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OPTIMUM CUTTING CONDITIONS
FOR CERAMIC-TIPPED TOOLS

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ABSTRACT

SPK-Cutting ceramics are high-performance cutting materials based on α-aluminium oxide. Inserts in SPK-cutting ceramics are unique in their high red hardness, extreme wear resistance and chemical stability. In addition, a fine-grained structure and suitable density provide these inserts with an extraordinary toughness and resilience.

In this study, a turning tests have been conducted using three selected ceramic-tipped grades for cutting two different heat treatable steels. The experiment out line was set to evaluate the effects of the following factors on the tool performance, using the values of the flank wear as the measured variables :

i) Tool Materials:
Grades: SN56, SN60, and SH 1.

ii) Work Materials:
DIN: CK60 and 42CrMo4.

iii) Cutting Conditions:
Cutting speed, feed rate, and cutting time.

The optimum cutting conditions for minimum tool wear and maximum chip volume were obtained.

The results shows that any increase in the cutting speed, feed or cutting time cause an increase in the wear. Therefore, the best cutting condition depends on the tool grades and work materials.

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INTRODUCTION

The development [1] of ceramic-tipped tool material towards higher strength, maintaining its large range of cutting speeds, now allows a wider range of exploitation. The application, not only for the large series production and heat treatable steels, but also for the machining of cast iron, and even smaller patch quantities in mechanical engineering, is now possible. The set-up of ceramic cutting material and the special wear behavior allows high performance in the machining process. Beside significantly higher tool life per workpiece, the use of ceramic cutting material opens a large scope of optimization factors.

Previous experimentation indicated that the tool wear is dependent on many factors such as the cutting conditions (Gomoll, [1] Anschutz, [2] Klicpera, [3] and Abel and Gomoll, [4]). In these experimentations one grade of ceramic cutting tools, and workpiece materials have been used. In the present work, five variables, cutting speed, feed rate, cutting time, workpiece materials and ceramic-tipped tool materials were changed at the same time and their effects on tool wear were studied and evaluated.

EXPERIMENTAL WORK

A) Selection of the independent variables :

i- Cutting tool materials.

Three types of ceramic cutting tools were used: SPK throw-away tip grades [5] SN56, SN60, and SH 1, see Table (1).

ii- Workpiece materials.

Two workpiece materials: heat treatable steel grades CK60 and 42CrMo4 were selected [5]. Their composition is shown in Table (2).

iii- Cutting conditions.

Preliminary tests were conducted using various combinations of cutting conditions, inserts and workpiece materials. The extreme values of cutting conditions [5 & 6] which contained a practical experimental range were found to be:

a- Cutting speed, (v): 120, 240 and 360 m/min.
b- Cutting time, (t): 12 , 24 and 36 min.
c- Cutting depth, (a): The depth of cut was kept constant at 1.5 mm.
d- Feed rate, (s): 0.12, 0.23 and 0.36 mm/rev.

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B) Selection of the dependent variables :

The flank wear length (f) was selected to represent the physical wear of the SPK throw-away tip, and its values were measured.

C) Experimental procedure :

Turning experiments were carried out on an "MARTIN KM 230" engine lathe. Three cutting tool materials (SN56, SN60 and SH 1) with respective SPK-indexable inserts [6 & 7] ISO designation (SNGN 15 08 08) chamfered 0.2 x 20^o and with corner radius, r = 0.8 mm, were employed to cut DIN CK60 and 42CrMo4 heat treatable steels. The tool holder had the geometry (-6, -6, 5, 5, 45, 45) ISO designation (CSSN 32 25P). For each machine set up specified time intervals, the value of the flank wear length was measured using the tool-maker's microscope is of the model "Einlage G60-240d", and data obtained was recorded in Table (3).

DISCUSSIONS

A) Numerical Results :

Numerical data are given in Table (3). Examination of these data pointed out the following:

i- With the increasing of cutting conditions (v, s,and t) the value of flank wear increases.

ii- Flank wear length value decreases at two cases:

a- An increase of tool hardness grades SN56, SN60 and SH 1, respectively.

b- An increase of workpiece hardness code 42CrMo4 and CK60, respectively.

