ELSEVIER

Journal of Materials Processing Technology 77 (1998) 59–63

Journal of Materials Processing Technology

Selection of cemented carbide turning tools using EMF and optimization criteria

A.K.M. Nurul Amin *, Md. Ruhul Amin Sarker, Mahiuddin Ahmed, A.N. Mustafizul Karim

Department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh

Abstract

Tool life and quality of surface finish of the workpiece influence production rate and production cost. Cemented carbide tools have found wide application in the production arena of Bangladesh. In the absence of any testing facility in the country for the selection of cost-effective tools, poor quality carbide tools are frequently imported. A testing method and a selection criteria were developed for testing carbide tools of different shapes and sizes and for selecting the most cost-effective tool. For each tool cutting tests were performed to generate tool life data under different cutting conditions. Mild steel served as the work material. The relationship between tool life and cutting speed was developed using a curve-fitting software on a PC. From these relationships the values of the constants of the Taylor's equation were determined. The cost equation was then derived for each tool for a given amount of work in a cutting speed range. Finally, the most cost-effective tool was selected on the basis of the relative location of the cost curves of the tools tested.

Keywords: Cemented carbide tools; Intensity of tool wear; Optimum cutting speed

1. Introduction

Bangladesh is a developing country and as with many other developing countries, it is dependent on imported technology for its heavy industries such as fertilizer factories, steel mills, jute mills, oil refineries, etc. However, the country has to perform a substantial amount of metal cutting and processing operations for the supply of these industries with spares, and for manufacturing machinery for use in various sectors, such as agriculture, transport, textile and others.

Cutting tools play a vital role in metal-cutting operations. For cutting cast iron, stainless steel, heat-resistant alloys etc., especially at high speeds, the cutting tool has to be heat- and wear-resistant. Until very recently, high speed steel (HSS) tools dominated the small scale production sector of Bangladesh. However, due to the clear competitive advantage of cemented carbide tools over HSS tools and also as a result of growing awareness amongst the local entrepreneurs, cemented carbide tools have replaced HSS tools, especially for turning, boring, milling, shaping, planning and similar other operations.

In the local market, a variety of single-poing cemented carbide turning tools of various shapes and sizes are available. In most of the cases the composition and cutting properties of these inserts are unknown. As a result it is difficult to choose the correct tool for a particular operation. The inserts are known in the local market by the brand–manufacturers' name. Inserts of China, India, Poland, Sweden, etc. are very popular in the local market. The local users select the inserts depending on their past experiences. In the absence of any testing facility in the country for checking the quality of cemented carbide tools poor quality tools were imported on various occasions by different organizations of the country. Keeping this in mind, a testing set-up for checking the quality of carbide inserts has been developed as part of the present work. Since the available carbide tools have variation not only in their properties but also in their purchase costs and dimensions, so cost effectiveness should be the criteria for tool selection rather than the properties of the tool alone.

* Corresponding author.

0924-0136/98/$19.00
PII S0924-0136(97)00394-4

2. Literature survey and aims and objectives

It is reported that the wear of a cemented carbide tool is mainly due to diffusion [1] especially above a limit of a cutting speed limit beyond which there exists no built-up edge. The process of diffusion is intensified by rise of cutting temperature, which bears a direct relationship with the cutting speed, thickness of cut, material hardness, etc. If other parameters are unchanged, the intensity of tool wear increases with the cutting speed. Markov [2] has successfully established a relationship between the intensity of tool wear and cutting temperature. However, it is very difficult to measure the temperature developed at the ship–tool interface, since at high cutting speeds the chip is fully welded to the tool surface [3].

As indirect and easier method has been adopted by various research schools to measure the temperature. Milton [4] has established that there exists a direct relationship between the cutting temperature and the Electro-Motive-Force (EMF) developed between the workpiece and the tool. In this case, the workpiece and the tool act as thermo-couple. If the tool is isolated and connected to the workpiece by an electric circuit as shown in Fig. 1, a small current would flow between them due to a voltage difference created by the EMF. This voltage may be measured by a milli-voltameter. Since both the intensity of tool wear and the EMF are functions of cutting temperature, the EMF may be used as a criterion for testing the performance of cemented carbide tools. For the simplicity of testing a small variation in the coefficients of proportionality between the developed EMF and the cutting temperature may be neglected for various groups of cemented carbide tools. Under this assumption a simple criterion [5] based on the EMF was developed to select the tool with the best cutting properties.

