⁽²⁰⁾, in his study concluded that only the volume of metal removed from the work material can definitely be coordinated with tool-wear.

The tool life enters in the 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 worn out tool.

Thus any attempt of improving the tool life results in a lower cost per piece and at the same time, higher production rate.

With a view to make a basis for such an improvement, much effort has been made to realize the nature of tool wear and other kinds of tool failure. The life of a cutting tool can be brought to an end in various ways, but these ways may be separated into two main groups:

- (i) the gradual or progressive wear of certain regions of face (crater wear) and flank (flank wear) of the tool.
- (ii) failure of tool life to a premature stage.

Brewer⁽¹¹⁾, "on the economics of the basic turning operation" explained that under all circumstances the wear at the tool flank is the sole guess in prescribing the useful life of a carbide tool.

Trent⁽³⁾ explained that the following forms of deterioration of a tool are possible:

- (i) flank or clearance face wear

- (ii) cratering wear on top or rake face of the tool
- (iii) build-up and associated deterioration of rake surface and cutting edge
- (iv) deformation of cutting edge due to high stress and temperature
- (v) cracking at the cutting edge due to thermal stresses
- (vi) chipping at the edge or fracture due to mechanical impact.

Flank or clearance face wear is important in a large majority of cutting applications. It is progressive with time and the rate of wear is easily estimated by measuring under a microscope the depth of wear land from the original cutting edge. In general, the rate of flank wear rises with the increasing cutting speed but the effect of increasing feed is very variable and it does not appear possible to give any general rule on the effect of feed rate. When speed and feed are increased to the limit where the cutting edge begins to deform, the rate of flank wear normally increases rapidly. Under these conditions, the presence of a cutting lubricant may have a very pronounced effect on the rate of flank wear.

The rate of wear is considerably affected by the tool geometry. In particular, increasing the clearance angle will often markedly decrease the rate of wear expressed in terms of the depth of wear land. The depth of cut, however, has a little

influence on the rate of the flank wear unless it is increased to a limit where the tool deforms.

It is often stated that cutting tools ought to be reground when the depth of the wear land reaches some definite figure e.g. 0.020 to 0.030 inch. If regrinding is not carried out at this stage, serious break-down of the tool may occur. The reason for this appears to be associated with the formation of thermal cracks due to the stresses involved when too large an area of worn surface is being heated by friction. A tool in this condition is liable to fail by sudden break away of a relatively large fragment.

The type of surface finish formed depends on the carbide tool alloy, the work material and cutting speed. The surfaces tend to become smoother as the cutting speed increases.

4.2. Experimental Results

Flank wear was measured each time using a metallurgical microscope (Model ZEISS 35196, CARL, GERMANY). Aqua regia ($\text{HCL} : \text{HNO}_3 = 1 : 3$) was also used to clean the metal over cemented carbide tool bits except high speed steel tool. With the experimental data, curves of tool flank wear (h_f) vs. time has been plotted from Figure 4.1 to 4.25.

To compare the intensity of tool flank wear and tool life of different carbide tool bits with the different cutting speeds ($v = 80, 100, 120, 150 \text{ m/min.}$) at the same feed and

depth of cut ($s = 0.20$ mm/rev. and $t = 1$ mm), the curves have been plotted in the same graph in Figure 4.26 and 4.27.

From Figure 4.1 to 4.25 (flank wear vs. time curves), it is seen that at a definite cutting speed, feed and depth of cut, flank wear increases as the time proceeds.

From Figure 4.26, (Intensity of tool wear vs. cutting speed curve) it is found that with the increase of cutting speed, intensity of tool wear increases. From Figure 4.27, (Tool life, T_L vs. cutting speed, v), it is found that tool life decreases with the increase of cutting speed.

4.3 Discussion

From Figure 4.1 to 4.25 (flank wear vs. time curves), it is found that at a particular cutting speed, feed and depth of cut, flank wear increases with the time. In these curves, it is also seen that initial wear is high. It may be due to the sharp edge of grinding. From Figure 4.26, (Intensity of tool wear vs. cutting speed), it is observed that intensity of tool wear increases with the increase of cutting speed. This is due to the cause that with the increase of cutting speed, temperature increases between the contact point of tool and work material and between the tool and chip.

From Figure 4.27, (Tool life vs. cutting speed), it is also found that tool life decreases with the increase of cutting speed.

TABLE - 2

Tool wear at different cutting speeds at depth of cut,
 $t = 1 \text{ mm}$ and feed $s = 0.2 \text{ mm/rev.}$

Manufacturer of tool bits	Diameter mm	Speed r.p.m.	Linear velocity m/min	Time	Flank wear mm
Poland (cemented carbide)	102	455	145.8	1 min.42 secs	0.085
				3 min.21 secs	0.105
				5 min.0.5 secs	0.115
				6 min.50.5 sec	0.125
	100	375	117.8	2 min. 5 secs	0.075
				4 min.18 secs	0.09
				6 min.23 secs	0.105
				8 min.43 secs	0.115
	74	455	105.8	1 min.45 secs	0.10
				3 min.19 secs	0.11
				4 min.54 secs	0.12
				6 min.44 secs	0.13
	96	260	78.4	3 min. 1 sec	0.105
				6 min. 5 secs	0.115
				9 min.	0.125
				12 min.14.5sec	0.135
	84	590	155.8	1 min.23 secs	0.06
				2 min.45 secs	0.09
				4 min.10 secs	0.13
				5 min.42 secs	0.152

Contd. Table-2

Manufacturer of tool bits	Diameter mm	Speed r.p.m.	Linear velocity m/min	Time	Flank wear mm
USSR 1st group (Cemented carbide)	98	375	115	2 min.2.5 secs 4 min.11.5 secs 6 min.13.5 secs 8 min.36.5 secs	0.065 0.10 0.13 0.165
	72	455	102.9	1 min.41 secs 3 min.16 secs 4 min.51 secs 6 min.40 secs	0.065 0.075 0.105 0.140
	94	260	76.8	2 min.55 secs 5 min.57 secs 8 min.51 secs 12 min.8 secs	0.06 0.08 0.095 0.130
USSR 2nd group (Cemented carbide)	82	590	152	1 min.23 secs 2 min.43 secs 4 min.4 secs 5 min.41 secs	0.06 0.075 0.095 0.11
	88	455	125.85	1 min.40 secs 3 min.17 secs 4 min.59 secs 6 min.51 secs	0.06 0.075 0.085 0.10
	70	455	100.05	1 min.37 secs 3 min.15 secs 4 min.52 secs 6 min.48 secs	0.10 0.11 0.12 0.14
	92	260	75	2 min.53 secs 5 min.54 secs 8 min.51 secs 12 min.8 secs	0.10 0.125 0.14 0.15

Contd. Table-2

Manufacturer of tool bits	Diameter mm	Speed r.p.m.	Linear velocity m/min	Time	Flank wear mm
USSR 3rd group (cemented carbide)	80	590	148.3	1 min.23 secs 2 min.47 secs 4 min.8 secs 5 min.48 secs	0.05 0.08 0.095 0.115
	86	455	122.9	1 min.38 secs 3 min.15 secs 4 min.53 secs 6 min.39 secs	0.05 0.08 0.095 0.12
	68	455	97.2	1 min. 36 sec 3 min.12 secs 4 min.47 secs 6 min.34 secs	0.055 0.085 0.10 0.115
	58	455	82.9	1 min.36 secs 3 min.14 secs 4 min.48 secs 6 min.31 secs	0.055 0.07 0.085 0.10
China (cemented carbide)	66	740	153.43	1 min. 3 secs 2 min. 4.5sec 3 min. 6.5sec 4 min.14.5sec	0.09 0.115 0.135 0.165
	54	740	125	1 min.2 secs 2 min.4 secs 2 min.26 secs	0.08 0.09 0.110
	56	590	103.8	1 min.21 secs 2 min.44 secs 4 min. 6 secs 5 min.31 secs	0.08 0.10 0.12 0.135
	74	375	85.8	2 min. 2 secs 4 min. 5 secs 6 min. 5 secs 7 min.15 secs	0.08 0.10 0.115 0.13

Contd. Table-2

Manufacturer of tool bits	Diameter mm	Speed r.p.m.	Linear velocity m/min	Time	Flank wear mm
India (cemented carbide.)	64	740	148.8	1 min. 2 secs 2 min. 2 secs 2 min.19 secs	0.11 0.125 0.13
	52	740	120	1 min. 1 sec 2 min. 4 secs 2 min.28 secs	0.09 0.10 0.11
	72	455	102.9	1 min.37 secs 3 min.15 secs 4 min.51 secs 5 min.41 secs	0.105 0.12 0.13 0.14
	70	375	82	1 min.58 secs 4 min. 6 min. 8 min. 5 secs	0.10 0.11 0.12 0.135
China (H.S.S.)	60	815	153.63	25 secs	1.15
	50	740	116	35 secs	0.88
	80	375	95	45 secs	0.70
	90	260	74	2 min.53 secs 5 min.56 secs 6 min.46 secs	0.29 0.40 0.68

TABLE - 3

Tool wear intensity and tool life at different cutting speeds at depth of cut, $t = 1$ mm and feed = 0.2 mm/rev.

Manufacturer of tool bits	Speed r.p.m.	Linear velocity m/min.	Cumulative time	Cumulative flank wear (h_f) mm	Intensity of tool wear (I) mm/m	Tool life (T_L) min.
Poland	455	145.8	6 min. 50.5 sec	0.125	6.5×10^{-5}	45.74
	375	117.8	8 min. 43 secs	0.115	6.02×10^{-5}	62.06
	455	105.8	6 min. 44 secs	0.130	5.86×10^{-5}	67.37
	260	78.4	12 min. 14.5 sec	0.135	4.24×10^{-5}	124.48
USSR 1st group	590	155.8	5 min. 42 secs	0.152	13.68×10^{-5}	22.0
	375	115	8 min. 36.5 sec	0.165	13.2×10^{-5}	30.0
	455	102.9	6 min. 40 secs	0.140	12.53×10^{-5}	35.42
	260	76.8	12 min. 8 secs	0.130	9.83×10^{-5}	61.0
USSR 2nd group	590	152.0	5 min. 41 secs	0.110	7.6×10^{-5}	39.22
	455	125.85	6 min. 51 secs	0.10	6.7×10^{-5}	55.33
	455	100.05	6 min. 48 secs	0.14	6.28×10^{-5}	66.4
	260	75.0	12 min. 8 secs	0.15	5.34×10^{-5}	99.4
USSR 3rd group	590	148.3	5 min. 48 secs	0.115	12.1×10^{-5}	25.55
	455	122.9	6 min. 39 secs	0.12	11.3×10^{-5}	33.9
	455	97.2	6 min. 34 secs	0.115	10.7×10^{-5}	43.0
	455	82.9	6 min. 31 secs	0.10	9.8×10^{-5}	55.9
China	740	153.43	4 min. 14.5 sec	0.165	14.71×10^{-5}	19.25
	740	125.0	2 min. 26 secs	0.110	14.64×10^{-5}	24.0
	590	103.8	5 min. 31 secs	0.135	13.9×10^{-5}	30.5
	375	85.8	7 min. 15 secs	0.130	12.06×10^{-5}	42.6
India	740	148.8	2 min. 19 secs	0.130	9.2×10^{-5}	29.3
	740	120.0	2 min. 28 secs	0.110	8.13×10^{-5}	43.04
	455	102.9	5 min. 41 secs	0.140	7.6×10^{-5}	52.0
	375	82.0	8 min. 5 secs	0.135	5.85×10^{-5}	85.0
H.S.S. (China)	260	74.0	6 min. 46 secs	0.68	134×10^{-5}	—

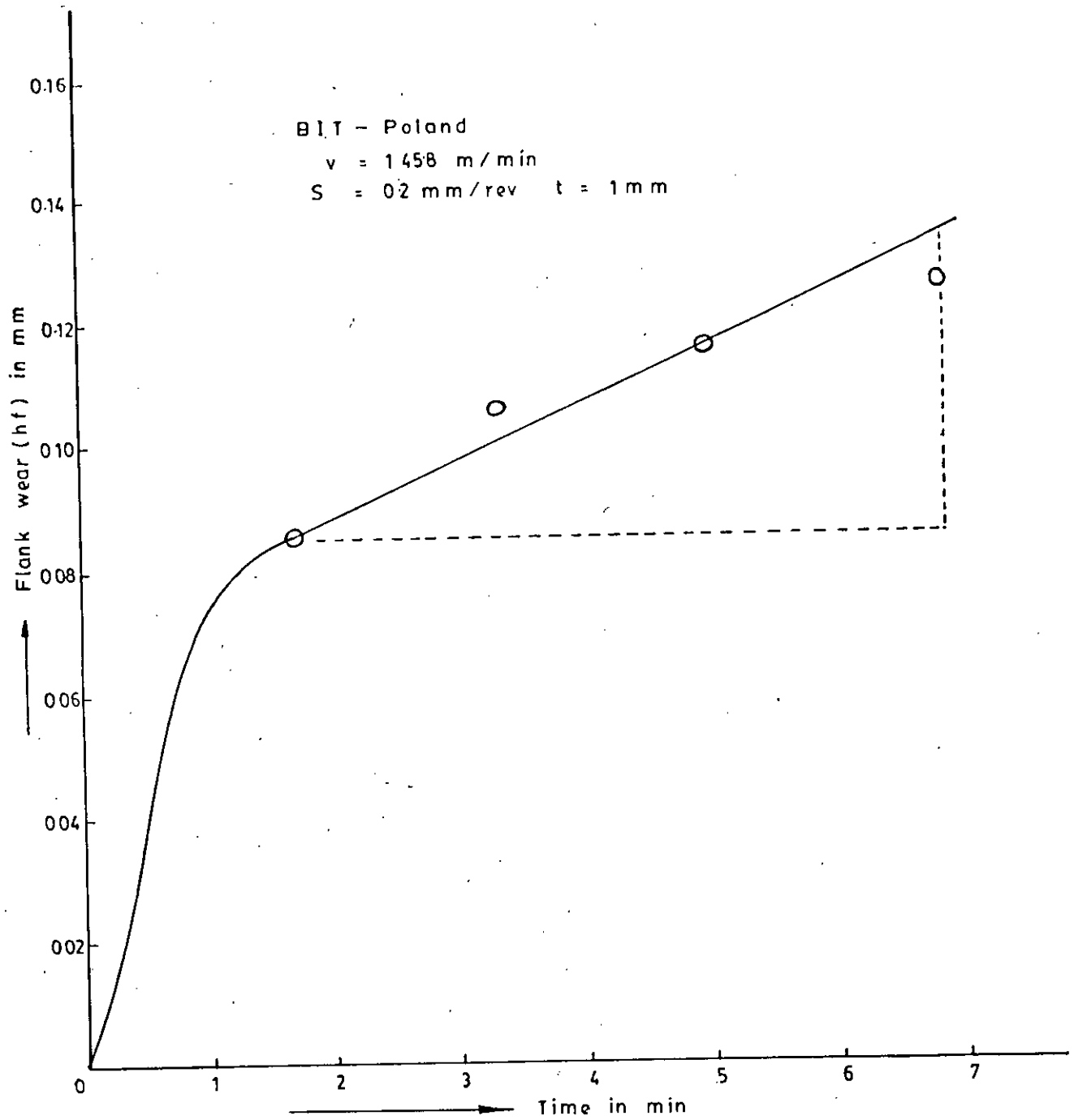


Fig.4.1: Flank wear Vs Time curve.

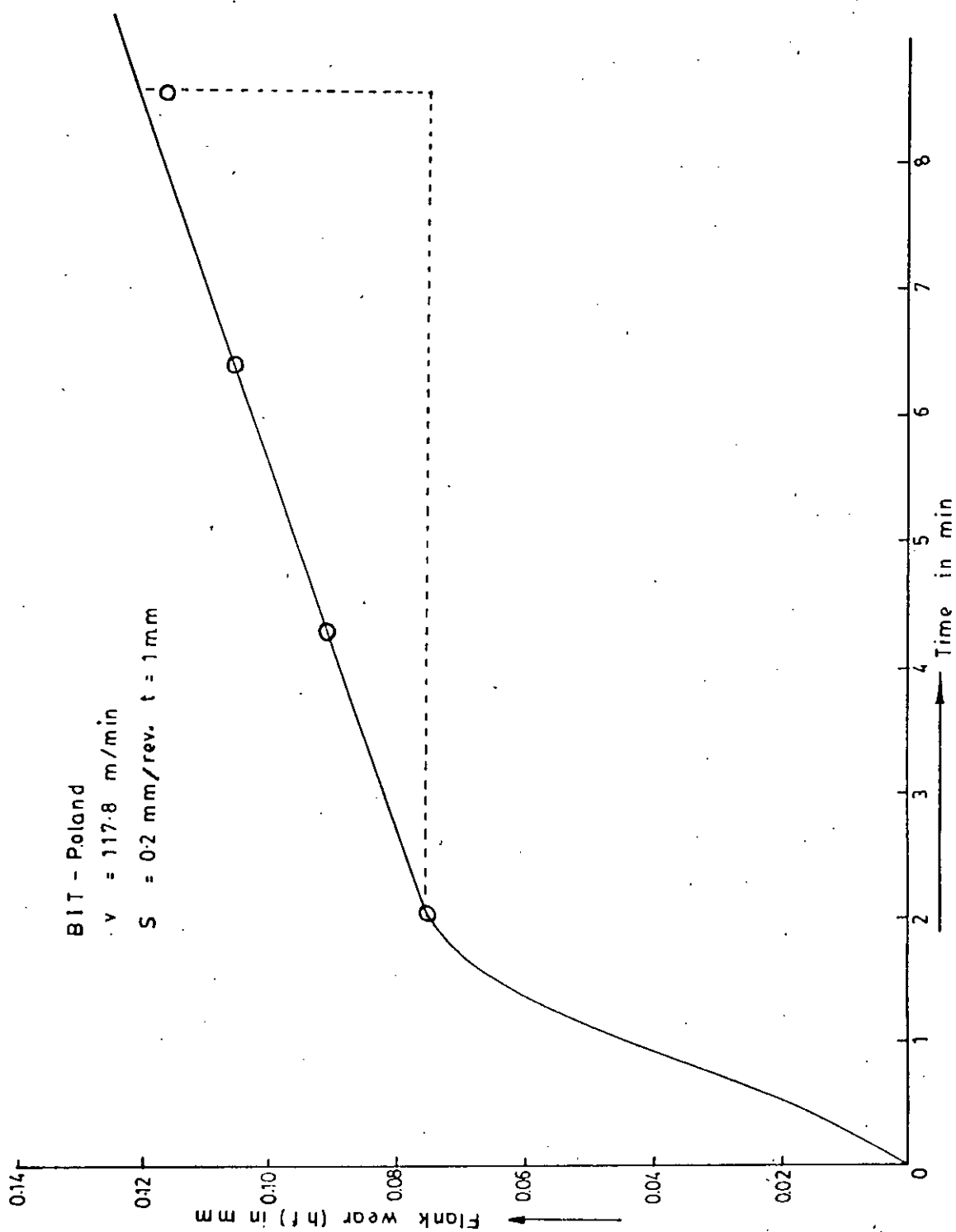


Fig.4.2: Flank wear Vs Time curve.

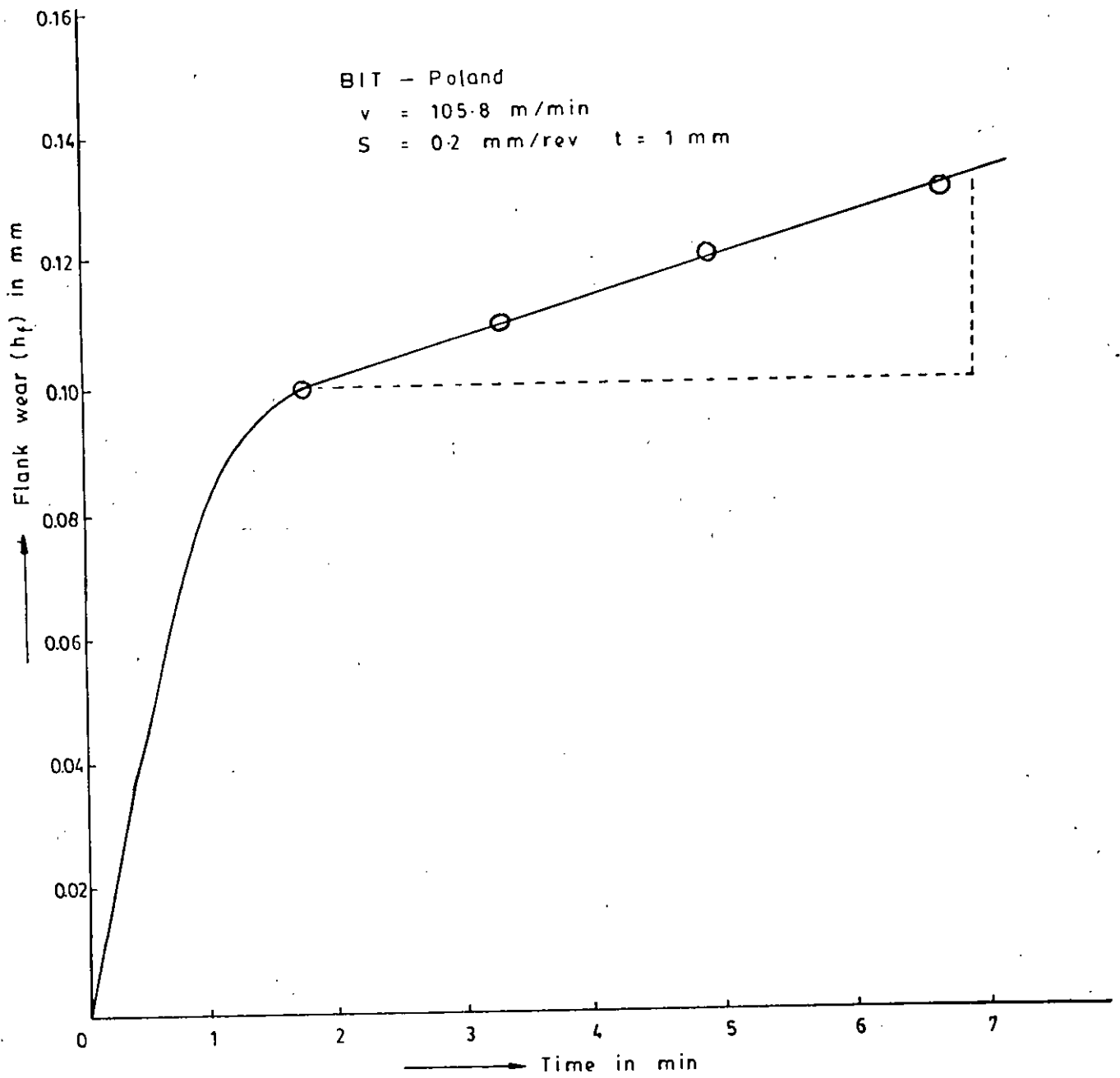


Fig.4.3: Flank wear Vs Time curve.

