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JACK P. MANATA

MARCH 15, 1993

TOOL LIFE ANALYSIS AND FORECASTING: 1 STATISTICAL ANALYSIS

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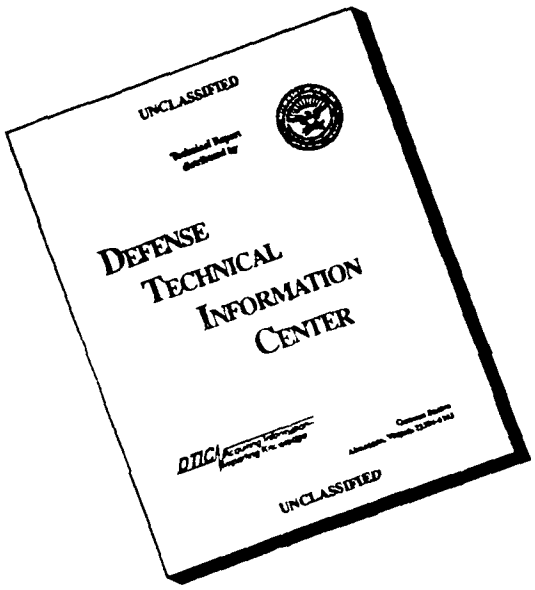

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TO ACHIEVE SEMI-UNTENDED OR UNTENDED MACHINE OPERATION IN A FACTORY ENVIRONMENT FORECASTING TOOL LIFE IS A PREREQUISITE. IN ORDER TO ACHIEVE THIS ROCK ISLAND ARSENAL INITIATED A TOOL LIFE TEST PROGRAM FOR 3/4 INCH DRILLS. AMCCOM SYSTEMS ANALYSIS OFFICE HAS STATISTICALLY ANALYZED THIS DATA AND EMPLOYED IN THE DEVELOPMENT OF A NEURAL NETWORK CAPABLE OF FORECASTING TOOL LIFE. IT HAS BEEN SHOWN THAT A NETWORK HAS THIS CAPABILITY TO FORECAST TOOL LIFE BASED ON THE AVERAGE THRUST VALUES PER WORKPIECE FOR THE FIRST NINE WORKPIECES.

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TABLE OF CONTENTS

SUMMARY_____PAGE 1

DATA_____PAGE 2

ANALYSIS
CRYOGENIC AND UNTREATED DRILLS_____PAGE 13

CORRELATION COEFFICIENTS_____PAGE 16

WORKPIECE AND TOOL HARDNESS_____PAGE 18

CORRELATION BETWEEN PERFORMANCE AND RATIO_____PAGE 20

POOREST, MID-RANGE, AND BEST PERFORMING DRILLS_____PAGE 20

ION IMPLANTED AND UNTREATED_____PAGE 21

SUBSET CORRELATION COEFFICIENT_____PAGE 21

PERFORMANCE-ION TREATED AND UNTREATED DRILLS_____PAGE 22

PERFORMANCE-118, 120, 122 DEGREE POINT ANGLE DRILLS___PAGE 23

PERFORMANCE DATA-NEW DRILLS AND REGROUND DRILLS_____PAGE 25

PERFORMANCE-MANUFACTURER 'A' NEW AND REGROUND DRILLS
CONVENTIONAL GRIND_____PAGE 26

PERFORMANCE-'A' NEW AND REGROUND DRILLS CONVENTIONAL
GRIND_____PAGE 28

PERFORMANCE-'A' REGROUND DRILLS-CONVENTIONAL AND FOUR
FACET GRINDS_____PAGE 28

DISCUSSION_____PAGE 29

CONCLUSION_____PAGE 31

BIBLIOGRAPHY_____PAGE 32

DISTRIBUTION_____PAGE 33

TABLES

TABLE		PAGE
1.0	CHARACTERISTIC VARIABLES	3
2.0	NEW DRILL DESCRIPTIVE DATA CONVENTIONAL POINT GRIND	5
3.0	REGROUND DRILLS DESCRIPTIVE DATA CONVENTIONAL POINT GRIND	6
4.0	REGROUND DRILLS DESCRIPTIVE DATA FOUR FACET POINT GRIND	7
5.0	REGROUND DRILLS DESCRIPTIVE DATA HELICAL POINT GRIND	7
6.0	NEW DRILLS PERFORMANCE DATA CONVENTIONAL POINT GRIND	8
7.0	REGROUND DRILLS PERFORMANCE DATA CONVENTIONAL POINT GRIND	9
8.0	REGROUND DRILLS PERFORMANCE DATA FOUR FACE POINT GRIND	10
9.0	REGROUND DRILLS PERFORMANCE DATA HELICAL POINT GRIND	10
10.0	MEAN TOOL LIFE NEW DRILLS MANUFACTURER 'A'	11
11.0	MEAN VALUES DESCRIPTIVE PARAMETERS	13
12.0	SPEARMAN'S RANK CORRELATION COEFFICIENTS	13
13.0	DESCRIPTIVE DATA NEW UNTREATED DRILLS	14
14.0	DESCRIPTIVE DATA NEW TREATED AND UNTREATED DRILLS	16
15.0	NEW DRILL DESCRIPTIVE DATA	18
16.0	SPEARMAN'S RANK CORRELATION COEFFICIENT	18
17.0	TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS	20
18.0	TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS	21

19.0 TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS 21

20.0 TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS 22

21.0 DESCRIPTIVE STATISTICS 'A' NEW DRILLS 22

22.0 DESCRIPTIVE STATISTICS 'A' REGROUND DRILLS CONVENTIONAL GRIND 23

23.0 DESCRIPTIVE STATISTICS 'A' REGROUND DRILLS FOUR FACET GRIND 23

24.0 TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS 24

25.0 TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS 24

26.0 TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS 25

FIGURES

FIGURE 1.0 DRILL GEOMETRY_____PAGE 3

FIGURE 2.0 WORKPIECE VS. AVERAGE THRUST_____PAGE 12

FIGURE 3.0 WORKPIECE VS. AVERAGE THRUST_____PAGE 16

FIGURE 4.0 WORKPIECE VS. AVERAGE THRUST_____PAGE 17

FIGURE 5.0 WORKPIECE VS. AVERAGE THRUST_____PAGE 19

1. SUMMARY:

The Rock Island Arsenal Operation Directorate is evolving into a Flexible Computer Integrated Manufacturing (FCIM) facility. The FCIM enhances production diversity. But, full FCIM benefits can only be achieved in agile facilities capable of untended or semi-untended operations. However, this capability creates tool replacement problems. In one-operator-one-machine environments the operator is always in the machine's vicinity and can receive sensory signals (aural, visual, olfactory, or tactile) from a worn tool and replace it before the workpiece is damaged. In untended or semi-untended operations the probability that the operator will be in the vicinity, when the tool signals, is reduced and the probability of a ruined workpiece is increased.

The Rock Island Arsenal solution for this problem and achievement of untended or semi-untended operations is to forecast tool life, monitor current tool age (inches drilled, workpieces completed, tool lip wear), and notify the operator when current tool age is within some range of forecasted tool life. The operator can then order a replacement tool and have it available for immediate replacement when current age equals forecasted tool life. This eliminates the possibility of the tool wearing out and ruining the workpiece and it alleviates the wait while a tool is brought to the machine from the tool crib.