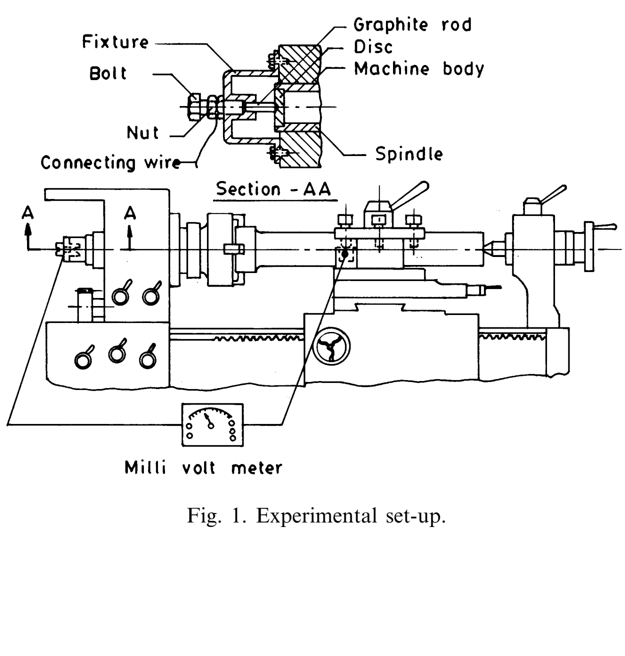

Fig. 1. Experimental set-up.

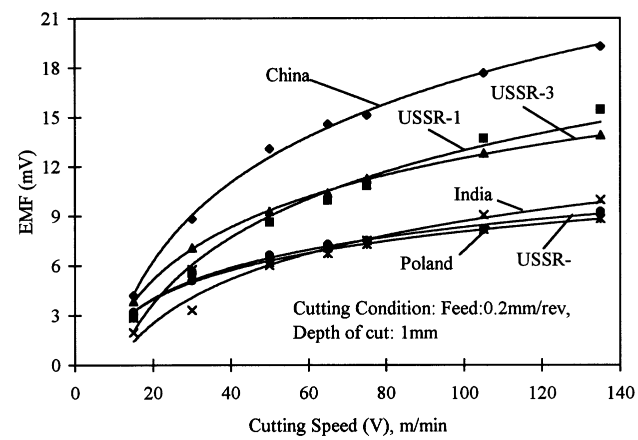

Fig. 2. Effect of the cutting speed on the EMF.

It was observed during earlier experiments that the shapes and sizes of the tools were different and that the purchase cost of these tools was not dependent on the sizes of the tools alone. Due to this variation in size and price neither the tool wear nor the purchase cost of a tool would be adequate to determine the overall performance in the selection of a tool. Evaluation of the economic tool life could be an appropriate approach in considering the above factors and the cutting conditions [6]. In the present study, the economic tool life was determined using the data [7] of previous experiments and used for the selection of the proper tools. A ranking of various tools was performed using this method as well as the EMF and the intensity of tool wear criteria.

3. Methodology and experimental setup

In this study, 12 categories of carbide inserts from different origins were tested. Of these inserts, three groups were manufactured in the former USSR, one in Poland, one in China, one in India, and the other six by a Local Government Organization (coded as BOF). The material of inserts USSR-1 was BK-8 having a composition of 92% WC and 8% Co; the material of inserts USSR-2 was T5K10 having a composition of 5%, TiC, 85% WC and 10% Co; and that of USSR-3 was T15K6 having a composition of 15% TiC, 79% WC and 6% Co. The composition of the other three groups was not available.

The tool geometry for the experimentation was taken as follows: rake angle, $\gamma = 0°$; side clearance angle, $\alpha = 10°$; end clearance angle, $\alpha_1 = 20°$; side cutting edge angle, $\phi = 45°$; end cutting edge angle, $\phi_1 = 25°$.

A lathe machine (model Celtic-14) having a four-foot (1215 mm) long bed and a swing over the bed of 75 mm was used in the test. A solid bar having a maximum diameter of 102 mm and a length of 630 mm was

Table 1
Available and calculated data on the various parameters for carbide tools