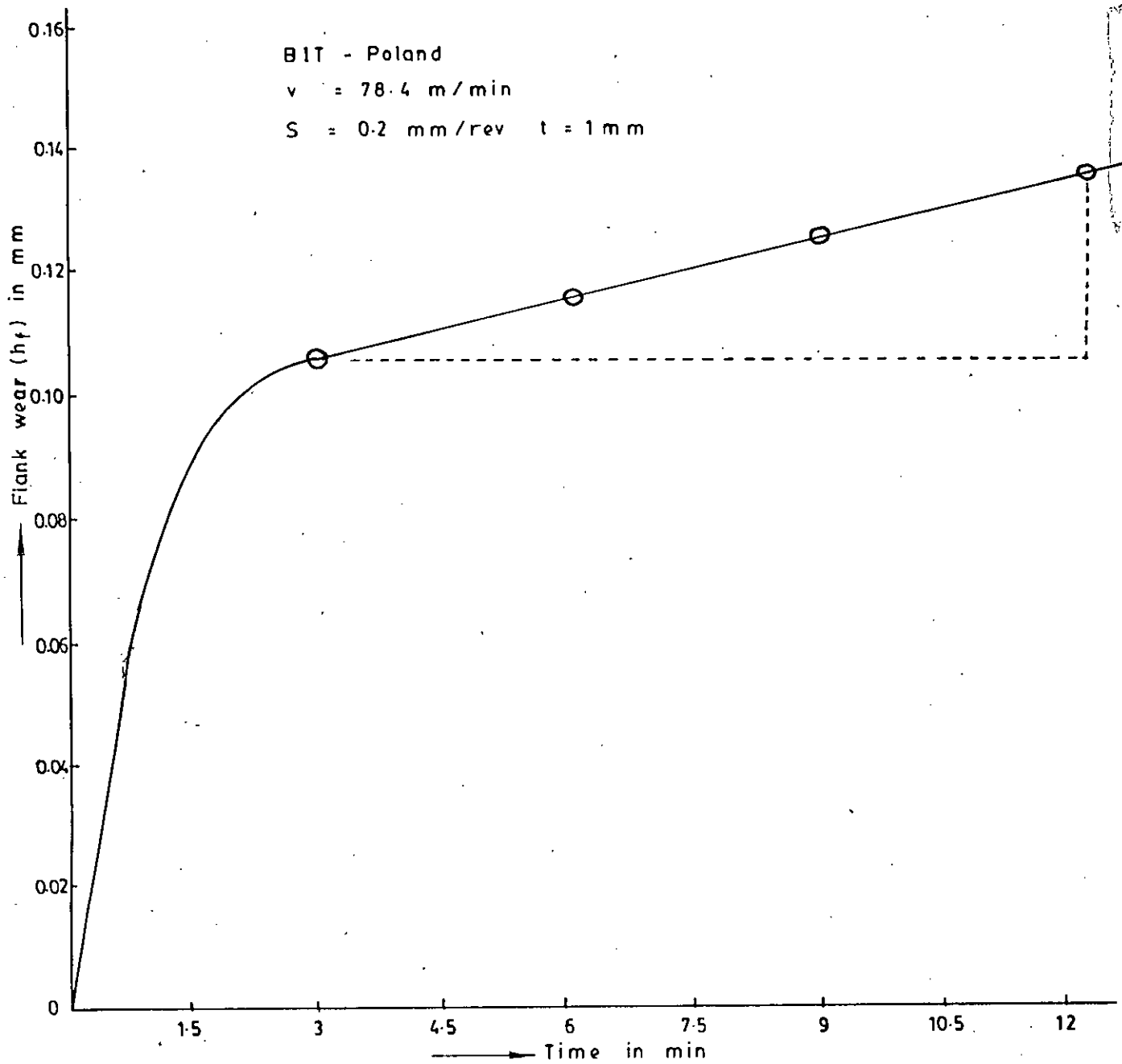


Fig.4.4: Flank wear Vs Time curve.

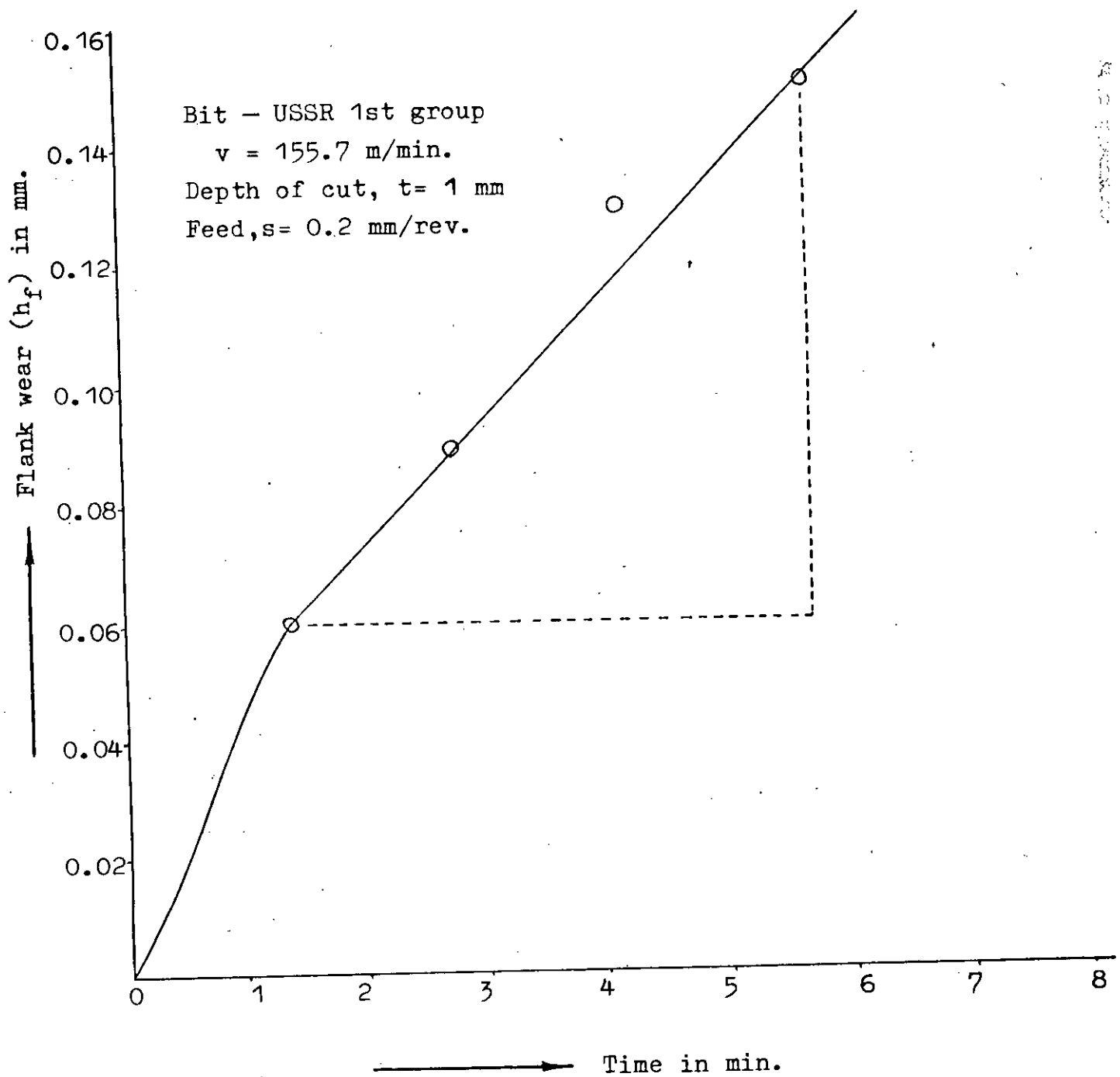


Fig. 4.5: Flank wear Vs Time curve.

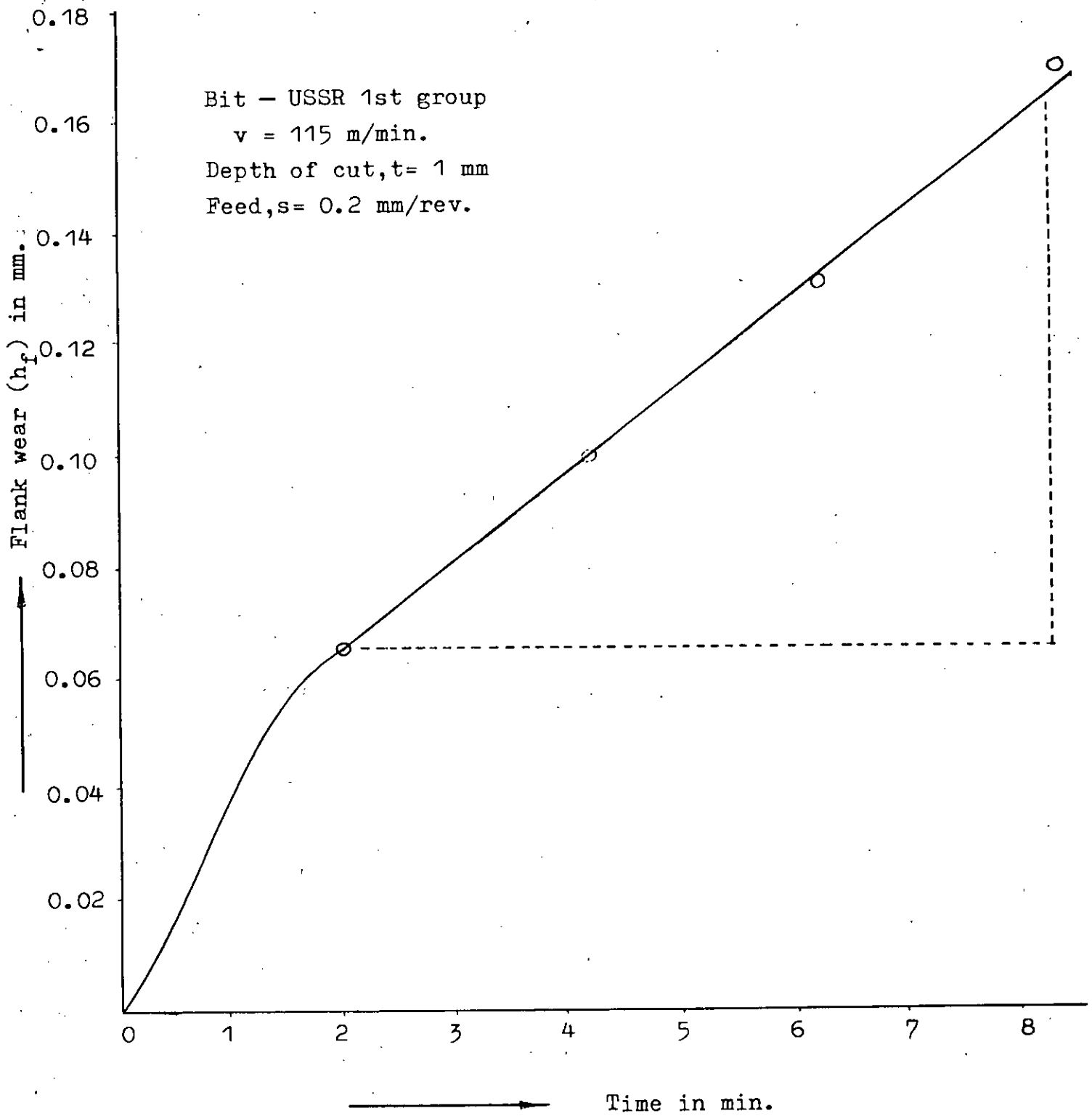


Fig.4.6: Flank wear Vs Time curve.

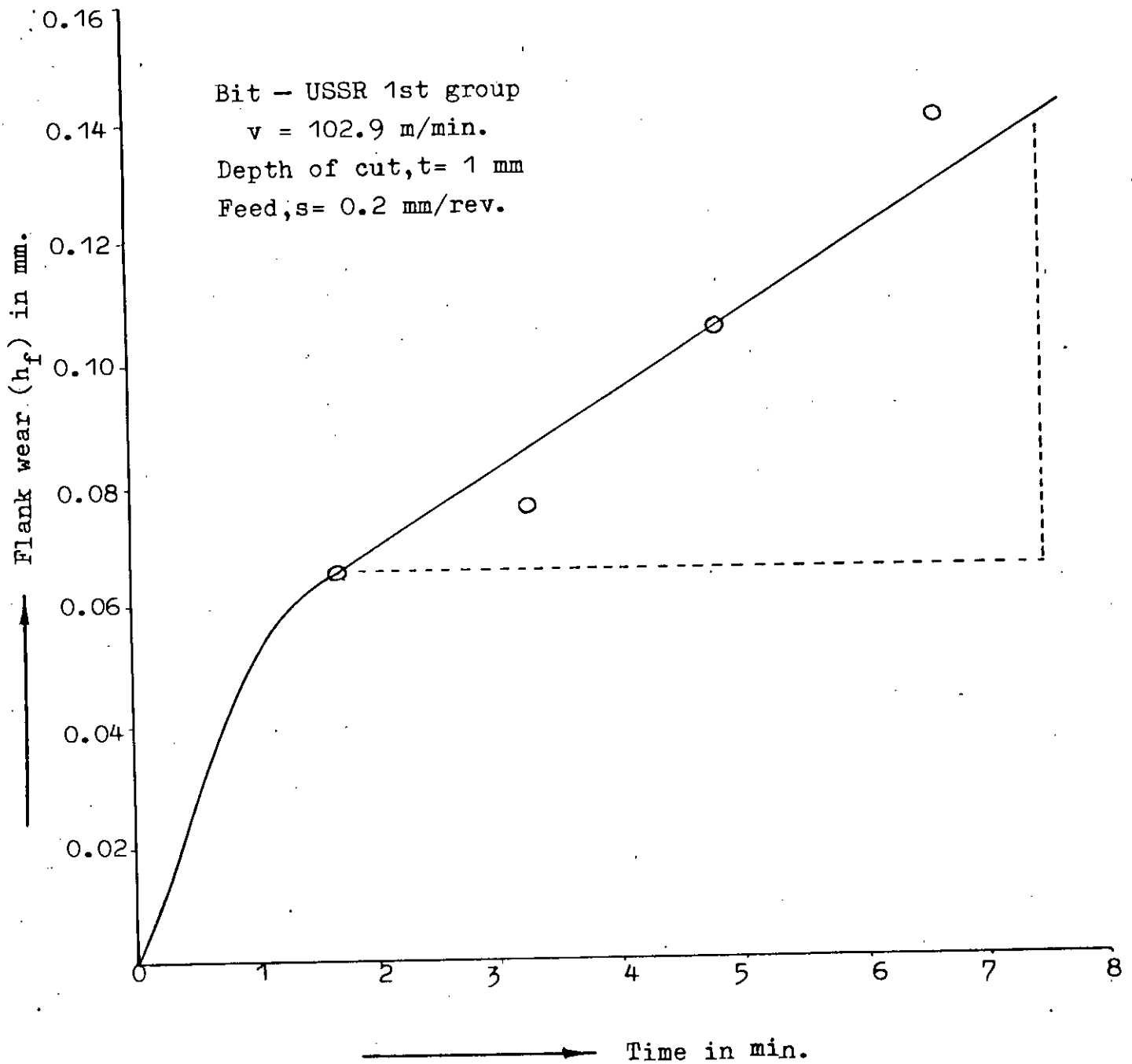


Fig.4.7: Flank wear Vs Time curve.

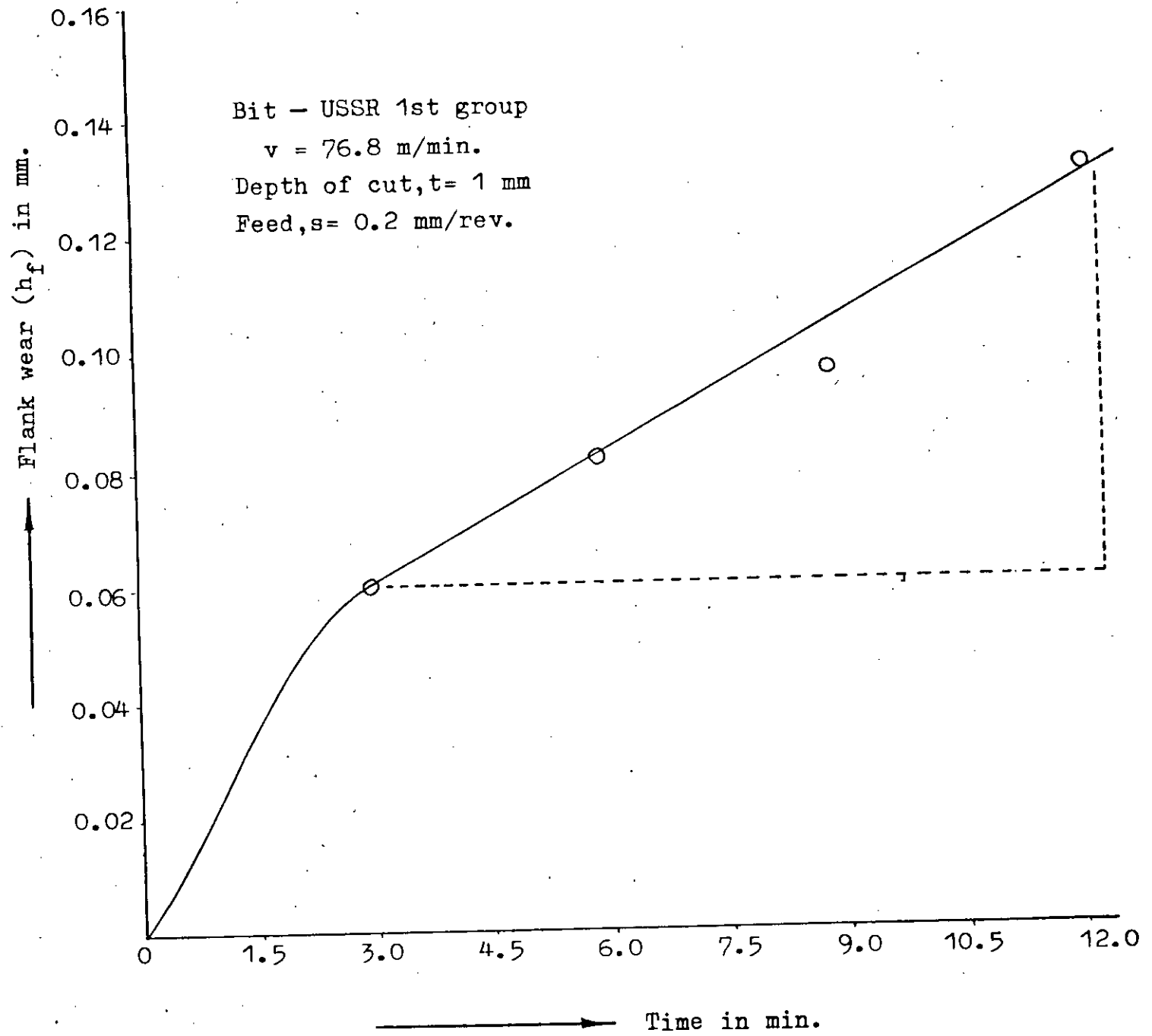


Fig.4.8: Flank wear Vs Time curve.