B) Statistical Analysis :

Tables 4 (a and b) present the analysis of variance tables [8] of the whole set of data and of the two subsets for the workpiece materials CK60 and 42CrMo4, respectively. Tabulated values given in the last three columns represent the F-values for SN56, SN60, and SH 1, respectively. The obtained F-values are to be compared with the corresponding tabulated value at a specified significance level.

The reslts show that :

i- All the single effects v, t, and s are highly significant, also the double effects tv for (grades SN60 and SH 1) in Table 4(a) and tv, ts for (grade SN60), vs for (grades SN56 and SN60) in Table 4(b), and tv for (grades SN60 and SH 1), ts for (grade SN56) are significant, at the 0.05 level in Table 4(a and b) respectively.

The effects of interactions tv for (grade SN56), ts for (grades SN56, SN60, and SH 1) and vs for (grade SH 1) do not prove significance at the indicated levels.

ii- Examination of Tables 4(a and b), reveals the high significance of the single effects of (v, t, and s) and (t, v, and s) respectively i.e. with increasing the work material hardness from (217 to 243 HB) take t except v factor. Also the increasing of the tool material hardness (2400 to 3000 HV) or decreasing grain size (3 to 2 µm) to decrease of high significant of F-values i.e. lead to a smaller wear value.

iii- Considering the results of the SH 1 tool grade almost parallelism in the results is observed, though its calculated F-values are less than, those of the SN60 tool grade, and also SN56 tool grade. This result is also "logic", since the SH 1 material is more resistant to wear than that of the tool grades SN56 and SN60.

C) Optimum Cutting Conditions :

To achieve optimum cutting conditions, it is desirable to minimize the flank wear length and maximize the chip volume (V) at the same time.

From points 1, 2, 3, 4, 5 and 6 on the graph, Figs.1(a, b, and c), it is clear that by proper adjustment of the variables levels, a higher chip volume could be achieved while maintaining a lower flank wear length. Point 5 shows a best conditions for all ceramic-tipped grades.

CONCLUSIONS

The results obtained lead to the following conclusions :

1. The selected factors have significantly affected the performance in the following:

a) Cutting conditions:

Any increase in the cutting speed, feed or experiment time let to an increase in the wear.

b) Workpiece materials:

Experimental results reveal the high significance of single condition effects of (v, t, and s) and (t, v, and s) for work materials CK60 and 42CrMo4, respectively.

2. Tool Best:

The best cutting conditions are depended on the tool grades and work materials are as follows:

- Cutting speed, v = 240 m/min

- Depth of cut, a = 1.5 mm
- Feed rate, s = 0.36 mm/rev
  = 0.23 mm/rev (for SH 1 and CK60)
- Cutting time, t = 24 min
  = 36 min (for SH 1 and CK60)

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NOMENCLATURE

a = Depth of cut, mm
f = Flank wear length, um
r = Corner radius, mm
s = Feed rate, mm/rev
t = Cutting time, min
T = Tool materials,
v = Cutting speed, m/min
V = Chip volume, cm^3

Table 1: Physical properties of ceramic cutting materials.

Cutting materials group:	Pure ceramic		Mixed ceramic
Production method:	Cold pressing		Hot pressing
Composition:	AL_2O_3		AL_2O_3 + TiC
Colour of the tips:	White		Black
S P K grades:	SN56	SN60	SH 1
Density, g/cm^3	3.91	3.97	4.30
Grain size, micron	3.0	3.0	2.0
Vickers hardness,	2400	2400	3000
E-module, N/mm^2	410000		360000
Bending strength, N/mm^2	350	380	380
Compressive strength, N/mm^2	4000	4000	4500
Breaking strength, $N/mm^{3/2}$	140	175	160
Heat conductivity, cal/cm.s.°C	0.05	0.05	0.09
Thermal shock resistance, °C	200	200	500

Table 2: Analysis of workpiece material.

DIN Designation	Brinell Hardness	C%	Si%	Mn%	P%	S%	Cr%	Mo%
42CrMo4	217	0.38-0.45	0.4	0.8	0.035	0.035	0.9-1.2	0.15-0.3
CK60	243	0.57-0.65	0.35	0.9	0.035	0.035		

Table 3:Experimental conditions, calculations and results.

