Chapter 6
Experimental Results

To calculate the tool life and the machining cost per workpiece, the number of workpieces per cutting edge can be approximated by the fraction of the tool used up per workpiece. In the experiment of each cutting condition, a new tool was used, and two cut workpiece tests were experimented with in order to measure flank wear. Then two flank wear values were used to calculate the number of workpieces per cutting edge. Table B.1-B.5 (Appendix B) display the calculations of the number of workpieces per cutting edge, the tool life, and the machining cost per workpiece for carbide cutting tool at starting cutting condition; 160 m/min cutting speed and 0.20 mm/rev feed rate and its components. For Table B.6, the calculation of gradient is displayed and the new cutting conditions are determined.

In order to optimize the cutting conditions by means of the optimum gradient method, the procedure is conducted in the flow chart as shown in Fig.5.5. For a carbide cutting tool, three sets of the starting cutting conditions were selected. The first starting cutting condition was 160 m/min cutting speed and 0.20 mm/rev feed rate. The total experimental results are shown in Table B.7-B.8 and Fig. 6.1. A total of 14 sets of 30 cutting conditions had been tested resulting in 172 m/min cutting speed and 0.5146 mm/rev feed rate as the optimum cutting condition where the machining cost per workpiece was 9.3902 baht.

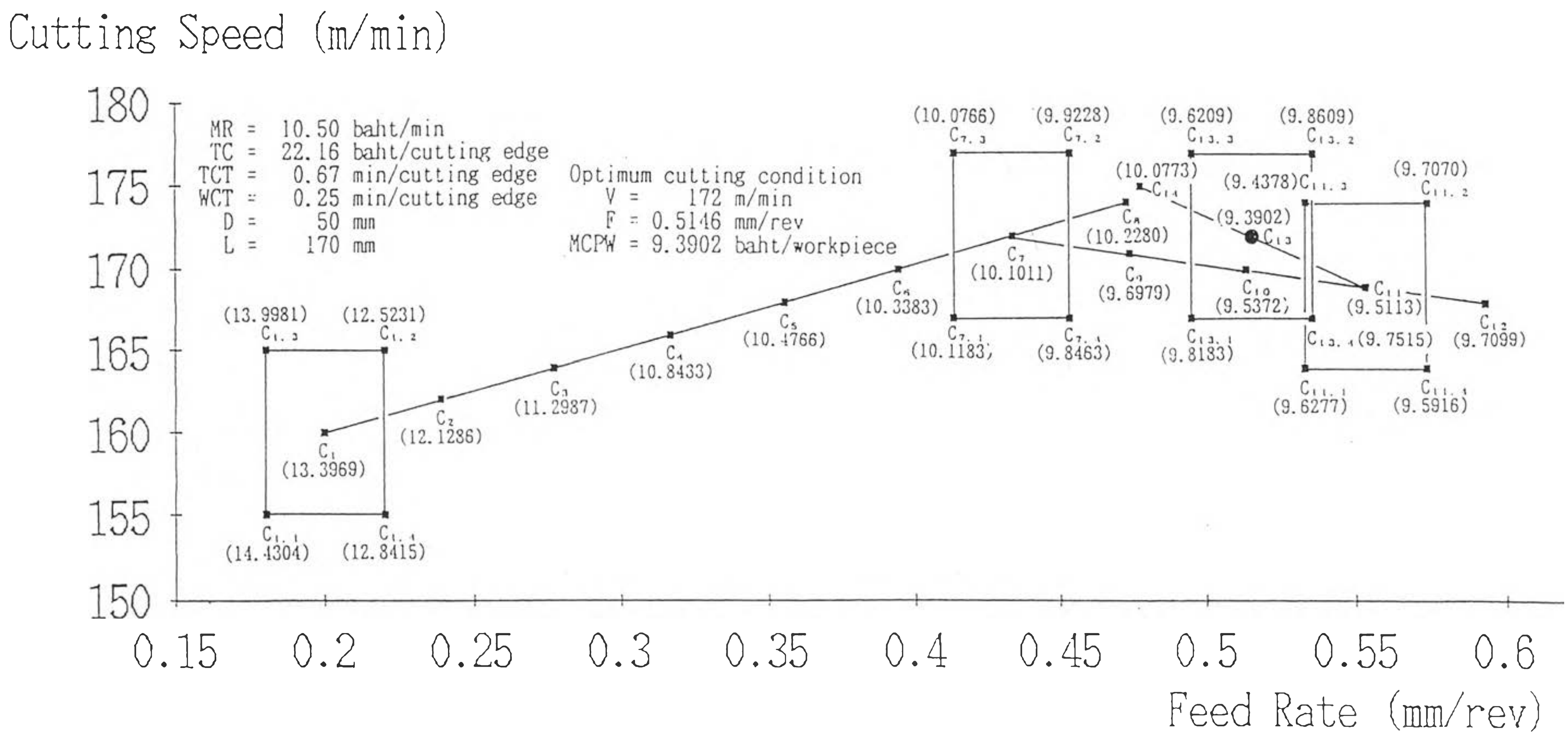


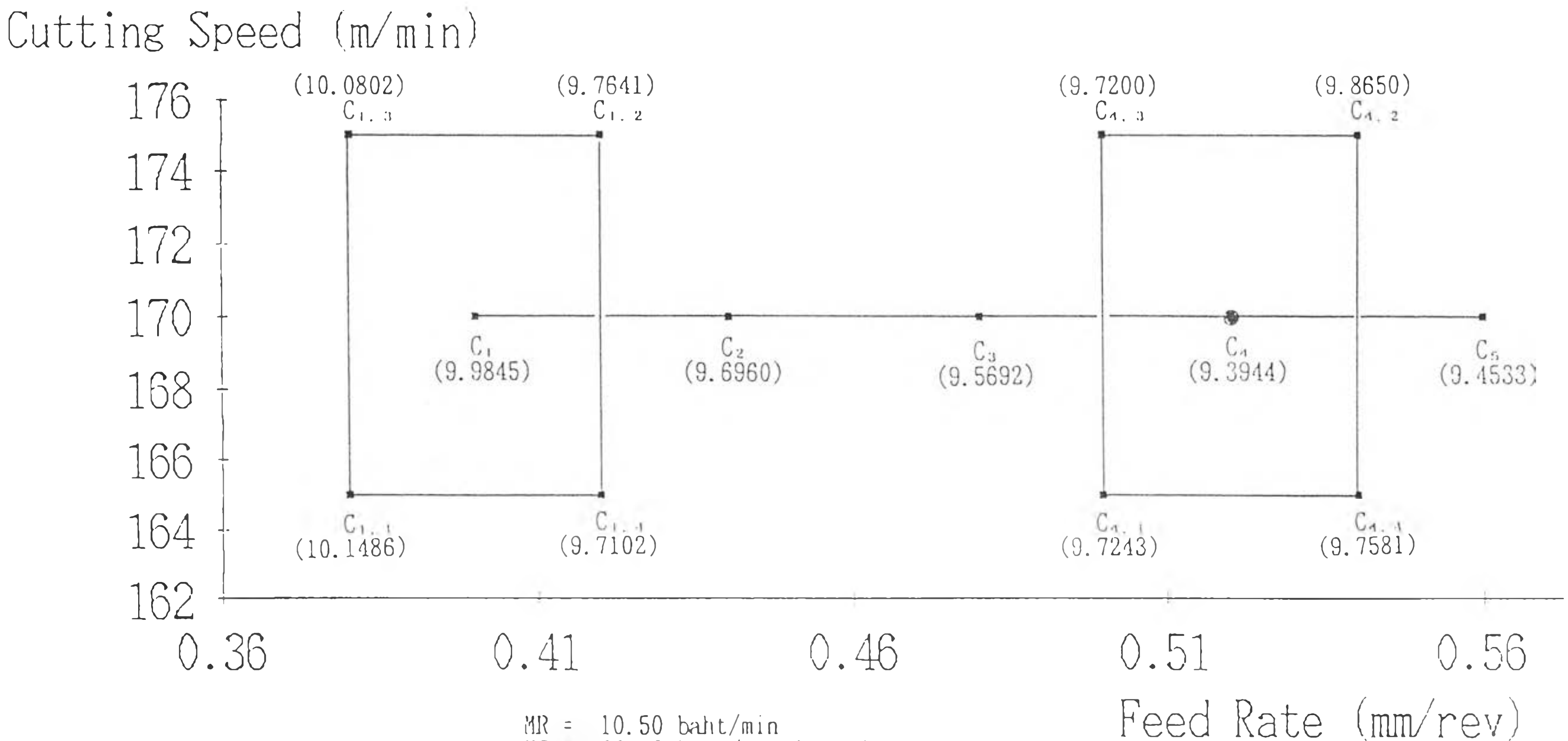
Fig. 6.1 Trajectory of carbide tool at the starting condition
160 m/min cutting speed and 0.20 mm/rev feed rate

To investigate the true optimum cutting condition, a total of 5 sets of 13 cutting conditions were tested in the second starting cutting condition 170 m/min cutting speed and 0.40 mm/rev feed rate. The results are shown in Table B.9-B.10 and Fig. 6.2. The recovered optimum cutting condition was 170 m/min cutting speed and 0.5200 mm/rev feed rate where the machining cost per workpiece was 9.3944 baht.

For the third starting cutting condition, the experiment were different not only with the starting cutting condition, but also with the different feed rate ($\triangle F$) used to determine the gradient of the optimum gradient method. Half of the different feed rate in the first and second experiments were used to investigate the effect of the true optimum cutting condition. A total of 3 sets of 11 cutting conditions, where the starting cutting condition was 180 m/min cutting speed and 0.5 mm/rev feed rate, were tested. The optimum cutting condition was 170 m/min cutting speed and 0.5053 mm/rev feed rate where the machining cost per workpiece was 9.4894 baht shown in Table B.11-B.12 and Fig. 6.3.