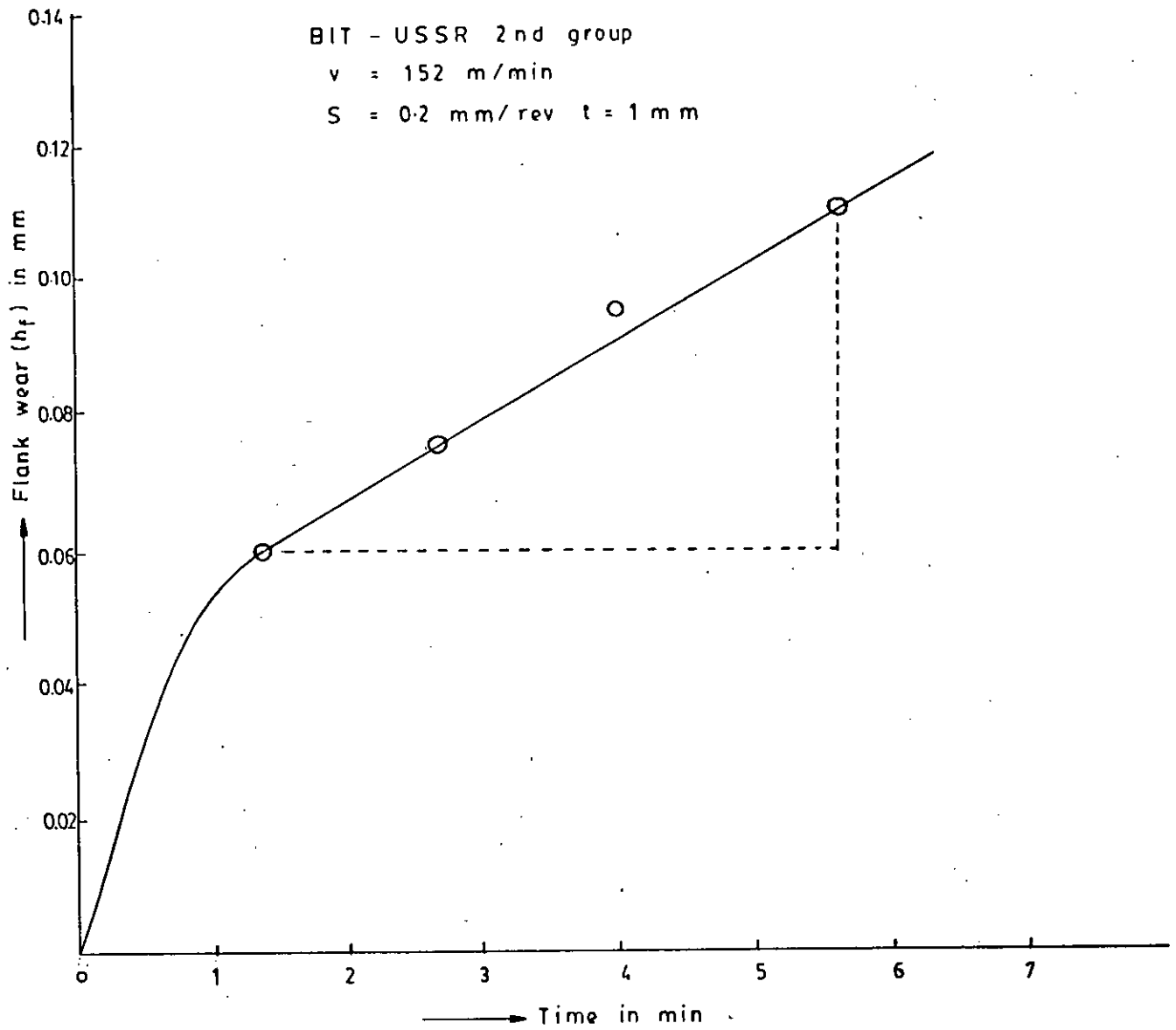


Fig.4.9: Flank wear Vs Time curve.

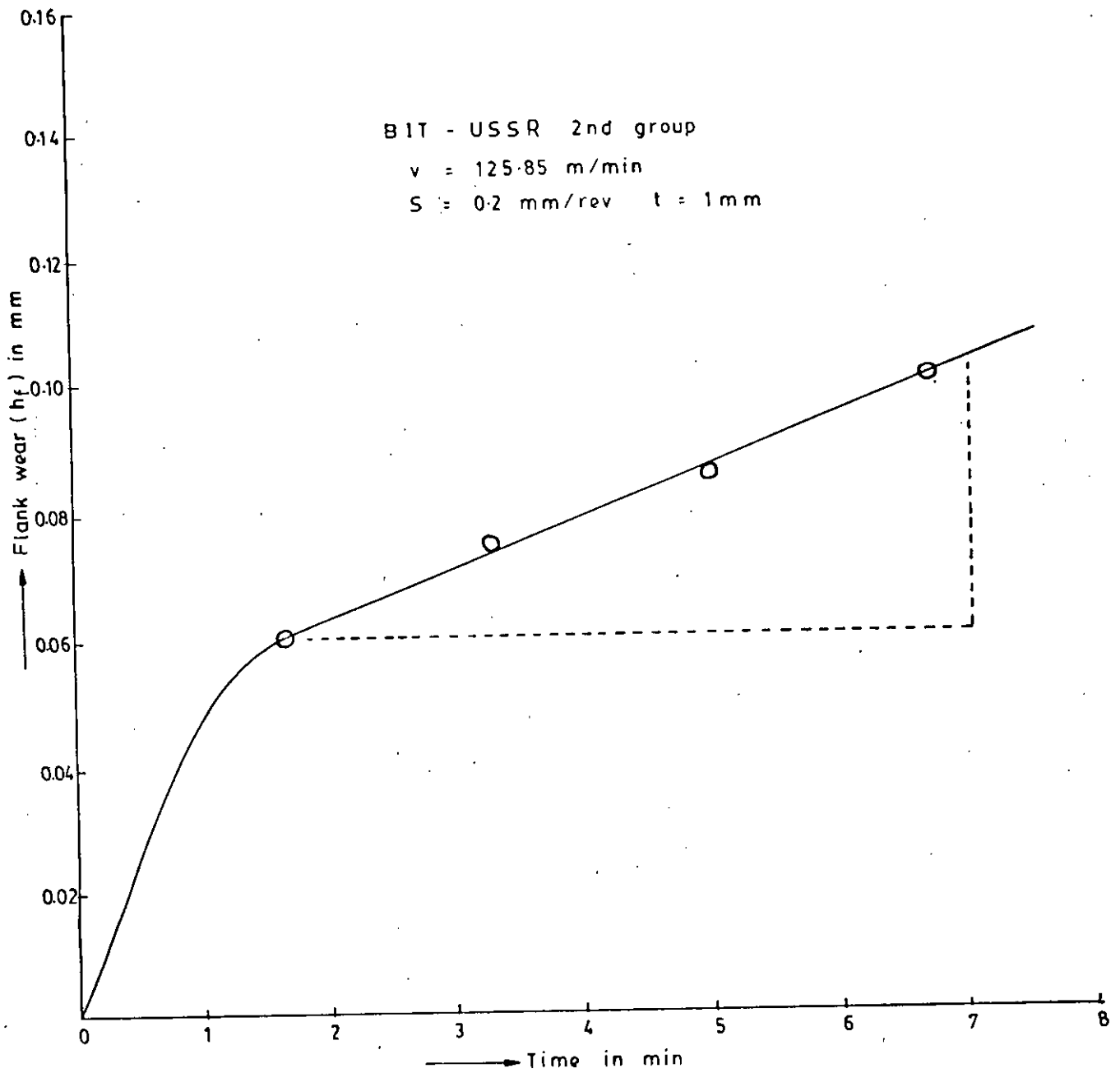


Fig.4.10: Flank wear Vs Time curve.

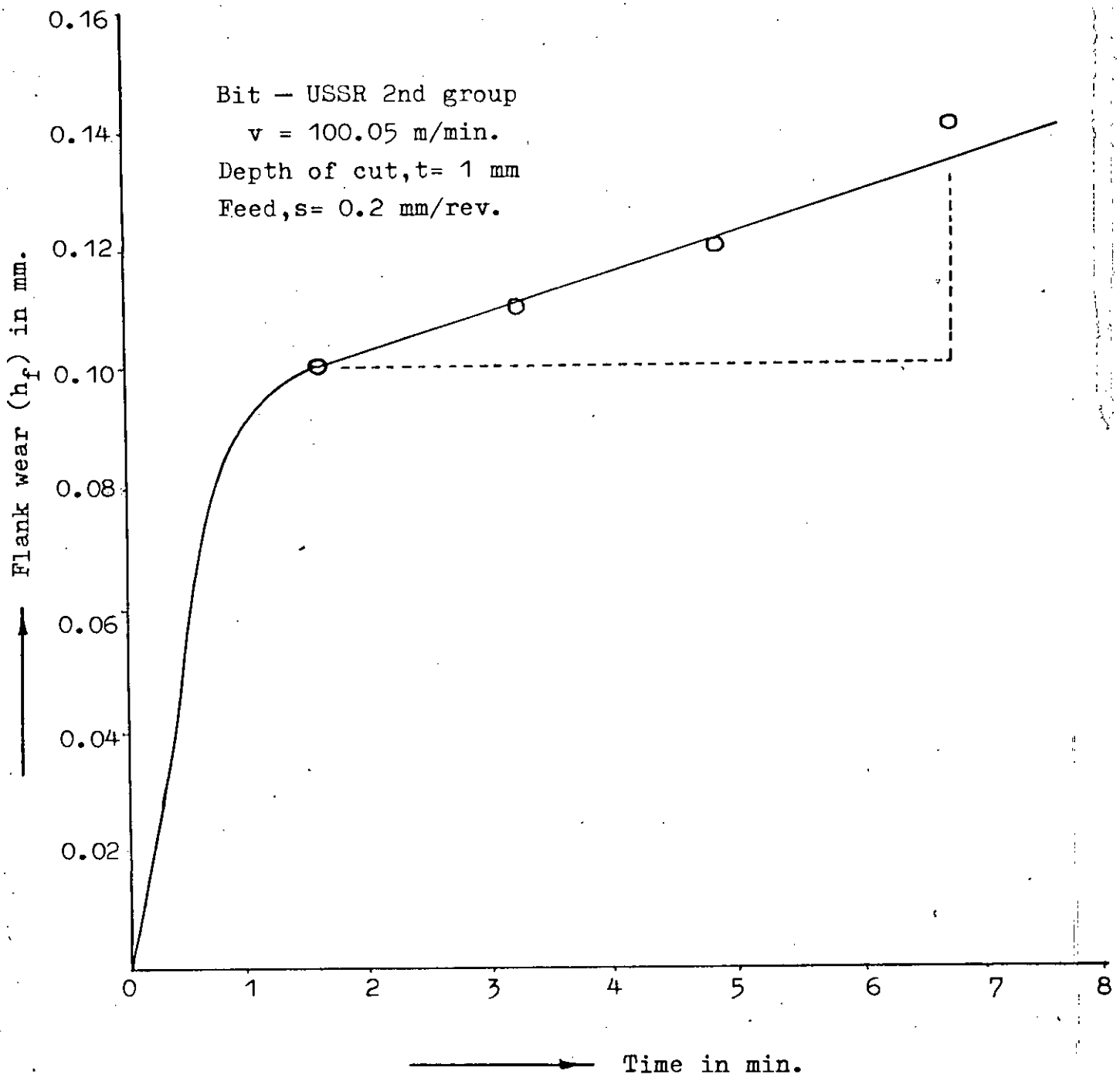


Fig.4.11: Flank wear Vs Time curve.

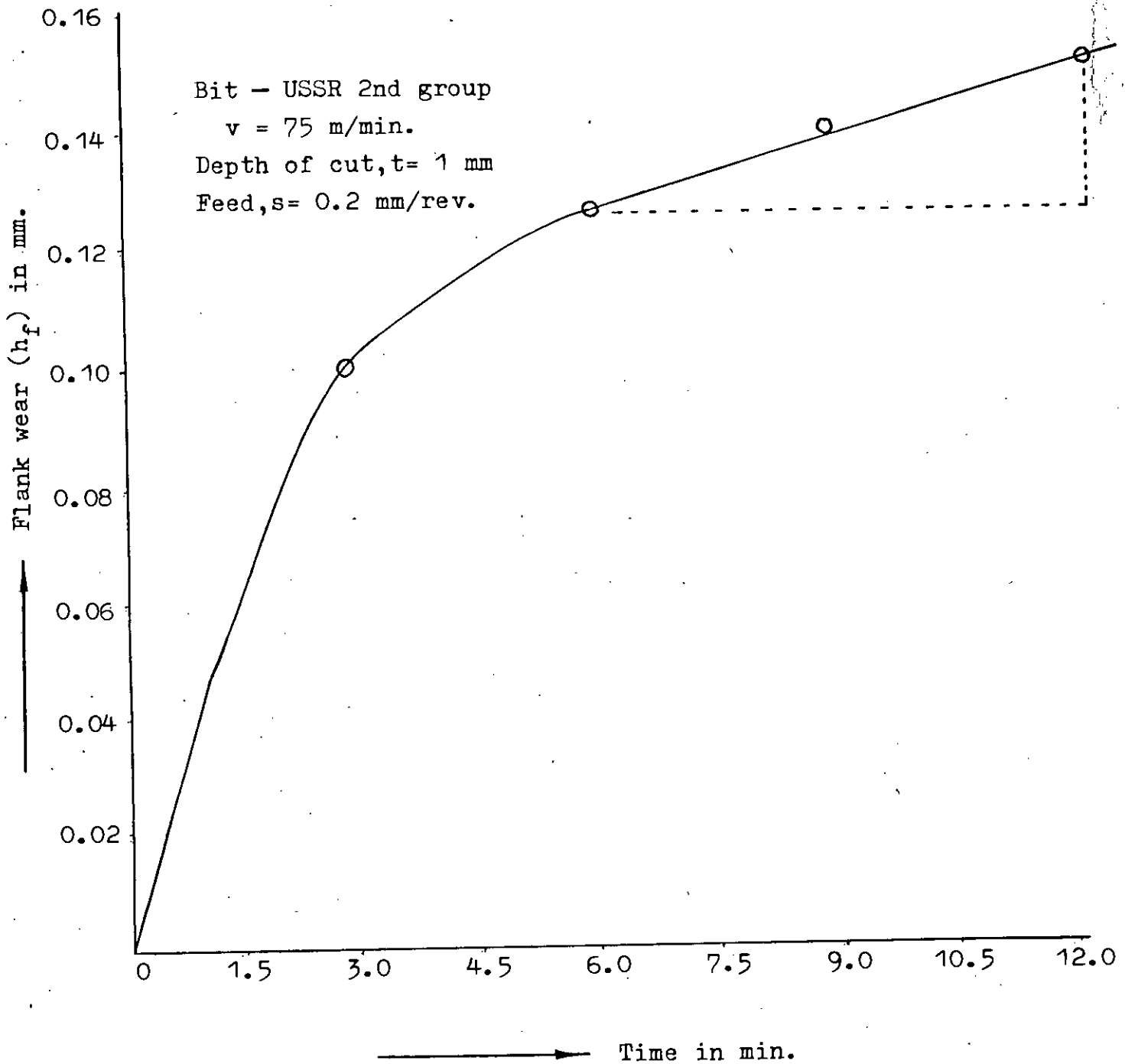


Fig.4.12: Flank wear Vs Time curve.

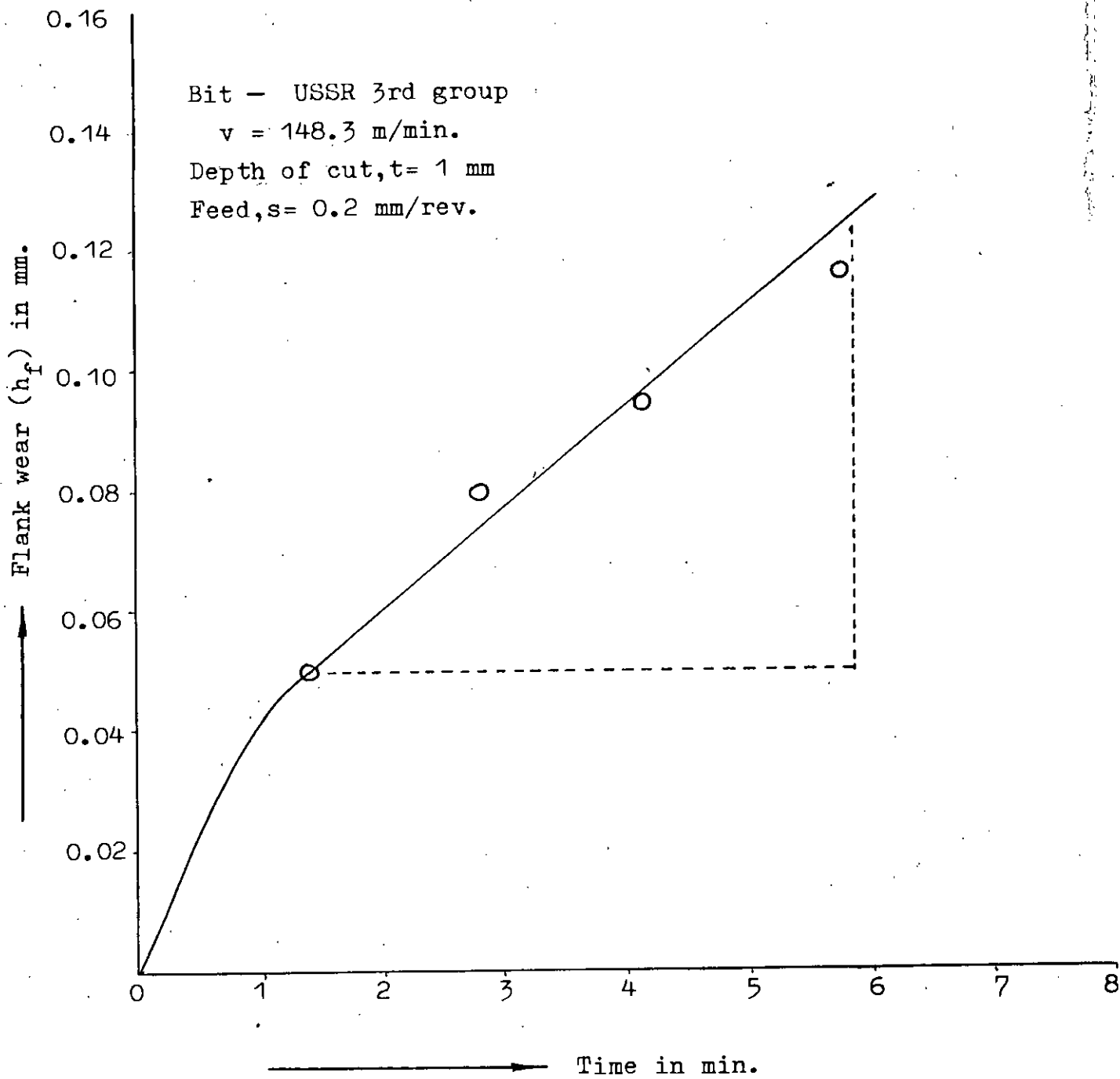


Fig.4.13: Flank wear Vs Time curve.

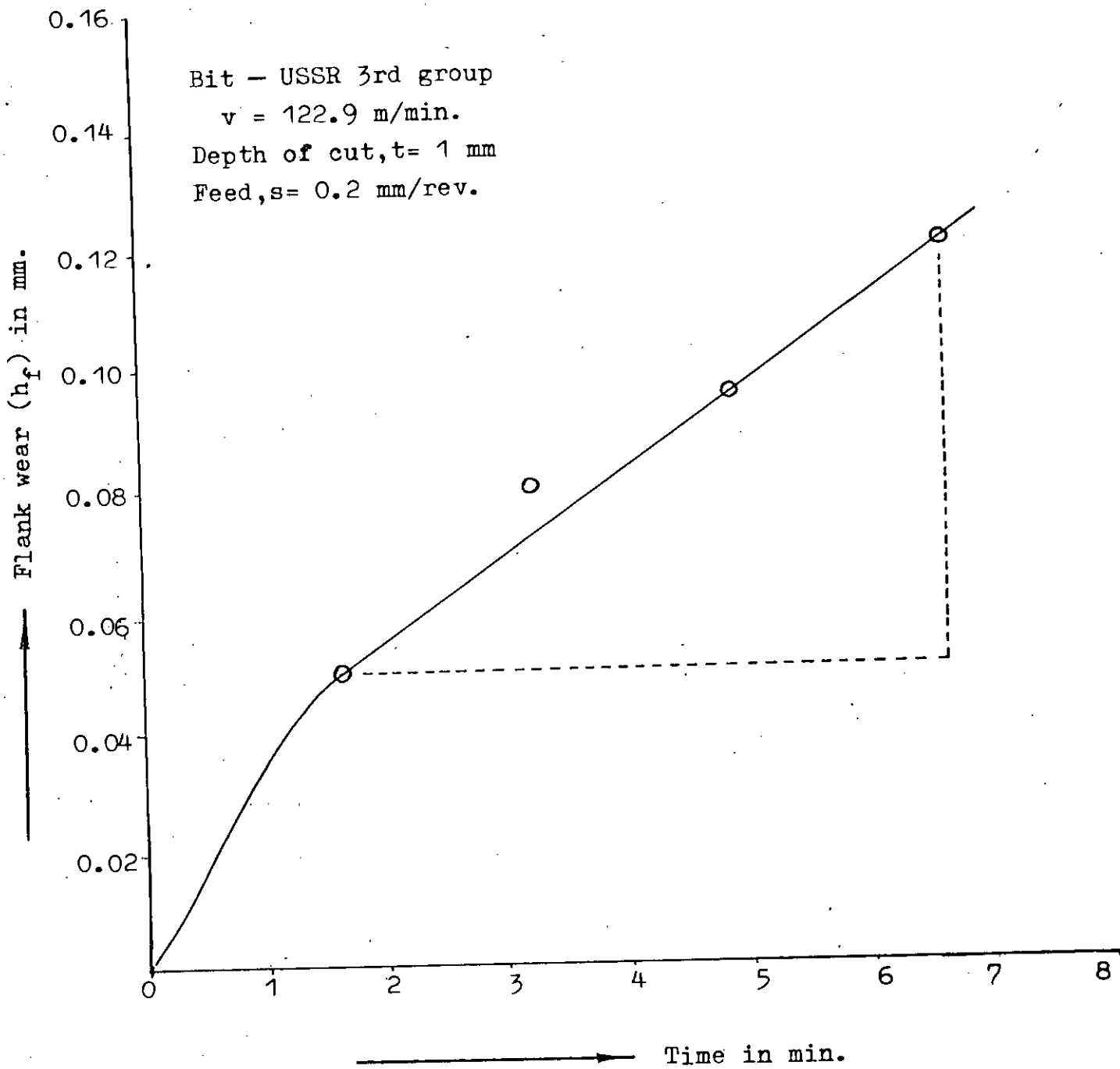


Fig.4.14: Flank wear Vs Time curve.