Tool code	Tip size (mm × mm)	Constant C	Constant n	No. of regrind N_t	Initial cost (Taka) C_T
Poland	13 × 25	553.45	0.3866	43	80.00
USSR1	15.5 × 25	476.42	0.4228	56	120.00
USSR2	15.5 × 25	791.47	0.4865	56	165.00
USSR3	15.5 × 25	608.29	0.4753	56	130.00
China	12 × 25	489.85	0.4434	37	80.00
India	12 × 12	571.98	0.4266	37	50.00
BOF1	14.6 × 6.5	596.05	0.4548	51	100.00
BOF2	14.6 × 6.5	527.40	0.4304	51	100.00
BOF3	7.8 × 8.1	679.52	0.4763	15	95.00
BOF4	7.8 × 8.1	484.32	0.3047	15	95.00
BOF5	14.8 × 21.9	523.65	0.3334	52	110.00
BOF6	14.8 × 21.9	631.59	0.3791	52	110.00

Note: *1 US$ = 42 Taka (approximately).

turned at cutting speeds of 80, 100, 120, 150 and 180 mm min^{-1}, with a feed of 0.20 mm rev^{-1} and a depth of cut of 1.0 mm.

According to the experimental set-up shown in Fig. 1, the EMFs developed in the cases of different tested cutting tools were measured [5] for identical cutting conditions. For this purpose the tool insert holder was kept completely insulated from the tool post of the lathe machine. The tool insert was connected with a probe to one end of the milli-voltmeter and the other end of the milli-voltmeter was connected to a bolt of the fixture body which, in turn, was connected to a graphite rod. This graphite rod was also connected to a steel disc which was placed in the hole of the lathe machine spindle. To obtain the values of the EMF, the work material was turned for a few seconds with each of the tool inserts and the corresponding milli-voltmeter readings were recorded. These experiments were performed taking three carbide tips from each type of insert. The average values of these three milli-voltmeter readings (i.e., EMF) for different groups of carbide tips were calculated and are plotted in Fig. 2.

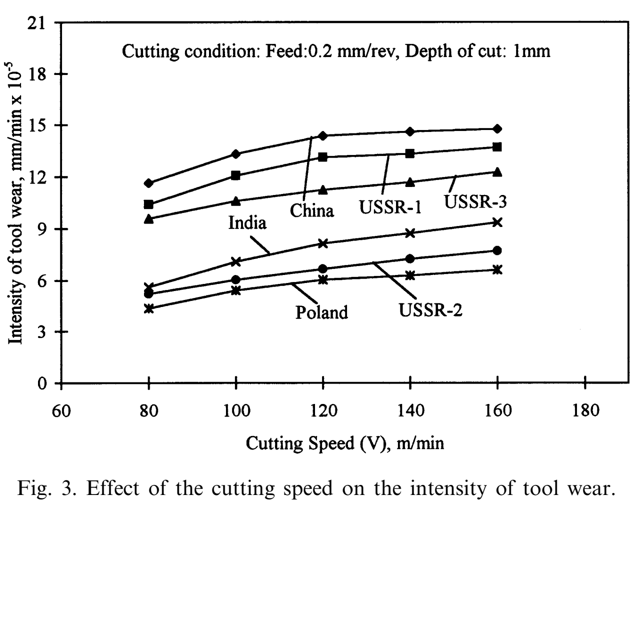

Fig. 3. Effect of the cutting speed on the intensity of tool wear.

An instrument microscope was used for measuring the tool wear. Readings were taken at a regular interval of turning. Using the experimental data of flank wear and cutting time, the intensities of tool wear were calculated. The tool life corresponding to a flank wear of 0.5 mm was calculated. The tool life data obtained during these experiments were used to evaluate the value of C and n, in the constants of Taylor's equation. The number of possible regrinds, N_t, of each tool was calculated on the basis of the initial and the final lengths of the tips and the length reground each time.

The following collected data [8] were utilized in determining the optimum cutting speed: tool changing time (t_1) = 3 min; time to grind a tool (t_2) = 15 min; labour and overhead rate (R_c and R_s) = 110 Taka* h^{-1}.

The computed values of constants of Taylor's equation for the different tools along with their number of possible regrinds and initial purchase cost data are presented in Table 1.

4. Formulation for cost analysis

Economic analysis [9] was performed to compare the tested groups of cemented carbide tools. The cost of a tool between two regrinds (C_t) can have three components, as follows: (i) tool changing costs, $C_1 = t_1 \times R_c$; (ii) grinding–sharpening costs, $C_2 = t_2 \times R_s$; (iii) proportion of the original cost of the tool, $C_3 = C_T – N_t$, in which: $C_t = C_1 + C_2 + C_3$, where: t_1 = time to change a tool (min); t_2 = time to grind or sharpen a tool (min); R_c = labor and overhead rate applied to the metal cutting operation (Taka–min); R_s = labor and overhead rate in the tool grinding department (Taka–min); N_t = number of times the tool can be ground (including grinding performed during manufacturing); C_T = original cost of the cutting tool (Taka).