Implementation of this solution is contingent on the capability to forecast tool life. Tool life can be forecast in millimeters of drill lip wear, linear inches of metal drilled, or workpieces completed. Tool lip wear is the primary indicator. However, monitoring lip wear requires that either a wear sensor be incorporated into the machine to dynamically measure lip wear or the wear has to be manually measured after each workpiece is completed. The first option increases the cost and complexity of the machine and the second option decreases productivity. These monitoring complications can be circumvented by forecasting tool life in either total inches drilled or workpieces completed, both of which are easy to monitor. Either of these variables can: (1) be forecasted directly, (2) can be derived by forecasting wear and wear rate (millimeter of wear per inch of metal drilled or millimeters of wear per workpiece) and dividing wear by wear rate; (3) can be derived by choosing a constant wear value, such as the mean wear for all tested drills, and using this value in conjunction with a forecasted wear rate to forecast tool life.

The objective of the current effort is to prove the feasibility of using neural networks in this forecasting role. However, data was gathered on many tool parameters so this effort also included a statistical analysis of the data. This was included for two reasons: to answer questions such as; does coating of the drills improve their performance? and to establish an understanding of the working phenomena that might be useful in development of a neural network. The statistical

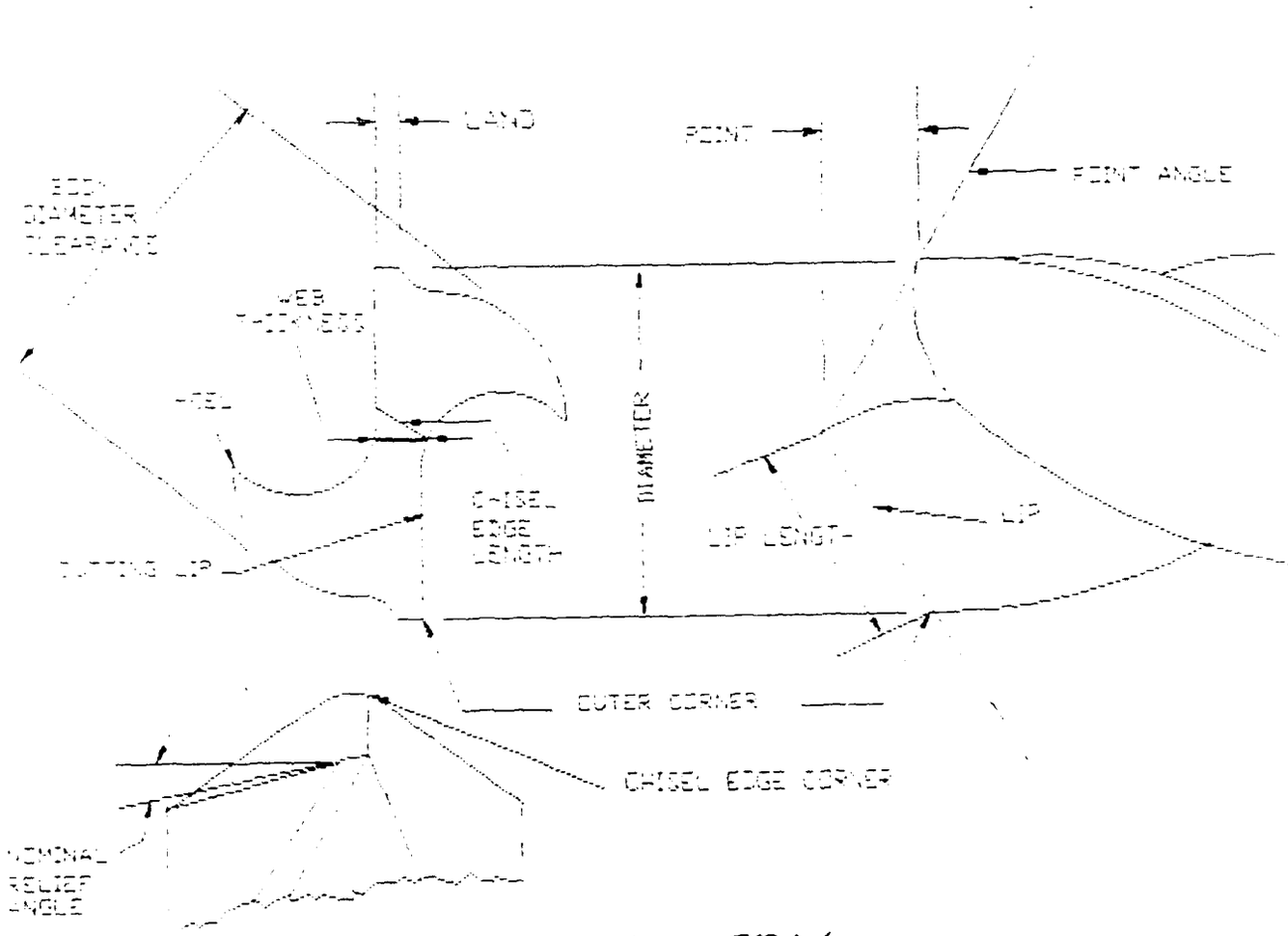
analysis was conducted prior to the neural network activity and is the subject of this report. Most of the statistical work and the neural network investigations were carried out on new drill data, even though three sets of data were available; new drill, reground conventional grind drills, and reground four facet drills. The experiments to obtain the data required for development of a forecasting capability are being conducted by Dr. T. L. Moriarty--of the Rock Island Arsenal Science and Engineering Directorate. The experiments are being conducted within a manufacturing instead of a laboratory environment. Because the experiments are being conducted in this environment the drills cannot be allowed to fail and ruin workpieces, they must be removed prior to failure. Drill removal is at the discretion of the machine operator. The operator's decision to remove a drill is based on sensory signals given off by the drill.

This environment also precludes standard experimental procedures for determining relationships between variables and output, normally used design of experiments.

2. DATA:

Characteristic variables, associated with the drill and workpiece, are listed in Table 1.0 and the relationship between these variables and drill geometry are shown in Figure 1.0. Data was collected on: the first thirteen parameters, plus tool life (inches drilled, workpieces completed, and wear), thrust--percent of maximum direct current required by the thrust motor--and specific energy (hp/(cu.in./min.)) provided by the spindle motor to turn the drill. The dynamic parameter data, thrust and specific energy, were collected every tenth of an inch drilled. For each workpiece 9.3 inches were drilled--8 inches for four 2 inch through holes--and an additional 1.3 inches for 2 additional blind holes. However, since there was little variation in the dynamic data averages per workpiece (9.3 inches) were used.

The descriptive parameters values are shown in Tables 2.0 - 5.0. The data for 25 new drills (23 manufacturer A and 2 manufacturer B) are shown in Table 2.0. Data for 27 reground drills (22 A and 5 B) with a conventional grind are presented in Table 3.0. Data for 18 reground drills with a four faceted grind are shown in Table 4.0, and Table 5.0 is for 2 reground helical grind drills. The drills in these last two tables are all 'A' drills. Regrinding was done by in-house machinists. Tables 6.0-9.0 contain performance data: inches drilled, workpieces, total wear (millimeters) and wear rate (millimeters/inch). Total wear was measured after the operator judged that the tool had reached the end of its useful life and removed it from the machine magazine. Measurements were taken directly from photos of the dull drill points. The constant wear rate was calculated from total wear and inches drilled.