In the Fig. 6.4 the three trajectories of the different starting cutting conditions for carbide tool are displayed. The results indicated that the recovered optimum cutting conditions are correct because the machining costs per workpiece and the optimum cutting conditions are located in the area of different cutting speed ($\triangle V=10$) and different feed rate ($\triangle F=0.04$). Finally, the tool life equation estimated by least square method is

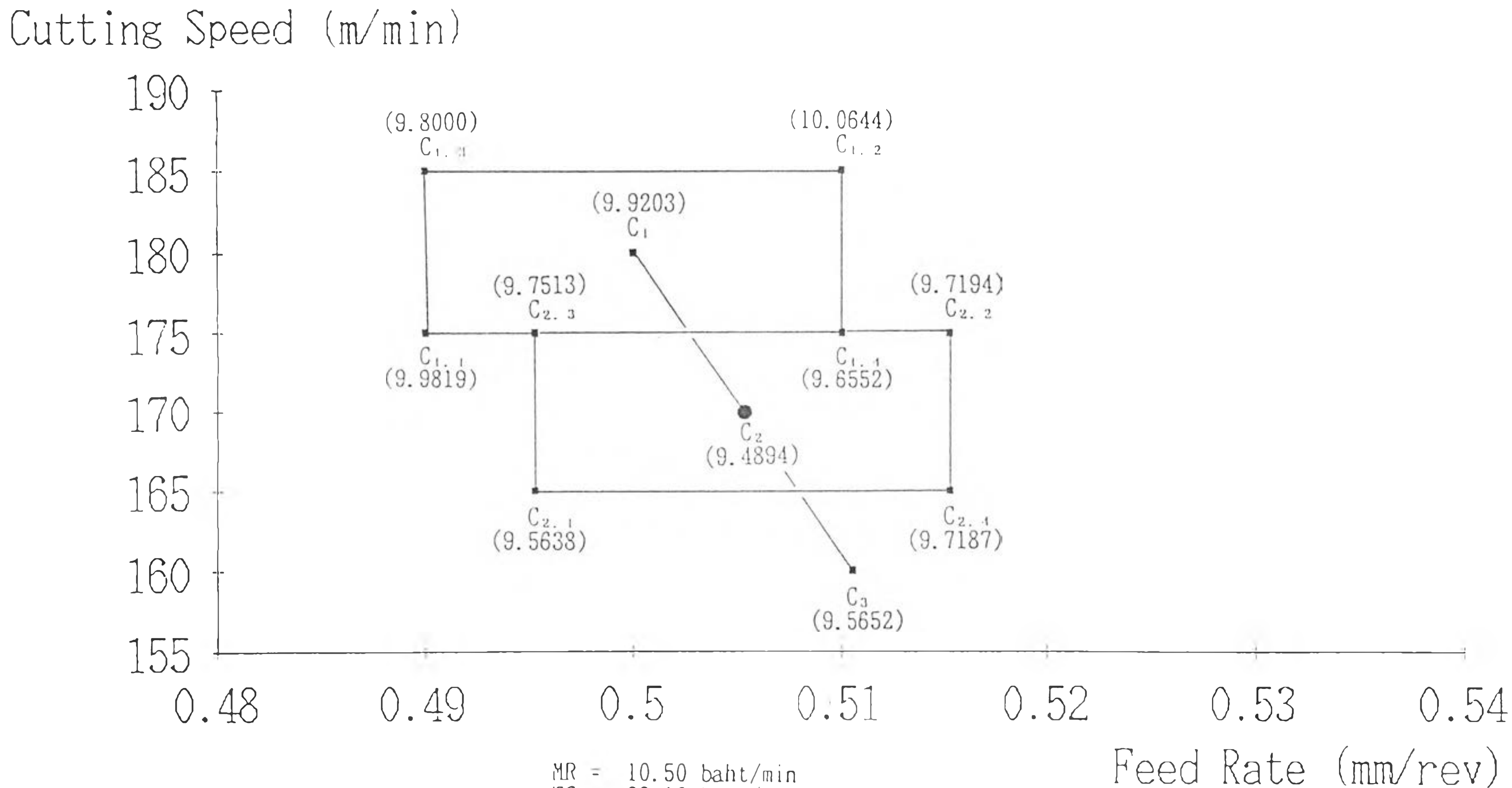
$$V F^{0.67} T^{0.39} = 150.885. \qquad (6.1)$$



MR = 10.50 baht/min
TC = 22.16 baht/cutting edge
TCT = 0.67 min/cutting edge
WCT = 0.25 min/cutting edge
D = 50 mm
L = 170 mm

Optimum cutting condition
V = 170 m/min
F = 0.5200 mm/rev
MCPW = 9.3944 baht/workpiece

Fig. 6.2 Trajectory of carbide tool at the starting condition 170 m/min cutting speed and 0.40 mm/rev feed rate



MR = 10.50 baht/min
TC = 22.16 baht/cutting edge
TCT = 0.67 min/cutting edge
WCT = 0.25 min/cutting edge
D = 50 mm
L = 170 mm

Optimum cutting condition
V = 170 m/min
F = 0.5053 mm/rev
MCPW = 9.4894 baht/workpiece

Fig. 6.3 Trajectory of carbide tool at the starting condition 180 m/min cutting speed and 0.50 mm/rev feed rate

