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CRANFIELD

MACHINABILITY OF ULTRA HIGH TENSILE STEEL

by

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A Note on the Machinability of Ultra High Tensile Steel

by

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SUMMARY

The requirements of this investigation were to determine optimum tool geometry and cutting conditions for turning Ultra High Strength Alloy Steel (fully heat treated to 120 tons per sq. ins.). The material will be used for bolts, whose screw threads will be produced by thread rolling. Dimensional accuracy required on the blanks is 0.0002". The material in the above state presents extremely severe conditions, especially on the nose of the turning tool, and results in rapid wear and loss of dimensional accuracy. Application of cutting coolants or lubricants made no measurable improvement on tool nose wear, benefits gained from the use of coolants being confined to reduction of flank wear.

Cross-Cord Tooling

To overcome the disadvantages of tool nose wear, the Cross-Cord tooling method was developed, details of which are included in Section 6 and Figs. 9A and 9B. Using this technique the following results were obtained:-

Cutting Speed	Feed Rev.	Flank Wearland	Tool Life (mins.)
135 F.P.M.	0.015	0.020"	30
75 F.P.M.	0.015	0.020"	60

Surface finish was good and dimensional accuracy over 6 in. lengths was within the limits specified.

SUMMARY (Cont'd)

Molybdenum Disulphide in Soluble Oil and water applied by the Norgren Spray-Lube technique gave some improvement in tool life, but the overhead method of coolant application was virtually ineffective.

Conventional Tooling

The optimum shape for a standard bar turning tool was found to be:

Cutting edge side rake	...	...	15°
Front to back rake	...	...	0°
Plan approach angle	...	...	0°
Plan trail angle	...	...	6°
Clearance angles	...	...	6°

Tool nose wear was rapid and dimensional accuracy was not achieved.

CONTENTS

NOTE: Tool nomenclature is shown in Figure 1.

SECTION 1. Machinability

1.1 The effect of surface speed on cutting tool forces.

Conditions of Tests

Machine: 15" centre lathe (see Section 7).

Workpiece: Ultra High Tensile Steel (120 Tons/sq.in.V.P.N.580/600), $1\frac{1}{2}$" dia. x 12" long.

Tool: Tungsten Carbide tipped Wimet XX grade.

Dynamometer: College of Aeronautics 3-component tool dynamometer.

Chip Proportions:
Depth of cut = 0.050"
Feed per rev. = 0.0039"/0.0078"

Tool Geometry:

Cutting edge back rake	$= 0^{o}$
Plan approach angle	$= 0^{o}$
Plan trail angle	$= 6^{o}$
Front and side clearance angles	$= 6^{o}$
Cutting edge side rake	$= 15^{o}$
Nose radius	= 0.010 ins.

All surfaces lapped to 5/10 micro-inches CLA.

Coolant: None.

Description of Tests

Tool Loads. Test cuts were made at various cutting speeds and the vertical and horizontal tool loads measured. The results, which are shown in Table 1 and Fig.2 reveal that, within the range of 40/140 F.P.M., cutting speed does not appreciably affect the cutting loads on the tool.

1.2 The effect of rate of feed on cutting forces and tool wear.

Workpiece: As in Section 1.1.

Chip Proportions: Depth of cut = 0.030"

Surface Speed: 23 ft. per min.

Tool: Tungsten carbide tipped Wimet Grade S58.
Carried in the C of A Lathe tool dynamometer.

Tool Geometry: As Section 1.1

Coolant: None.

Description of Tests

Cutting Tests With the above conditions a series of test cuts was made at various feed rates and vertical and horizontal tool forces were measured. Results are shown in Table 2 and Fig.3. These indicate that more severe conditions proportionally, are presented at the lower feed rates. Reference to the curve of feed forces in Fig.3 will reveal a definite change in the cutting characteristics, at approximately 0.007 ins. per rev.

Tool Wear To test the validity of the above assumption wear tests were conducted at two rates of feed, one greater and one less than 0.007". A solid tool was used (tungsten carbide tipped) and tests were run for equal duration of time; one at 0.0039 ins./rev and one at 0.078 ins./rev, and flank wearland and nose wear were measured. Results are shown in Table 3 and Fig. 3A.

These show that wear at both feed rates is approximately equal, thus underlining the adverse conditions at low rates of feed; similar results were established at two surface speeds. The machining characteristics thus revealed, suggest a preference for high feed rates where possible.

SECTION 2. Cutting tool material selection tests.

This series of tests was designed to enable the most suitable cutting material to be selected, for:-

(a) continuous cutting and
(b) intermittent cutting.

A number of cutting tool materials were selected, all were prepared to the following constant conditions

Tool Geometry: As Section 1.1

Tool Shank size = 1 in. x $\frac{3}{4}$ in.

Chip proportions:

Depth of cut = 0.050 ins.
Feed rates per rev. = 0.0039 and 0.0078 ins.

Surface Speed = 57 ft per min.

Coolant: None

Workpiece - as in Section 1.1

2.1 Description of tests

2.11 Continuous Cutting Each tool was applied under the above constant conditions for a period of 1 minute cutting time, and flank wearland and top face cratering were compared.

The tools which suffered least wear in the above test were selected, and after reserving, applied under the constant conditions for a cutting period of 5 minutes. This resulted in the following tool materials showing least wear.

Wimet grade XX tungsten carbide	- 0.012 ins Flank wear.
Stellite 100 grade	- 0.012 ins. Flank wear.
Per Pro Grade A.U.	- 0.009 ins. Flank wear.

2.12 Intermittent Cutting

For this test the workpiece had a flat of 1" wide machined along the $1\frac{1}{2}$" dia. x 12" long. The workpiece was carried in the machine as previously described. All tool geometry remained constant. Chip section constant as previous test. Surface speed = 40 ft. per minute. Cutting time = 9 mins.