DRILL GEOMETRY
FIGURE 1.0

TABLE 1.0
CHARACTERISTIC VARIABLES

1. POINT ANGLE
2. RELIEF ANGLE
3. CHISEL EDGE LENGTH (CEL)
4. WEB THICKNESS (WEB)
5. DRILL SURFACE TREATED OR UNTREATED
6. CRYOGENIC TREATMENT
7. ION IMPLANTATION SURFACE TREATMENT
8. LOW, MEDIUM, OR HIGH ION FLUX
9. DRILL COATED OR NOT COATED WITH TiN
10. DRILL MANUFACTURERS-2
11. DRILL NEW OR REGROUND
12. TYPE OF GRIND-CONVENTIONAL, HELICAL, FOUR FACET
13. DRILL STRESS RELIEVED OR NOT
14. DRILL HARDNESS
15. WORKPIECE HARDNESS

TABLE 2.0
NEW DRILL DESCRIPTIVE DATA
CONVENTIONAL POINT GRIND

TEST SEQ.	MFG.	PT. ANGLE	RELIEF ANGLE	CEL	WEB	CEL/WEB	CRYO TRTD	ION TRTD	FLUX LEVEL	TiN CTD
1	A	118	10	.050	.042	1.190	NO	NO	N/A	YES
6	A	118	10	.056	.045	1.240	NO	NO	N/A	YES
9	A	118	10	.062	.051	1.220	YES	NO	N/A	YES
10	A	118	10	.068	.056	1.210	YES	NO	N/A	YES
11	B	118	8	.110	.099	1.110	NO	NO	N/A	YES
12	B	118	8	.110	.099	1.110	NO	NO	N/A	YES
13	A	118	10	.050	.042	1.190	YES	NO	N/A	YES
17	A	120	8	.066	.058	1.140	NO	NO	N/A	YES
20	A	122	10	.069	.061	1.130	NO	NO	N/A	YES
26	A	120	11	.088	.076	1.160	NO	NO	N/A	YES
27	A	12[illegible]	10	.062	.053	1.[illegible]	NO	NO	N/A	YES
28	A	120	11	.041	.034	1.210	NO	NO	N/A	YES
33	A	120	11	.054	.047	1.150	NO	NO	N/A	YES
38	A	118	10	.062	.054	1.150	NO	NO	N/A	YES
58	A	120	8	.072	.065	1.110	NO	YES	LOW	YES
61	A	120	6	.059	.051	1.160	NO	YES	HIGH	YES
62	A	120	4	.063	.055	1.150	NO	YES	MED	YES
63	A	118	4	.068	.054	1.260	NO	NO	N/A	YES
67	A	122	4	.053	.044	1.200	NO	NO	N/A	YES
71	A	124	4	.053	.045	1.180	NO	NO	N/A	YES
79	A	122	10	.072	.062	1.160	NO	YES	MED	YES
80	A	122	8	.071	.063	1.130	NO	YES	MED	YES
81	A	122	8	.072	.062	1.160	NO	YES	MED	YES

83	A	120	8	.075	.065	1.150	NO	NO	N/A	YES
91*	A	122	7	.052	.045	1.156	NO	NO	N/A	YES

*NOT USED IN STATISTICAL ANALYSIS AND SOME NEURAL NETWORKS BECAUSE ANALYSIS WAS COMPLETED BEFORE TESTING WAS COMPLETED.
MFG = MANUFACTURER
A = GUHRING
B = PTD
PT = POINT
CEL = CHISEL EDGE LENGTH IN INCHES
WEB = WEB THICKNESS IN INCHES

TABLE 3.0

REGROUND DRILLS DESCRIPTIVE DATA
CONVENTIONAL POINT GRIND

TEST SEQ.	MFG.	PT. ANGLE	RELIEF ANGLE	CEL	WEB	CEL/WEB	CRYO TRTD	ION TRTD	FLUX LEVEL	TiN CTD	STRESS RELIEF
4	A	120	7	.143	.113	1.270	NO	NO	N/A	NO	NO
5	A	118	9	.063	.052	1.210	NO	NO	N/A	NO	NO
7	A	118	4	.044	.041	1.070	NO	NO	N/A	NO	NO
8	A	118	7	.075	.069	1.090	NO	NO	N/A	NO	NO
16	B	118	7	.062	.053	1.170	NO	NO	N/A	NO	NO
18	A	120	6	.059	.053	1.110	NO	NO	N/A	NO	NO
22	A	120	8	.062	.038	1.630	NO	NO	N/A	NO	NO
24	A	120	5	.053	.045	1.180	NO	NO	N/A	NO	NO
29	A	120	10	.042	.037	1.300	NO	NO	N/A	NO	NO
30	A	120	10	.046	.040	1.150	NO	NO	N/A	NO	NO
31	A	120	12	.042	.030	1.400	NO	NO	N/A	NO	NO
32	A	124	12	.048	.037	1.300	NO	NO	N/A	NO	NO
34	A	120	10	.035	.031	1.130	NO	NO	N/A	NO	NO
36	A	120	11	.071	.050	1.420	NO	NO	N/A	NO	NO
39	A	116	12	.053	.048	1.100	NO	NO	N/A	NO	NO
45	A	122	14	.044	.025	1.760	NO	NO	N/A	NO	NO
50	B	120	9	.044	.035	1.260	NO	NO	N/A	NO	NO
51	B	120	8	.044	.035	1.260	NO	NO	N/A	NO	NO
52	A	120	5.	.069	.058	1.19	NO	NO	N A	NO	NO
54	A	118	4	.040	.034	1.180	NO	NO	N/A	NO	NO
55	A	120	4	.094	.067	1.400	NO	NO	N/A	NO	NO
64	A	120	6	.069	.054	1.290	NO	NO	N/A	NO	YES
66	A	120	7	.063	.048	1.310	NO	NO	N/A	NO	YES
70	B	122	5	.125	.099	1.260	NO	NO	N/A	NO	NO
82	A	120	5	.066	.051	1.290	NO	NO	N/A	YES	NO
85	B	120	5	.058	.047	1.230	NO	NO	N/A	YES	NO
87	A	120	5	.072	.058	1.240	NO	NO	N/A	YES	NO

STRESS RELIEF = A NON-HEAT TREATMENT

TABLE 4.0

REGROUND DRILLS DESCRIPTIVE DATA
FOUR FACETED POINT GRIND

TEST SEQ	MFG	PT. ANGLE	RELIEF ANGLE	CEL	WEB	CEL/WEB	CRYO TRTD	ION TRTD	FLUX LEVEL	TiN CTD	STRES RELII
37	A	118	11	.016	.012	1.330	NO	NO	N/A	NO	NO
40	A	120	13	.016	.014	1.140	NO	NO	N/A	NO	NO
53	A	120	6	.056	.048	1.170	NO	NO	N/A	NO	NO
56	A	123	9	.056	.047	1.190	NO	NO	N/A	NO	NO
57	A	118	5	.047	.033	1.420	NO	NO	N/A	NO	NO
59	A	118	8	.094	.075	1.250	NO	NO	N/A	NO	NO
72	A	122	7	.025	.019	1.320	NO	NO	N/A	NO	NO
73	A	122	5	.100	.071	1.410	NO	NO	N/A	NO	NO
74	A	120	5	.069	.052	1.330	NO	NO	N/A	NO	NO
75	A	124	5	.019	.014	1.360	NO	NO	N/A	NO	NO
77	A	122	6	.022	.015	1.470	NO	NO	N/A	NO	NO
84	A	120	5	.016	.013	1.230	NO	NO	N/A	YES	NO
86	A	120	5	.010	.008	1.250	NO	NO	N/A	YES	NO
88	A	122	6	.016	.013	1.230	NO	NO	N/A	YES	NO
89*	A	120	5	.022	.017	1.290	NO	NO	N/A	NO	NO
90*	A	120	5	.014	.011	1.270	NO	NO	N/A	NO	NO
92*	A	124	7	.025	.020	1.250	NO	NO	N/A	NO	NO
93*	A	124	6	.020	.015	1.330	NO	NO	N/A	NO	NO

*NOT USED IN STATISTICAL ANALYSIS AND SOME NEURAL NETWORKS BECAUSE ANALYSIS WAS COMPLETED BEFORE TESTING WAS COMPLETED.