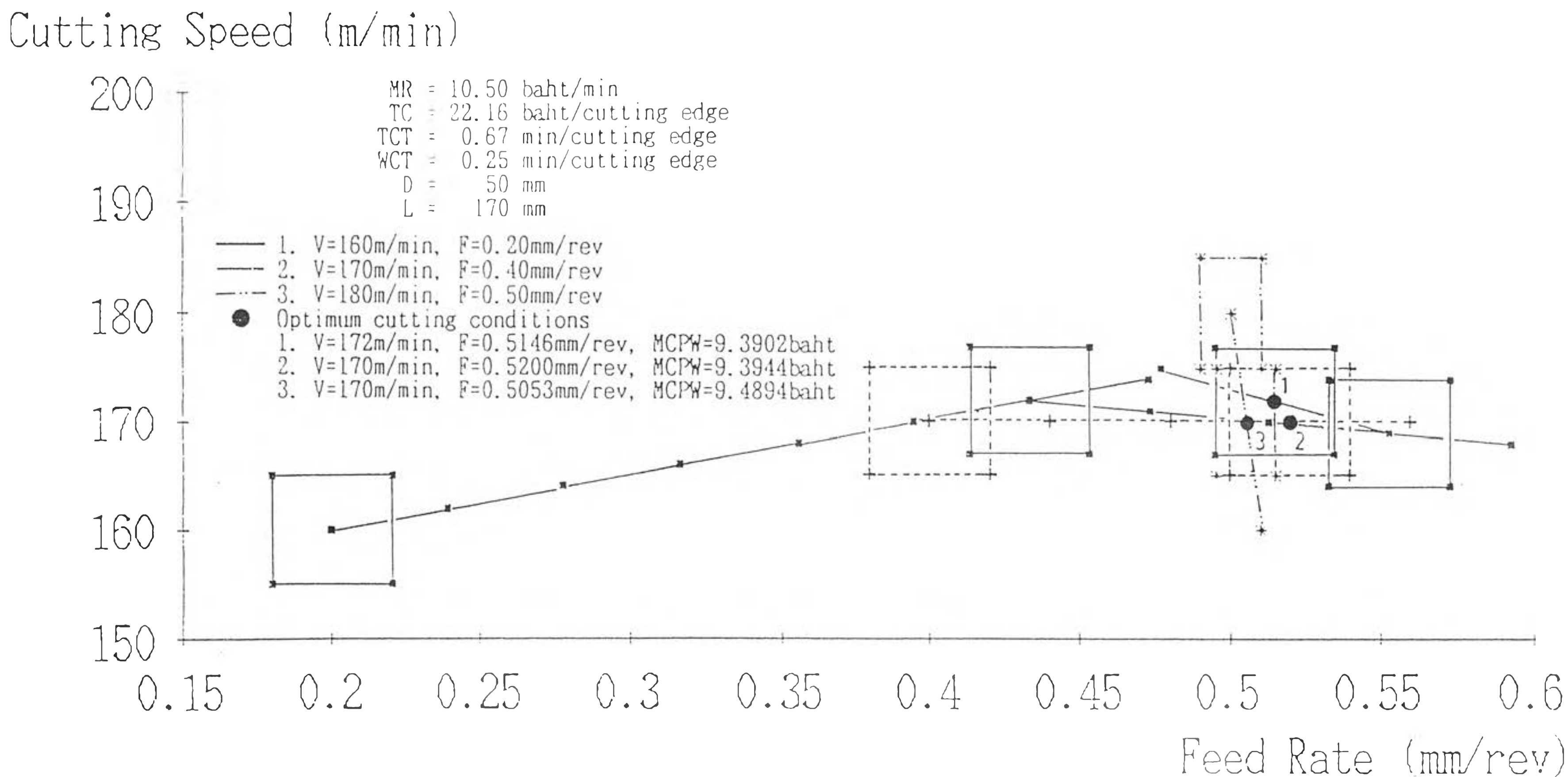


Fig. 6.4 Three trajectories of carbide tool at the different starting cutting conditions

For coated cutting tools, the only starting cutting condition 160 m/min cutting speed and 0.02 mm/rev feed rate was selected to compare with the carbide cutting tool. A total of 12 sets of 24 cutting conditions were tested and the result of the optimum cutting condition was 185 m/min cutting speed and 0.4994 mm/rev feed rate where minimum machining cost per workpiece was 8.8289 baht shown in Table B.13-B.14 and Fig. 6.5. Similarly, the tool life equation estimated by least square method is

$$V\,F^{0.62}\,T^{0.36} = 152.475. \tag{6.2}$$

For the economic comparison, minimum machining cost per workpiece and corresponding production times for a rough-turning operation using carbide and coated tools, shown in Table 6.1, indicates that when the optimum cutting conditions for minimum machining cost per workpiece were similar for both a carbide tool and a coated tool, the machining cost per workpiece and the production time using the carbide tool was reduced 5.98% and 4.22% respectively. The result was obtained by using a coated tool.

In the Fig. 6.6 the trajectories of carbide and coated cutting tool are displayed. The results indicated that, in steel AISI 1045, the machining cost per workpiece, using a coated cutting tool, is lower than the machining cost per workpiece using a carbide cutting tool at the optimum cutting conditions by means of the optimum gradient method. The solution was found on the side of the higher feed rate where the machining cost per workpiece was proportional to the cutting speed and feed rate. To reduce the machining cost per workpiece tool wear rate, or tool