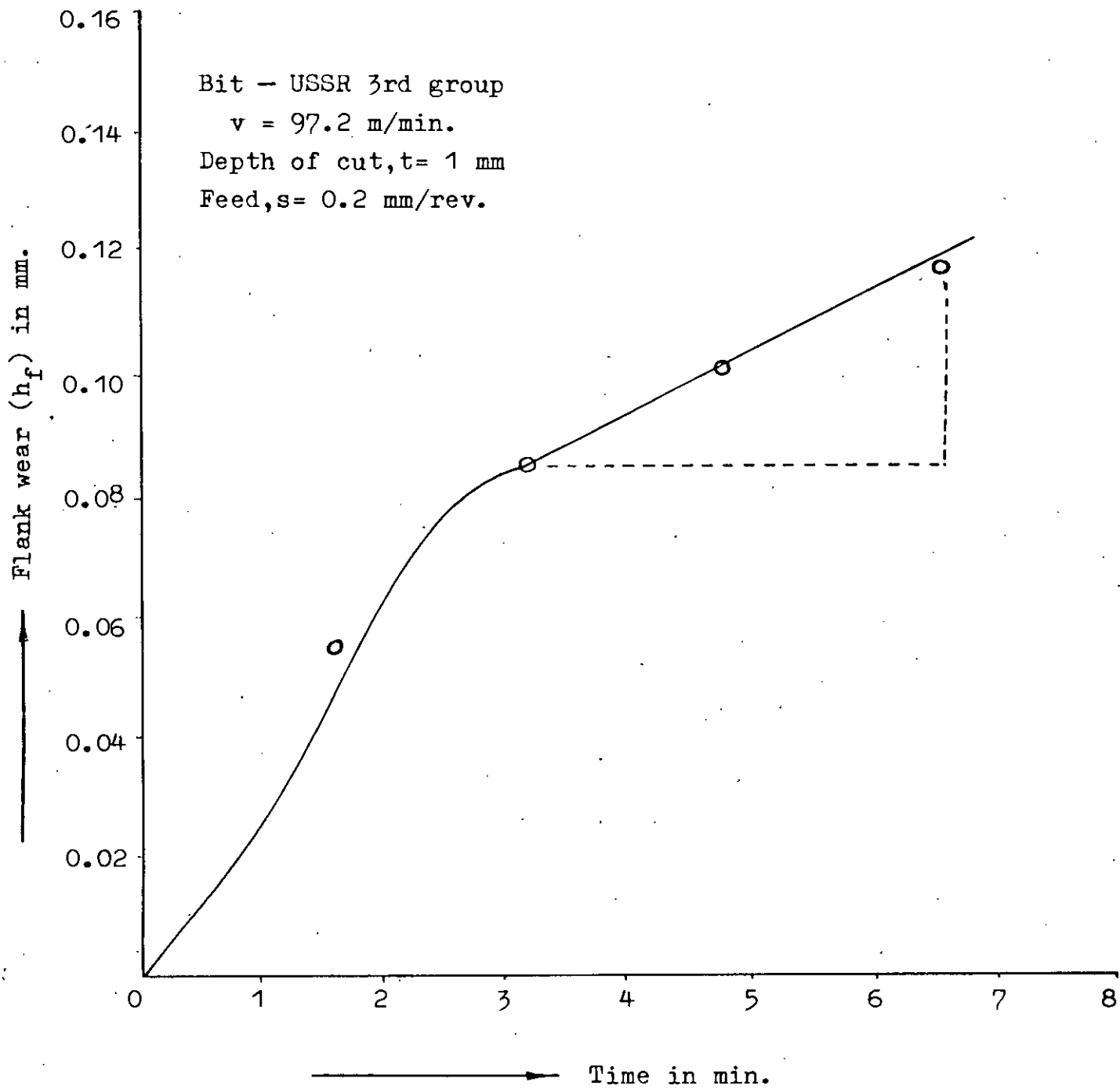


Fig.4.15: Flank wear Vs Time curve.

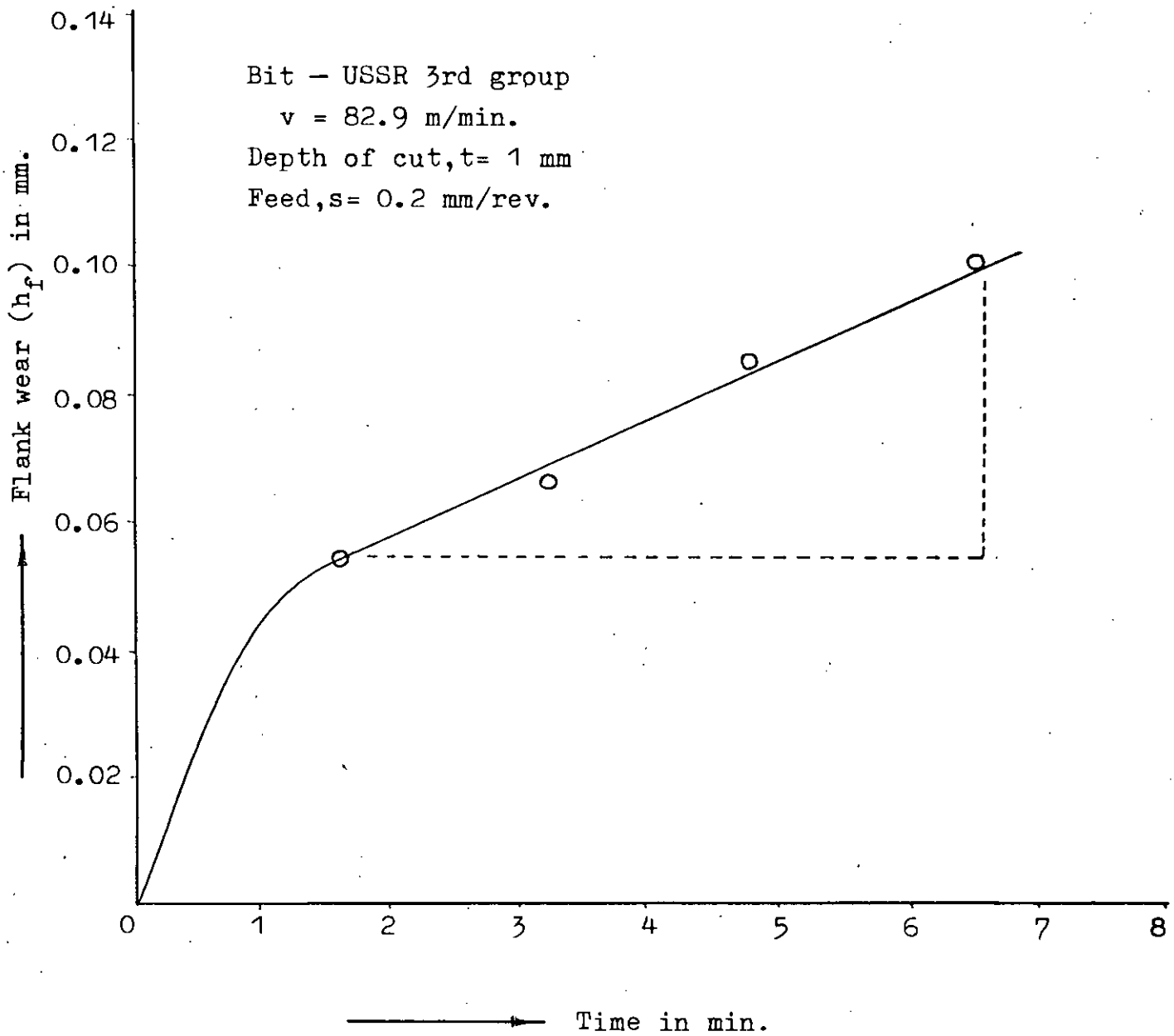


Fig.4.16: Flank wear Vs Time curve.

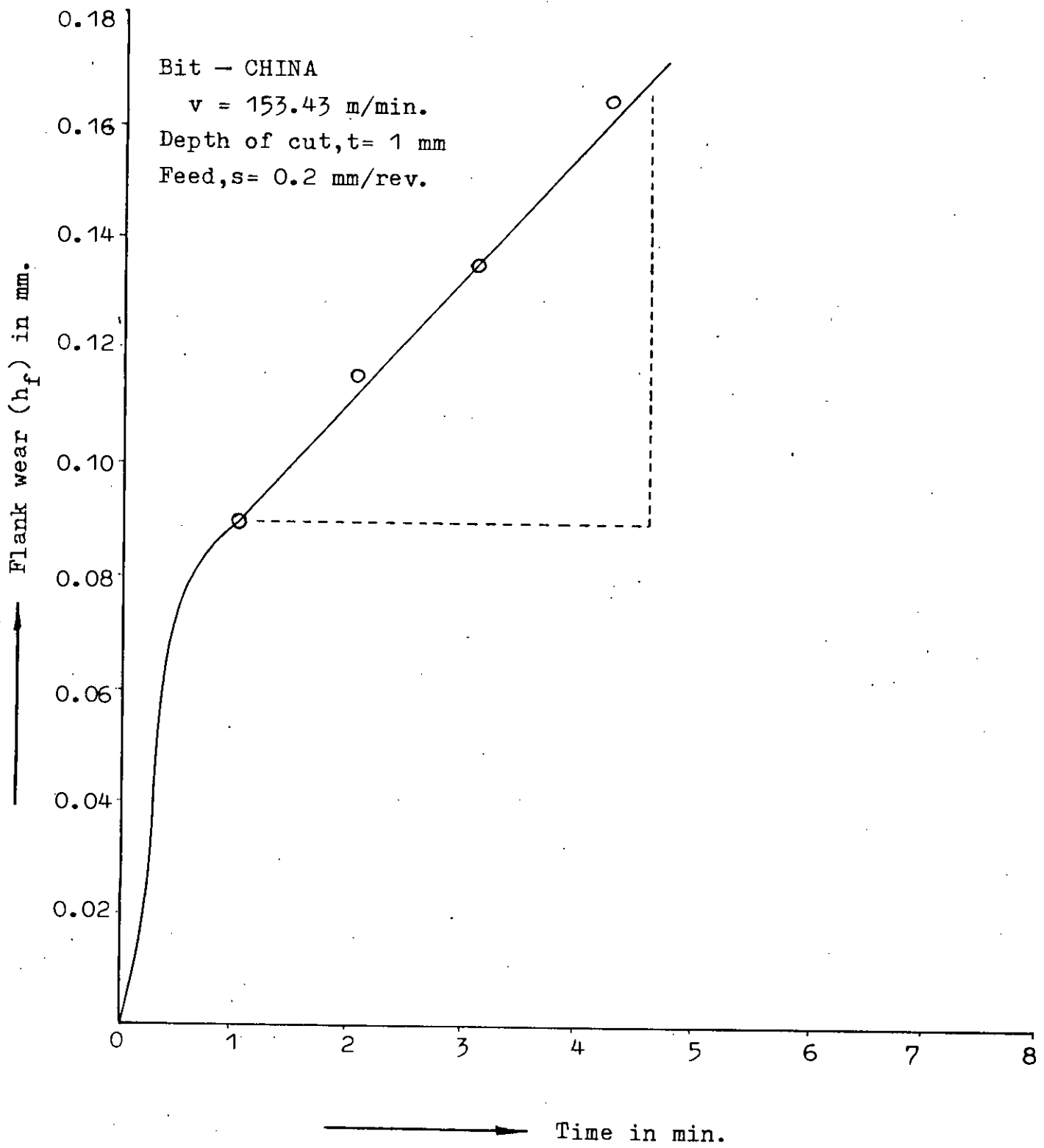


Fig.4.17: Flank wear Vs Time curve.

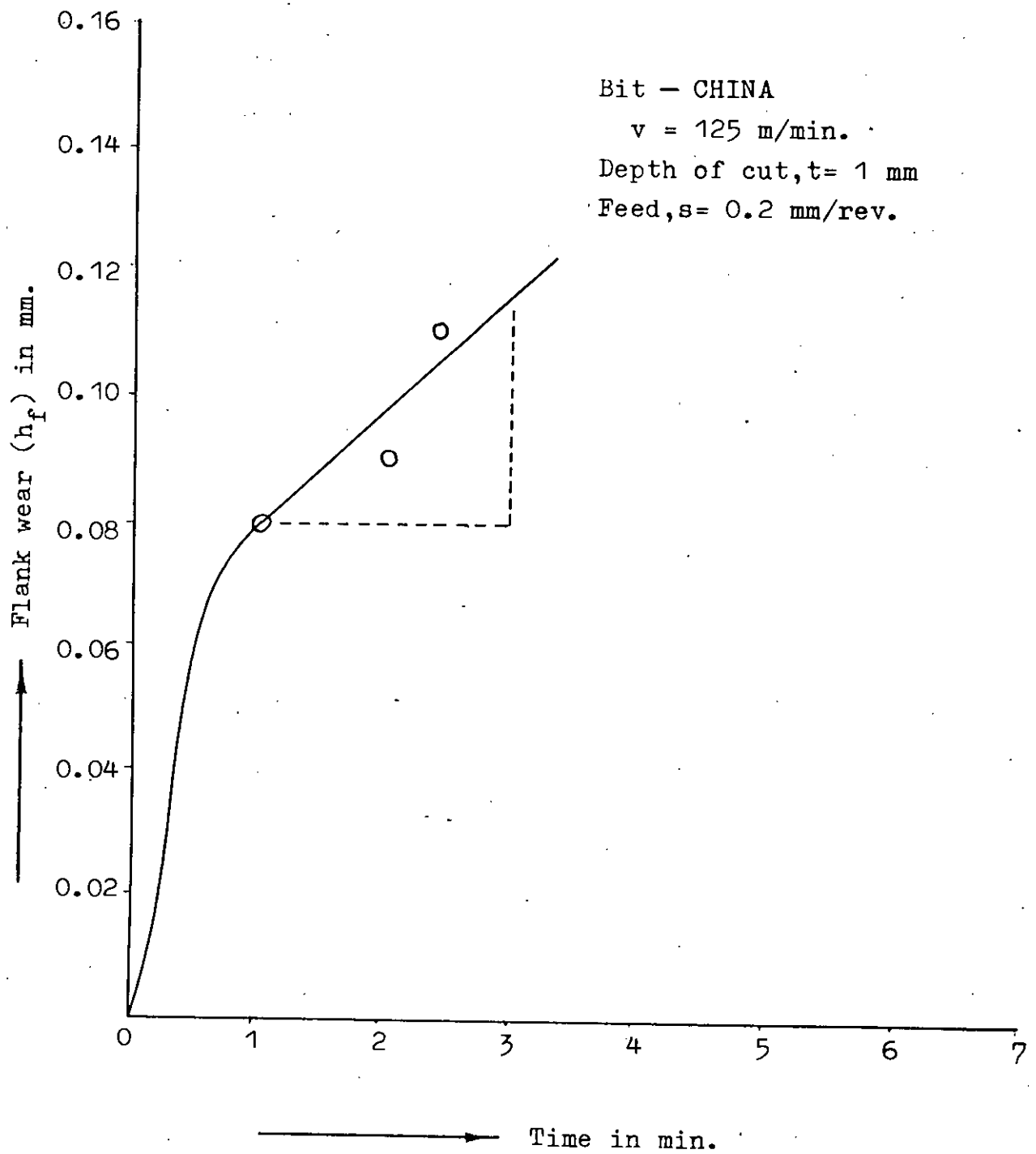


Fig.4.18: Flank wear Vs Time curve.

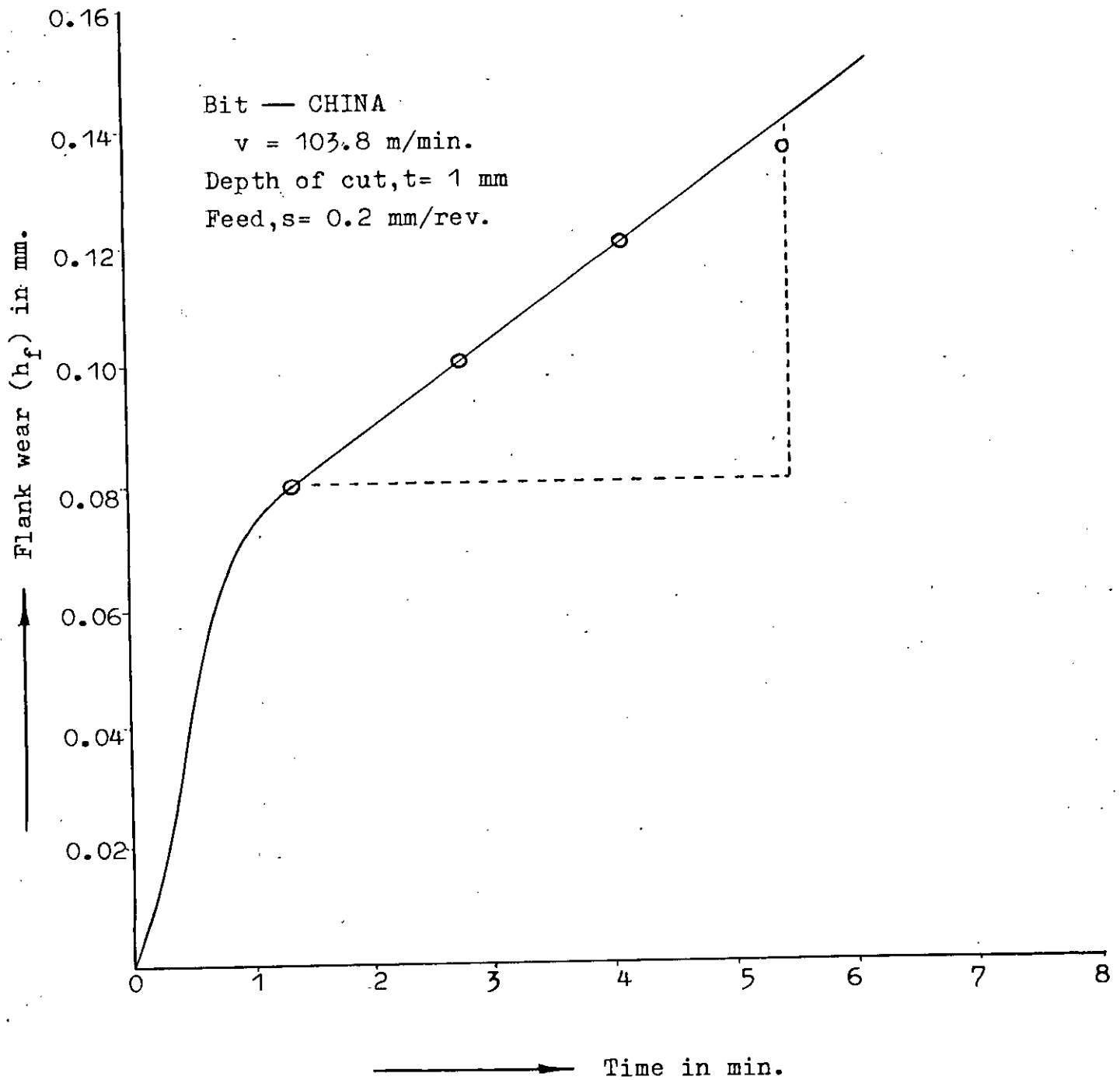


Fig.4.19: Flank wear Vs Time curve,

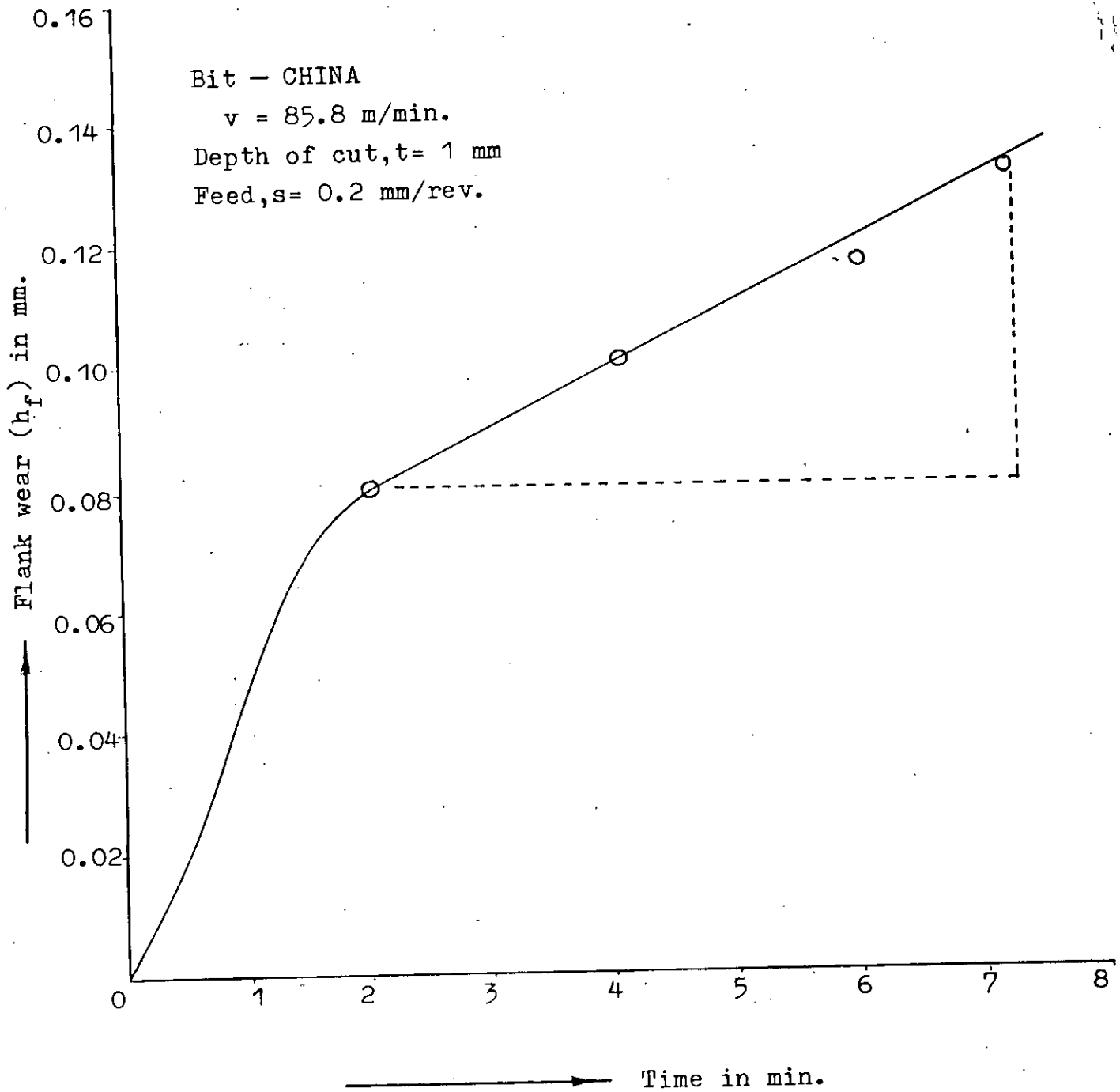


Fig.4.20: Flank wear Vs Time curve.