Cutting speed v m/min	Feed rate s mm/r	Cutting time t min	Chip volume V cm^3	Flank wear length, f , µm CK60 SN56	CK60 SN60	CK60 SH 1	42CrMo4 SN56	42CrMo4 SN60	42CrMo4 SH 1
120	0.12	12	259.2	40	35	10	90	80	55
120	0.12	24	518.4	85	55	20	130	120	90
120	0.12	36	777.6	130	70	40	180	160	100
120	0.23	12	496.8	70	50	15	130	90	75
120	0.23	24	993.6	105	70	30	180	155	140
120	0.23	36	1490.4	145	100	75	265	185	190
120	0.36	12	777.6	60	75	55	135	95	100
120	0.36	24	1555.2	110	95	95	205	140	120
120	0.36	36	2332.8	165	110	125	285	185	175
240	0.12	12	518.4	60	50	40	165	130	100
240	0.12	24	1036.8	110	120	60	230	170	150
240	0.12	36	1555.2	140	130	90	290	220	200
240	0.23	12	993.6	65	60	50	175	110	90
240	0.23	24	1987.2	115	125	85	250	220	160
240	0.23	36	2980.8	175	170	100	310	265	215
240	0.36	12	1555.2	95	90	85	185	145	140
240	0.36	24	3110.4	160	160	130	260	210	200
240	0.36	36	4665.6	225	220	170	360	350	250
360	0.12	12	777.6	120	110	70	145	160	135
360	0.12	24	1555.2	180	150	135	265	210	195
360	0.12	36	2332.8	245	240	210	370	290	270
360	0.23	12	1490.4	135	140	80	180	160	135
360	0.23	24	2980.8	220	180	170	290	240	230
360	0.23	36	4471.2	250	260	210	395	340	305
360	0.36	12	2332.8	175	170	130	245	240	160
360	0.36	24	4665.6	290	300	225	375	320	270
360	0.36	36	6998.4	425	400	330	545	500	360

Table 4(a): Analysis of variance table of data (Table 3). For CK60 material.

ource of ariation	Degree of freedom	Sum of squares SN56	SN60	SH 1	Mean square SN56	SN60	SH 1	F-values SN56	SN60	SH 1
Due to v	3-1=2	80274.08	94850.00	68116.67	40137.04	47425.00	34008.33	98.24"	122.82"	117.89"
Due to t	3-1=2	67890.74	47038.88	31705.55	33945.37	23519.44	15852.77	83.08"	60.91"	54.87"
Due to s	3-1=2	22124.08	25550.00	33355.55	11062.03	12775.00	16677.77	27.07"	33.08"	57.73"
nter. tv	2x2=4	4237.08	11477.77	12194.45	1059.27	2869.44	3048.61	2.59	7.43"	10.55"
nter. ts	2x2=4	3570.37	2211.11	772.22	892.59	552.77	193.05	2.18	1.43	0.66
nter. vs	2x2=4	8020.37	7133.33	561.11	2005.09	1783.33	140.28	4.91'	4.61'	0.48
xper.Error	8	3268.48	3088.90	2311.04	408.56	386.11	288.88			
otals	27-1=26	189385.19	191350.00	149016.60						

Table 4(b): Analysis of variance table of data (Table 3). For 42CrMo4 material.

ource of ariation	Degree of freedom	Sum of squares SN56	SN60	SH 1	Mean square SN56	SN60	SH 1	F-values SN56	SN60	SH 1
ue to v	3-1=2	102205.55	88266.67	61198.18	51102.77	44133.33	30599.1	255.51"	141.85"	119.84"
ue to t	3-1=2	136172.22	95116.67	65220.41	68086.11	47558.33	32610.2	340.43"	152.86"	127.72"
ue to s	3-1=2	36038.89	25272.22	15209.29	18019.45	12636.11	7604.6	90.09"	40.61"	29.78"
nter. tv	2x2=4	13988.89	7983.33	5374.04	3497.27	1995.83	1343.5	17.48"	6.41'	5.26'
nter. ts	2x2=4	4155.55	8794.44	796.26	1038.88	2198.61	199.1	5.19'	7.06"	0.78
nter. vs	2x2=4	12205.56	12544.44	2101.81	3051.39	3136.11	525.4	15.27"	10.08"	2.06
xper.Error	8	1599.99	2488.89	2042.63	199.99	311.11	255.33			
otals	27-1=26	306366.67	240466.67	151942.63						

' = Significant at 0.05 level,

" = Significant at 0.01 level.