TABLE 5.0

REGROUND DRILLS DESCRIPTIVE DATA
HELICAL POINT GRIND

TEST SEQ	MFG	PT. ANGLE	RELIEF ANGLE	CEL	WEB	CEL/WEB	CRYO TRTD	ION TRTD	FLUX LEVEL	TiN CTD	STRES RELII
68	G	122	5	.119	.104	1.140	NO	NO	N/A	NO	NO
69	G	122	5	.126	.113	1.120	NO	NO	N/A	NO	NO

TABLE 6.0

NEW DRILLS PERFORMANCE DATA
CONVENTIONAL POINT GRIND

TEST SEQ	TOOL LIFE INCHES DRILLED	TOOL LIFE TOTAL WEAR MM	WEAR RATE MM/INCH	TOOL LIFE WORKPIECES
1	204.6	.31	.00152	22
6	241.8	.34	.00141	26
9	213.9	.27	.00126	23
10	167.4	.21	.00125	18
11	260.4	.28	.00107	28
12	269.7	.28	.00104	29
13	279.0	.31	.00111	30
17	446.4	.34	.00076	48
20	390.6	.31	.00079	42
26	204.6	UNK	UNK	22
27	260.4	.28	.00108	28
28	241.8	.31	.00128	26
33	288.3	.30	.00104	31
38	306.9	.30	.00098	33
58	474.3	.39	.00082	51
61	344.1	.31	.00090	37
62	195.3	.28	.00143	21
63	204.6	.25	.00122	22
67	158.1	.31	.00196	17
71	316.2	.28	.00088	34
79	241.8	.28	.00116	26
80	139.5	.22	.00158	15
81	241.8	.32	.00132	26
83	325.5	.25	.00077	35
91	465.0	.31	.00067	50

UNK = TOTAL WEAR WAS NOT MEASURED FOR THIS DRILL

TABLE 7.0

REGROUND DRILLS PERFORMANCE DATA
CONVENTIONAL POINT GRIND

TEST SEQ	TOOL LIFE INCHES DRILLED	TOOL LIFE TOTAL WEAR MM	WEAR RATE MM/INCH	TOOL LIFE WORKPIECES
4	65.1	.16	.00245	7
5	65.1	.13	.00199	7
7	102.1	.16	.00156	11
8	167.4	.28	.00167	18
16	65.1	.16	.00245	7
18	223.2	.37	.00165	24
22	148.8	.27	.00181	16
24	55.8	.17	.00304	6
29	93.0	UNK	UNK	10
30	176.7	.39	.00220	19
31	139.5	UNK	UNK	15
32	83.7	UNK	UNK	9
34	186.0	.33	.00177	20
36	120.9	UNK	UNK	13
39	167.4	.25	.00149	18
45	148.8	.28	.00188	16
50	102.3	.23	.00224	11
51	297.6	.39	.00131	32
52	83.7	.23	.00274	9
54	120.9	.28	.00231	13
55	55.8	.15	.00268	6
64	158.1	.31	.00196	17
66	46.5	.18	.00387	5
70	241.8	.23	.00095	26
82	353.4	.39	.00110	38
85	306.9	.28	.00091	33
87	334.8	.34	.00102	36

TABLE 8.0

REGROUND DRILLS PERFORMANCE DATA
FOUR FACETED POINT GRIND

TEST SEQ	TOOL LIFE INCHES DRILLED	TOOL LIFE TOTAL WEAR MM	WEAR RATE MM/INCH	TOOL LIFE WORKPIECES
37	139.5	.17	.00121	15
40	316.2	.44	.00139	34
53	288.3	.39	.00135	31
56	83.7	.23	.00274	9
57	186.0	.39	.00209	20
59	204.6	.39	.00190	22
72	139.5	.23	.00164	15
73	102.3	.13	.00127	11
74	120.9	.23	.00190	13
75	167.4	.39	.00232	18
77	213.9	.40	.00187	23
84	446.4	.36	.00080	48
86	344.1	.26	.00072	36
88	455.7	.36	.00079	49
89	269.7	.36	.00149	26
90	297.6	.42	.00141	32
92	418.5	.39	.00093	45
93	344.1	.36	.00105	37

TABLE 9.0

REGROUND DRILLS PERFORMANCE DATA
HELICAL POINT GRIND

TEST SEQ	TOOL LIFE INCHES DRILLED	TOOL LIFE TOTAL WEAR MM	WEAR RATE MM/INCH	TOOL LIFE WORKPIECES
68	130.2	.31	.00238	14
69	148.8	.34	.00228	16

There are 25 new drills of which 23 are from the same manufacturer. The analysis of drill variables; point angle, angle, etc., will usually be limited to 22 of these 23 drills unless otherwise noted.

WORKPIECE VS. AVERAGE THRUST
NEW DRILLS - MANUFACTURER "A"
DRILL 1 - NO ION OR CYROGENIC TREATMENT
DRILL 13 - CRYOGENIC TREATMENT