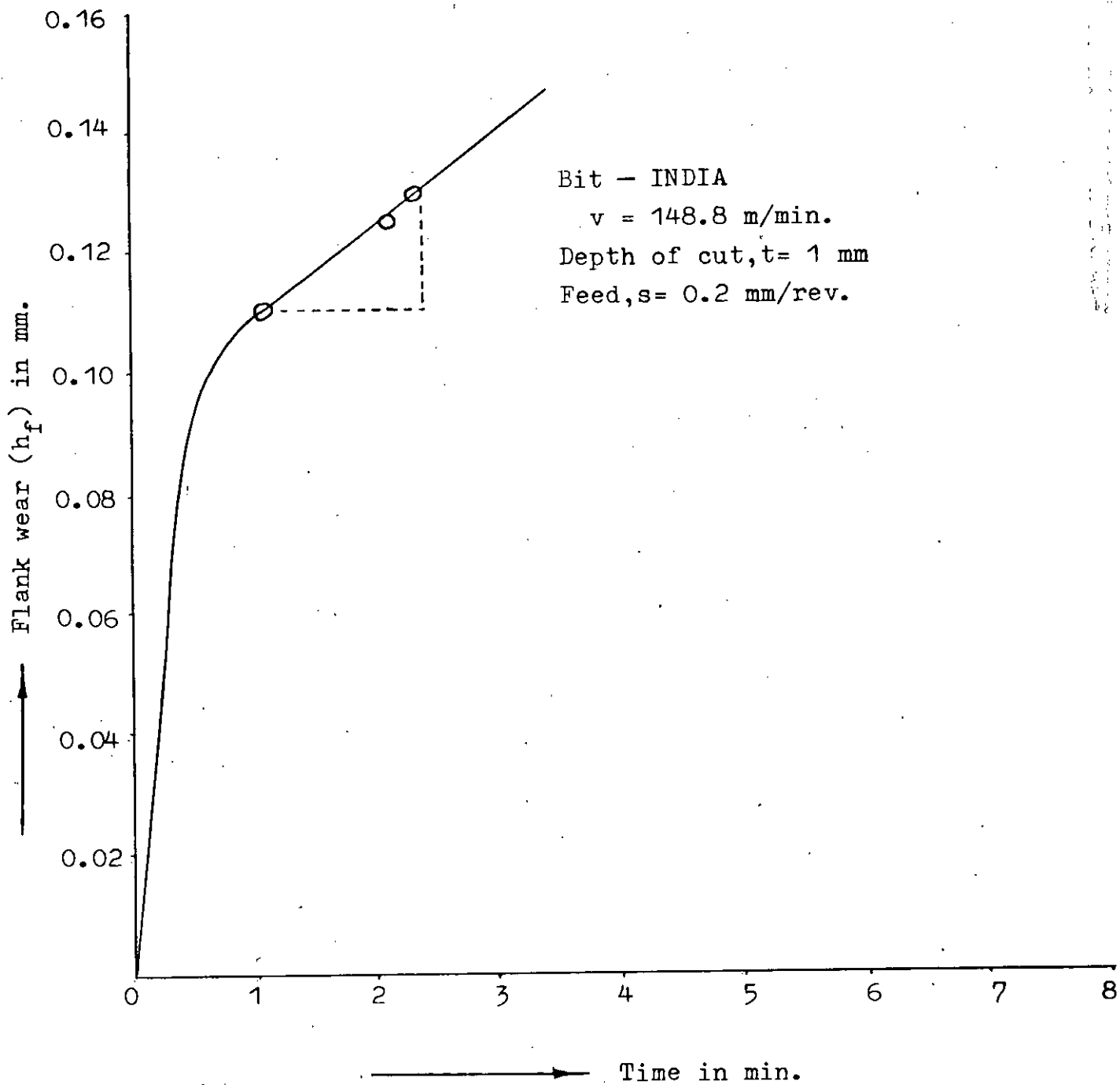


Fig.4.21: Flank wear Vs Time curve.

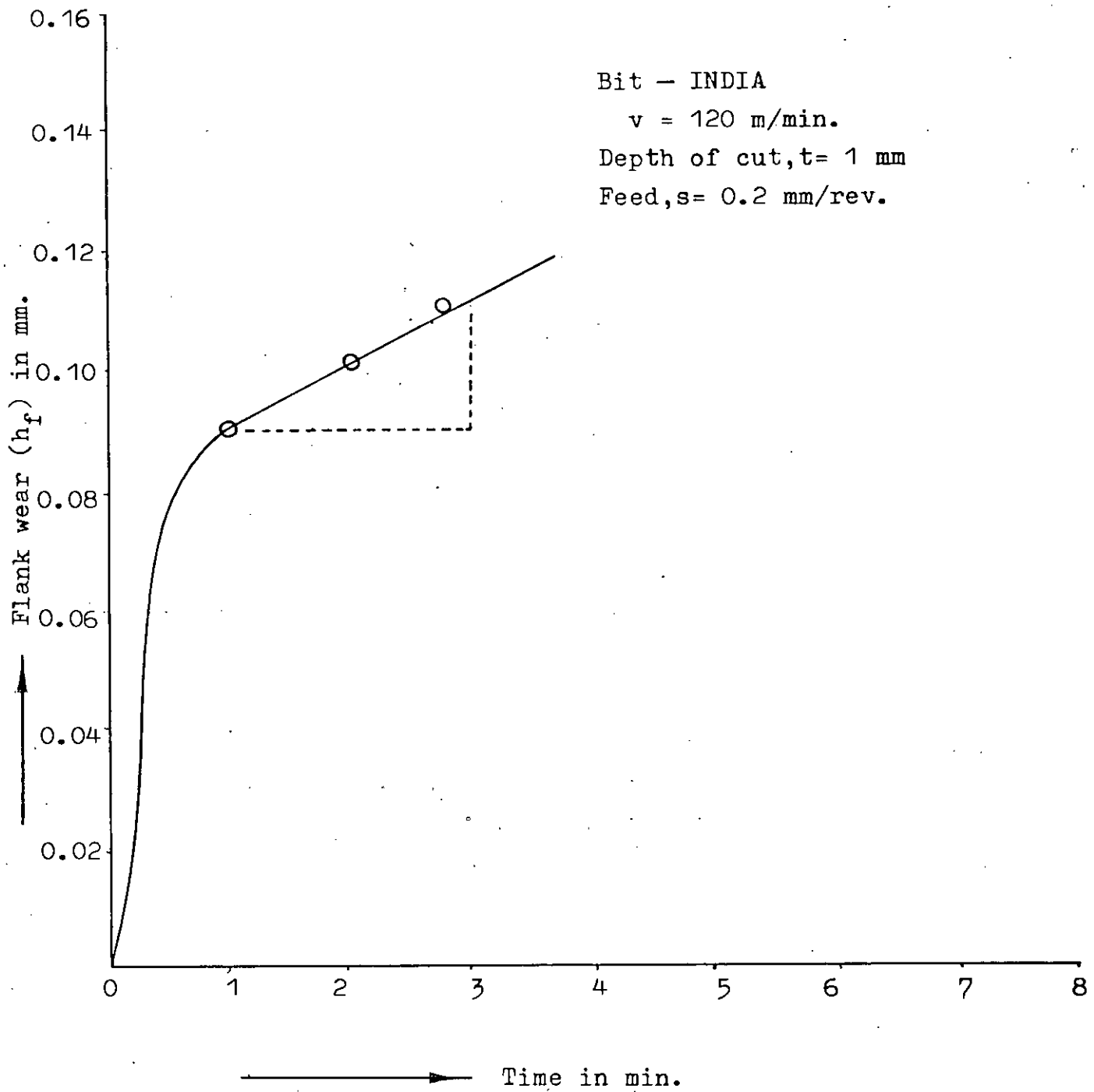


Fig.4.22: Flank wear Vs Time curve.

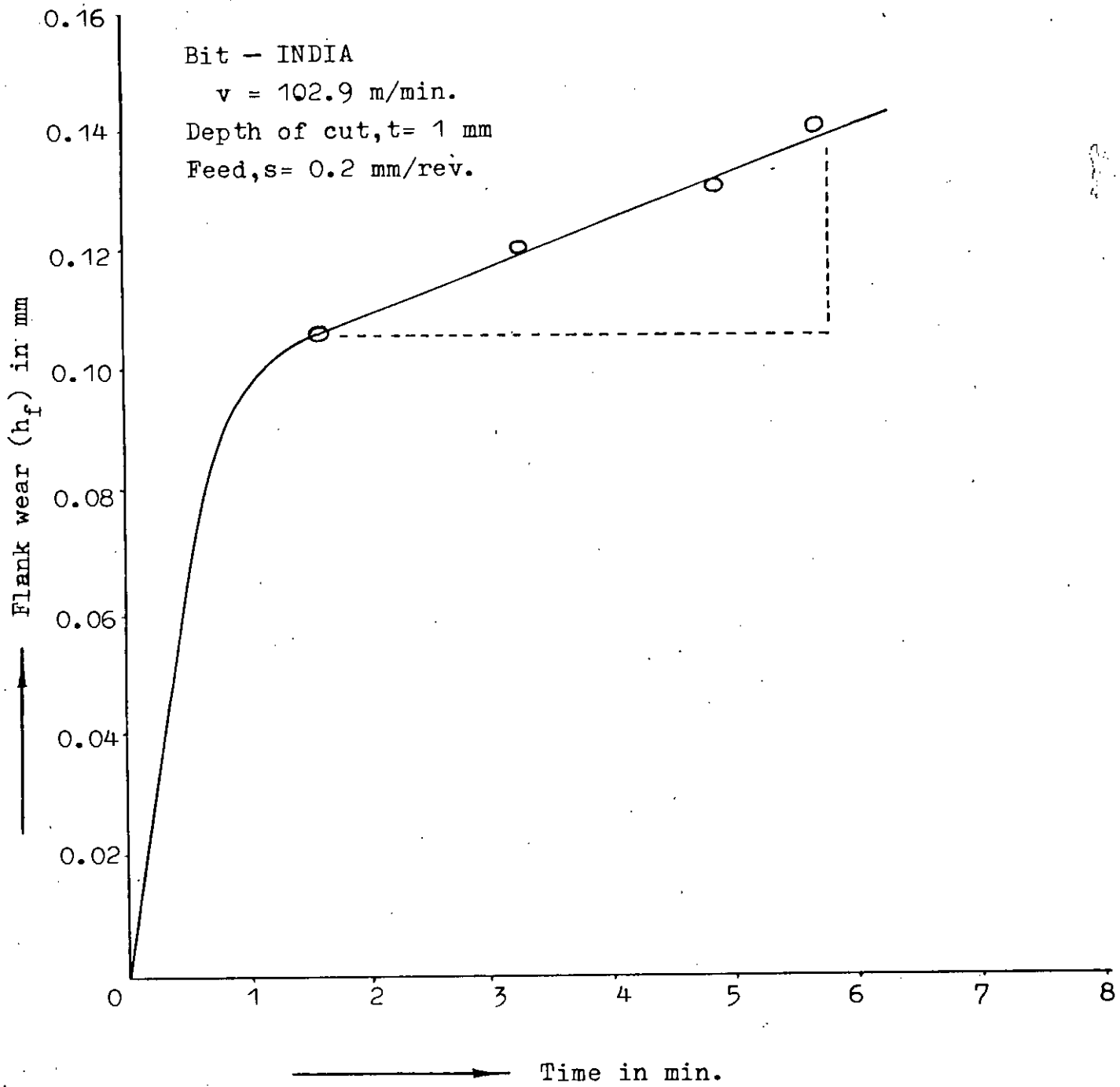


Fig.4.23: Flank wear Vs Time curve.

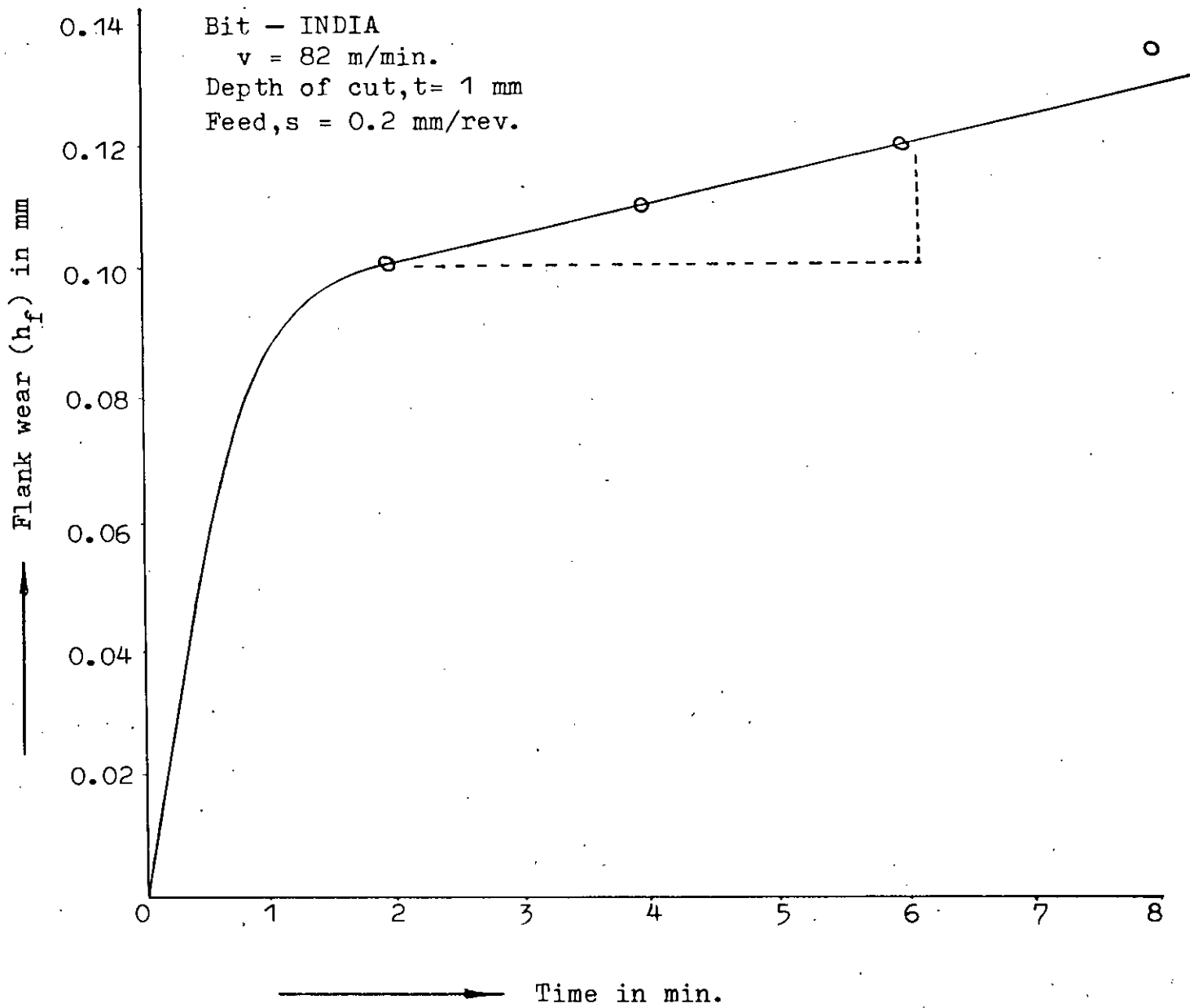


Fig.4.24: Flank wear Vs Time curve.

