Experimental Investiqation of chip tool Contact process and Determination of Optimum Cutting Speed for Steel of any Composition

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ABSTRACT

Cutting Speed is one of the most important factors on which production cost and productivity of any machining operation mainly depend. One of the reasons for high production cost of local products is the lack of technical knowhow regarding the selection of optimum cutting condition of which cutting speed is the principal parameter. One of the main source of raw materials for local mechanical parts are easily avilable steel scraps, whose composition in most cases are unknown and the facilities for determination of the same are inadequate and costly. For such steel scraps of unknown composition and even for imported steel of known composition it is difficult to determine the optimum cutting conditions without perfoming tool wear test due to the absence of informations regarding optimum cutting conditions of these materials. In the present work an experimental method has been developed to determine the optimum cutting speed for a given set of values of feed and depth of cut, when cutting is performed with cemented carbide tool material of a given composition. Eliminating the legnthy and labourious method of determining composition and the conventional tool wear test for the purpose of determining optimum cutting speed, the new method presents a easy means of determing the optimum cutting speed for steel including scrabs of any composition.

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Introduction

Most of the metal cutting industries in Bangladesh don't use scientific methods in selecting the cutting parameters. It is mainly because of the absence of a technical data base and adequate technical and scientific know how. This is one of the primary cause of high machining cost and poor surface finish of most of our mechanical products which contribute to the failure of our products in the competetive market. This causes a chain effect, which adversely affects our industrialization endeavours. Thus the mother industry fails to play the appropriate role in the industrialization process. And consequently spare parts for services industries are required to be imported. This entangles the country into a viscious circle of foreign dependence. In order to overcome such a gloomy situation proper attention must be paid to Research and Development works in this particular field. Transfer and diffusion of technical know how is essential to ensure growth of this vital sector. The present work is a samll endeavour in this direction.

A detailed survey of literature shows that by optimum cutting speed most authors of the field of principles of metal cutting (1), (2), (3) indicate the cutting speed at which the tool undergoes minimum intensity of wear. As such in the present work the work "Optimum cutting" has been used to transmit the same meaning. It has been established by different authors (3), (4), (5) that there is one optimum speed when turning steel with a single carbide tool material and two optimum speeds in turning steel with a double carbide tool material. It has been established by economic analysis (5) that in the case of a single carbide cutting tool the cutting speed with minimum intensity of tool wear, Vopt. and in the case of a double carbide cutting tool the higher of the two "optimum cutting" speeds, Vopt.2 are respectively the most economic cutting speeds. In the absence of a dropping tool apparatus in one of the works (5) the value of optimum cutting speed was determined by an approximate method - by measuring coefficient of chip shrinkage. In the present work an attempt has been made to design and manufacture a dropping tool apparatus and with its help study the chip-tool contact process and determine more accurately the above mentioned optimum cutting speed for a single carbide tool material in machining steel of an unknown composition. Then performing tool wear test to varify whether the above hypothesis holds good in this particular case also.

Experimental setup and Procedure:

The experiments were performed on an engine lathe model celtic-14 having the following values of spindle speeds: 12, 15, 19, 24, 30, 38, 46, 58, 76, 96, 120, 150, 185, 305, 380, 600 rpm.

The power of the driving motor was 3.5 KW. The feed used was 0.20 mm/rev and depth of cut I mm. *The work material was a shaft of mild steel with* initial diameter: 86 mm and length: 400 mm. The tools were rectangular shaped mechanically clamped single carbide inserts of USSR grade BK-8 (92% We and 8% Co). In order to instantly freeze the cutting operation a dropping tool apparatus was used. The apparatus was specially designed and fabricated for this purpose. A photograph of the different compoaments of the same is shown in Fig. 1. In Fig. 2 the apparnatas is shown in the working condition fitted inside the square turret of the lathe. The details of design of the dropping tool apparatus is given in reference

(6). Since the lathe machine used did not have facilities for stepless variation of spindle speeds, a computer program was developed to ensure variation of cutting. speed at a desired interval, corresponding to the given spindle speeds and available job diameters. The flow chart of the computer program is shown in Fig. 3. A printout of the computer program is shown in Table 1.