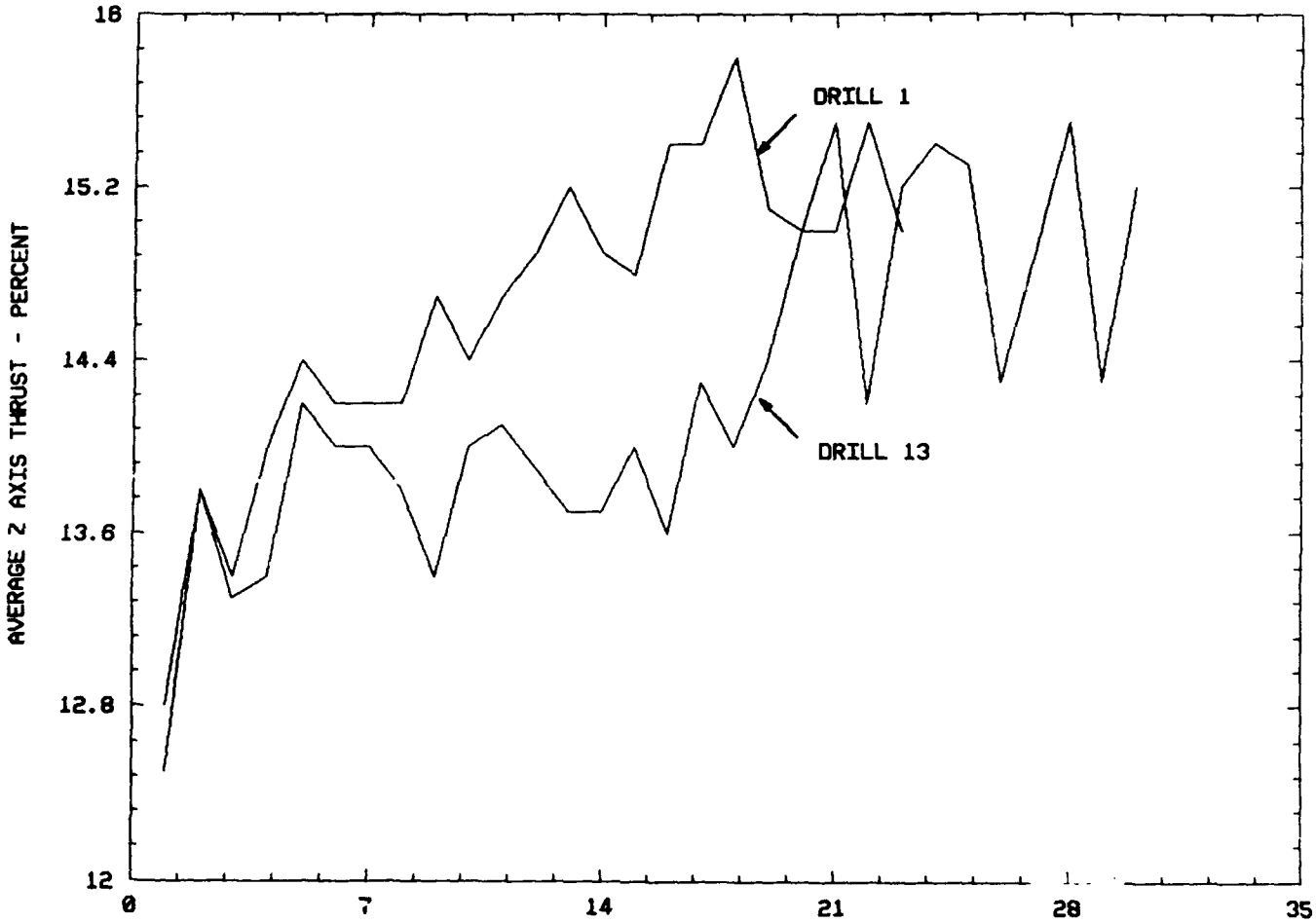


FIGURE 2.0

3. ANALYSIS:

(1) LIFE SPAN OF CRYOGENIC TREATED DRILLS VS. UNTREATED DRILLS:

The drills can be grouped by treatment: ion treatment (with low, medium, and high flux), cryogenic treatment, and untreated. The cryogenic treatment is not a surface treatment since the drills are immersed in the cooling liquid (-300 F). The ion implantation is a surface treatment and is restricted to the titanium nitride coating. It was hypothesized that drills treated with one of these methods could exhibit increased life.

The cryogenic and untreated groups have 3 and 12 members respectively. Because of the limited number of members in the cryogenic group it is not realistic to statistically compare these two groups. However, even if comparisons are not statistically significant they can be informative. In this instance, through happenstance, one member of each group (drill 1 untreated, drill 13 treated, see Table 2.0) have identical point angles, relief angles, chisel edge lengths, web thicknesses, and wear (.31mm when removed by the operator). The unknowns are: distribution of workpiece hardnesses--encountered by each drill--, and individual drill hardness. It is possible that the distribution of workpiece hardness encountered by each drill is unique, but all workpieces are processed the same, so it is probably safe to assume equal distributions. It can also be assumed that the drills, as received from a given manufacturer, prior to subsequent treatment had equal or nearly equal hardness. Therefore, it can be hypothesized that the observed differences in new drill results are due to treatment or lack thereof.

Figure 2.0 is a graph of average thrust vs. workpiece number (each work piece equals 9.3 inches of drilling) for drills 1 and 13 described in the previous paragraph. If the thrust trajectories, shown in Figure 2.0, are considered surrogates for wear trajectories then cryogenic treatment slowed wear rate and reduced average thrust per workpiece. But, can two tests be considered a general result applicable to all drills? Because of the small size of the cryogenic group, statistical techniques cannot be applied to answer this question. However, mean wear and mean inches drilled for the three groups can be used as supporting evidence, either for or against a general application of this one comparison, see Table 10.0.

TABLE 10.0

MEAN TOOL LIFE
NEW DRILLS
MANUFACTURER A

TREATMENT	SAMPLE SIZE	MEAN TOOL LIFE WEAR (MM)	MEAN TOOL LIFE INCHES DRILLED	MEAN TOOL LIFE WORKPIECES
NONE	12	.298	276.1	29.69
CRYOGENIC	3	.263	220.1	23.66
ION	6	.300	272.8	29.33

There is little difference in mean wear and mean inches drilled for the untreated and ion treated drills. The cryogenic treated drills are poorer performers than either of the other subsets. It would appear that cryogenic treatment decreases performance. But, these differences could also be due to drill geometry: point angle, relief angle chisel edge length (cel), web thickness (web), and the ratio between cel and web. The mean values for these parameter are shown in Table 11.0.

TABLE 11.0

MEAN VALUES DESCRIPTIVE PARAMETERS

TREATMENT	SAMPLE SIZE	POINT ANGLE	RELIEF ANGLE	CEL	WEB	RATIO
NONE	13	120	8.5	.061	.052	1.18
CRYOGENIC	3	118	10	.060	.050	1.21
ION	6	121	7.3	.068	.060	1.14

There does not seem to be any relationship between the Table 10.0 mean values and those in Table 11.0. However, to determine if comparing means is logical, Spearman's rank correlation coefficient was calculated for each pair of these parameters, Table 12.0.

WORKPIECE VS. AVERAGE THRUST
NEW DRILLS - MANUFACTURER "A"