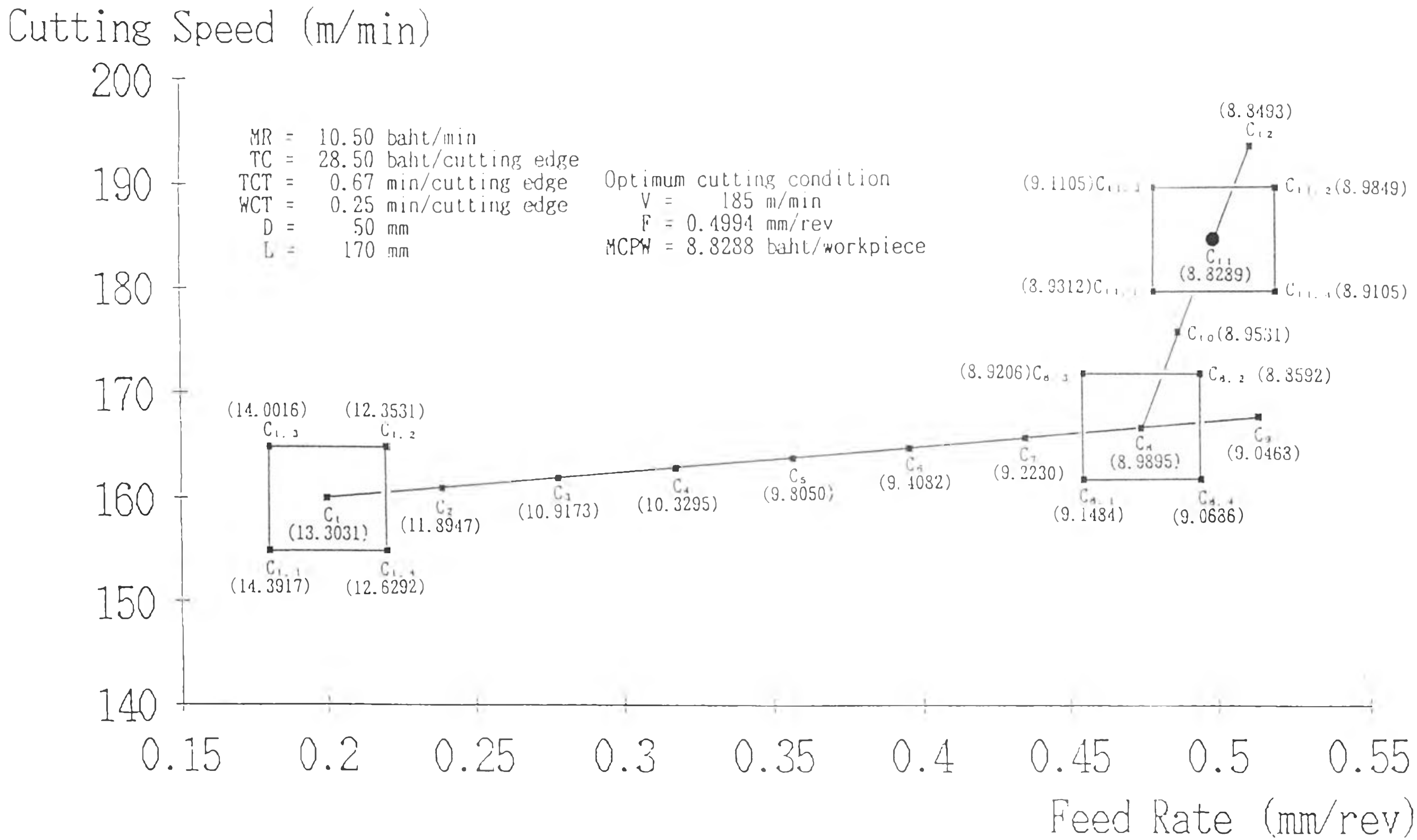


Fig. 6.5 Trajectory of coated tool at the starting condition
160 m/min cutting speed and 0.20 mm/rev feed rate

Table 6.1 Minimum machining costs and corresponding production times for a rough-turning operation using carbide and coated tool

Machining costs and production time	Type of tool	
	carbide	coated
Machine operation rate (baht/min)	10.50	10.50
Tool cost per cutting edge (baht)	22.17	28.50
Tool changing time (min)	0.67	0.67
Exponent of tool life (n)	0.39	0.36
Exponent of feed rate (a)	0.67	0.62
Tool life constant (C)	150.885	152.475
Tool life for minimum machining cost (mim)	2.514	3.335
Cutting speed for minimum machining cost (m/min)	172	185
Feed rate for minimum machining cost (mm/rev)	0.5146	0.4994
Depth of cut (mm)	2	2
Workpiece length (mm)	170	170
Before and after cut length (mm)	5	5
Actual machining time (min)	0.3017	0.2890
Total tool feed time (min)	0.3106	0.2975
Number of workpieces per cutting edge (pieces)	8.333	11.538
Machining cost per workpiece (baht)	9.3902	8.8289