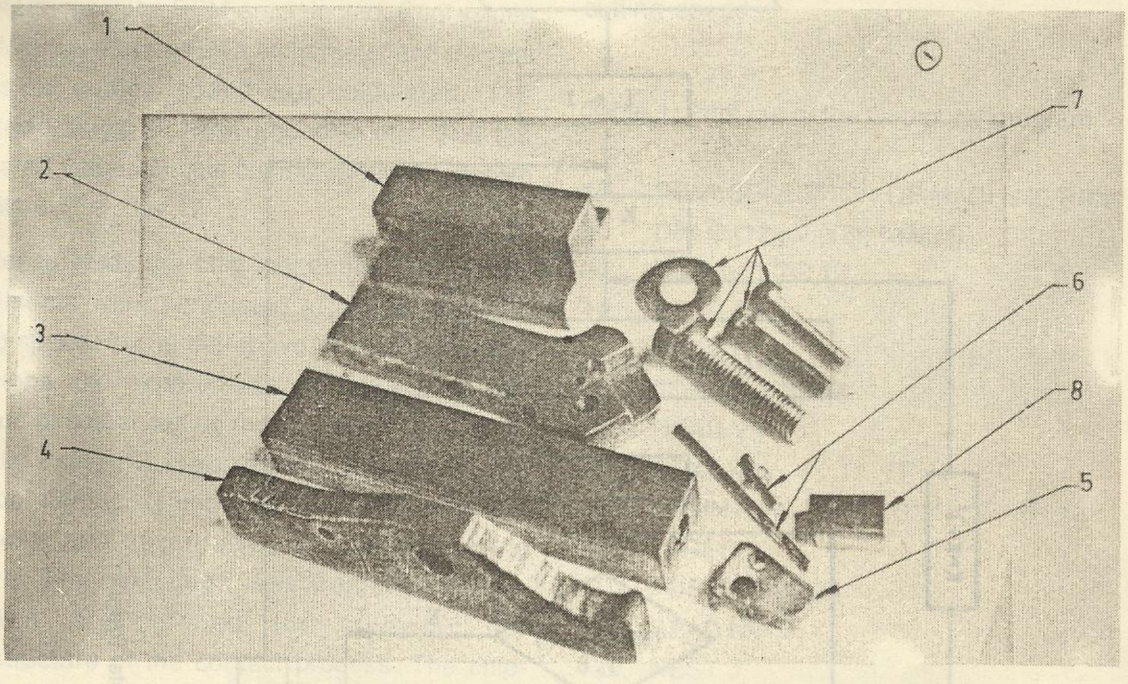

Fig. 1: Different parts of Dropping Tool Apparatus

1. Fixture Body	5. Clamping Flate	3. Dropper Plate holder	7. Standard Fasteners
2. Tool bit holder	6. Pins	4. Dropper plate	8. Tool bit

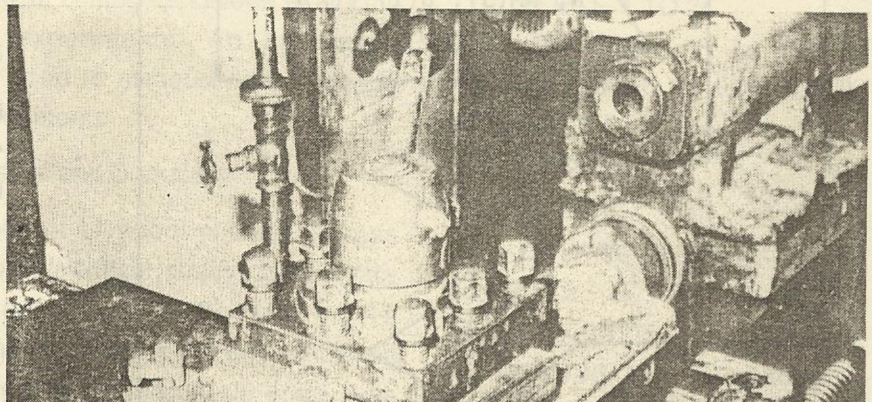

Fig. 2: Dropping Tool Apparatus fitted in the sqare turret of the lathe during cutting operation.