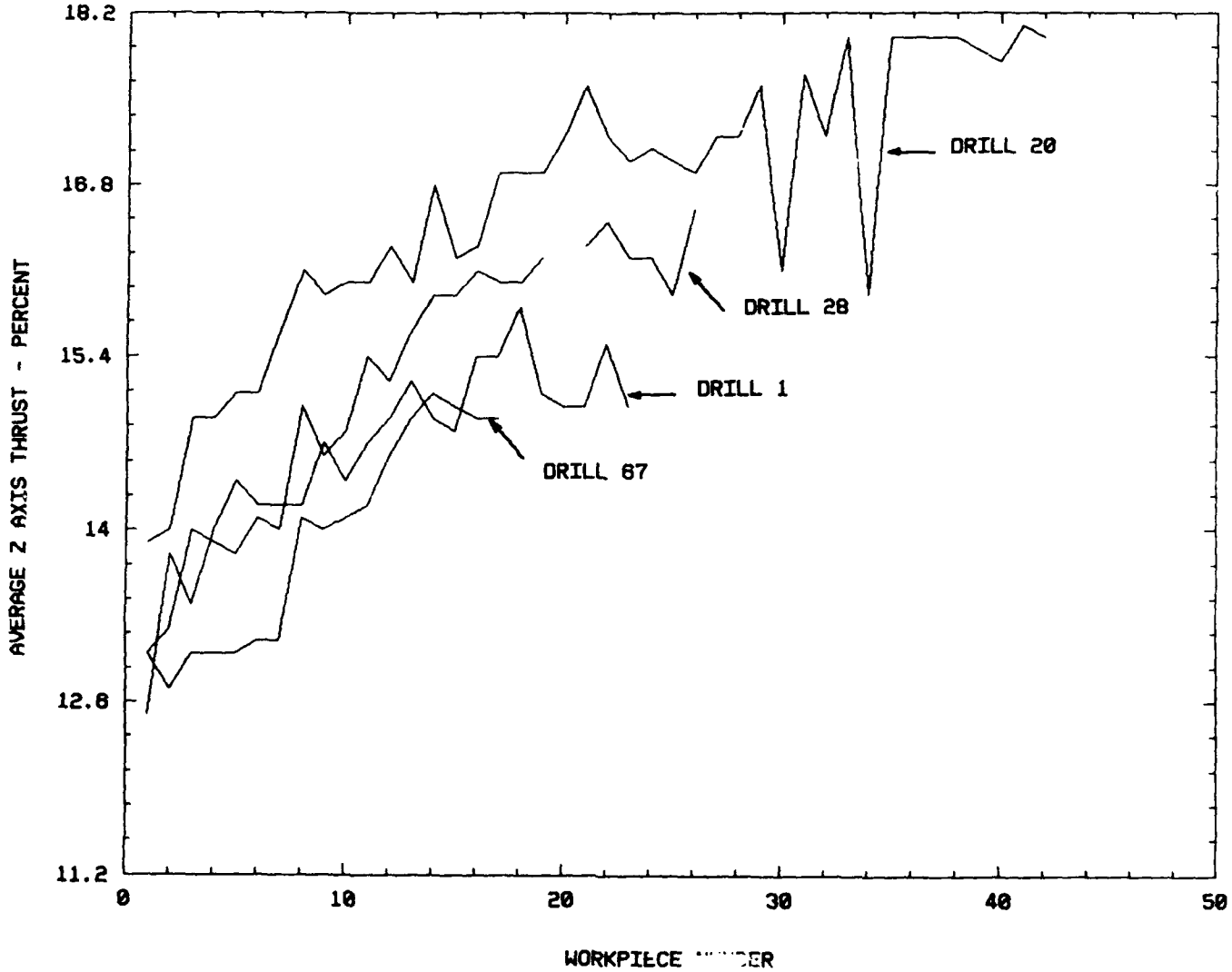


FIGURE 3.0

(2) CORRELATION COEFFICIENTS:

TABLE 12.0

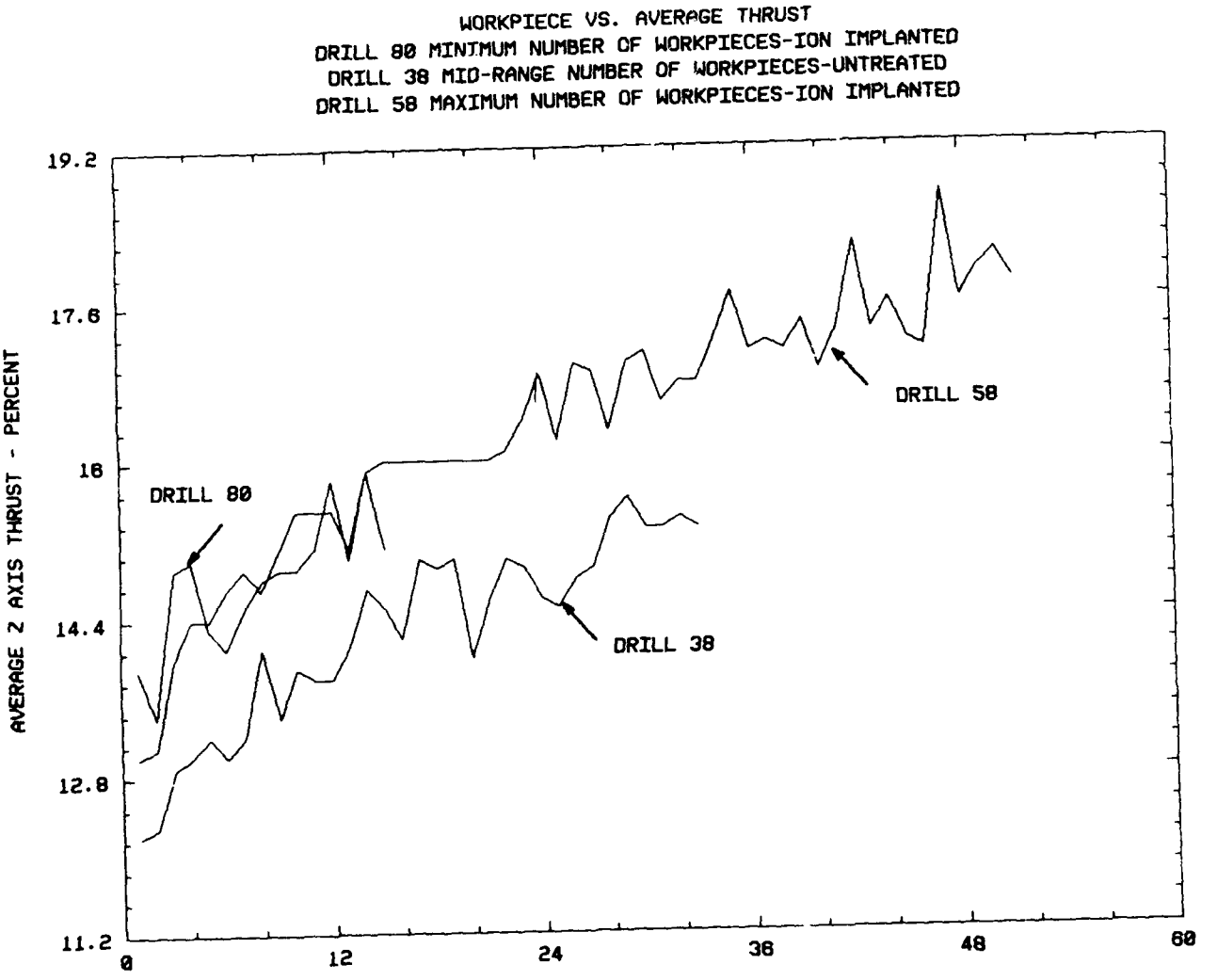
SPEARMAN'S
RANK CORRELATION COEFFICIENTS

RELATIONSHIP	CORRELATION COEFFICIENT	STATISTICALLY SIGNIFICANT
PIECES AND WEAR	.46644	YES*
PIECES AND POINT ANGEL	.02938	NO
PIECES AND RELIEF ANGLE	.08967	NO
PIECES AND CEL	.04265	NO
PIECES AND WEB	.10818	NO
PIECES AND RATIO	-.46819	YES*
WEAR AND POINT ANGLE	-.03136	NO
WEAR AND RELIEF ANGLE	.15936	NO
WEAR AND CEL	-.23593	NO
WEAR AND WEB	-.19797	NO
WEAR AND RATIO	-.16319	NO
POINT AND RELIEF ANGLES	-.31975	NO
CEL AND WEB	.98043	YES*

* 5% RISK

Statistically significant linear relationships exists between: workpieces and wear, workpieces and ratio (cel/ web), and cel and web.