The test procedure as for continuous cutting was repeated, with the following results.

	Flank wear	Cratering
Stellite 100 grade	0.023 ins.	slight
Wimet XX grade carbide	0.027 ins.	none
Per Pro Grade A.U.	0.019 ins.	slight

SECTION 3. Development of a single point tool geometry

Workpiece: as in Section 1.1

Chip Section:

Depth of cut - 0.050 ins.

Feed per rev.	- 0.0038 - 0.0058 and 0.0078 ins.
Surface Speed	- 52 ft. per min.
Coolant	- None.

The Tool:

Tungsten Carbide (Per Pro A.U.), mounted in the C. of A. lathe tool dynamometer.

Tool Geometry:

Cutting edge side rake (true rake)	- (various)
Cutting edge back rake	- 0°
Plan approach angle	- 0°
Plan trail angle	- 6°
Front and side clearance angle	- 6°
Nose radius	- 0.010 ins.

Ground and diamond lapped to 5-10 micro ins. CLA.

Description of Tests

Cutting Edge Side Rake

Test cuts were taken with various cutting edge side rake angles and the vertical and horizontal cutting forces measured.

Results are shown in Table 4 and Figs. 4 and 5.

Examination of these results indicate (from previous experience) that the most favourable tool angle would be in the neighbourhood of $17\frac{1}{2}^\circ$.

In order to determine conclusively the best Cutting rake angle, wear tests were made at angles of $12\frac{1}{2}^\circ$, 15°, $17\frac{1}{2}^\circ$ and 20°. For these tests the dynamometer was replaced by a solid tool (tungsten carbide tipped) and under the previous cutting conditions, test runs of 6 mins. duration were made, flank wear and top cratering being measured. A Cutting Edge Side Rake of 15° was found to be the best.

Front to Back Rake

Similar tests under constant cutting conditions were made to find the effect of varying the front to back rake. Variations from 10° negative to 5° positive were made, but no improvement on the original tool with 0° rake, was found.

Side Clearance Angle

Side clearance angle was also varied over the range 4°, 5°, 7° and 8°, but again no improvement in wear from the original 6° clearance was found.

Since the characteristics of the curves shown in Fig.3 show some change with change in feed rate, this necessitated the above wear tests being carried out for low and higher feed rates, to check consistency for all rates of feed.

The results of the tests made at 0.0038 and 0.0078 showed that the tool geometry was at optimum for both feed rates and is as follows:

Optimum tool geometry

Cutting edge side rake	- 15°
Front to back rake	- 0°
Plan approach angle	- 0°
Plan trail angle	- 6°
Front and side clearance angles	- 6°
Nose radius	- not less than 0.010 ins.

All surfaces diamond lapped to 5-10 micro ins. CLA.

SECTION 4. The determination of Tool life/Surface speed relationship

4.1 For continuous cutting conditions

Tool life, when referring to carbide tools, is usually quoted as a permissible amount of tool flank wear. In the following tests it was found that the maximum wearland that could be sustained before rapid failure was 0.020". Therefore tool life is based on this value.

Workpiece: As in Section 1.1

Chip Section

Depth of cut = 0.050 ins.
Feed rates = 0.0078 ins/rev.

Surface Speed = Various

Tool

Shank size = 1 in. x $\frac{3}{4}$ ins.

Tool Geometry as finalised in Section 3.

Description of tests

At one cutting speed, test cuts were made of 1, 2, 4, 8, 12 and 24 minutes duration, and wear on the flank and nose of the tool was measured. These tests were then repeated for a range of cutting speeds.

Results are shown in Table 5 and Figs. 6. A and B.

From this family of curves, the curve in Fig. 7 may be drawn, which shows the tool life for 0.020" wearland when speed is the variable. Fig. 8 shows these values on log/log paper.

4.2 For intermittent cutting conditions

The material was prepared as for intermittent cutting in Section 2.12.

The tool geometry was as finalised in section 3. The procedure used was similar to life versus surface speed tests, for continuous cutting above.

Results are shown in Figs. 7 and 8.

SECTION 5. A special tooling technique

Cross Cord Tool

Many of the higher strength and heat resisting materials appear to wear the tool nose far more rapidly than the flank cutting edge of the tool and to overcome these adverse conditions, the Cross-Cord tool was developed. The tooling technique, shown schematically in Fig. 9 eliminates the tool nose and allows high surface speeds and feed rates to be used whilst retaining good surface finish and dimensional accuracy.

Description of Cross-Cord Tooling

The tool bit is of triangular or rectangular shape with equal length sides, hence reservicing is speedy and simple. The tool bit is clamped into the holder, which allows the 6 or 8 right angled edges of the tool bit to be used for cutting before total reservicing is necessary.

The cutting edge is displaced across the cord of the depth of cut, thus providing means whereby all cutting takes place within the extreme corners of the tool bit, so eliminating the isolated corner or nose.

Tests results using the bext tool material and the cross cord technique are recorded on Table 6.

Cross cord tooling leaves the tool approach angle on the workpiece, and if this is unacceptable the tool holder incorporating a vertical slide and using a triangular bit is used. The procedure then is to produce the cylinder with the longitudinal traverse provided in the machine tool and by means of the tool holder slide traverse the tool bit vertically beyond the diameter of the workpiece; this allows the corner of the tool bit to form the right angle shoulder on the workpiece.

SECTION 6. The effect of Coolants on cutting tool life.

Wear of the cutting tool on this high strength material is very much more pronounced on the tool nose than on the flank of the tool.

The overhead method of coolant application proved ineffective and no measurable improvement in tool wear was achieved.