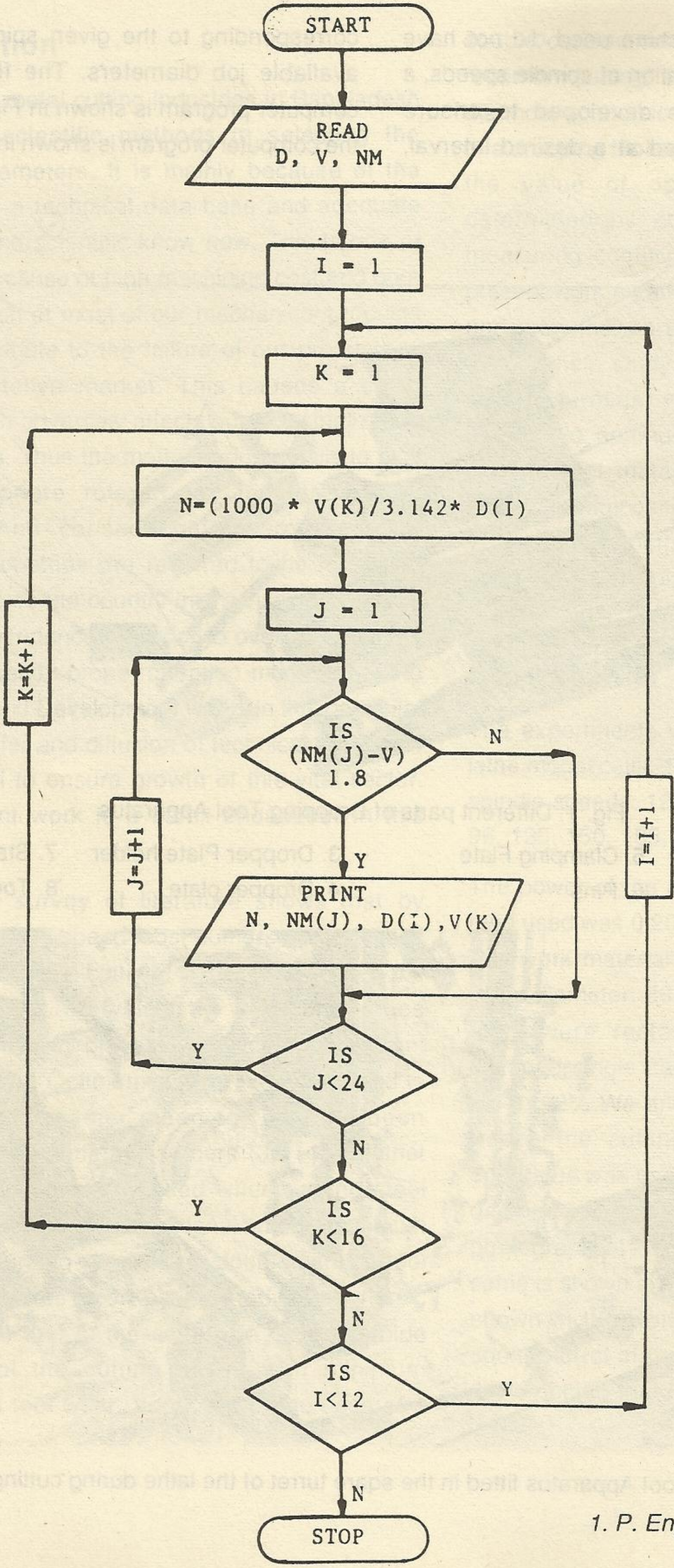

Fig. 3 : Flow Chart of the Computer Program

Cutting speed values are printed out in the descending order of workpiece diameter as shown in Table-2. From Table-2 the sixteen required values of cutting speeds, and the corresponding diameters machine RPM are selected. Real values of RPM are measured by a techometer and the real values of cutting speed are calculated. The selected values of RPM and diameter and the calculated values of real cutting speed are shown in Table-3.

In order to study the chip-tool contect processes experiments were conducted at the 16 selected cutting speeds using the above mentioned cutting conditions and experimental setup. After a few seconds of actual cutting the process was stopped instantly using the dropping tool apparatus. The chip-tool contact region was sawed off from the workpiece and frozen using a special freezing mixture. The specimen was properly ground, polished and etched for studying the microstructure of the contact process. The chip-tool contact area is then photographed on a microhardness tester using a magnification of 400. Tool wear tests were then performed on the same setup using identical cutting conditions as for the first series of experiments. An instrument microscope was used to measure the tool wear during these experiments.

Experimental Results and Discussion:

Micro photographs of chip-tool contact process corresponding to few critical cutting speeds are shown in Fig. 4(a, b, c, d, e, f). From the 16 different photographs. similar to the ones shown in Fig. 4, the height of the built-up-edge was measured and a curve of height of built-up-edge (BUE) versus cutting cutting speed was plotted, as shown in Fig. 5. In the same figure the type of built-up-edge is also indicated. Three different types of buil-up-edges are observed: type A, Type B and Type C. Built-up-edges type A are those, which are more stable in nature and observed at lower cutting speed.