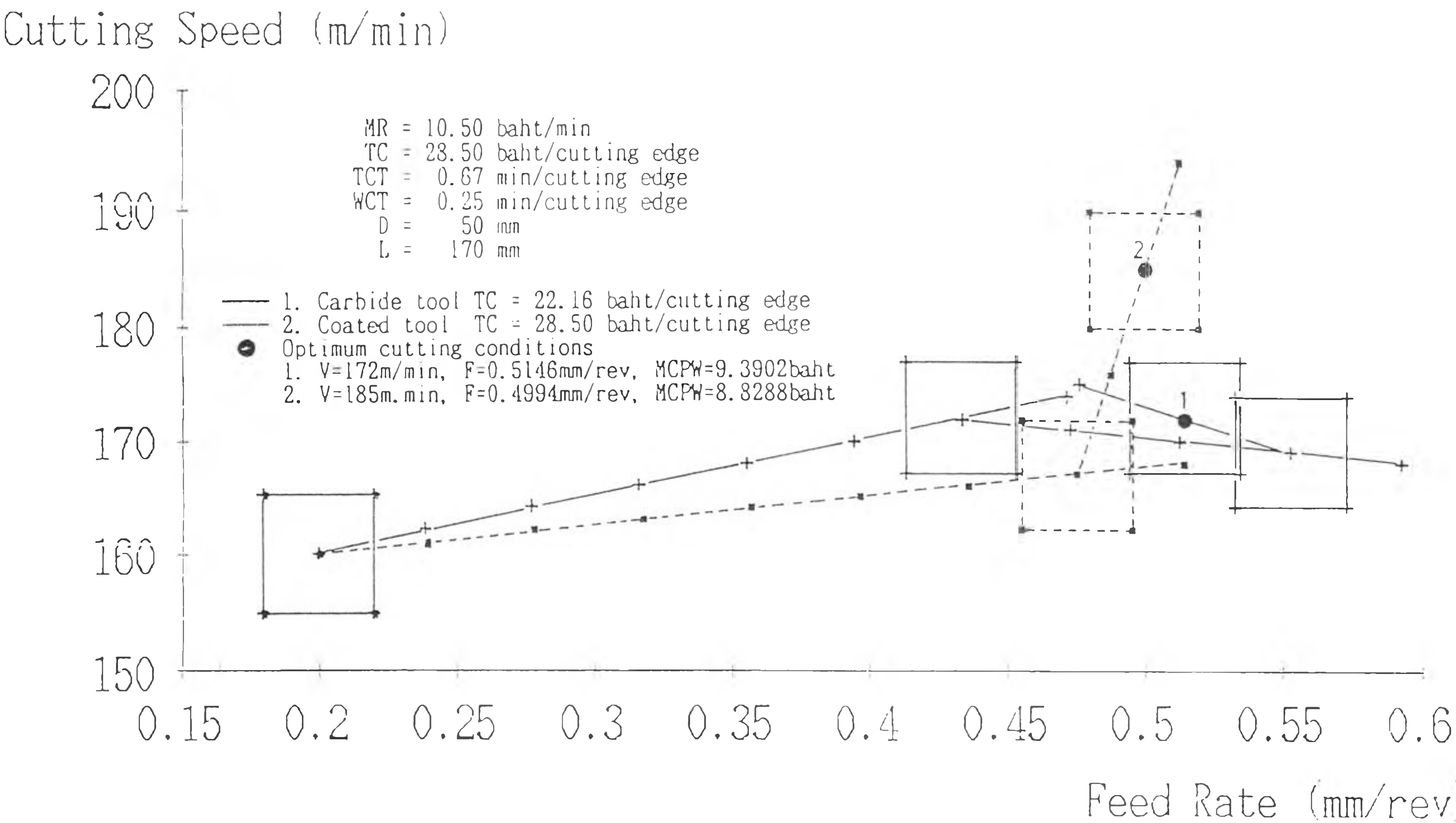


Fig. 6.6 Trajectories of carbide and coated tool at the starting condition 160 m/mincutting speed and 0.20 mm/rev feed rate

life, was much more predominantly governed by cutting speed than by feed rate.

To prove that this proposed method can efficiently determine the optimum cutting conditions, the conventional tool life tests were performed and the results were analyzed by the statistic method. The two tested groups of each cutting tools at the optimum cutting conditions were repeated. By using a carbide cutting tool at the optimum cutting conditions; 172 m/min cutting speed and 0.5146 mm/rev feed rate, the eight same workpieces of a tested group were tested. The results of flank wear measurement were shown in Table B.15 and Fig. 6.7. For a coated cutting tool, the eleven same workpieces of a tested group were also tested at the optimum cutting conditions; 185 m/min cutting speed and 0.4994 mm/rev feed rate, and the results were shown in Table B.16 and Fig.6.8.

The results illustrated that the total tested groups had the flank wear levels after testing near the wear criterion determined. For example, after each two groups of each eight workpieces using each carbide cutting tools were cut, the flank wear levels were 0.362 mm and 0.360 mm in which the proposed method could estimate the flank wear level at 0.363 mm. Hence, the obtained results illustrated that the flank wear levels were indeed into the second stage of flank wear growth.