Tabulted F - values [8]

Degree of freedom	$F_{0.05}$	$F_{0.01}$
2,8	4.46	8.65
4,8	3.84	7.01

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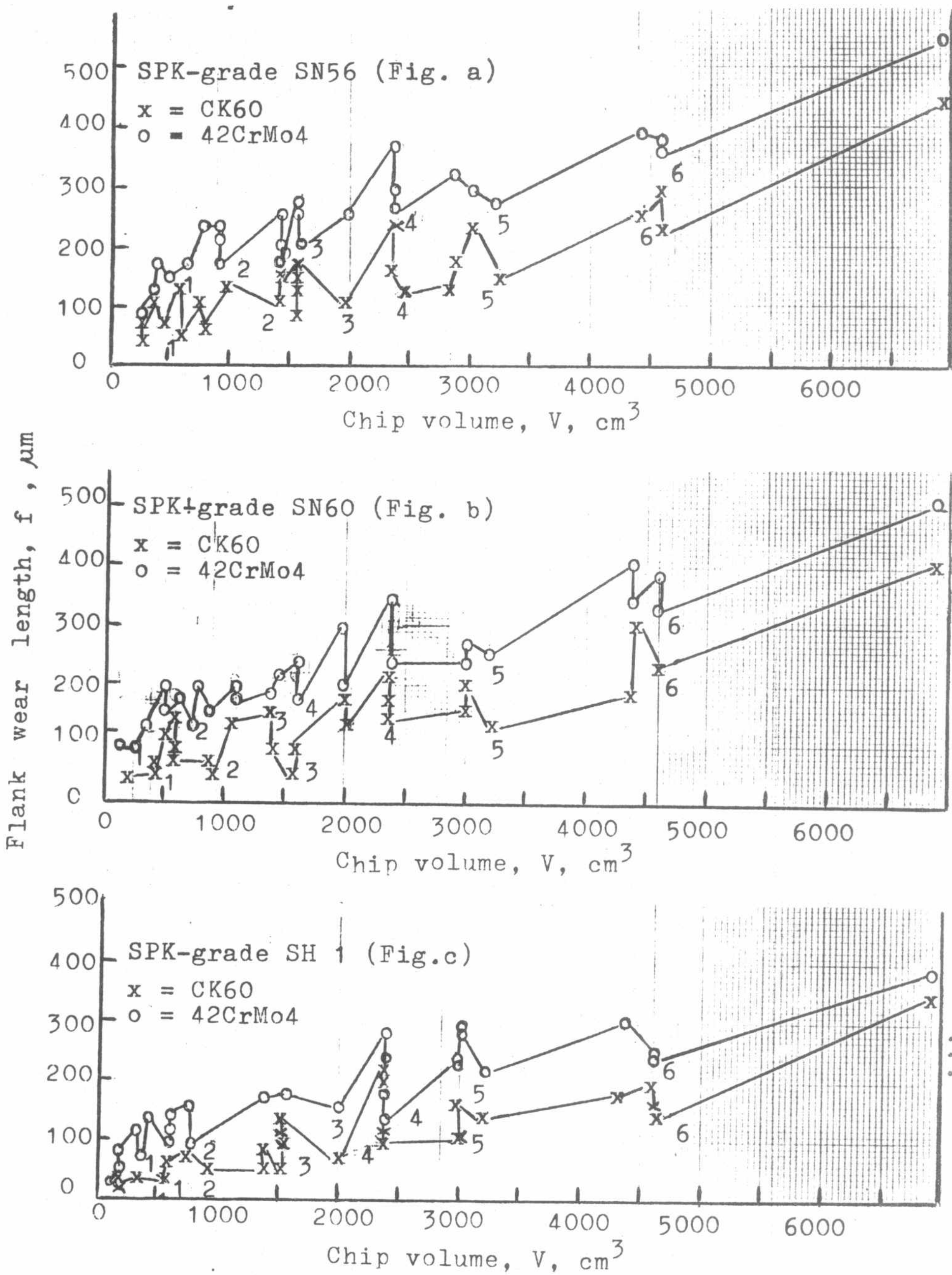

Figs. 1(a,b and c):Chip volume versus flank wear length.