For a tool life of T min, the cutting cost over the life of the tool is $C_c = R_c \times T$. During this time, the amount of metal removed in cm^3 is:

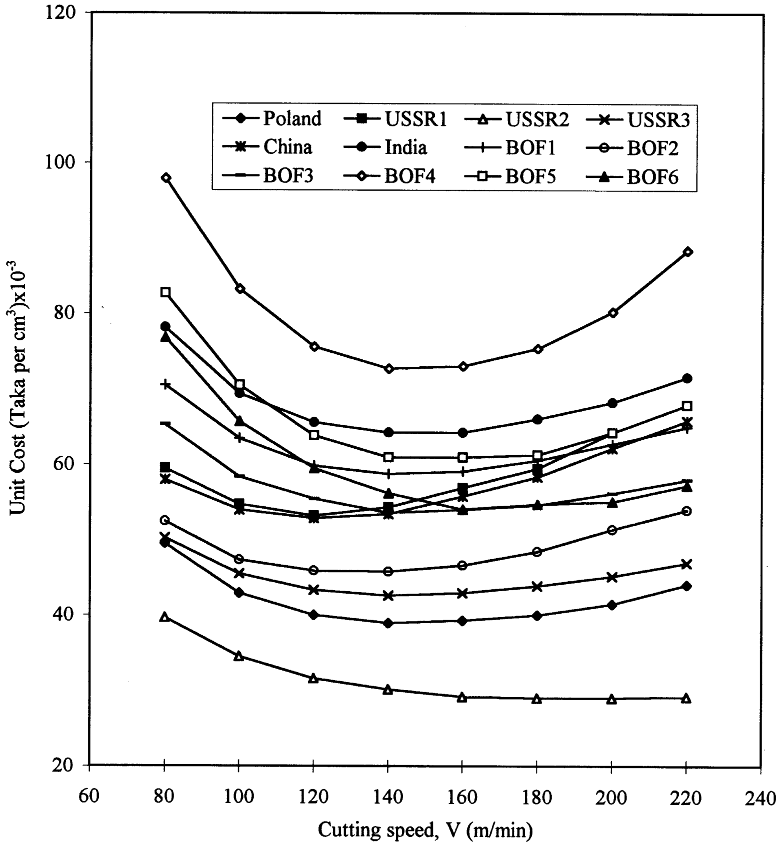

Fig. 4. Unit cost vs. cutting speed for different carbide tools.

$$Q_T = V_m Tfd$$

where: f = feed equivalent to width of cut (mm rev^{-1}); d = depth of cut (mm); V_m = linear velocity (m min^{-1}).

If C–T^n is substituted for V_m (since $V_m T^n = C$) [8] in the above equation, then:

$$Q_T = \frac{C}{T^n} Tfd = \frac{Cfd}{T^{n-1}} = \frac{C_G}{T^{n-1}}$$

where $C_G = Cfd$.

The total unit cost in Taka cm^{-3} is:

$$C_u = \frac{C_C + C_t}{Q_T} = \frac{T^{n-1}(R_C T + C_t)}{C_G}$$

If C_u is differentiated with respect to T and set equal to zero to find the minimum, the expression for the economic tool life becomes:

$$T_e = \left(\frac{1}{n} - 1\right)\frac{C_t}{R_c}$$

It is observed from the above equation that, if the parameter n is fixed, the economic tool life increases with the increase of C_t and–or decrease of R_c. This indicates that both the labor and overhead rate as well as the cost of the tool influence the economic tool life. The corresponding optimum cutting speed can be found from Taylor's equation, $VT^n = C$ i.e.:

$$V = \frac{C}{T_e^n}$$

5. Results and discussion

The relationships between the EMF and the cutting speed are shown (up to a limited value of cutting speed) in Fig. 2. The intensities of tool wear versus cutting speed are shown in Fig. 3. It may be observed from Figs. 2 and 3 that above a cutting speed of 80 m min^{-1} the intensity of tool wear is approximately proportional to the EMF developed by the different tests inserts. Thus, an insert which develops lower a EMF during cutting in this cutting speed range is likely to show a lower intensity of wear and consequently have a greater tool life.

The cutting speed (m min^{-1}) versus the unit cost (Taka–cm^3) curves for different carbide tools is shown in Fig. 4. The optimum cutting speed and its corresponding unit cost for all tools are given in Table 2.