Table 1: Print out of the Computer program

```
10   REM" SELECTION OF MACHINE RPM"
20   DIM D (12), V (16), NM(24)
30   FOR 1= 1 TO 12
40   READ D(1)
50   NEXT 1
60   FOR K= 1 TO 16
70   READ V(K)
80   NEXT K
90   LPRINT "N", "NM", "D", "V"
100  LPRINT
110  FOR J= 1 TO 24
120  READ NM (J)
130  NEST J
140  FOR 1=1 TO 12
150  FOR K= 1 TO 16
160  LET N= (1000*V (K) )/ (3. 142*D (1)
170  FOR J= 1 TO 24
180  IF ABS (NM (J) -N) <1.8 THEN LPRINT N,
NM(J), D(1), V(K)       ELSE GOTO 190
190  NEXT J
200  NEXT K
210  NEXT 1
220  DATA 86, 84, 82, 80, 78, 75, 70, 68, 66, 60,
56, 53,1, 2.5, 5, 7.5, 10, 12, 5, 15, 20, 25, 30, 30,
35, 40, 45, 50, 75, 100, 12, 12, 15, 19, 24, 30, 38,
46, 58, 76,96, 120, 150, 185, 230, 305, 380, 460,
480, 600, 610, 765, 955, 1200, 1500
230  BEEP
240  END
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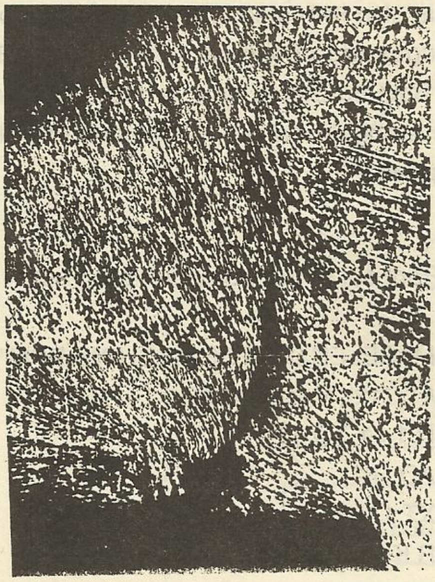

Figure 4a: Photograph of chip tool contact region
V= 2.0 m/min, T = 1 mm, S = 0.20 mm/rev .
Magnificant = 1400

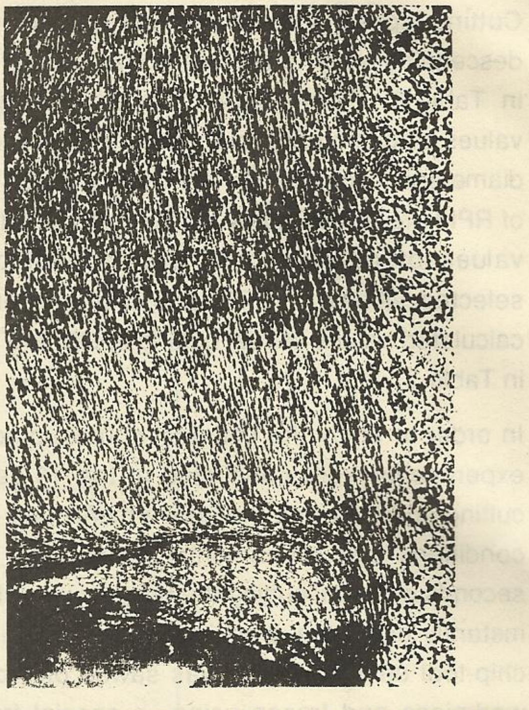

Figure 4b: Photograph of chip-tool contact region at
V = 5.2 m/min, t = 1 mm, S = 0.20 mm/rev .
Magnification = 1400.

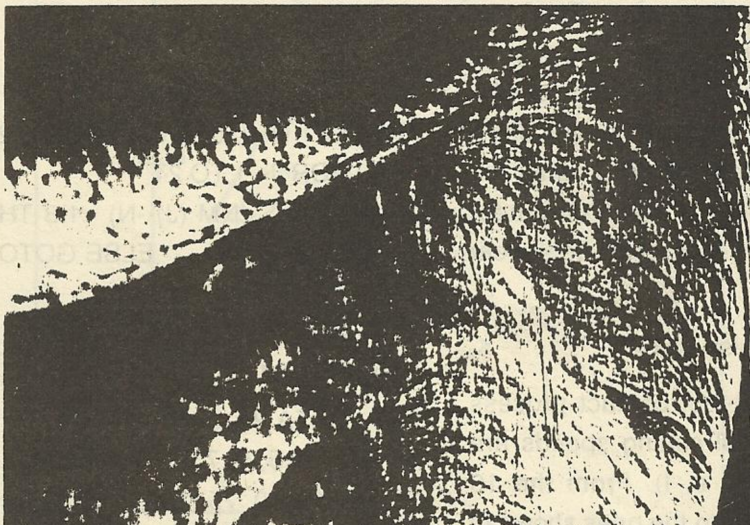

Figure 4c: Photograph of chip-tool contact region.
V = 15.9 m/min, t = 1 mm, S = 0.20 mm/rev.
Magnification = 1400

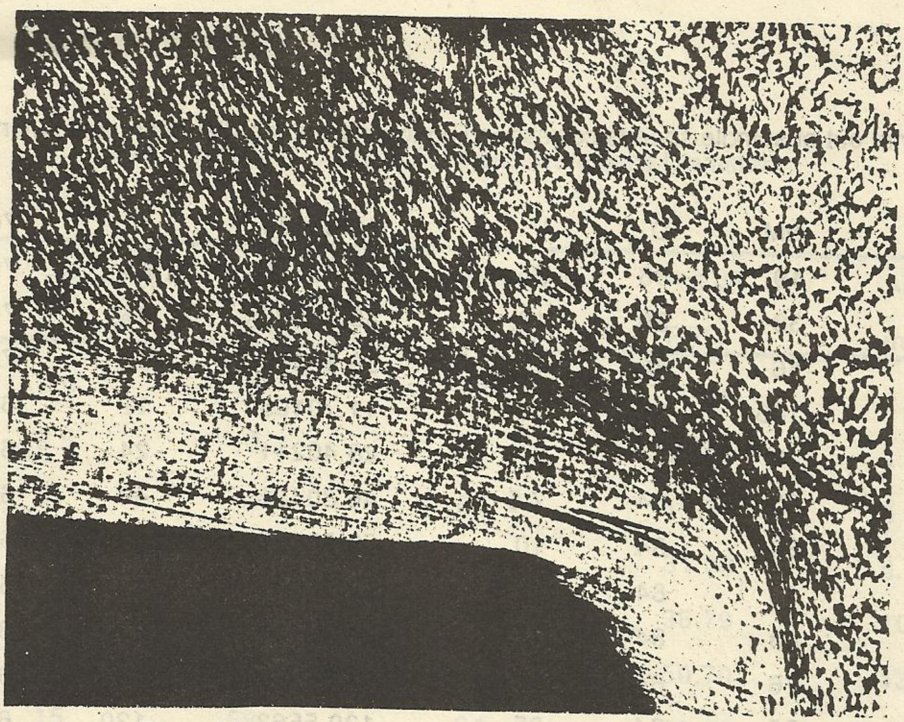

Figure 4d: Photograph of Chip-tool contact region
V = 40.5 m/min, t = 1 mm, S = 0.20 mm/rev.
Magnification = 1400

Figure 4e: Photograph of chip-tool contact region
V = 46.5 m/min, T = I mm, S = 0.20 mm/rev.
Magnification = 1400

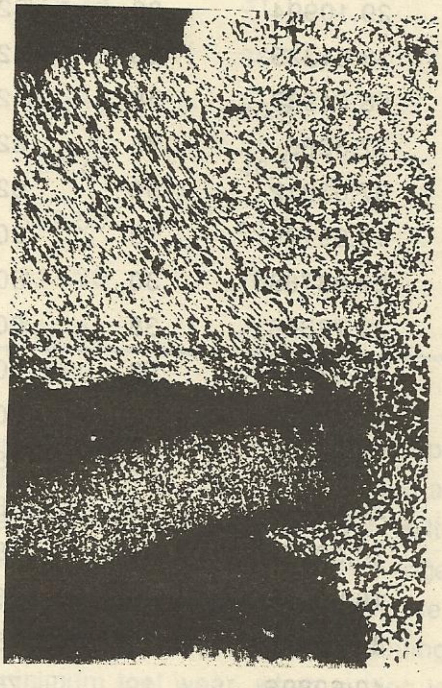

Figure 4f:
Photograph of Chip-tool contact region
V = 76.7 m/min, T= I mm, S = 0.20 mm/rev.
Magnification = 1400

Table-2: Print out of spindle speeds corresponding to different job diameters and cutting speeds

N	NM	D	V
18.50399	19	86	5
37.00798	38	86	10
46.25997	46	86	12.5
185.0399	185	86	50
18.94456	19	84	5
28.41684	30	84	7.5
37.88912	38	84	10
47.36141	46	84	12.5
56.83369	58	84	15
75.77825	76	84	20
94.72281	96	84	25
151.5565	150	84	40