The Norgren Spray-Lube method of applying coolant was much more effective. Life tests were carried out using this method with a Standard bar turning tool og optimum tool geometry as stated in Section 3 and also using the Per Pro Cross-Cord tool.

The results of the above tests are recorded on Tables 6 and 7. Figs. 10 and 11 show the data plotted on natural bases, whilst Fig. 9 which includes the VT^n curves for the Cross-Cord tooling, (derived from Tables 6 and 7) shows the data on log/log scales.

The Coolant found to be most effective was as follows:

Shell soluble oil, (1 vol. in 20 vols. of water),
Plus DAG Product 113S Colloidal Molybdenum
Disulphide in water, (1 volume in 600 volumes
of the soluble oil dilute).

APPENDIX I

Description of the equipment.

The Centre lathe

This machine is in new condition.

12 ins. centre height, 25 h.p. motor.
Speed range 12.5 to 1000 r.p.m.
Surface speed indicated by Smith's tachometer.

Tool Servicing

100 grit grinding wheel.
320 grit diamond lap.
Surface finish recorded by Taylor Hobson Talysurf.
Tool wear measured by ZEISS toolmakers microscope

Stop watch.

Tool forces measured by The College of Aeronautics, three component Lathe Dynamometers.

Tool Dynamometers manufactured and supplied by Coventry Grinders Limited, Earlsden Avenue, Coventry.

Cross Cord Tooling by Production Tool Alloy Co.Ltd., Harlington Works, Sharpenhoe. Bedford.

Norgren Spray-Lube Equipment by C.A.Norgren Ltd., Shipston-on-Stour, Warwickshire.

Molybdenum Disulphide by Acheson Colloids Ltd., 18 Pall Mall, London. S.W.1.

TABLE 1

120 Tons H/T Steel

Experiment: The effect of Surface Speed on Cutting Forces

Coolant: None.

CUTTING FORCE TESTS

Tool Material WIMET XX Grade

Tool Geometry

Cutting edge side rake = 15°
Front to Back rake = 0°
Plan Approach Angle = 0°
Plan Trail Angle = 6°
Front and Side Clearance Angle = 6°
Depth of Cut = 0.050 ins.

TEST RESULTS

Surface Speed F.P.M.	Feed Per Rev. ins.	Vertical Force Pounds	Feed Force Pounds
10	0.0039	97	54
17	"	77	42
24	"	96	56
34	"	106	66
48	"	100	64
105	"	96	57
140	"	85	63
10	0.0078	316	90
17	"	272	55
24	"	240	56
34	"	256	48
48	"	256	44
105	"	256	56
140	"	254	56

TABLE 2

120 Tons Ultra H/T Steel

Experiment: The effect of rate of feed on Cutting Forces.

Coolant: None.

CUTTING FORCE TESTS

Tool Geometry - as Table 1.

Tool Material WIMET S.58.

Surface speed = 23 ft/Min.
Depth of Cut = 0.030 ins.

Beed Per rev. ins.	Vertical Force Pounds	Feed Force Pounds
0.00195	31	14
0.0039	72	36
0.00585	99	56
0.0078	115	63
0.0097	144	70
0.0117	156	77
0.0150	168	84
0.018	180	91
0.022	194	98
0.026	208	106

TABLE 3

120 Tons Ultra H/T Steel

Experiment: The effect of feed rate on tool wear (This test checks tool force results)

Coolant: None.

Tool Geometry

Constant as for Table 1.

Feed rates = 0.0039 and 0.0078 ins. per revolution.
Depth of cut = 0.050 ins.
Surface speed = 45 ft. per minute

Duration of cut minutes	Feed ins. per rev.	Flank Wear ins.	Nose Wear ins.	Increase in work Diameter ins.
1	0.0039	0.0005	0.006	0.003
2	"	0.0008	0.010	0.004
4	"	0.0010	0.014	0.006
8	"	0.0028	0.018	0.008
12	"	0.0045	0.021	0.0083
24	"	0.0064	0.026	0.009
1	0.0078	0.0015	0.0068	0.0012
2	"	0.003	0.0078	0.0036
4	"	0.008	0.010	0.0048
8	"	0.012	0.0129	0.0056
16	"	0.0172	0.0172	0.006
24	"	0.021	0.023	0.0068

TABLE 4

120 Tons Ultra H/T Steel

Experiment: The effect of cutting edge side rake (True Rake)

Tool: Pre Pro A.U. Grade Tungsten Carbide Tipped

Tool Geometry

Plan approach angle = 0°
Plan Trail Angle = 6°
Front to Back Rake = 0°
Front and Side Clearance Angles. = 6°

Surface Speed 52 ft. per min.
Depth of Cut = 0.050 ins.

Coolant: None

Side Rake	Feed ins. per Rev.	Vertical Force Pounds	Feed Force Pounds
-15°	0.0039	125	147
-10°	"	117	143
-5°	"	110	102
0°	"	104	90
5°	"	85	70
10°	"	77	63
15°	"	70	52
20°	"	65	50
25°	"	65	38
30°	"	80	40
-15°	0.0058	Chipped cutting edge	
-10°	"	174	171
-5°	"	164	156
0°	"	148	118
5°	"	118	95
10°	"	110	84
15°	"	90	70
20°	"	90	64
25°	"	97	61
30°	"	101	66

TABLE 4 (Cont'd)

Side Rake	Feed ins. per Rev.	Vertical Force Pounds	Feed Force Pounds
-15°	0.0078	194	171
-10°	"	164	156
- 5°	"	185	144
- 0°	"	180	130
5°	"	165	112
10°	"	155	98
15°	"	135	86
20°	"	127	76
25°	"	120	75
30°	"	131	85

TABLE 5

120 Tons Ultra H/T Steel

Experiment: To determine tool life surface speed relationship.