It is clear from Fig. 4 that the USSR-2 curve is almost flat after the cutting speed of 160 m min^{-1}, which means that it is less sensitive in this speed range. With this tool, it is possible to lower the cutting speed (in case of machine limitation) without sacrificing much cost. The curve of BOF6 is the most sensitive curve,

Table 2
Optimum cutting speeds and costs for different tools

Tool code	Optimum speed, V (m mm^{-1})	Optimum unit cost (Taka per cu cm)$\times 10^{-3}$	Rank
Poland	148.17	38.45	(2)
USSR1	119.59	53.06	(6)
USSR2	181.08	28.65	(1) Best tool
USSR3	142.12	42.17	(3)
China	119.43	52.48	(5)
India	144.29	63.62	(11)
BOF1	143.49	58.61	(9)
BOF2	131.33	45.27	(4)
BOF3	150.67	53.35	(7)
BOF4	147.92	72.19	(12)
BOF5	155.22	59.76	(10)
BOF6	170.92	53.76	(8)

which means that the change of cost for this tool with respect to the speed is the highest amongst all of the tools. If USSR-2, Poland, USSR-3, and BOF2 tools are not available in the market, then there is no single group of tools which is better for the whole range of cutting speed considered in this research. For example, the China tool is better for a cutting speed range of less than 140 m min^{-1} and BOF4 tool is better for a cutting speed of greater than 170 m min^{-1}. The optimum cutting speed and its corresponding unit cost, as per the curves discussed, for all the tools are given in Table 2.

Ranking of the tested inserts according to the EMF criteria in the cutting speed range of 25–60 m min^{-1} above a cutting speed of 80 m min^{-1} is presented in Table 3. According to the tool wear criteria, the ranking of the inserts for cutting speeds of above 80 m min^{-1} is also given in Table 3. Ranking of the tool inserts according to the minimum cost criteria summarized in Table 3 indicates that there has been a re-arrangement of the ranking positions of the inserts as compared to the ranks according to the EMF and the tool wear criteria. This is due to the influence of the procurement cost and size and shape of the individual insert.

Table 3
Ranking of tool inserts according to different criteria

Criteria of judgement	Ranking of tool inserts (from best to worst)
Electro Motive Force (EMF)	India, Poland, USSR2, USSR1, USSR3, China (for 25 m min^{-1} < V < 60 m min^{-1}). Poland, USSR2, India, USSR3, USSR1, China (for V > 80 m min^{-1}).
Intensity of tool wear	Poland, USSR2, India, USSR3, USSR1, China (for V > 80 m min^{-1}).
Minimum cost criteria	USSR2, Poland, USSR3, BOF2, China, USSR1, BOF3, BOF6, BOF1, BOF5, India, BOF4 (for 80 m min^{-1} < V < 220 m min^{-1}).

6. Conclusions

A method of testing the quality of carbide inserts has been established using electromotive-force (EMF) as the criterion. It has been observed that the EMFs developed during turning with different carbide inserts are almost proportional to the intensities of wear of these inserts under identical cutting conditions.

An alternative method is proposed to choose the most cost-effective tool from a number of different carbide tools using a minimum-cost criterion. This method appears to be appropriate where a variety of tools is available with unknown chemical composition and physical properties.

References

[1] T.N. Loladze, Metal Cutting Tool Wear, Moscow, 1958, p. 356.
[2] A.D. Markov, Tool Wear and Tool Life, Moscow Machine Building, 1966, p. 262 (translated from Russian).
[3] N.V. Talantov, N.P. Cheriomushnikov, A.I. Kurchenko, Influence of Cutting Speed on Different Characteristics of Metal Cutting Process and Tool Wear, Technology of Machine Building and Automation of Production Process, Volgograd, 1978, pp. 29–49.
[4] M.C. Shaw, Metal Cutting Principles, 3rd edn., India, 1957.
[5] A.K.M.N. Amin, M.R. Islam, Investigation of a new method for testing the cutting properties of different cemented carbide tools, J. Inst. Eng. Bangladesh 21 (1) (1993) 55–61.
[6] G.C. Sen, A. Bhattacharyya, Principles of Metal Cutting, 2nd ed., Calcutta, 1969, p. 412–553.
[7] M.R. Islam, 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, M. Eng. Project, Dept. of IPE, BUET, Dhaka, 1989.
[8] Personal communication with Bangladesh Industrial and Technical Assistance Centre (BITAC), Dhaka.
[9] L.E. Doyle et al., Manufacturing Process and Materials for Engineers, 3rd edn., Prentice Hall Inc., Englewood Cliffs, New Jersey, 1985.