378.8912	380	84	100
19.40662	19	82	5
29.10994	30	82	7.5
38.81325	38	82	10
58.21987	58	82	15
77.6265	76	82	20
97.03312	96	82	25
19.89179	19	80	5
29.83768	30	80	7.5
39.78358	38	80	10
59.67537	58	80	15
119.3507	120	80	30
10.20092	12	78	2.3
20.40184	19	78	5
30.60275	30	78	7.5
183.6165	185	78	45
306.0275	305	78	75
10.60896	12	75	2.5
148.5254	150	75	35
11.36674	12	70	2.5
22.73347	24	70	5
45.46696	46	70	10
56.83368	58	70	12.5
11.70105	12	68	2.5
23.40211	24	68	5
46.80421	46	68	10
58.50527	58	68	12.5
12.05563	12	66	2.5
24.11126	24	66	5
96.44504	96	66	20
120.5563	120	66	25
10.60896	12	60	2
13.26119	12	60	2.5
13.26119	15	60	2.5
39.78358	38	60	7.5
185.6567	185	60	35
11.36674	12	56	2
14.20842	15	56	2.5
28.41684	30	56	5
56.83369	58	56	10
12.01014	12	53	2
15.01267	15	53	2.5
30.02534	30	53	5
45.03801	46	53	7.5
75.06336	76	53	12.5
120.1014	120	53	20
150.1267	150	53	25
600.5068	600	63	100

Table 3: Selected Machine RPM and Workpiece Diameters

No. of obs.	Designed Speeds	Selected RPM (NM)	Selected Dia. mm	Actual RPM	Actual Speeds m/min
1	2.0	12	53	12.00	2.00
2	2.5	12	66	12.00	2.50
3	5	19	86	19.58	5.2
4	7.5	30	84	31.03	8.1
5	10	38	86	38.79	10.4
6	12.5	46	86	50.70	13.6
7	15	58	84	60.22	15.9
8	20	76	84	78.30	20.6
9	25	96	84	99.76	26.3
10	30	120	80	124.14	31.1
11	35	150	75	155.75	36.7
12	40	150	84	153.71	40.5
13	45	185	78	189.75	46.5
14	50	185	86	189.50	51.1
15	75	305	78	313.20	76.7
16	100	380	84	393.80	103.9

After breaking they have the tendency to be sweeped away along the face of the tool. Built-up-edge type B are unstable and overhangs the tool nose. After breaking they are swept away along the face as well as the flank surface of the tool. Built-up-edge Type-C is formed at higher cutting speed and hence is softer. The height of this types is less than the previous two types and it slides along the tool face after breaking. At higher cutting speed chip-tool contact without built-up-edge is establised (Fig. 4f). The cutting speed at which this transition of contact process with built-up-edge to contact process without built-up-edge occurs is known as critical cutting speed (Fig. 4e; Fig. 5). The optimum cutting speed, or cutting speed with minimum tool wear, when cutting is performed by a single carbide tool material, is supposed to be abit lower than this critical cutting speed (5).