Tool: PER PRO A.U. Grade Tungsten Carbide Tipped.

Depth of Cut = 0.050"
Feed Per Rev = 0.0078"

Coolant: None.

Surface Speed ft. per minute	Cutting Time mins.	Tool Wear: inches	
		NOSE	FLANK
50	1	0.0032	0.0036
"	2	0.0054	0.005
"	3	0.008	0.006
"	6	0.0092	0.008
"	9	0.0114	0.0092
"	12	0.0132	0.0102
"	18	0.016	0.012
"	24	0.020	0.0154
67.5	1	0.0025	0.002
"	3	0.006	0.005
"	6	0.0075	0.0065
"	12	0.002	0.010
"	18	0.017	
"	20	FAILED	
28	1	0.004	0.001
"	3	0.005	0.0014
"	6	0.007	0.002
"	12	0.008	0.004
"	24	0.008	0.008
"	36	0.020	0.0088 Small nose fracture
"	45	0.024	0.009 Small nose fracture

TABLE 6

120 Tons Ultra H/T Steel

Experiment: Tool wear Vs. Cutting Time.

Tool: PER PRO A.U. Grade Tungsten Carbide.

Constants.

Depth of Cut 0.030 ins.
Feed Rate = 0.015 ins/Rev.

Surface Speed RPM	Cutting Time mins.	Tool Wear: inches	
		Dry	with coolant O/H application
350	1 4 8 12	0.004 0.008 0.014 0.021	0.004 0.008 0.012 0.020
200	1 6 12 24	0.004 0.008 0.0125 0.019	0.004 0.008 0.012 0.0175
105	45 20 30 45	0.004 0.010 0.015 0.021	0.0025 0.009 0.0125 0.017

TABLE 7

12 Tons Ultra H/T Steel

Experiment: The effect of Coolants, applied by Norgren Mistcool Method.
Remarks: Coolant Delivery 4 spots per minute air pressure 40 p.s.i.

Constants

Tool: bar type turning.
Depth of cut = 0.050 ins.
Feed per Rev. = 0.0037 ins.
Surface Speed = 50 ft./min.

Coolant	Cutting Time one min. Wear inches		Cutting Time 3 mins. Wear inches		Cutting Time 6 mins. Wear inches	
	Flank	Nose	Flank	Nose	Flank	Nose
Shell Straight Cutting Oil Plus 1 Vol. in 250 DAG Product Molybdenum Disulphide	0.002	0.008	0.004	0.010	0.008	0.014
Shell M3 Soluble Oil. 1 Vol. in 40 Vols. Water	0.002	0.006	0.0035	0.008	0.006	0.013
Shell Straight Cutting Oil	0.002	0.004	0.003	0.008	0.008	0.013
Shell Soluble Oil M3 1 Vol. in 40 Vols. Water Plus 1 vol. in 600 volts. DAG Product 1138 Molybdenum Disulphide in Water	0.0002	0.007	0.0005	0.010	0.0015	0.014
Shell Soluble Oil M3, 1 Vol in 20 vols. water Plus 1 vol. in 600 DAG Product 1138 Molybdenum Disulphide in Water	0.0002	0.008	0.0007	0.010	0.001	0.012

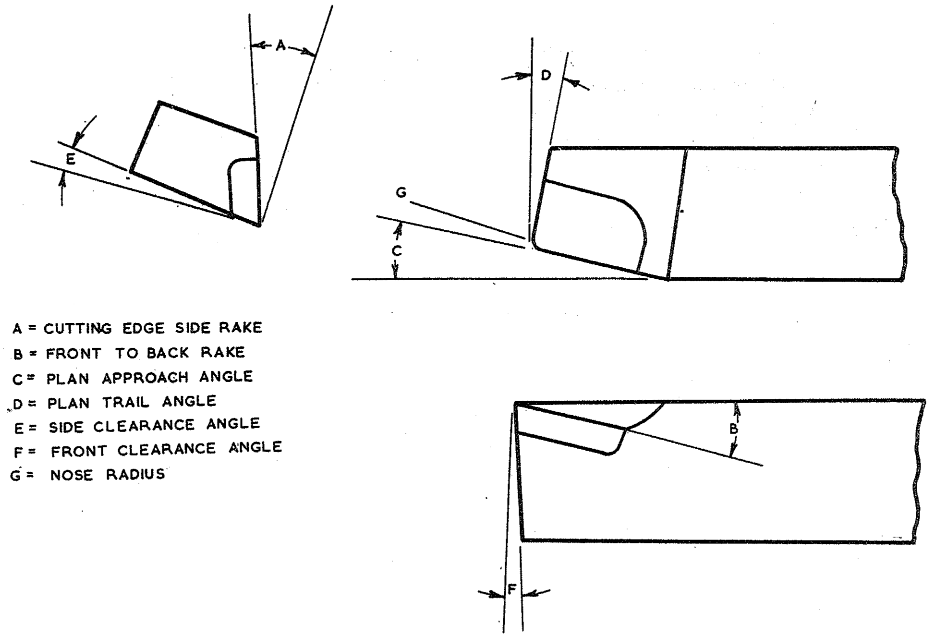

FIG I CUTTING TOOL NOMENCLATURE.