It is interesting that significant correlations exist between workpieces and ratio, workpieces and wear, but not between wear and ratio. In addition there is a relationship between cel and web and between the ratio of these variables and pieces but not between pieces and either of these variables alone. The only parameter in Table 11.0 that seems to explain some of the tool life differences shown in Table 10.0 is ratio. The workpieces-ratio relationship is negative so that as ratio increases workpieces decreases. But, this is not a strong relationship; it only explains sixteen percent of the variance. The tool life values in Table 10.0 and ratios in Table 11.0 can be used as supporting evidence for this weak relationship. The cryogenic subset has the highest mean ratio and lowest workpieces, the ion subset has the lowest ratio and the second highest workpieces, the untreated subset is in between with respect to ratio and it completed the most workpieces.


WORKPIECE VS. AVERAGE THRUST
DRILL 80 MINIMUM NUMBER OF WORKPIECES-ION IMPLANTED
DRILL 38 MID-RANGE NUMBER OF WORKPIECES-UNTREATED
DRILL 58 MAXIMUM NUMBER OF WORKPIECES-ION IMPLANTED
AVERAGE Z AXIS THRUST - PERCENT
19.2
17.6
16
14.4
12.8
11.2
0
12
24
36
48
60
DRILL 80
DRILL 58
DRILL 38
WORKPIECE NUMBER
FIGURE 4.0

The tool life differences shown in Table 10 0 cannot be attributed to either treatment or drill point geometry. If these are not the cause of the differences it is possible that the assumptions of equal distribution of workpiece hardness or equal drill hardness cannot be supported and the differences are caused by differences in workpiece hardness and/or drill hardness.

(3) WORKPIECE AND TOOL HARDNESS:

It is possible to determine whether or not the assumptions concerning workpiece hardness distribution and drill hardness are supportable. From the Figure 2.0 curves it can be implied that a shallow thrust trajectory and low thrust values signal a low wear rate and more workpieces. This can be examined further, and by doing so the assumptions about hardness can also be examined. In addition to the previous two drills (1 and 13), four other drills (untreated) had a lip wear of .31mm when removed. Characteristics for these four drills are repeated in Table 13.0 and Figure 3.0 is a graph of average thrust vs. workpiece. It is assumed that comparing these drills is valid because the previous work has indicated that there isn't any strong correlation between descriptive parameters (cel, web, ratio, etc.) and performance.

TABLE 13.0

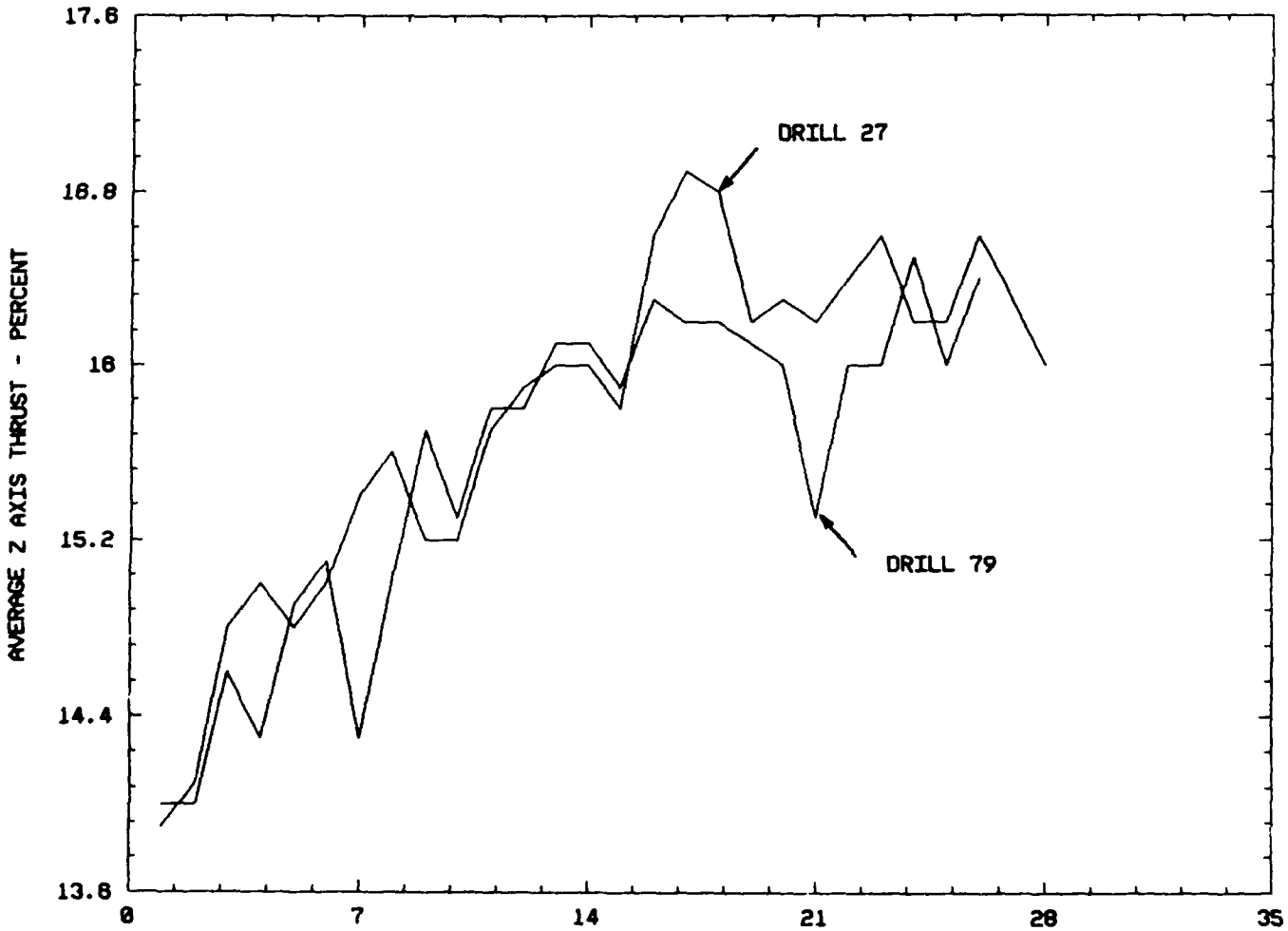
DESCRIPTIVE DATA
NEW UNTREATED DRILLS

TEST SEQ.	MFG	PT ANGLE	RELIEF ANGLE	CEL	WEB	CEL/WEB	CRYO TREATED	ION TREATED	TOOL LIFE WORKPIECES	TiN COATED
1	A	118	10	.050	.042	1.190	NO	NO	22	YES
20	A	122	10	.069	.061	1.130	NO	NO	42	YES
28	A	120	11	.041	.034	1.210	NO	NO	26	YES
67	A	122	4	.053	.044	1.200	NO	NO	17	YES

The four trajectories have the same general shape and slope, however, there is a reversal from Figure 2.0. For this set of drills the one with the highest thrust values drilled more workpieces and the one with the lowest values had the poorest performance. If the assumption is correct; that the thrust trajectory is a surrogate for the wear trajectory, then the drill with the shallowest trajectory should have performed the best. This data does not support that assumption.

If the assumption is correct; that workpiece hardness distribution is same for all drills then the higher thrust levels should indicate a poorer tool and the lower levels a better tool. But, according to the data the poorer tool performed better and vice versa.