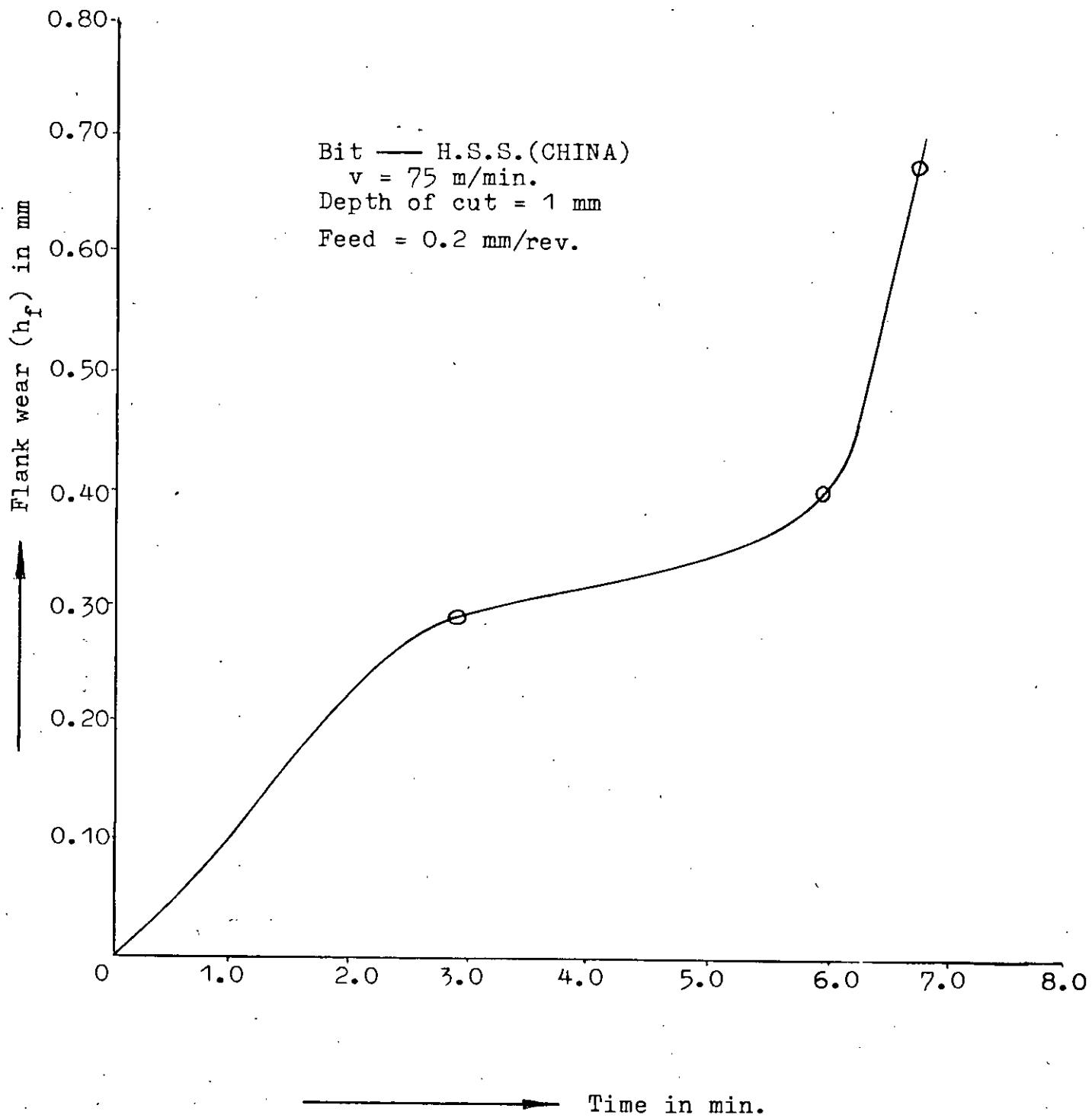


Fig.4.25: Flank wear Vs Time curve

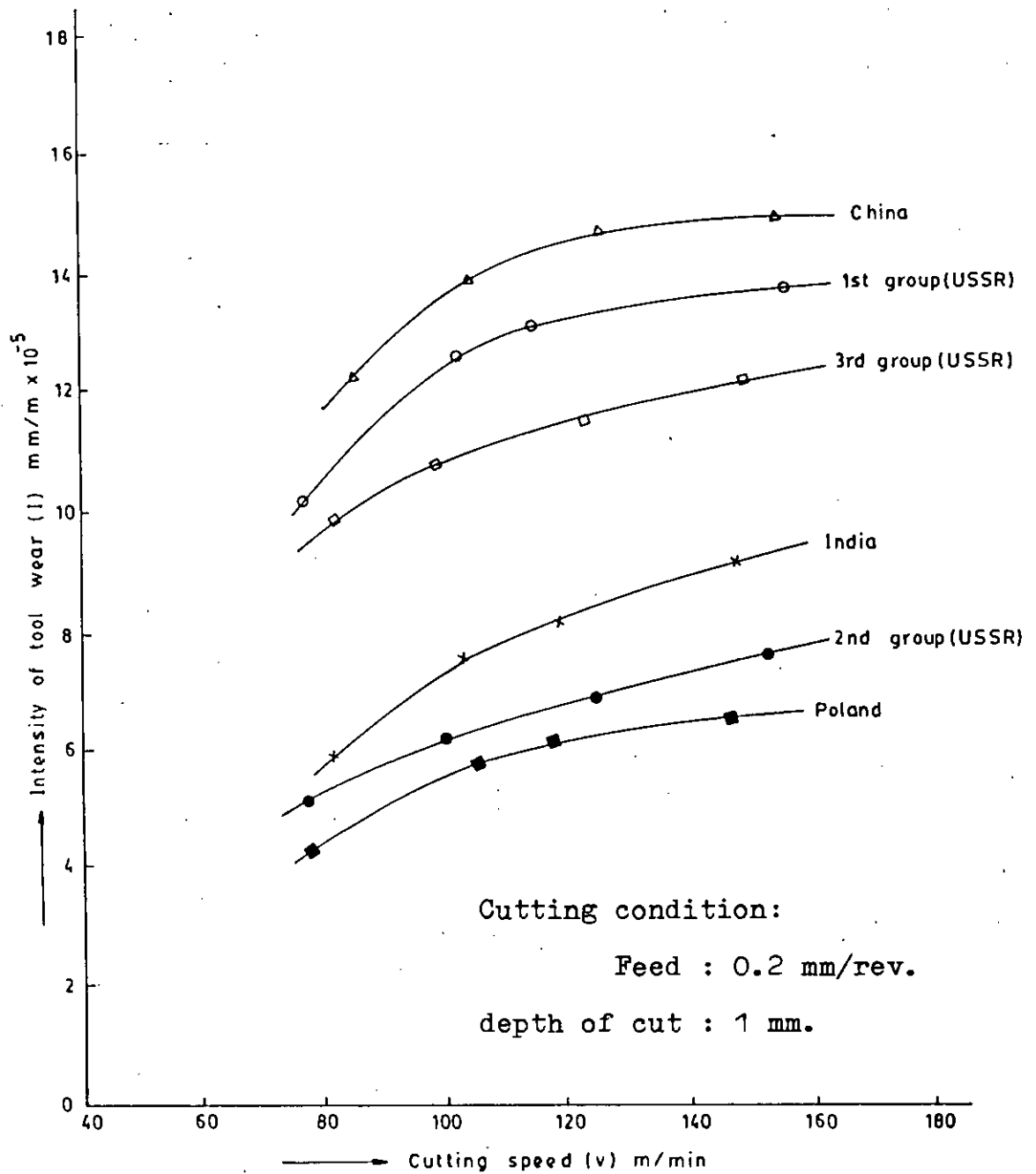


Fig.4.26: Effect of cutting speed on intensity of tool wear

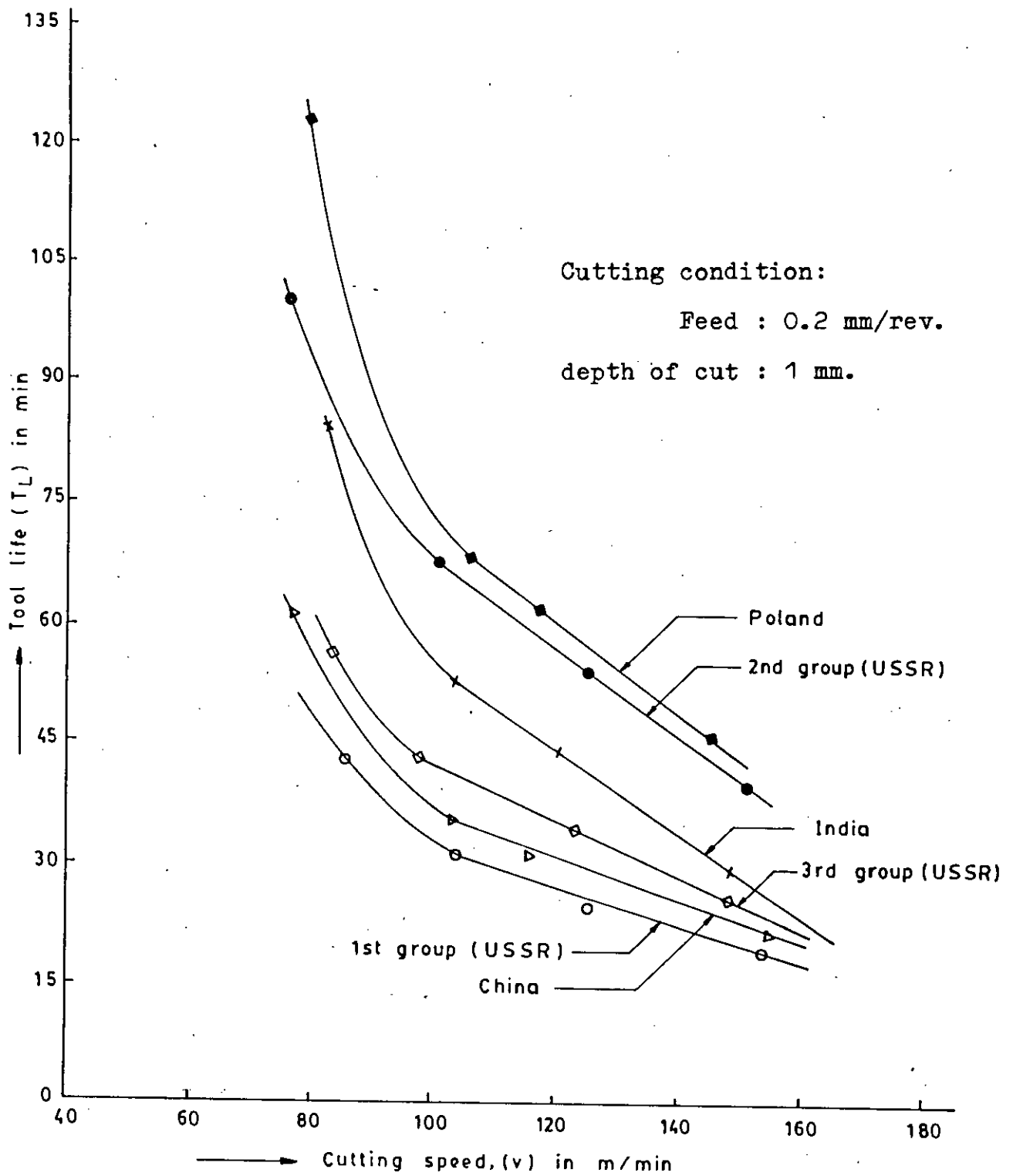


Fig.4.27: Relationship between tool life and cutting speed

Since intensity of tool wear increases, tool life decreases with the increase of cutting speed. From this Figure, it is visualized that tool life of bit of Poland is highest and then bit of USSR 2nd group, India, USSR 3rd group, USSR 1st group and lastly bit of China. The nature of these curves is same as the nature of curves of tool flank wear vs. time (after Arshinov) and the nature of curves of tool life vs. cutting speed (after Milton C. shaw) shown in Chapter-1. Intensity of tool wear of H.S.S. tool was not possible to calculate, because at higher cutting speeds like $v = 100, 120, 150$ m/min., H.S.S. tool wears within a few seconds. So, it is also not possible to show the comparison of intensity of tool wear and tool life of carbide bits and H.S.S. tool in the same graph paper. At the cutting speed, $v = 80$ m/min., tool wear intensity of H.S.S. tool was approx. 100 times higher than the carbide tools. It is due to the fact that H.S.S. tool can not retain its hardness at high temperatures like cemented carbides.

4.4 Conclusion

It has been confirmed that intensity of tool wear is directly proportional to the emf developed during turning with different types of carbide tips within the range of cutting speed maintained.

CHAPTER-5

ECONOMIC ANALYSIS

5.1 Introduction

The experiment has been performed in the machine tools laboratory of BUET with the lathe machine (of size 4 feet bed length and maximum machinable job diameter 150 mm) having a square turret. But this economical analysis has been made on the basis of turning operation of lead screw of a lathe machine building workshop in Dholaikhal. Some assumptions have been made for calculating production cost e.g. (i) when a worker works for tool grinding, the machine remains idle, (ii) lot of work pieces is just beside the worker and after turning, he keeps it near the machine (iii) allowable tool wear has been taken 0.50 mm before regrinding etc. So, this economical results may not conform to the actual economical results. Yet from this result, it will be observed that how much higher the production cost during turning operation in case of H.S.S. tools with compare to cemented carbide tools.

5.2 Theory

The production of lead screw involves several machining operations. But here only turning operation has been considered throughout this experimental investigation.

$$\text{Cost per piece, } C_p = C_I + C_c + C_{tc} + C_{tg} + C_{td} \quad \dots \quad (5.1)$$

After analysing each cost term of the above equation, Brewer⁽¹¹⁾ concluded that the cost/piece is a function of four variables, viz. v, s, t and h_f . It is true that for optimum values of t and s , a maximum amount of wear, $h_f = 0.5$ mm is permitted before regrinding the tool. From equation (5.1), the cost terms may be written in the following form:

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

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

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

$$\text{Tool cost per piece, } C_{tg} + C_{td} = \frac{N_t}{N_b} C_t$$

To avoid material handling cost (holder cost is also avoided because it costs Tk. 20 and it can be used minimum one year), it is assumed that the solid bars are stacked near the machine ready to be picked up by the operator and that the operator will stack the machined piece conveniently near the machine. In this experiment, the turning operation has been carried out in four different cutting speeds e.g. 80, 100, 120 and 150 m/min. and

each cutting speed has been considered as a variant. There are four variants, the cutting conditions are as follows:

1. VARIANT-I

Cutting conditions: Cutting speed, $v = 80$ m/min.,

$t = 1$ mm, $s = 0.20$ mm/rev.

$n = 630$ rpm.

2. VARIANT-II

Cutting conditions: Cutting speed, $v = 100$ m/min.,

$t = 1$ mm, $s = 0.20$ mm/rev.

$n = 800$ rpm.

3. VARIANT-III

Cutting conditions: Cutting speed, $v = 120$ m/min.,

$t = 1$ mm, $s = 0.20$ mm/rev.

$n = 1000$ rpm.

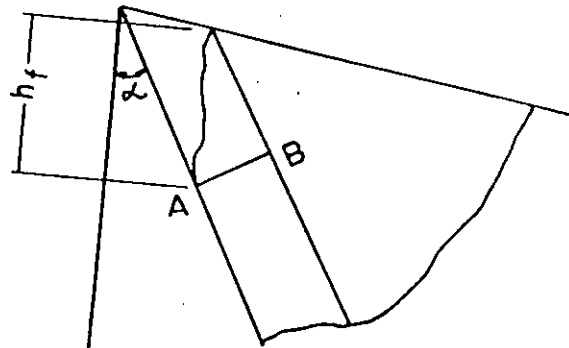
4. VARIANT-IV

Cutting conditions: Cutting speed, $v = 150$ m/min.,

$t = 1$ mm, $s = 0.20$ mm/rev.

$n = 1200$ rpm.

5.3 Determination of the Number of Regrinds Possible for Each 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 in order to produce a satisfactory flank is, $AB = h_f \sin \alpha$. But in practice, an amount $(h_f \sin \alpha + \Delta)$ must be ground-off as the worn face is not a well defined line. Let the tool be reground 'R' times before it is of no use for the operation and 'Q' be then the 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. $h_f = 0.50\text{mm}$.

$$\alpha = \text{side clearance angle} = 13^\circ \quad \Delta = 0.075 \text{ mm (let)}$$

Q = The limiting amount which can be ground off

$$\text{So, } R = \frac{Q}{h_f \sin \alpha + \Delta} \quad \dots \quad \dots \quad (5.2)$$

For tool bit of USSR 1st, 2nd and 3rd group

$$Q = 15.5 - 5 = 10.5 \text{ mm (from Table-5)}$$

For tool bit of Poland, $Q = 13 - 5 = 8 \text{ mm.}$

$$\text{China, } Q = 12 - 5 = 7 \text{ mm.}$$

$$\text{India, } Q = 12 - 5 = 7 \text{ mm.}$$

$$\text{H.S.S. } Q = 150 - 60 = 90 \text{ mm.}$$

Number of grinds possible is calculated according to formula (5.2) as follows:

For USSR 1st, 2nd and 3rd group,

$$R = \frac{Q}{h_f \sin \alpha + \Delta} = \frac{10.5}{0.5 \sin 13^\circ + 0.075} = 56 \text{ times.}$$

$$\text{For Poland, } R = \frac{Q}{h_f \sin \alpha + \Delta} = \frac{8}{0.5 \sin 13^\circ + 0.075} = 42.67 \approx 43 \text{ times.}$$

$$\text{For China, } R = \frac{Q}{h_f \sin \alpha + \Delta} = \frac{7}{0.5 \sin 13^\circ + 0.075} = 37.33 \approx 37 \text{ times.}$$

$$\text{For India, } R = \frac{Q}{h_f \sin \alpha + \Delta} = \frac{7}{0.5 \sin 13^\circ + 0.075} = 37.33 \approx 37 \text{ times.}$$

$$\text{For H.S.S. } R = \frac{Q}{h_f \sin \alpha + \Delta} = \frac{90}{0.5 \sin 13^\circ + 0.075} = 480 \text{ times.}$$

TABLE-4

Records from various workshops of Dholaikhal regarding Lead Screw and Factory rates:

Length of the solid bar to be turned,	$L = 1270 \text{ mm}$
Initial diameter of the bar,	$D_w = 43 \text{ mm}$
Final diameter of the bar,	$D_m = 35 \text{ mm}$
Cost of Lathe,	= Tk. 78000 (8 ft length)
Electricity bill per month	= Tk. 1000
House rent (120 sq.ft. area and 3 m/c's are placed)	= Tk. 1000 per month and advance Tk.200000
Cost of grinding machine	= Tk. 2000
Grinding wheel cost per piece	= Tk. 120
Labour cost (highly skilled) per month	= Tk. 2000 (8 hours duty per day)
Helper cost per month	= Tk. 300 (8 hours duty per day)
Administrative overhead (indirect labour rate)	= Tk. 3500 (8 hours duty per day)
Job loading and unloading time including centering, tool approach and engage time, t_1	= 40 mins.
Tool changing and resetting time, t_{ct}	= 3 mins.
Tool grinding time including loading and unloading	= 15 mins.
Auxiliary cutting time per cut	= 1 min.

TABLE-5

Carbide tip size:	USSR 1st group	: 15.5 x 25 mm.
	USSR 2nd group	: 15.5 x 25 mm.
	USSR 3rd group	: 15.5 x 25 mm.
	Poland	: 13 x 25 mm.
	China	: 12 x 25 mm.
	India	: 12 x 12 mm.
	H.S.S. (China)	: 12.5 x 150 mm.

The limiting amount of tool bit upto which the bit can be ground	: 5 mm (for carbide tipped tools)
	: 60 mm (for H.S.S. tool)

Initial tool cost:

USSR 1st group	: Tk. 120
USSR 2nd group	: Tk. 165
USSR 3rd group	: Tk. 130
Poland	: Tk. 80
China	: Tk. 80
India	: Tk. 50
H.S.S.	: Tk. 150

From Table-4,

$$\text{Direct labour rate} = \frac{\text{Tk. } (2000 + 300)}{30 \times 8 \text{ hour}} = \text{Tk. } 9.58 \approx \text{Tk. } 10 \text{ per hour}$$

$$\text{Indirect labour rate} = \frac{\text{Tk. } 3500}{30 \times 8 \text{ hour}} = \text{Tk. } 14.58 \approx \text{Tk. } 15 \text{ per hour}$$

$$\begin{aligned} \text{Machine cost} &= \text{Lathe machine cost} + \text{Grinding machine cost} \\ &= \text{Tk. } 78000 + \text{Tk. } 2000 \\ &= \text{Tk. } 80000 \end{aligned}$$

Assuming that the life of these machines are 15 years.

After 15 years, the value of Tk. 80000 will be Tk. 571035

(Taking 14% interest rate)

$$\text{Now, machine cost per hour} = \frac{(571035 - 10000)}{15 \times 365 \times 8} = \text{Tk. } 12.80$$

Assuming salvage value of the machines = Tk. 10000

Again assuming that a grinding wheel can be used for two months.

$$\text{Therefore, grinding wheel cost} = \frac{\text{Tk. } 120}{2 \times 30 \times 8} = \text{Tk. } 0.25 \text{ per hour}$$

House rent is Tk. 1000 per month and advance Tk. 200000 for

15 years. The value of Tk. 200000 after 15 years will be

Tk. 1427587 (Taking 14% interest rate).

$$\text{House rent} = \frac{1427587}{15 \times 12} = \text{Tk. } 7931 \text{ per month.}$$

Again per month Tk. 1000 is given.

Therefore, total house rent per month = Tk. 7931 + 1000 = Tk. 8931.

$$\begin{aligned} \text{Overhead cost due to house rent} &= \frac{\text{Tk. } 8931}{30 \times 8} = \text{Tk. } 37 \text{ per hour for} \\ &\quad \text{three machines.} \end{aligned}$$

Therefore, $\frac{37}{3} = \text{Tk. } 12.40 \text{ per hour per machine.}$

Overhead cost due to electricity = $\frac{\text{Tk. } 1000}{30 \times 8 \times 3} = \text{Tk. } 1.38$

Therefore, machine rate including overhead

$$= \text{Tk. } (12.80 + 0.25 + 12.40 + 1.38)$$

$$= \text{Tk. } 26.83 \text{ per hour}$$

Machine and operator rate,

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

$$= \text{Tk. } 26.83 + \text{Tk. } 10 + \text{Tk. } 15$$

$$= \text{Tk. } 51.83 \text{ per hour.}$$

5.4 Determination of Grinding Cost

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

Cost of grinding a tool

= Machine cost + Direct labour cost + Indirect labour cost

$$= \text{Tk. } 26.83 \times \frac{15}{60} + \text{Tk. } 10 \times \frac{15}{60} + \text{Tk. } 15 \times \frac{15}{60}$$

$$= \text{Tk. } 6.75 + \text{Tk. } 2.50 + \text{Tk. } 3.75$$

$$= \text{Tk. } 13$$

Tool depreciation per grind

$$\text{For USSR 1st group} = \frac{\text{Tool cost}}{\text{Total no. of regrinds}} = \text{Tk. } \frac{120}{56} = \text{Tk. } 2.15$$

$$\text{For USSR 2nd group} = \frac{\text{Tool cost}}{\text{Total no. of regrinds}} = \text{Tk. } \frac{165}{56} = \text{Tk. } 2.95$$

Tool depreciation per grind,

$$\text{For USSR 3rd group} = \frac{\text{Tool cost}}{\text{Total no. of regrinds}} = \text{Tk. } \frac{130}{56} = \text{Tk. } 2.32$$

$$\text{For Poland} = \frac{\text{Tool cost}}{\text{Total no. of regrinds}} = \text{Tk. } \frac{80}{43} = \text{Tk. } 1.86$$

$$\text{For China} = \frac{\text{Tool cost}}{\text{Total no. of regrinds}} = \text{Tk. } \frac{80}{37} = \text{Tk. } 2.16$$

$$\text{For India} = \frac{\text{Tool cost}}{\text{Total no. of regrinds}} = \text{Tk. } \frac{50}{37} = \text{Tk. } 1.35$$

$$\text{For H.S.S.} = \frac{\text{Tool cost}}{\text{Total no. of regrinds}} = \text{Tk. } \frac{150}{480} = \text{Tk. } 0.32$$

Total tool cost per grind,

C_t = cost of grinding + tool depreciation.

$$\text{For USSR 1st group, } C_t = \text{Tk. } 13 + \text{Tk. } 2.15 = \text{Tk. } 15.15$$

$$\text{For USSR 2nd group, } C_t = \text{Tk. } 13 + \text{Tk. } 2.95 = \text{Tk. } 15.95$$

$$\text{For USSR 3rd group, } C_t = \text{Tk. } 13 + \text{Tk. } 2.32 = \text{Tk. } 15.32$$

$$\text{For Poland, } C_t = \text{Tk. } 13 + \text{Tk. } 1.86 = \text{Tk. } 14.86$$

$$\text{For China, } C_t = \text{Tk. } 13 + \text{Tk. } 2.16 = \text{Tk. } 15.16$$

$$\text{For India, } C_t = \text{Tk. } 13 + \text{Tk. } 1.35 = \text{Tk. } 14.35$$

$$\text{For H.S.S. (China) } C_t = \text{Tk. } 13 + \text{Tk. } 0.32 = \text{Tk. } 13.32$$

5.5 Cost Analysis for Different Kinds of Tools At Different Cutting Speeds

Initial job diameter, $D_w = 43$ mm.

Final job diameter, $D_m = 35$ mm.

Avg. diameter = 39 mm.

At cutting speed, $v = 80$ m/min.

$$n = \frac{v \times 1000}{\pi \times d} = \frac{80 \times 1000}{\pi \times 39} \quad \left(\text{Since } v = \frac{\pi d n}{1000} \text{ m/min.,} \right. \\ \left. d \text{ is in mm.} \right)$$

Therefore, $n = 650$ rpm.

At cutting speed, $v = 100$ m/min.

$$n = \frac{100 \times 1000}{\pi \times 39} = 815 \text{ rpm.}$$

At cutting speed, $v = 120$ m/min.

$$n = \frac{120 \times 1000}{\pi \times 39} = 980 \text{ rpm.}$$

At cutting speed, $v = 150$ m/min.

$$n = \frac{150 \times 1000}{\pi \times 39} = 1224 \text{ rpm.}$$

The available rpm's of the lathe machine are 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1200, 1600, 2000 rpm. So, from the above calculation, for cutting speed, $v = 80, 100, 120, 150$ m/min., we can use $n = 630, 800, 1000$ and 1200 rpm respectively. Feed and depth of cut is 0.2 mm/rev. and 1 mm respectively.

VARIANT-I5.5.1 Cost for Cutting Speed $v = 80$ m/min.