The results of the tool wear tests, performed at 7 different cutting speeds are show in Table-4, Using the date of Table-4, curves of tool wear versus length of cut are plotted as shown in Fig. 6. Using the curves of Fig. 6, intensity of tool wear was calculated corresponding to each cutting speed and a curve of intensity of tool wear against cutting speed was drawn as shown in Fig. 7.

Experimental results show that initially tool wear is higher than normal wear at almost all the Cutting Speeds (Fig. 6). This is due to the fact that the tools were not given initial wear by grinding - thus it is obvious that the rate of wear would be higher for a sharp edge. However intial wear was avoided in calculating the intensity of Tool Wear. It can be observed from Fig. 7 that at low cutting speeds intensity of tool wear is high. This is because of the absence of BUE (Fig. 4a, 5) in this speed range and due to the formation of discontinuous chip which causes chipping of on the tool. BUE Type-A started appearing after cutting speed, V=2.5 m/min (Fig 4b, 5). Because of this intensity of tool wear started decreasing form this sped onwards. This may be explained by the fact that with the increase in cutting speed, BUE became stable in nature and it was hardened and welded on the Tool face, protecting the tool from intensive wear. This process continued upto the speed, V=10.4 m/min (Fig. 5). Then starting from the speed, V=13.6 m/min (Fig. 4.c) BUE type B was formed, which extended beyond the rake surface. From this speed on wards tool wear started increasing. This process was observed upto the speed, V=31.1 m/min. (Fig. 5). This may be explained by the fact that BUE type B is unstable and it has the tendency of brittle of breakage and being dragged along the flank surface the tool. Further increase in