To prove that the wear of cutting tool with cutting time is uniform, the following statistic method (18) were used:

1. Regression; To determine the relationship between the cutting time and the flank wear, the linear model (2) was assumed as:

$$W = W_0 + W_R * t \qquad (6.3)$$

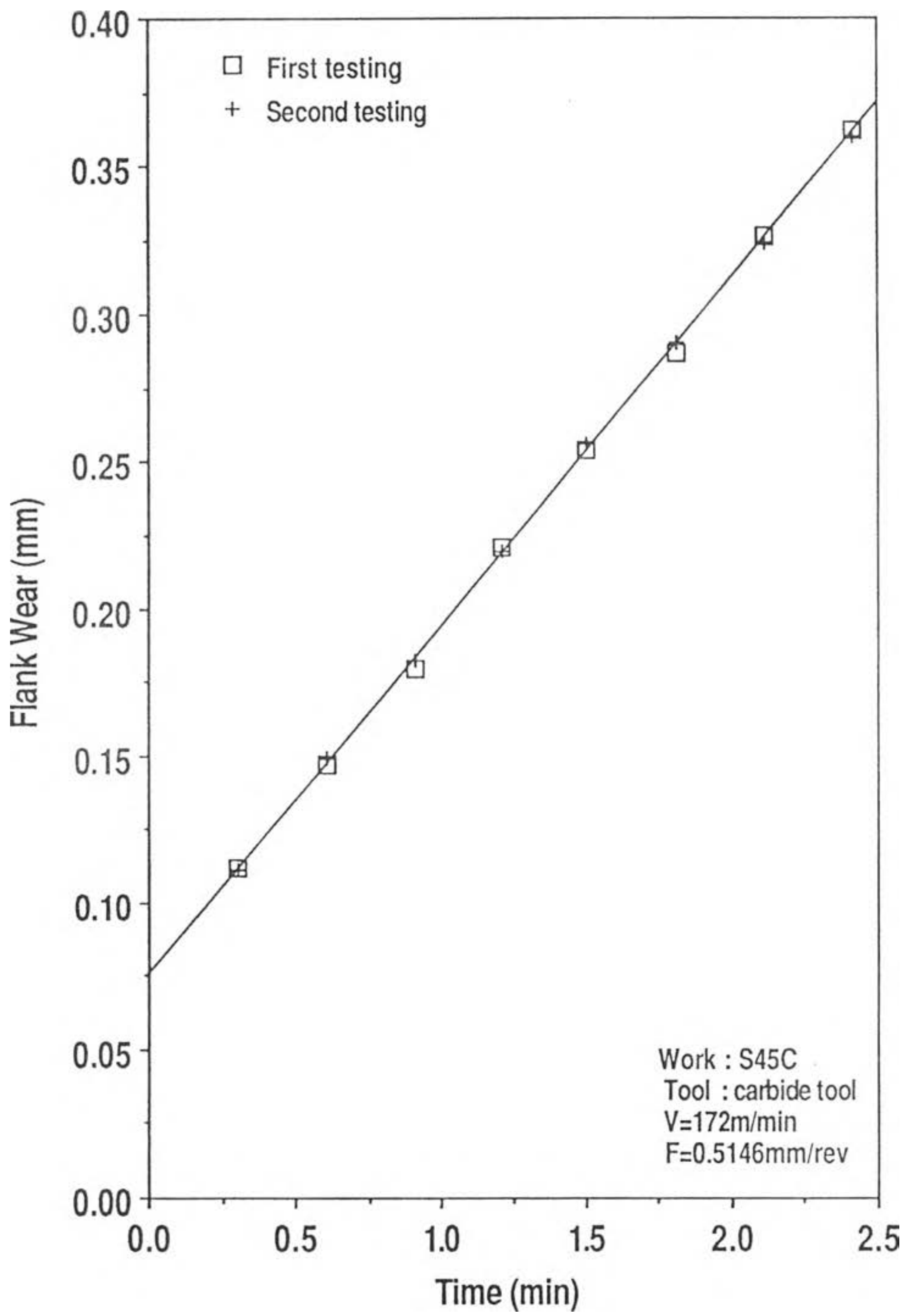


Fig. 6.7 Conventional wear tests of carbide tool at the optimum cutting condition