Feed, $s = 0.20$ mm/rev. Depth of cut, $t = 1$ mm, $n = 630$ rpm

Auxiliary cutting time is 4 minutes, since four passes are used.

$$\text{Actual turning time} = \frac{L}{s \cdot n} \times 4 = \frac{1270}{0.2 \times 630} \times 4 = 40.32 \text{ mins.}$$

$$\text{Total turning (machining) time, } t_m = 40.32 + 4 = 44.32 \text{ mins.}$$

$$\text{Idle time, } t_1 = 40 \text{ mins. from Table-4}$$

$$\text{Tool changing time, } t_{ct} = 3 \text{ mins. from Table-4.}$$

For Tool Bit of Poland

$$\text{From Table-2 and Fig.4.4, } T_1 = 181 \text{ secs} = 3.01 \text{ mins. } h_{f1} = 0.105 \text{ mm}$$

$$T_2 = 553.5 \text{ secs} = 9.225 \text{ mins. } h_{f2} = 0.03 \text{ mm}$$

$$\text{Tool wear during operation} = \frac{0.03 \times (40.32 - 3)}{9.225} + 0.105 = 0.226 \text{ mm}$$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.226} = 2.2 \text{ pieces.}$$

$$\text{Therefore, } \frac{N_t}{N_b} = \frac{1}{2.2} = 0.452, \text{ since number of tool, } N_t = 1.$$

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{44.32}{60} = \text{Tk. } 38.28$$

$$\begin{aligned}\text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.452 \times \frac{3}{60} \\ &= \text{Tk. } 1.17\end{aligned}$$

Tool cost per piece,

$$C_{td} + C_{tg} = \frac{N_t}{N_b} C_t = 0.452 \times \text{Tk. } 14.86 = \text{Tk. } 6.71$$

$$\begin{aligned}\text{Therefore, total cost per piece, } C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 38.28 + 1.17 + 6.71) \\ &= \text{Tk. } 80.71\end{aligned}$$

$$\begin{aligned}\text{If 1000 pieces are turned, total cost} &= C_p \times 1000 = \text{Tk. } 80.71 \times 1000 \\ &= \text{Tk. } 80710\end{aligned}$$

For Tool Bit of India

From Table-2 and Fig. 4.24, $T_1 = 118 \text{ secs} = 1.97 \text{ mins.}$ $h_{f1} = 0.10 \text{ mm.}$

$T_2 = 250 \text{ secs} = 4.17 \text{ mins.}$ $h_{f2} = 0.020 \text{ mm.}$

$$\text{Tool wear during operation} = \frac{0.02 \times (40.32 - 1.97)}{4.17} + 0.10 = 0.284 \text{ mm.}$$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.284} = 1.76 \text{ pieces.}$$

$$\text{Therefore, } \frac{N_t}{N_b} = \frac{1}{1.76} = 0.568, \quad \text{since, } N_t = 1$$

In order to calculate cost per piece, C_p according to equation (5.1), the values of its components are calculated as follows

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{44.32}{60} = \text{Tk. } 38.28$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.568 \times \frac{3}{60} \\ &= \text{Tk. } 1.47 \end{aligned}$$

Tool cost per piece,

$$C_{tg} + C_{td} = \frac{N_t}{N_b} C_t = \text{Tk. } 0.568 \times 14.35 = \text{Tk. } 8.15$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 38.28 + 1.47 + 8.15) = \text{Tk. } 82.45 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 82.45 \times 1000$$

$$= \text{Tk. } 82450$$

For Tool Bit of USSR 2nd Group

From Table-2 and Fig.4.12, $T_1 = 354 \text{ secs} = 5.9 \text{ mins.}$ $h_{f1} = 0.125 \text{ mm.}$

$T_2 = 374 \text{ secs} = 6.23 \text{ mins.}$ $h_{f2} = 0.025 \text{ mm.}$

Tool wear during operation = $\frac{0.025 \times (40.32 - 5.9)}{6.23} + 0.125 = 0.263 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.263} = 1.9 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.9} = 0.526$, since, $N_t = 1$.

For calculating cost per piece, C_p according to equation (5.1),

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \cdot \frac{44.32}{60} = \text{Tk. } 38.28$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.526 \times \frac{3}{60} \\ &= \text{Tk. } 1.36 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.526 \times \text{Tk. } 15.95 \\ &= \text{Tk. } 8.39 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 38.28 + 1.36 + 8.39) = \text{Tk. } 82.58 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 82.58 \times 1000$$

$$= \text{Tk. } 82580$$

For Tool Bit of USSR 1st Group

From Table-2 and Fig.4.8, $T_1 = 175 \text{ secs} = 2.92 \text{ mins.}$ $h_{f1} = 0.06 \text{ mm.}$

$T_2 = 572 \text{ secs} = 9.53 \text{ mins.}$ $h_{f2} = 0.072 \text{ mm.}$

Tool wear during operation = $\frac{0.072 \times (40.32 - 2.92)}{9.53} + 0.06 = 0.342 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.342} = 1.46 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.46} = 0.68$, since, $N_t = 1$

To calculate cost per piece C_p , the components are

Idle cost, $C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$

Machining cost, $C_c = M t_m = \text{Tk. } 51.83 \times \frac{44.32}{60} = \text{Tk. } 38.28$

Tool changing cost, $C_{tc} = M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.68 \times \frac{3}{60}$
 $= \text{Tk. } 1.76$

Tool cost per piece,

$$C_{tg} + C_{td} = \frac{N_t}{N_b} C_t = 0.68 \times \text{Tk. } 15.15 = \text{Tk. } 10.30$$

Therefore, total cost per piece,

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

$$= \text{Tk. } (34.55 + 38.28 + 1.76 + 10.30) = \text{Tk. } 84.89$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 84.89 \times 1000$$

$$= \text{Tk. } 84890$$

For Tool Bit of USSR 3rd Group

From Table-2 and Fig.4.16, $T_1 = 96 \text{ secs} = 1.6 \text{ mins.}$ $h_{f1} = 0.055 \text{ mm.}$

$T_2 = 300 \text{ secs} = 5 \text{ mins.}$ $h_{f2} = 0.041 \text{ mm.}$

Tool wear during operation = $\frac{0.041 \times (40.32 - 1.6)}{5} + 0.055 = 0.372 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.372} = 1.35 \text{ pieces.}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.35} = 0.74$, since, $N_t = 1$

To calculate cost per piece, C_p , the components are,

Idle cost, $C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$

Machining cost, $C_c = M t_m = \text{Tk. } 51.83 \times \frac{44.32}{60} = \text{Tk. } 38.28$

Tool changing cost, $C_{tc} = M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.74 \times \frac{3}{60}$
 $= \text{Tk. } 1.91$

Tool cost per piece,

$$C_{tg} + C_{td} = \frac{N_t}{N_b} C_t = 0.74 \times \text{Tk. } 15.32 = \text{Tk. } 11.33$$

Therefore, total cost per piece,

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

$$= \text{Tk. } 34.55 + \text{Tk. } 38.28 + \text{Tk. } 1.91 + \text{Tk. } 11.33 = \text{Tk. } 86.07$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 86.07 \times 1000$$

$$= \text{Tk. } 86070$$

For Tool Bit of China

From Table-2 and Fig.4.20, $T_1 = 122 \text{ secs} = 2.04 \text{ mins.}$ $h_{f1} = 0.08 \text{ mm.}$

$T_2 = 313 \text{ secs} = 5.22 \text{ mins.}$ $h_{f2} = 0.054 \text{ mm.}$

Tool wear during operation = $\frac{0.054 \times (40.32 - 2.04)}{5.22} + 0.08 = 0.476 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.476} = 1.05 \text{ pieces.}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.05} = 0.952$, since, $N_t = 1$

To calculate cost per piece, C_p , the components are,

Idle cost, $C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$

Machining cost, $C_c = M t_m = \text{Tk. } 51.83 \times \frac{44.32}{60} = \text{Tk. } 38.28$

Tool changing cost, $C_{tc} = M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.952 \times \frac{3}{60}$
 $= \text{Tk. } 2.46$

Tool cost per piece, $C_{tg} + C_{td} = \frac{N_t}{N_b} C_t = 0.952 \times \text{Tk. } 15.16$
 $= \text{Tk. } 14.43$

Therefore, total cost per piece,

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

$$= \text{Tk. } (34.55 + 38.28 + 2.46 + 14.43) = \text{Tk. } 89.72$$

If 1000 pieces are turned, total cost = $C_p \times 1000 = \text{Tk. } 89.72 \times 1000$
 $= \text{Tk. } 89720$

For H.S.S. Tool

From Table-2 and Fig.4.25, $T_1 = 173$ secs = 2.88 mins. $h_{f1} = 0.29$ mm.

$T_2 = 233$ secs = 3.88 mins. $h_{f2} = 0.41$ mm.

Tool wear during operation = $\frac{0.41 \times (40.32 - 2.88)}{3.88} + 0.29 = 4.24$ mm.

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{4.24} = 0.118 \text{ pieces.}$$

Now, $\frac{N_t}{N_b} = \frac{1}{0.118} = 8.48$, since number of tool, $N_t = 1$

To calculate cost per piece, C_p , the components are,

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{44.32}{60} = \text{Tk. } 38.28$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 8.48 \times \frac{3}{60} \\ &= \text{Tk. } 21.98 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 8.48 \times \text{Tk. } 13.32 \\ &= \text{Tk. } 112.95 \end{aligned}$$

Total cost per piece,

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

$$= \text{Tk. } (34.55 + 38.28 + 21.98 + 112.95) = \text{Tk. } 207.76$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 207.76 \times 1000$$

$$= \text{Tk. } 207760$$

VARIANT-II

5.5.2 Cost for Cutting Speed, $v = 100 \text{ m/min.}$

Feed, $s = 0.20 \text{ mm/rev.}$, Depth of cut, $t = 1 \text{ mm}$, $n = 800 \text{ rpm}$.

Auxiliary cutting time is 4 minutes, since four passes are used.

$$\text{Actual turning time} = \frac{L}{s \cdot n} \times 4 = \frac{1270 \times 4}{0.2 \times 800} = 31.75 \text{ minutes}$$

Total turning (machining) time, $t_m = 31.75 + 4 = 35.75 \text{ minutes.}$

Idle time, $t_i = 40 \text{ minutes from Table-4}$

Tool changing time, $t_{ct} = 3 \text{ minutes from Table-4}$

For Tool Bit of Poland

From Table-2 and Fig.4.3, $T_1 = 105 \text{ secs} = 1.75 \text{ mins.}$ $h_{f1} = 0.10 \text{ mm.}$

$T_2 = 315 \text{ secs} = 5.25 \text{ mins.}$ $h_{f2} = 0.032 \text{ mm.}$

$$\begin{aligned} \text{Tool wear during operation} &= \frac{0.032 \times (31.75 - 1.75)}{5.25} + 0.10 \\ &= 0.282 \text{ mm} \end{aligned}$$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.282} = 1.77 \text{ pieces.}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.77} = 0.564$, since number of tool, $N_t = 1$

To calculate the cost per piece, C_p according to equation (5.1), the components are,

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{35.75}{60} = \text{Tk. } 30.88$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.564 \times \frac{3}{60} \\ &= \text{Tk. } 1.46 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.564 \times \text{Tk. } 14.86 \\ &= \text{Tk. } 8.38 \end{aligned}$$

Therefore, total cost per piece,

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

$$= \text{Tk. } (34.55 + 30.88 + 1.46 + 8.38) = \text{Tk. } 75.27$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 75.27 \times 1000$$

$$= \text{Tk. } 75270$$

For Tool Bit of India

From Table-2 and Fig.4.23, $T_1 = 97 \text{ secs} = 1.62 \text{ mins.}$ $h_{f1} = 0.105 \text{ mm.}$

$$T_2 = 253 \text{ secs} = 4.22 \text{ mins.}$$
 $h_{f2} = 0.033 \text{ mm.}$

$$\text{Tool wear during operation} = \frac{0.033 \times (31.75 - 1.62)}{4.22} + 0.105 = 0.341 \text{ mm}$$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.341} = 1.47 \text{ pieces.}$$

$$\text{Therefore, } \frac{N_t}{N_b} = \frac{1}{1.47} = 0.682, \quad \text{since, } N_t = 1$$

In order to calculate cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{35.75}{60} = \text{Tk. } 30.88$$

$$\begin{aligned}\text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.682 \times \frac{3}{60} \\ &= \text{Tk. } 1.76\end{aligned}$$

Tool cost per piece,

$$C_{tg} + C_{td} = \frac{N_t}{N_b} C_t = 0.682 \times \text{Tk. } 14.35 = \text{Tk. } 9.78$$

Now, total cost per piece,

$$\begin{aligned}C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 30.88 + 1.76 + 9.78) = \text{Tk. } 76.97\end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 76.97 \times 1000$$

$$= \text{Tk. } 76970$$

For Tool Bit of USSR 2nd Group

From Table-2 and Fig.4.11, $T_1 = 97 \text{ secs} = 1.62 \text{ mins.}$ $h_{f1} = 0.10 \text{ mm.}$

$T_2 = 311 \text{ secs} = 5.18 \text{ mins.}$ $h_{f2} = 0.032 \text{ mm.}$

Tool wear during operation = $\frac{0.032 \times (31.75 - 1.62)}{5.18} + 0.10 = 0.286 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.286} = 1.75 \text{ pieces.}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.75} = 0.572$, since, $N_t = 1$

In order to calculate cost per piece, C_p , the components are

Idle cost, $C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$

Machining cost, $C_c = M t_m = \text{Tk. } 51.83 \times \frac{35.75}{60} = \text{Tk. } 30.88$

Tool changing cost, $C_{tc} = M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.572 \times \frac{3}{60}$
 $= \text{Tk. } 1.48$

Tool cost per piece,

$C_{tg} + C_{td} = \frac{N_t}{N_b} C_t = 0.572 \times \text{Tk. } 15.95 = \text{Tk. } 9.12$

Therefore, total cost per piece,

$C_p = C_I + C_c + C_{tc} + C_{tg} + C_{td}$
 $= \text{Tk. } (34.55 + 30.88 + 1.48 + 9.12) = \text{Tk. } 76.03$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$= \text{Tk. } 76.03 \times 1000$

$= \text{Tk. } 76030$

For Tool Bit of USSR 1st Group

From Table-2 and Fig.4.7, $T_1 = 101 \text{ secs} = 1.683 \text{ mins.}$ $h_{f1} = 0.065 \text{ mm.}$

$T_2 = 349 \text{ secs} = 5.82 \text{ mins.}$ $h_{f2} = 0.075 \text{ mm.}$

$$\text{Tool wear during operation} = \frac{0.075 \times (31.75 - 1.68)}{5.82} + 0.065 = 0.452 \text{ mm.}$$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.452} = 1.11 \text{ pieces}$$

$$\text{Therefore, } \frac{N_t}{N_b} = \frac{1}{1.11} = 0.90, \quad \text{since, } N_t = 1$$

For calculating cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{35.75}{60} = \text{Tk. } 30.88$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.90 \times \frac{3}{60} \\ &= \text{Tk. } 2.33 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} \times C_t = 0.90 \times \text{Tk. } 15.15 \\ &= \text{Tk. } 13.63 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 30.88 + 2.33 + 13.63) = \text{Tk. } 81.39 \end{aligned}$$

$$\begin{aligned} \text{If 1000 pieces are turned, total cost} &= C_p \times 1000 = 81.39 \times 1000 \\ &= \text{Tk. } 81390 \end{aligned}$$

For Tool Bit of USSR 3rd Group

From Table-2 and Fig.4.15, $T_1 = 192 \text{ secs} = 3.2 \text{ mins.}$ $h_{f1} = 0.085 \text{ mm.}$

$T_2 = 202 \text{ secs} = 3.37 \text{ mins.}$ $h_{f2} = 0.035 \text{ mm.}$

Tool wear during operation = $\frac{0.035 \times (31.75 - 3.2)}{3.37} + 0.085 = 0.382 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.382} = 1.31 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.31} = 0.763$, since, $N_t = 1$

To calculate cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{35.75}{60} = \text{Tk. } 30.88$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.763 \times \frac{3}{60} \\ &= \text{Tk. } 1.97 \end{aligned}$$

Tool cost per piece,

$$C_{tg} + C_{td} = \frac{N_t}{N_b} C_t = 0.763 \times \text{Tk. } 15.32 = \text{Tk. } 11.68$$

Total cost per piece,

$$\begin{aligned}
 C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\
 &= \text{Tk. } 34.55 + \text{Tk. } 30.88 + \text{Tk. } 1.97 + \text{Tk. } 11.68 \\
 &= \text{Tk. } 79.08
 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 79.08 \times 1000$$

$$= \text{Tk. } 79080$$

For Tool Bit of China

From Table-2 and Fig.4.19, $T_1 = 81 \text{ secs} = 1.35 \text{ mins.}$ $h_{f1} = 0.08 \text{ mm.}$

$T_2 = 250 \text{ secs} = 4.17 \text{ mins.}$ $h_{f2} = 0.06 \text{ mm.}$

Tool wear during operation = $\frac{0.06 \times (31.75 - 1.35)}{4.17} + 0.08 = 0.518 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.518} = 0.97 \text{ pieces}$$

$$\text{Therefore, } \frac{N_t}{N_b} = \frac{1}{0.97} = 1.03, \quad \text{since, } N_t = 1$$

To calculate cost per piece, C_p , the components are,

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{35.75}{60} = \text{Tk. } 30.88$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 1.03 \times \frac{3}{60} \\ &= \text{Tk. } 2.67 \end{aligned}$$

Tool cost per piece,

$$C_{tg} + C_{td} = \frac{N_t}{N_b} C_t = 1.03 \times \text{Tk. } 15.16 = \text{Tk. } 15.61$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 30.88 + 2.67 + 15.61) \\ &= \text{Tk. } 83.71 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 83.71 \times 1000$$

$$= \text{Tk. } 83710$$

VARIANT-III5.5.3 Cost For Cutting Speed, $v = 120$ m/min.

Feed, $s = 0.20$ mm/rev., Depth of cut, $t = 1$ mm, $n = 1000$ rpm.

Auxiliary cutting time is 4 minutes, since four passes are used.

$$\text{Actual turning time} = \frac{L}{s \cdot n} \times 4 = \frac{1270 \times 4}{0.2 \times 1000} = 25.4 \text{ minutes.}$$

$$\text{Total turning (machining) time, } t_m = 25.4 + 4 = 29.4 \text{ mins.}$$

Idle time, $t_1 = 40$ minutes from Table-4

Tool changing time, $t_{ct} = 3$ minutes from Table-4

For Tool Bit of Poland

From Table-2 and Fig.4.2, $T_1 = 125$ secs = 2.08 mins. $h_{f1} = 0.075$ mm.

$T_2 = 398$ secs = 6.63 mins. $h_{f2} = 0.047$ mm.

$$\text{Tool wear during operation} = \frac{0.047 \times (25.4 - 2.08)}{6.63} + 0.075 = 0.240 \text{ mm.}$$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.240} = 2.08 \text{ pieces.}$$

$$\text{Therefore, } \frac{N_t}{N_b} = \frac{1}{2.08} = 0.48, \quad \text{since, } N_t = 1$$

To calculate the cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{29.4}{60} = \text{Tk. } 25.40$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.48 \times \frac{3}{60} \\ &= \text{Tk. } 1.24 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.48 \times \text{Tk. } 14.86 \\ &= \text{Tk. } 7.13 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 25.40 + 1.24 + 7.13) = \text{Tk. } 68.32 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 68.32 \times 1000$$

$$= \text{Tk. } 68320$$

For Tool Bit of India

From Table-2 and Fig.4.22, $T_1 = 61 \text{ secs} = 1.02 \text{ mins.}$ $h_{f1} = 0.09 \text{ mm.}$

$T_2 = 123 \text{ secs} = 2.05 \text{ mins.}$ $h_{f2} = 0.02 \text{ mm.}$

Tool wear during operation = $\frac{0.020 \times (25.4 - 1.02)}{2.05} + 0.09 = 0.328 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.328} = 1.52 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.52} = 0.656$, since, $N_t = 1$

To calculate cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{29.4}{60} = \text{Tk. } 25.40$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.656 \times \frac{3}{60} \\ &= \text{Tk. } 1.70 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.656 \times \text{Tk. } 14.35 \\ &= \text{Tk. } 9.41 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 25.40 + 1.70 + 9.41) = \text{Tk. } 71.06 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 71.06 \times 1000$$

$$= \text{Tk. } 71060$$

For Tool Bit of USSR 2nd Group

From Table-2 and Fig. 4.10, $T_1 = 100 \text{ secs} = 1.67 \text{ mins.}$ $h_{f1} = 0.06 \text{ mm.}$

$T_2 = 322 \text{ secs} = 5.37 \text{ mins.}$ $h_{f2} = 0.044 \text{ mm.}$

$$\text{Tool wear during operation} = \frac{0.044 \times (25.4 - 1.67)}{5.37} + 0.06 = 0.254 \text{ mm.}$$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.254} = 1.96 \text{ pieces.}$$

$$\text{Therefore, } \frac{N_t}{N_b} = \frac{1}{1.96} = 0.509, \quad \text{since, } N_t = 1$$

To calculate cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{29.4}{60} = \text{Tk. } 25.40$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.509 \times \frac{3}{60} \\ &= \text{Tk. } 1.32 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.509 \times \text{Tk. } 15.95 \\ &= \text{Tk. } 8.12 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 25.40 + 1.32 + 8.12) = \text{Tk. } 69.39 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 69.39 \times 1000$$

$$= \text{Tk. } 69390$$

For Tool Bit of USSR 1st Group

From Table-2 and Fig.4.6, $T_1 = 122.5 \text{ secs} = 2.04 \text{ mins.}$ $h_{f1} = 0.065 \text{ mm.}$

$T_2 = 387.5 \text{ secs} = 6.5 \text{ mins.}$ $h_{f2} = 0.10 \text{ mm.}$

Tool wear during operation = $\frac{0.10 \times (25.40 - 2.04)}{6.5} + 0.065 = 0.4267 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.4267} = 1.2 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.2} = 0.84$, since, $N_t = 1$

For calculating cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{29.4}{60} = \text{Tk. } 25.40$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.84 \times \frac{3}{60} \\ &= \text{Tk. } 2.17 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.84 \times \text{Tk. } 15.15 \\ &= \text{Tk. } 12.72 \end{aligned}$$

Total cost per piece,

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

$$= \text{Tk. } (34.55 + 25.40 + 2.17 + 12.72) = \text{Tk. } 74.84$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 74.84 \times 1000 = \text{Tk. } 74840$$

For Tool Bit of USSR 3rd Group

From Table-2 and Fig.4.14, $T_1 = 98 \text{ secs} = 1.64 \text{ mins.}$ $h_{f1} = 0.05 \text{ mm.}$

$T_2 = 301 \text{ secs} = 5.02 \text{ mins.}$ $h_{f2} = 0.07 \text{ mm.}$

Tool wear during operation = $\frac{0.07 \times (25.40 - 1.64)}{5.02} + 0.05 = 0.381 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.381} = 1.31 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.31} = 0.762$, since, $N_t = 1$

To calculate the cost per piece C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{29.40}{60} = \text{Tk. } 25.40$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.762 \times \frac{3}{60} \\ &= \text{Tk. } 1.97 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.762 \times \text{Tk. } 15.32 \\ &= \text{Tk. } 11.67 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 25.40 + 1.97 + 11.67) = \text{Tk. } 73.59 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 73.59 \times 1000 = \text{Tk. } 73590$$

For Tool Bit of China

From Table-2 and Fig.4.18, $T_1 = 62 \text{ secs} = 1.04 \text{ mins.}$ $h_{f1} = 0.08 \text{ mm.}$

$T_2 = 118 \text{ secs} = 1.97 \text{ mins.}$ $h_{f2} = 0.036 \text{ mm.}$

Tool wear during operation = $\frac{0.036 \times (25.40 - 1.04)}{1.97} + 0.08 = 0.525 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.525} = 0.953 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{0.953} = 1.05$, since, $N_t = 1$

To calculate the cost per piece C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{29.4}{60} = \text{Tk. } 25.40$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ot} = \text{Tk. } 51.83 \times 1.05 \times \frac{3}{60} \\ &= \text{Tk. } 2.72 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 1.05 \times \text{Tk. } 15.16 \\ &= \text{Tk. } 15.91 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 25.40 + 2.72 + 15.91) = \text{Tk. } 78.58 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 78.58 \times 1000$$

$$= \text{Tk. } 78580$$

VARIANT-IV5.5.4 Cost for Cutting Speed, $v = 150$ m/min.