cutting speed caused decrease of Tool Wear. This is because of the change in chip-tool contact process. In this speed range BUE, type-C was formed (Fig. 4d, 5). This type of BUE is quite soft due to high cutting temperature. It has the tendency to move along the rake surface of the tool in case of its breakage. Height of such a BUE is also small unlike type A and B. All these factors facilitate extremely low wear rate of the tool in this cutting speed range. Starting from the speed V=46.5 m/min (Fig. 4e, 5), BUE disappeared completely and a continuous contact of chip and tool was observed. Therefore tool wear started rising abruptly from this speed. A good indication to identify this speed is that the tool touching face of the chip formed just above this speed has a mirror-like surface finish.

Table 4 : Tool Wear at different cutting length

Machine RPM --	Actual RPM E	Actual Speed V m/min	Length of cut L mm	Time of cut T min	Initial Flank wear hf h_{f_0} mm	Final Flank wear hf h_{f_1} mm	Flank Wear $h_f = h_{f_1} - h_{f_0}$ mm	Cumulative cut length mm
19	19.58	5.2	45.8	11.69	0.00	0.027	0.02	45.8
			47.19	12.05	0.027	0.06	0.04	92.99
			45.03	11.50	0.06	0.08	0.02	138.02
			47.48	12.12	0.08	0.098	0.018	185.50
38	38.79	10.4	46.00	5.93	0.00	0.025	0.025	46.00
			44.91	5.79	0.025	0.030	0.005	90.99
			46.62	6.01	0.030	0.039	0.009	137.53
			49.41	6.37	0.039	0.050	0.011	186.94
58	60.22	16.0	48.1	3.993	0.00	0.022	0.022	48.1
			46.9	3.98	0.022	0.040	0.018	97.00
			47.8	3.97	0.040	0.050	0.010	144.80
			42.2	3.50	0.050	0.059	0.009	187.00
120	124.14	31.1	49.35	1.60	0.00	0.030	0.030	49.35
			46.55	1.51	0.030	0.055	0.025	95.90
			44.60	1.45	0.055	0.078	0.023	140.50
			47.90	1.55	0.078	0.100	0.022	188.40
150	153.71	40.5	47.50	1.26	0.00	0.025	0.025	47.50
			47.20	1.24	0.025	0.041	0.016	94.70
			44.80	1.18	0.041	0.048	0.007	139.50
			45.50	1.198	0.048	0.056	0.007	185.00
185	189.75	46.5	44.40	1.169	0.00	0.010	0.010	44.40
			47.50	1.251	0.010	0.015	0.005	91.90
			43.55	1.147	0.015	0.020	0.001	135.45
			48.55	1.279	0.020	0.025	0.005	184.00