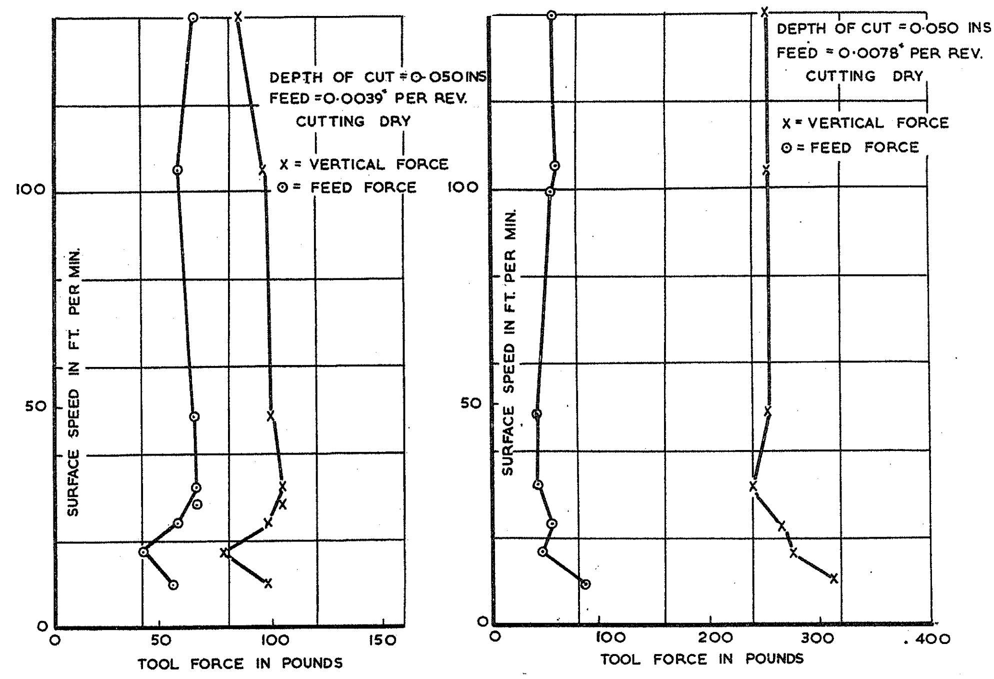

FIG 2. SURFACE SPEED Vs CUTTING FORCES
STANDARD BAR TOOL

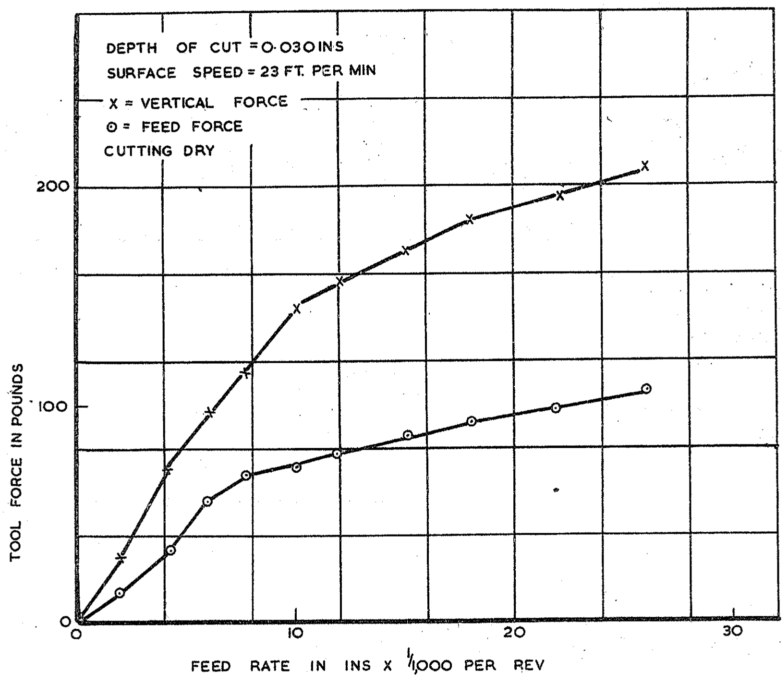

FIG 3. TOOL FORCE Vs FEED RATE PER REV

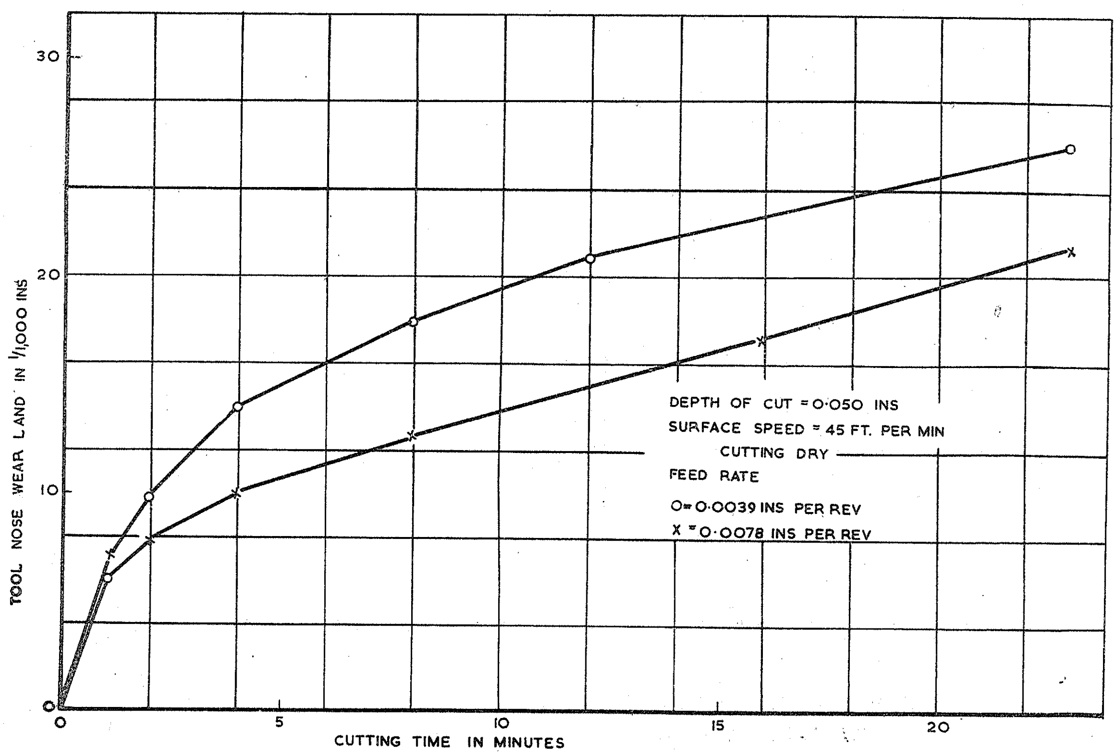