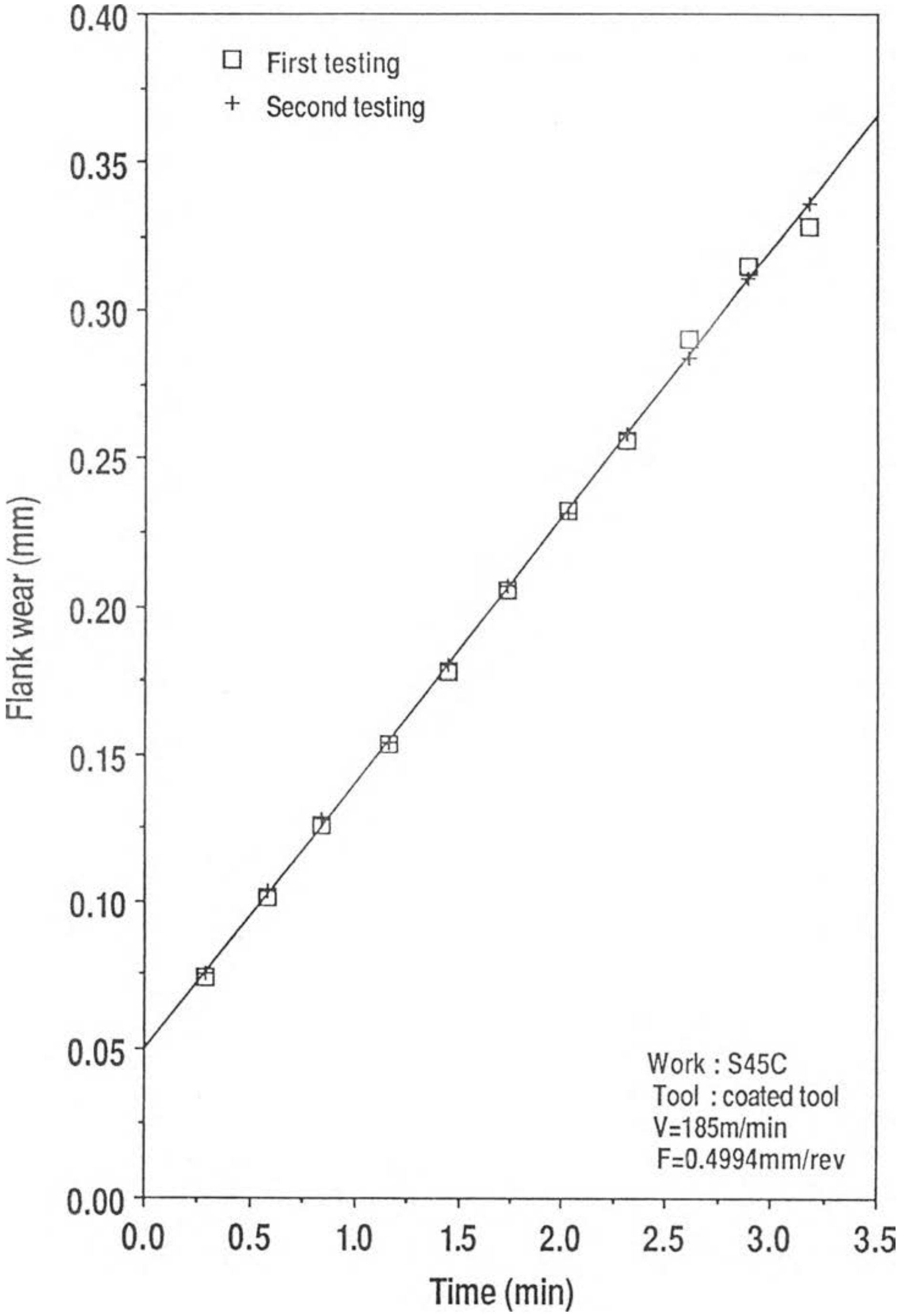


Fig. 6.8 Conventional wear tests of coated tool at the optimum cutting condition

where W = flank wear level at time t (min);

W_0 = initial wear level (mm);

W_R = wear rate (mm/min);

and t = cutting time (min).

The flank wear model of carbide cutting tool at 172 m/min cutting speed and 0.5146 mm/rev feed rate could be determined as:

$$W = 0.076+0.1180 * t \tag{6.4}$$

and the flank wear model of coated cutting tools at 185 m/min cutting speed and 0.4994 mm/rev feed rate was also:

$$W = 0.049+0.0903 * t . \tag{6.5}$$

2. Lack of fit: As results shown in Fig. 6.7 and 6.8, a linear medel shoud have been used in Eq. 6.3. Therefore, the test of the goodness of fit of regression model must be confirmed whether the order of the model tentatively assumed is correct for the validity of this assumption. The hypotheses to test were:

$$H_0 = \text{The model adequately fits the data.} \tag{6.6}$$

$$H_1 = \text{The model does not fit the data.} \tag{6.7}$$

in which the null hypothesis is rejected if $F_0 > F\alpha_{(\nu_1, \nu_2)}$.

The analysis of variance of both the cutting tools were summarized in Table C.1 and C.2 (Appendix C). The results cannot reject the hypotheses for both the cutting tools. It means that the linear model adequately fits the data between flank wear and cutting time at 5% significant level.

3. Hypothesis testing: The wear rate and initial wear level should be tested to confirm whether the tool life in the determination of the optimum cutting conditions is correct. As the results of determination of the optimum cutting conditions for carbide cutting tool at 172 m/min cutting speed and 0.5146 mm/rev feed rate, the wear rate was 0.1193 mm/min and the initial wear level was 0.075 mm. Therefore, the hypotheses to test for wear rate were:

$$H_0 : \quad W_R = 0.1193 \tag{6.8}$$

$$H_1 : \quad W_R \neq 0.1193 \tag{6.9}$$

and for initial wear level were:

$$H_0 : \quad W_0 = 0.075 \tag{6.10}$$

$$H_1 : \quad W_0 \neq 0.075. \tag{6.11}$$

Similarly, for coated cutting tool at 185 m/min cutting speed and 0.4994 mm/rev feed rate, the wear rate was 0.0899 mm/min and the initial wear level was 0.050 mm, the hypotheses to test for wear rate were also:

$$H_0 : \quad W_R = 0.0899 \tag{6.12}$$

$$H_1 : \quad W_R \neq 0.0899 \tag{6.13}$$

and for initial wear level were:

$$H_0 : \quad W_0 = 0.050 \tag{6.14}$$

$$H_1 : \quad W_0 \neq 0.050 \tag{6.15}$$

in which the null hypothesis is rejected if $|t_0| > t_{\alpha/2, n-2}$.

The hypothesis tests in linear wear model were summarized in Table C.3 for carbide cutting tool and coated cutting tool. It could be concluded that the tests of tool life for determination of the optimum cutting conditions were 5% significant level to the conventional tool life tests for both the cutting tools. Hence, the analysis by the statistic method indicated that the proposed method for the determination of tool life can be used correctly at the optimum cutting conditions.