Feed, $s = 0.20$ mm/rev., Depth of cut, $t = 1$ mm $n = 1200$ rpm.

Auxiliary cutting time is 4 minutes, since four passes are used.

$$\text{Actual turning time} = \frac{L}{s \cdot n} \times 4 = \frac{1270 \times 4}{0.2 \times 1200} = 21.2 \text{ minutes.}$$

$$\text{Total turning (machining) time, } t_m = 21.2 + 4 = 25.2 \text{ mins.}$$

Idle time, $t_1 = 40$ minutes from Table-4

Tool changing time, $t_{ct} = 3$ minutes from Table-4

For Tool Bit of Poland

From Table-2 and Fig.4.1, $T_1 = 102$ secs = 1.7 mins. $h_{f1} = 0.085$ mm.

$T_2 = 312$ secs = 5.2 mins. $h_{f2} = 0.049$ mm.

$$\text{Tool wear during operation} = \frac{0.049 \times (21.2 - 1.7)}{5.2} + 0.085 = 0.268 \text{ mm.}$$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.268} = 1.86 \text{ pieces}$$

$$\text{Therefore, } \frac{N_t}{N_b} = \frac{1}{1.86} = 0.538, \quad \text{since number of tool, } N_t = 1$$

To calculate the cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{25.2}{60} = \text{Tk. } 21.76$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.538 \times \frac{3}{60} \\ &= \text{Tk. } 1.39 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.538 \times \text{Tk. } 14.86 \\ &= \text{Tk. } 7.99 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 21.76 + 1.39 + 7.99) = \text{Tk. } 65.69 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 65.69 \times 1000$$

$$= \text{Tk. } 65690$$

For Tool Bit of India

From Table-2 and Fig.4.21, $T_1 = 62 \text{ secs} = 1.04 \text{ mins.}$ $h_{f1} = 0.11 \text{ mm.}$

$T_2 = 87 \text{ secs} = 1.45 \text{ mins.}$ $h_{f2} = 0.02 \text{ mm.}$

Tool wear during operation = $\frac{0.02 \times (21.2 - 1.04)}{1.45} + 0.11 = 0.388 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.388} = 1.29 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.29} = 0.776$, since, $N_t = 1$

To calculate the cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{25.2}{60} = \text{Tk. } 21.76$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.776 \times \frac{3}{60} \\ &= \text{Tk. } 2.01 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.776 \times \text{Tk. } 14.35 \\ &= \text{Tk. } 11.13 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 21.76 + 2.01 + 11.13) = \text{Tk. } 69.45 \end{aligned}$$

$$\begin{aligned} \text{If 1000 pieces are turned, total cost} &= C_p \times 1000 \\ &= \text{Tk. } 69.45 \times 1000 \\ &= \text{Tk. } 69450 \end{aligned}$$

For Tool Bit of USSR 2nd Group

From Table-2 and Fig.4.9, $T_1=83$ secs = 1.38 mins. $h_{f1}= 0.06$ mm.

$T_2=258$ secs = 4.3 mins. $h_{f2}= 0.05$ mm.

$$\text{Tool wear during operation} = \frac{0.05 \times (21.2 - 1.38)}{4.3} + 0.06 = 0.290 \text{ mm.}$$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.29} = 1.72 \text{ pieces}$$

$$\text{Therefore, } \frac{N_t}{N_b} = \frac{1}{1.72} = 0.58, \quad \text{since } N_t = 1$$

To calculate the cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{25.2}{60} = \text{Tk. } 21.76$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.58 \times \frac{3}{60} \\ &= \text{Tk. } 1.50 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.58 \times \text{Tk. } 15.95 \\ &= \text{Tk. } 9.25 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 21.76 + 1.50 + 9.25) = \text{Tk. } 67.06 \end{aligned}$$

$$\text{If 1000 pieces are turned, total cost} = C_p \times 1000$$

$$= \text{Tk. } 67.06 \times 1000$$

$$= \text{Tk. } 67060$$

For Tool Bit of USSR 1st Group

From Table-2 and Fig.4.5, $T_1 = 83 \text{ secs} = 1.38 \text{ mins.}$ $h_{f1} = 0.06 \text{ mm.}$

$T_2 = 259 \text{ secs} = 4.32 \text{ mins.}$ $h_{f2} = 0.092 \text{ mm.}$

Tool wear during operation = $\frac{0.092 \times (21.2 - 1.38)}{4.32} + 0.06 = 0.482 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.482} = 1.04 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.04} = 0.96$, since $N_t = 1$

To calculate the cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{25.2}{60} = \text{Tk. } 21.76$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.96 \times \frac{3}{60} \\ &= \text{Tk. } 2.48 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.96 \times \text{Tk. } 15.15 \\ &= \text{Tk. } 14.54 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 21.76 + 2.48 + 14.54) = \text{Tk. } 73.33 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 73.33 \times 1000$$

$$= \text{Tk. } 73330$$

For Tool Bit of USSR 3rd Group

From Table-2 and Fig.4.13, $T_1 = 83 \text{ secs} = 1.38 \text{ mins.}$ $h_{f1} = 0.05 \text{ mm.}$

$T_2 = 255 \text{ secs} = 4.25 \text{ mins.}$ $h_{f2} = 0.076 \text{ mm.}$

Tool wear during operation = $\frac{0.076 \times (21.2 - 1.38)}{4.25} + 0.05 = 0.404 \text{ mm.}$

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.404} = 1.24 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{1.24} = 0.806$, since $N_t = 1$

To calculate the cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{25.2}{60} = \text{Tk. } 21.76$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 0.806 \times \frac{3}{60} \\ &= \text{Tk. } 2.09 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 0.806 \times \text{Tk. } 15.32 \\ &= \text{Tk. } 12.34 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 21.76 + 2.09 + 12.34) = \text{Tk. } 70.74 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 70.74 \times 1000$$

$$= \text{Tk. } 70740$$

For Tool Bit of China

From Table-2 and Fig.4.17, $T_1 = 63$ secs = 1.05 mins. $h_{f1} = 0.09$ mm.

$T_2 = 213$ secs = 3.55 mins. $h_{f2} = 0.08$ mm.

Tool wear during operation = $\frac{0.08 \times (21.2 - 1.05)}{3.55} + 0.09 = 0.544$ mm.

Number of parts that each tool will produce before regrinding,

$$N_b = \frac{\text{Maximum wear for tool life}}{\text{Tool wear after operation}} = \frac{0.5}{0.544} = 0.92 \text{ pieces}$$

Therefore, $\frac{N_t}{N_b} = \frac{1}{0.92} = 1.08$, since $N_t = 1$

To calculate the cost per piece, C_p , the components are

$$\text{Idle cost, } C_I = M t_1 = \text{Tk. } 51.83 \times \frac{40}{60} = \text{Tk. } 34.55$$

$$\text{Machining cost, } C_c = M t_m = \text{Tk. } 51.83 \times \frac{25.2}{60} = \text{Tk. } 21.76$$

$$\begin{aligned} \text{Tool changing cost, } C_{tc} &= M \frac{N_t}{N_b} t_{ct} = \text{Tk. } 51.83 \times 1.08 \times \frac{3}{60} \\ &= \text{Tk. } 2.80 \end{aligned}$$

$$\begin{aligned} \text{Tool cost per piece, } C_{tg} + C_{td} &= \frac{N_t}{N_b} C_t = 1.08 \times \text{Tk. } 15.16 \\ &= \text{Tk. } 16.37 \end{aligned}$$

Total cost per piece,

$$\begin{aligned} C_p &= C_I + C_c + C_{tc} + C_{tg} + C_{td} \\ &= \text{Tk. } (34.55 + 21.76 + 2.80 + 16.37) = \text{Tk. } 75.48 \end{aligned}$$

If 1000 pieces are turned, total cost = $C_p \times 1000$

$$= \text{Tk. } 75.48 \times 1000$$

$$= \text{Tk. } 75480$$

- : TABLE-6 : -

A Comparative Study Of The Four Variants For Turning 1000 Pieces.

Tool Bit materials	Manufacturing countries.	Variant- I (cutting speed $v = 80$ m/min. $s = 0.20$ mm/rev. $t = 1$ mm.)		Variant - II (cutting speed $v = 1000$ m/min. $s = 0.20$ mm/rev. $t = 1$ mm.)		Variant - III (cutting speed $v = 120$ m/min. $s = 0.20$ mm/rev. $t = 1$ mm.)		Variant- IV (cutting speed $v = 150$ m/min. $s = 0.20$ mm/rev. $t = 1$ mm.)	
		For 1000 pcs	Rate	For 1000 pcs.	Rate	For 1000 pcs	Rate	For 1000 pcs	Rate
		(Tk)		(Tk)		(Tk)		(Tk)	
Cemented carbide	Poland.	80710.00	80.71	75270.00	75.27	66320.00	66.32	65690.00	65.69
	India.	82450.00	82.45	76970.00	76.97	71060.00	71.06	69450.00	69.45
	USSR 2nd Group.	82580.00	82.58	76030.00	76.03	69390.00	69.39	67060.00	67.06
	USSR 1st Group.	84890.00	84.89	81390.00	81.39	74840.00	74.84	73330.00	73.33
	USSR 3rd Group.	86070.00	86.07	79080.00	79.08	73590.00	73.59	70740.00	70.74
	China.	89720.00	89.72	83710.00	83.71	78580.00	78.58	75480.00	75.58
High speed steel.	China	207760.00	207.76	-	-	-	-	-	-

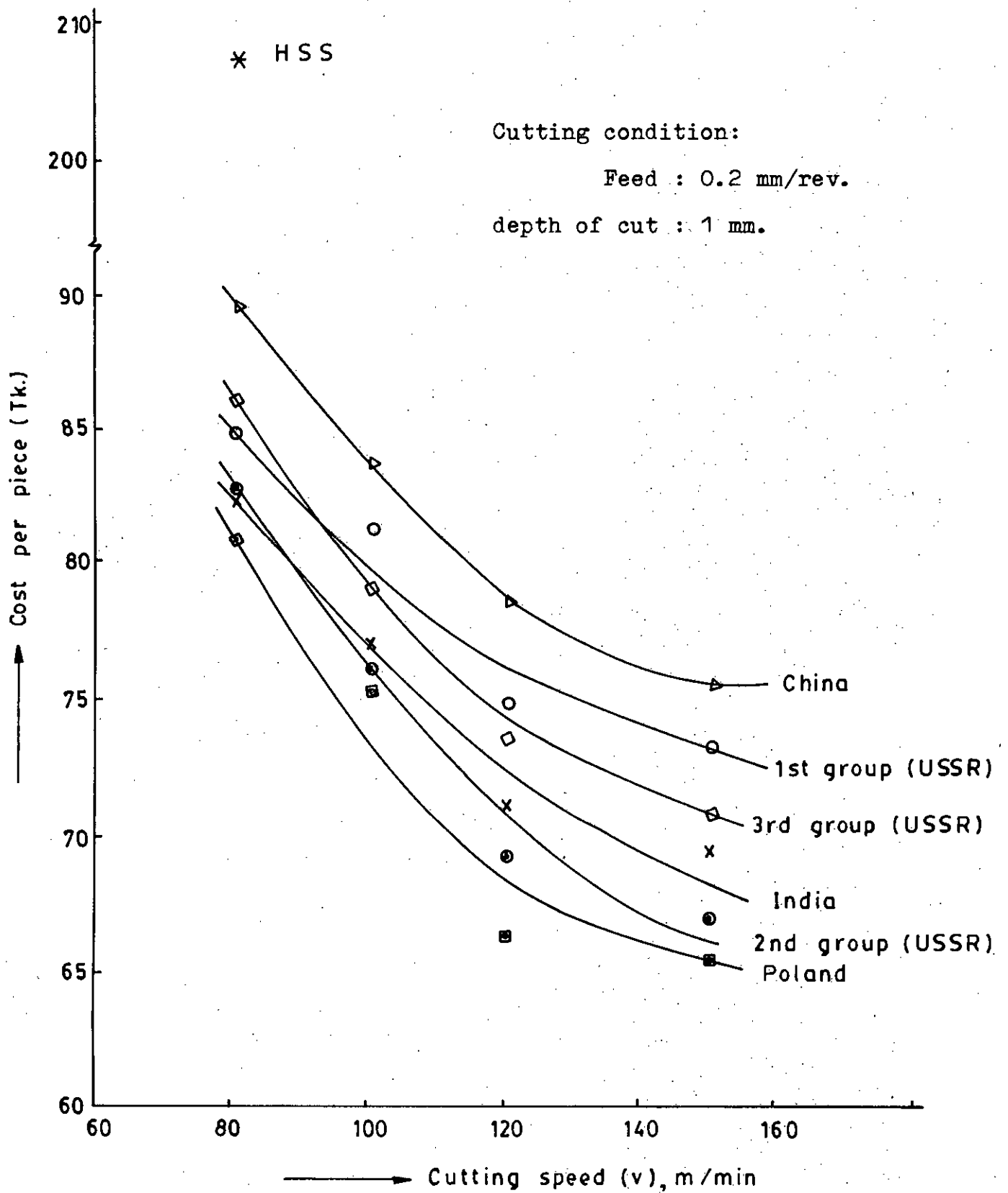


Fig. 5.1 Effect of cutting speed on cost of production.

5.6 Results and Recommendation

From the above mentioned cost calculation and comparative study (Table-6) for four variants, it can be come to a conclusion that among the six tool bits of four countries, tool bit of Poland is the best and then USSR 2nd group though at cutting speed, $v = 80$ m/min., bit of India is better than USSR 2nd group. So, we can recommend,

(1) Bit of Poland: $v = 150$ m/min. $t = 1$ mm
 $s = 0.20$ mm/rev. then

(2) Bit of USSR 2nd group: $v = 150$ m/min. $t = 1$ mm
 $s = 0.20$ mm/rev.

CHAPTER-6

DISCUSSION AND CONCLUSION

6.1 Discussion

From experimental results, it is observed from Figure 3.1 (emf vs. cutting speed) that there exists a relationship between emf and cutting speed. The relationship is that at the lower cutting speed, emf is low and with the increase of cutting speed, emf increases. It may be due to the temperature rise at the contact point of tool and work-material.

Experimental results also show that initially wear is higher (from Figure 4.1 to 4.25, flank wear vs. time curves at a definite cutting speed, feed and depth of cut) than normal wear at almost all the cutting speeds. This is due to the fact that the tools were not given initial wear by grinding-hence, it is obvious that rate of wear is always higher at the initial stage for a sharp edge. However, initial wear was avoided in calculating the intensity of tool wear. From Figure 4.26, (intensity of flank wear (I) vs. cutting speed (v)), it is found that intensity of tool flank wear increases with the increase of cutting speed and from Figure 4.27 (Tool life (T_L) vs. cutting speed (v)), it is observed that tool life is high at lower cutting speed and decreases with the increase of cutting speed. It can be interpreted that with the increase of cutting speed, temperature increases

at the tool-chip interface (the contact surface between the tool face and chip). The portion of heat which leaves the tool-chip interface and flows into the tool causes very high temperature in the vicinity of the tool point. As the temperature increases, the hardness or resistance of the metal to shear decreases. In some extreme cases, the edge of the tool point actually gives away by melting. Tool wear intensity of H.S.S. tool was not possible to calculate because at higher cutting speeds like $v = 100, 120, 150$ m/min., H.S.S. tool wears within a few seconds. Therefore, it was also not possible to show the comparison of tool wear intensity and tool life between cemented carbide tools and H.S.S. tool in the same graph paper. At the cutting speed around $v = 80$ m/min., wear intensity of H.S.S. tool was approx. 100 times higher than the worst cemented carbide tool tested in this experiment. It can be explained that wear resisting power of H.S.S. tool is not very high like cemented carbide tools. Because H.S.S. can retain its hardness upto 600°C at room temperature whereas cemented carbide can retain its hardness upto 2500°C at room temperature. This feature of high speed steel makes cutting tools inoperative when its friction surfaces are heated in cutting to 600°C or higher. So, the wear rate of H.S.S. tool is much more greater than that of cemented carbides at higher cutting speeds. For this, high speed steel is now the general purpose material for use in machining operations performed at low or moderate speeds. But cemented carbide tools can be operated at speeds considerably in excess of those used with high speed steel tools.

From the comparative study of economic analysis (Table-6), it can be demonstrated that the tool bit of Poland is the best in all respect among the tool bits tested in this experiment. At the higher cutting speed, the turning cost of the work material is less and also the surface finish of the job is highly polished.

From the comparative study, it is also found that the turning cost of work material with H.S.S. tool (commercially called white bit) is approximately two times greater even if the worst bit of cemented carbide (of manufacturer of China) is used at the lower cutting speed, $v = 80$ m/min. At the higher cutting speed (more than $v = 80$ m/min.), it was not possible to calculate the turning cost of work material in case of H.S.S. tool. Because at higher cutting speeds, the H.S.S. tool wears within a few seconds and since, to calculate the tool wear intensity the initial wear of each tool was avoided, so it was not possible.

Though it has been told that the experiment was carried out at cutting speed, $v = 80, 100, 120, 150$ m/min., but actually it was kept within the range of $v = (80 \pm 5), (100 \pm 5), (120 \pm 5)$ and (150 ± 5) m/min. in order to proper using of the work material.

However, from the above cost analysis, it is, of course, a break through over factory's present method of metal cutting and it will also gear up the industrial growth in the country.

This method can be applied everywhere irrespective of small as well as large enterprises and workshops where metal cutting process is involved. It is moral duty to all to improve and increase the national production by using proper cutting tools. It will not only improve and increase national production but also give higher (Mirror - like) surface finish and less cost per piece production. It is believed that test results and the experimental works will encourage the industrial sector for planning future development and improvement of metal cutting processes.

Though the study was performed with few tools and steel work material, yet these experimental results will play an important role as a guide line and also will grow interest everybody to work for any other cemented carbide tool bits, work material and working conditions and cutting variables.

The test results may differ slightly during practical application due to its various limitations of experimental facilities. In spite of all the hinderances, the experimental study was performed carefully.

It is desired that this experimental study has been analyzed to select a tool with the help of millivoltmeter and has confirmed a method of predicting a good quality tool by only knowing the millivoltmeter reading e.g. emf. Because tool wear intensity has certain similarity with the emf with respect

to cutting speed in case of the shape of curves. The higher the emf i.e. millivoltmeter reading, the higher is the tool wear intensity, lower the tool life and lower the emf, lower the tool wear intensity, higher the tool life i.e. the best tool.

6.2 Conclusion

1. It has been established that intensity of tool wear is directly proportional to the emf developed during turning with different types of carbide tips. So, milli-voltmeter can be successfully used for testing the quality of carbide tool bits. Quality of high speed steel tool can be found out in case of work-materials apart from steel.

2. It has been established by economic analysis that during turning a lead screw of a lathe machine, cost of turning with high speed steel tool requires, on the average, two and a half times greater than that of carbide tools at the cutting speed, $v = 80$ m/min. At the higher cutting speed like $v = 100, 120, 150$ m/min., it is not possible to use a high speed steel tool.

6.3 Future Recommendation

The following shortcomings might have been observed in the work:

The recommended method was developed on the basis of experiments of steel as work material. So, there remains scope of further investigation by changing the work material and the composition of work material to prove the validity of the proposed method.

In this experiment, the values of tool geometry which were selected, were kept unchanged throughout the whole experiment. Therefore, now there remains a scope of further study by changing the values of tool geometry, because tool geometry has an important effect on tool wear.

This investigation work was conducted without using cutting fluid. Though cutting fluid has negligible effect as lubricant on tool during high speed turning, yet there is also a scope to study the effect of it on experimental results.

In this research work, feed and depth of cut was kept constant throughout the whole experiment. Though feed has small effect on tool life but depth of cut has important effect on tool life. Increasing depth of cut gives increased deformation if the other conditions remain the same. So, there is a scope of study by changing the feed and depth of cut.

Since this experiment was performed at high cutting speeds (specially beyond the critical speed), so there remains a scope to compare cemented carbide and H.S.S. tools at lower range of cutting speeds.

This 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 affect the values of test results. Though in our opinion, the general pattern of the curves developed from the test data will remain unchanged, further investigation may be made to correlate the test results with actual one.

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