FIG.3A. TOOL WEAR Vs CUTTING TIME

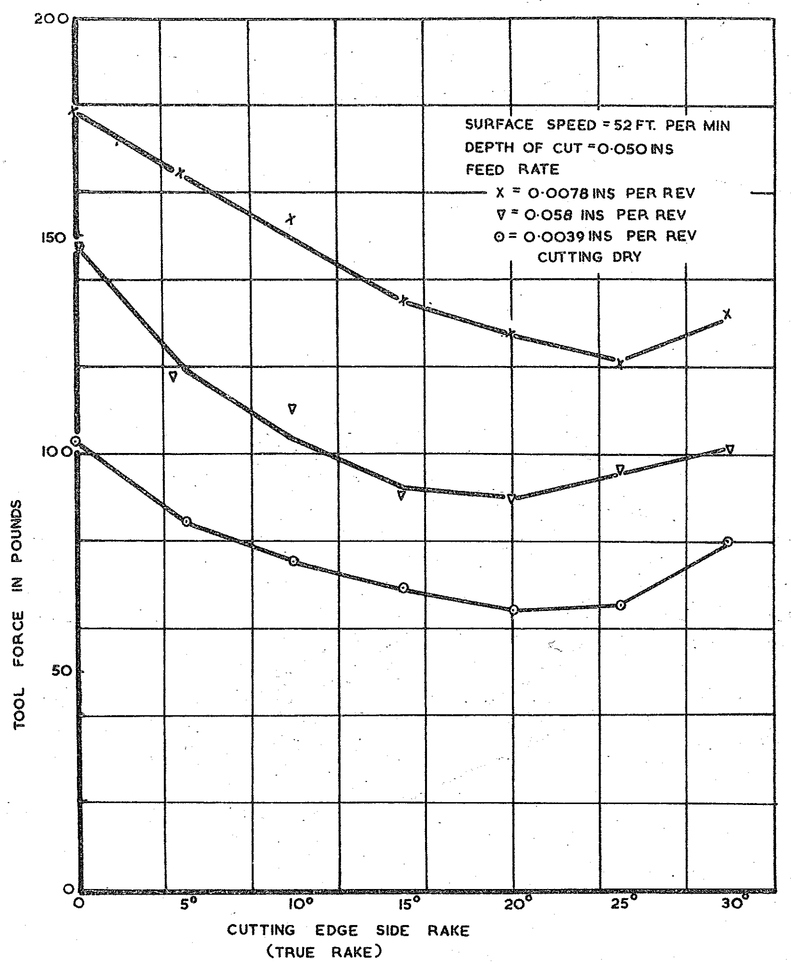

FIG. 4 CUTTING FORCE Vs SIDE RAKE VERTICAL FORCE

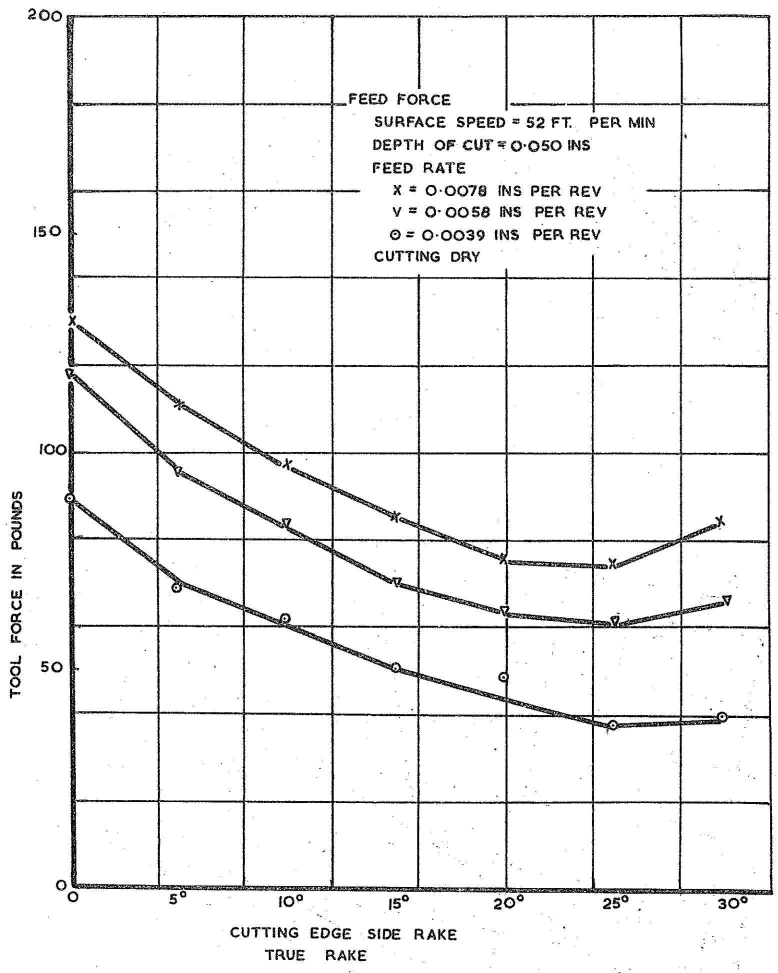