380	393.2	76.7	47.7	0.761	0.00	0.01	0.01	47.7
			45.6	0.727	0.010	0.028	0.018	93.3
			45.7	0.727	0.028	0.046	0.018	139.0
			46.1	0.735	0.046	0.063	0.017	185.1

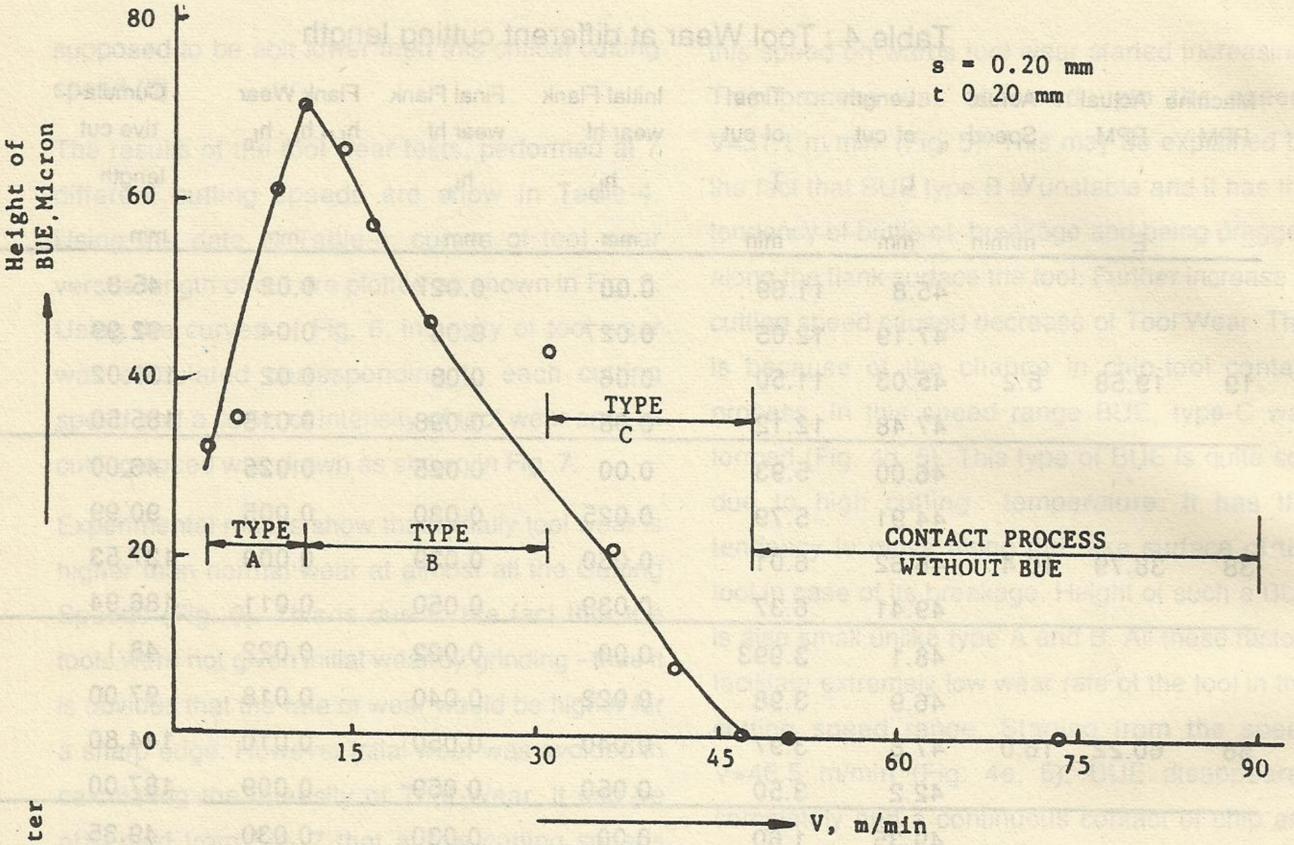

Figure - 5 : Height of BUE Vs. Cutting Speed

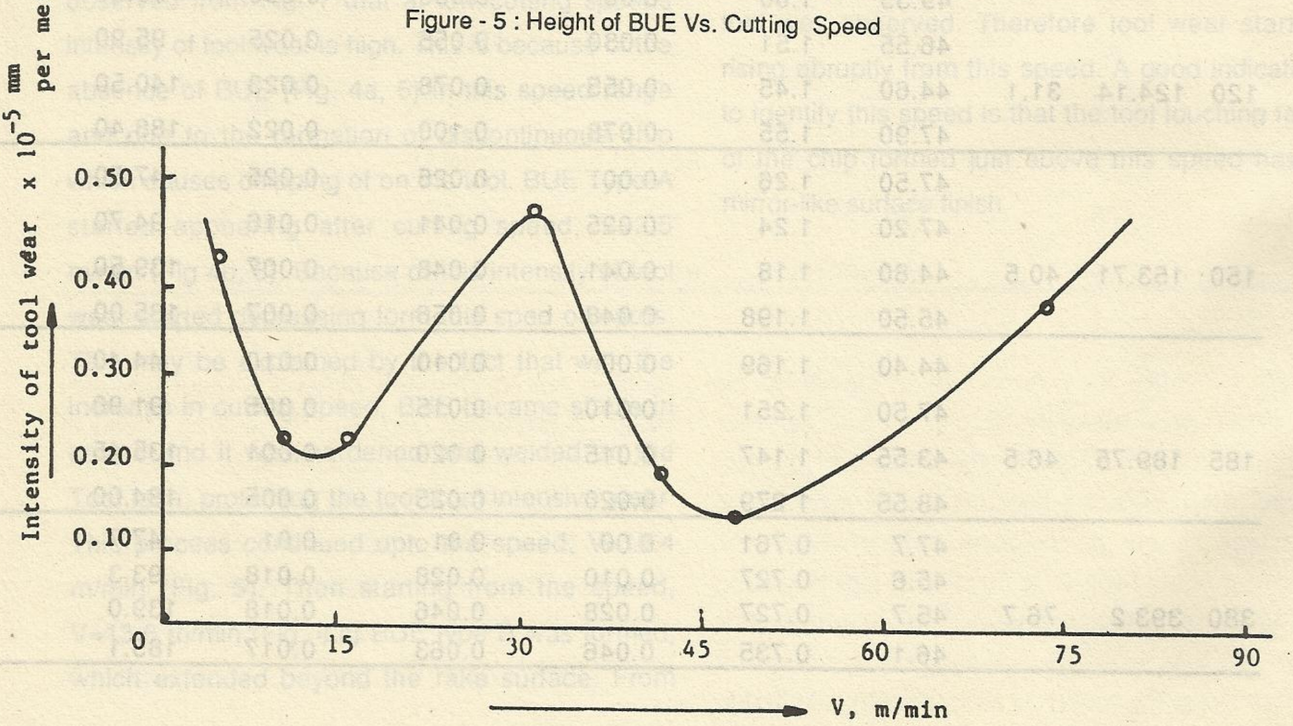

Figure - 7 : Intensity of tool wear Vs. Cutting Speed

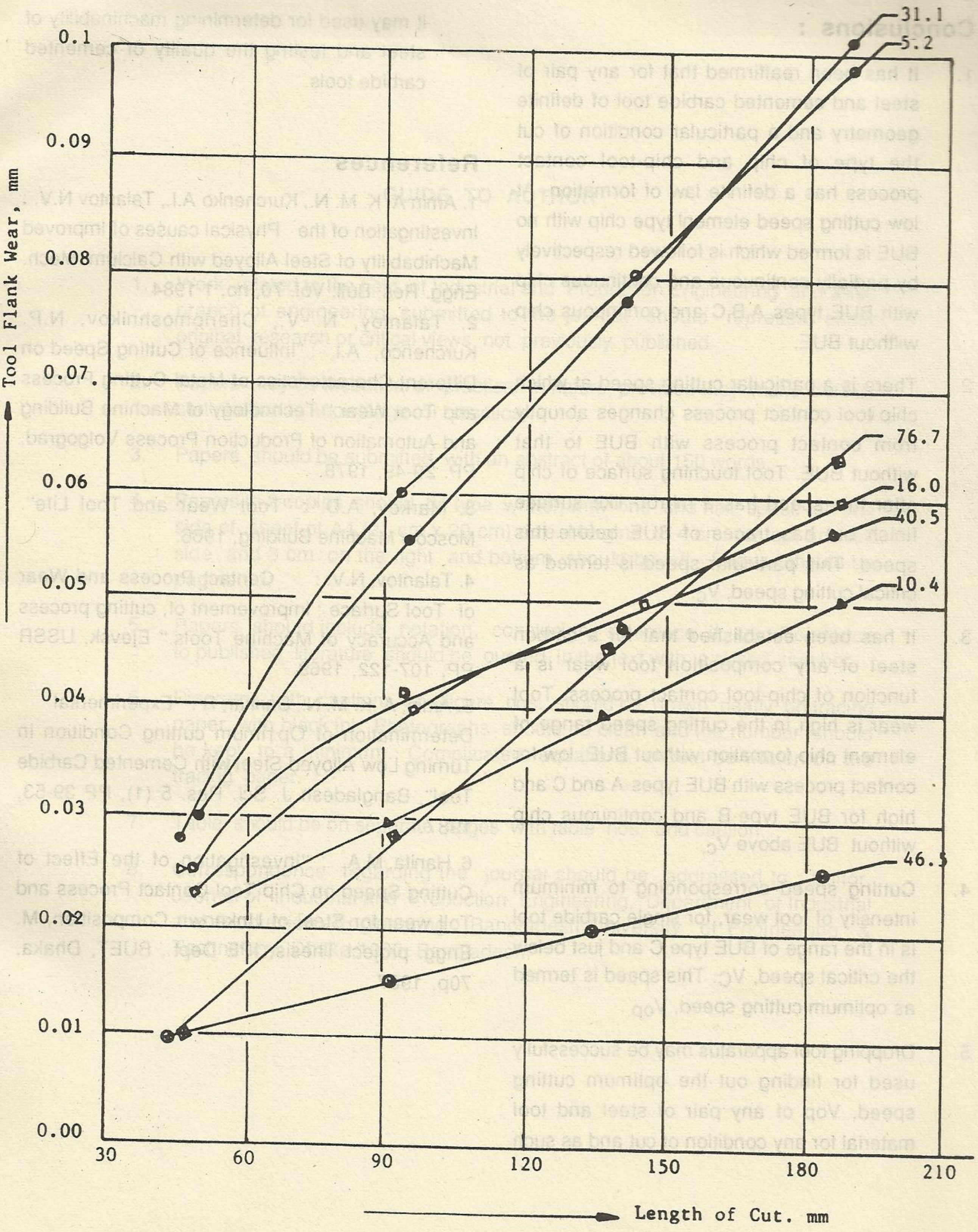

Figure-6 : Tool wear Vs. Length of Cut at Different Cutting Speed

Conclusions :

1. It has been reaffirmed that for any pair of steel and cemented carbide tool of definite geometry and a particular condition of cut the type of chip and chip-tool contact process has a definite law of formation. At low cutting speed elemenl type chip with no BUE is formed which is followed respectively by partially continuous and continuous chip with BUE types A,B,C and continuous chip wilthout BUE.

2. There is a particular cutting speed at which chip-tool contact process changes abruptly from contact process with BUE to that without BUE. Tool touching surface of chip after this speed has a mirror- like surface finish but has traces of BUE before this speed. This particular speed is termed as critical cutting speed, V_C.

3. It has been established that for a carbon steel of any composition tool wear is a function of chip-tool contact process. Tool wear is high in the cutting speed range of element chip formation without BUE, low for contact process with BUE types-A and C and high for BUE type-B and continuous chip without BUE above V_C.

4. Cutting speed corresponding to minimum intensity of tool wear, for single carbide tool is in the range of BUE type C and just below the critical speed, V_C. This speed is termed as optimum cutting speed, V_{op}.

5. Dropping tool apparatus may be successfully used for finding out the optimum cutting speed, Vop of any pair of steel and tool material for any condition of cut and as such it may used for determining machinability of steel and testing the quality of cemented carbide tools.

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