FIG. 5 CUTTING FORCE Vs SIDE RAKE

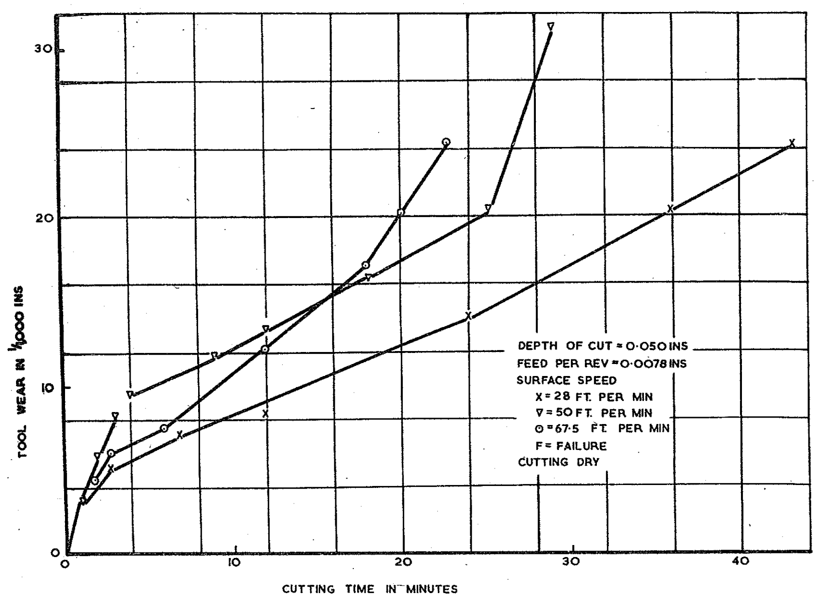

FIG. 6A. TOOL WEAR Vs SURFACE SPEED NOSE WEAR

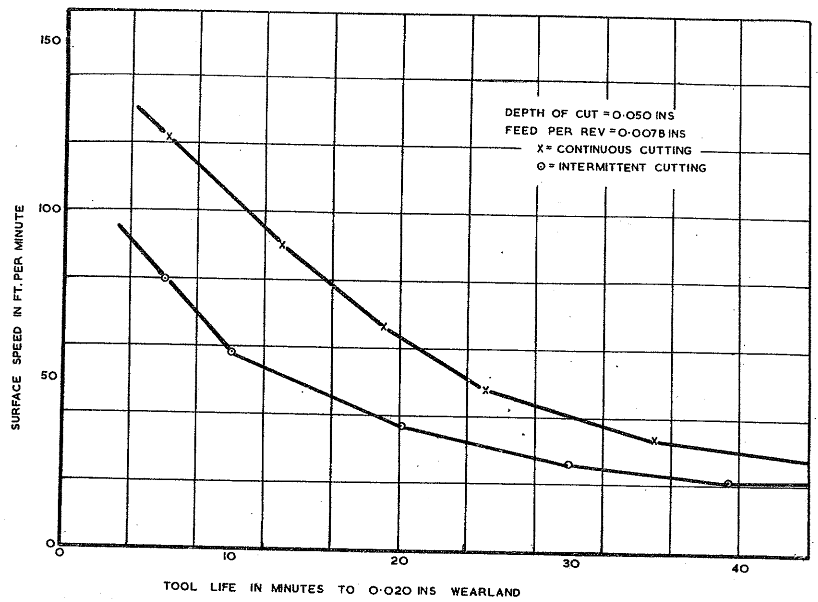

FIG. 7 TOOL LIFE Vs SURFACE SPEED. STANDARD BAR TOOL.

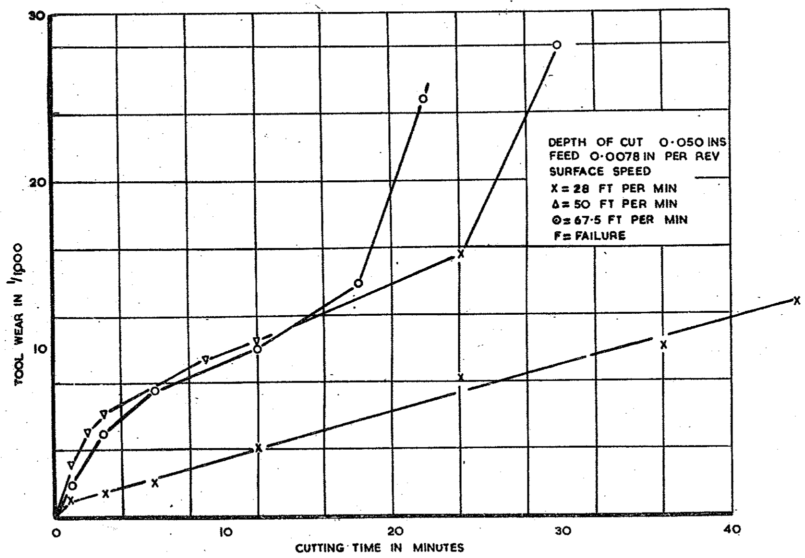

FIG. 6B. TOOL WEAR Vs SURFACE SPEED FLANK WEAR

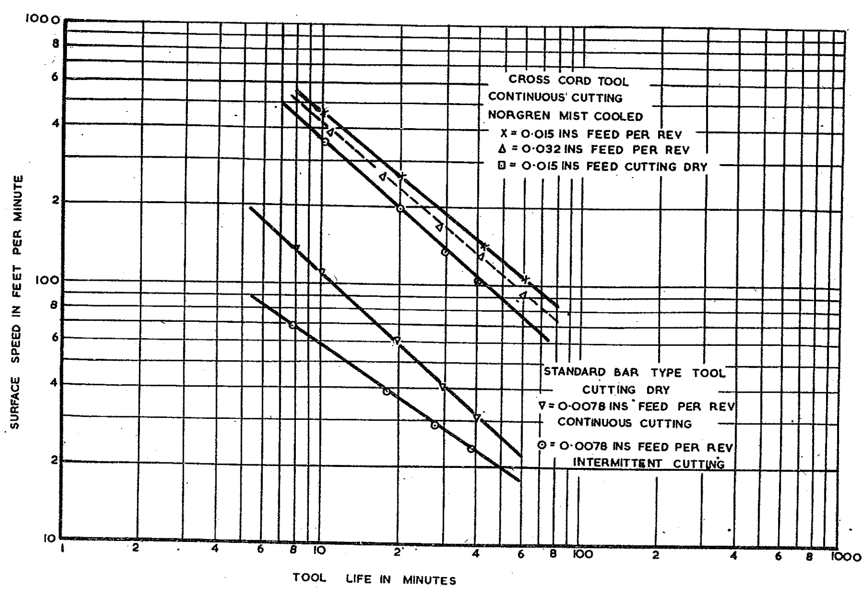

FIG 8 TOOL LIFE Vs SURFACE SPEED TO 0·020 INS WEARLAND.

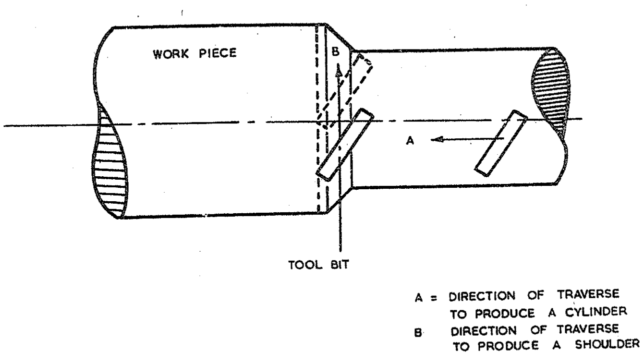

FIG 9. SCHEMATIC PRESENTATION OF PER PRO CROSS-CORD TOOLING

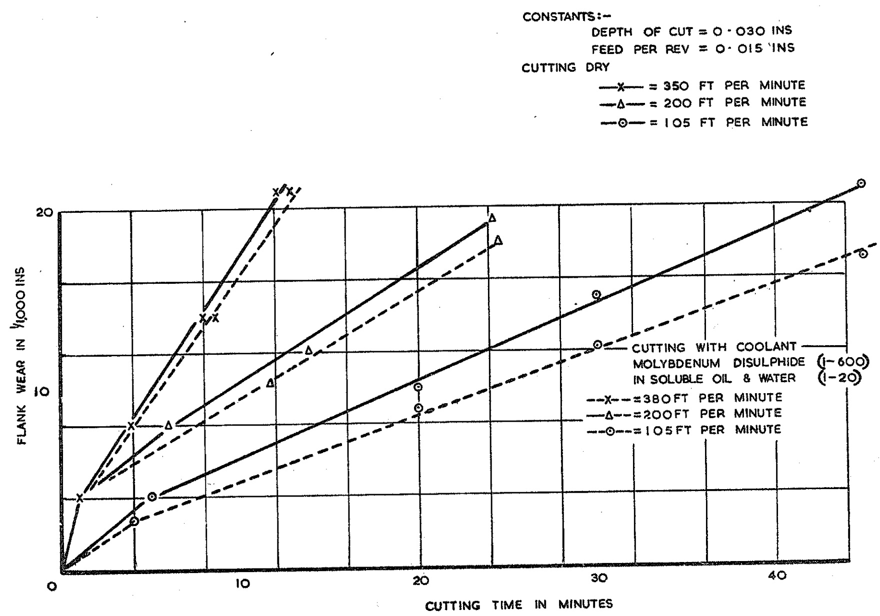

FIG. 10. TOOL WEAR Vs CUTTING TIME CROSS-CORD TOOL

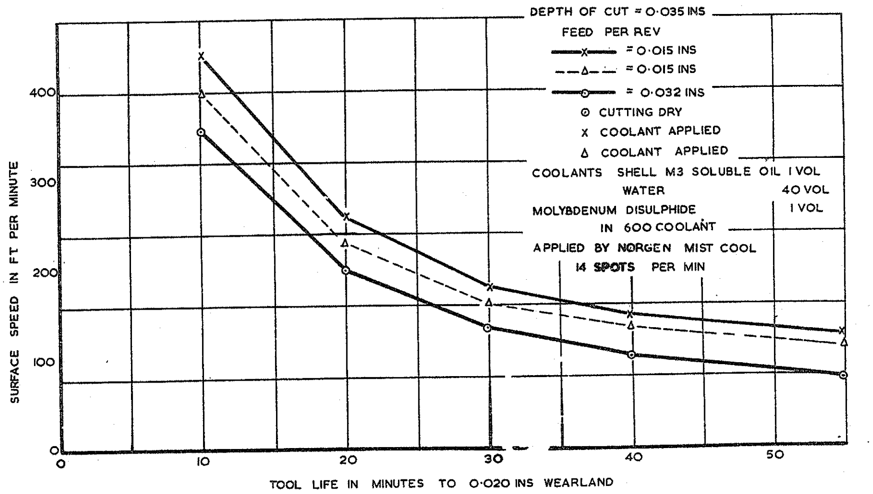

FIG. 11 TOOL LIFE Vs SURFACE SPEED CROSS CORD TOOL