WORKPIECE VS. AVERAGE THRUST
DRILL 27 - UNTREATED
DRILL 79 - ION TREATED MEDIUM FLUX



WORKPIECE NUMBER
FIGURE 5.0

If the assumption is correct; that all tools have approximately the same hardness then the distribution of workpiece hardness is different since all the trajectories are different. If, however, it is assumed that high thrust levels are associated with workpiece hardness, then the data indicates that the harder workpieces result in lower tool wear rates.

(4) CORRELATION BETWEEN PERFORMANCE AND RATIO:

The comparison of these four drills provides additional evidence that the correlation between tool life and ratio (cel/web) is not a strong one. Drill 20 has the lowest ratio and the highest tool life, which agrees with the correlation. But, drill 28 has the highest ratio and the second best tool life, and this doesn't support the correlation.

(5) POOREST, MID-RANGE, BEST PERFORMING DRILLS:

Figure 4.0 is the same type plot as Figure 3.0 for three other new drills. These drills were chosen because they are the poorest, mid-range, and best performers. It just happened that two of the drills have identical ratios and the other's are slightly less. Drill 80, the poorest, had worn .22mm when removed, drill 38, the mid-range performer, had worn .30mm, and drill 58, the best, had worn .39mm.

TABLE 14.0

DESCRIPTIVE DATA
NEW TREATED AND UNTREATED DRILLS
POOREST, MID-RANGE, BEST PERFORMING DRILLS

TEST SEQ.	MFG	PT ANGLE	RELIEF ANGLE	CEL	WEB	CEL/WEB	TOOL LIFE WORKPIECES	ION TREATED	FLUX LEVEL	TiN COATED
80	A	122	8	.071	.063	1.130	15	YES	MED	YES
38	A	118	10	.062	.054	1.150	33	NO	N/A	YES
58	A	120	8	.072	.065	1.110	51	YES	LOW	YES

For these drills its the untreated one that has the shallow thrust trajectory and low thrust values. This is in contraposition to those shown in Figure 2.0 where the cryo treated drill had these characteristics. The thrust trajectories of the poorest and best performers have the same shape and magnitudes, at least up to the 15 workpieces completed by drill 80. This provides additional evidence that thrust trajectory is not a good surrogate for wear trajectory.

The negative correlation between workpieces and ratio is not strongly supported by this comparison; the mid-range performer had the highest ratio the poorest performer had the second highest ratio and the best performer had the lowest ratio.

(6) ION IMPLANTED AND UNTREATED:

The first comparison, Figure 2.0, was between an untreated and a cryogenically treated drill. The last comparison, Figure 4.0, involved two ion treated drills and an untreated one. To make a comparison comparable to the one shown in Figure 2.0 but for an untreated and an ion treated drill; two drills were chosen whose characteristics are very close, see Table 15.0 and Figure 5.0.

TABLE 15.0

NEW DRILL DESCRIPTIVE DATA

TEST SEQ.	MFG	PT ANGLE	RELIEF ANGLE	CEL	WEB	CEL/WEB	TOOL LIFE WORKPIECES	ION TREATED	FLUX LEVEL	TiN COATED
27	A	120	10	.062	.053	1.170	28	NO	N/A	YES
79	A	122	10	.072	.062	1.160	26	YES	MED	YES

The trajectories are almost identical in shape and values and the final results differ by only two workpieces or 18.6 inches drilled. This suggests that ion implantation is not effective.

(7) SUBSET CORRELATION COEFFICIENTS:

Previously, Table 12.0, Spearman's rank correlations were calculated fc all new drills produced by manufacturer A and a significant correlation exists between inches drilled and cel/web ratio. It is possible that significant correlations might exist for subsets of these drills when a significant correlation doesn't exist for the whole set. Table 16.0 shows coefficients for all drills, a repeat of Table 12.0, plus untreated and ion implanted ones. Cryogenic drills are not shown separately because the subse only consists of three members.

TABLE 16.0

SPEARMAN'S RANK
CORRELATION COEFFICIENTS

RELATIONSHIP	CORRELATION COEFFICIENT ALL NEW DRILLS	CORRELATION COEFFICIENT UNTREATED	CORRELATION COEFFICIENT ION IMPLANTATION
PIECES AND WEAR	.46644*	-.01439	.86765*
PIECES AND POINT ANGEL	.02938	.11159	-.49507
PIECES AND RELIEF ANGLE	.08967	.02504	.09241
PIECES AND CEL	.04265	.31068	.21561
PIECES AND WEB	.10818	.43967	.05882
PIECES AND RATIO	-.46819*	-.76495*	.03080
WEAR AND POINT ANGLE	-.03136	-.21643	-.39606
WEAR AND RELIEF ANGLE	.15936	.42138	.00000
WEAR AND CEL	-.23532	-.32741	.36962
WEAR AND WEB	-.19787	-.32382	.16176
WEAR AND RATIO	-.16319	-.04333	.03080
POINT AND RELIEF ANGLES	-.31975	-.15994	.72587
CEL AND WEB	.98043*	.97514*	.70845

* SIGNIFICANT AT 5% RISK LEVEL

Significant correlations exist between: (1) workpieces completed and wear for the set of all drills tested and the subset of ion implanted ones, it is not significant for the subset of untreated drills; (2) workpieces completed and ratio for the set of all drills and the subset of untreated ones; it is not significant for the subset of ion implanted drills; (3) ce and web for all and untreated. With respect to this last statement it woul seem that all subsets should exhibit a correlation between cel and web because of manufacturing geometry. The lack of such a significant correlation for the ion implanted subset might indicate that the ion implantation process affects this geometry. The lack of a significant correlation between workpieces completed and total wear for the subset of untreated drills seems to contradict common sense if tool hardness and the distribution of workpiece hardnesses are the same for all drills. The lack of a significant correlation between workpieces completed and ratio for the subset of ion implanted drills might be what is prohibiting the use of rati as a predictor for tool life.

(8) PERFORMANCE-ION TREATED AND UNTREATED DRILLS

Previously, mean tool life for the subsets--untreated, cryogenically treated, and ion treated--,was used to determine if cryogenic treatment improved performance, Table 10.0. However, because the cryogenic subset wa small, statistical comparisons of subset means could not be performed. But it is possible to conduct a statistical comparison of the ion and untreated subsets. Specifically, are the means and standard deviation of workpieces completed and drill wear for the two subsets equal? The results are shown Table 17.0.

TABLE 17.0

TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS
TOOL LIFE - INCHES DRILLED AND MILLIMETERS OF WEAR
ION IMPLANTED DRILLS AND UNTREATED DRILLS

VARIABLE	SAMPLE 1 NO TREATMENT SAMPLE SIZE	SAMPLE 2 ION TREATMENT SAMPLE SIZE	MEAN 1	MEAN 2	STD DEV 1	STD DEV 2	P-LEVEL MEAN*	P-LEVEI STD DE\
LIFE INCHES DRILLED	12	6	276.1	272.8	81.8	119.5	.848	.274
LIFE MM WEAR	12	6	.2983	.3000	.029	.056	.934	.065

* RISK OF REJECTING A TRUE NULL HYPOTHESIS

The null hypotheses of equal means and standard deviation for inches drilled for the subsets cannot be rejected. This result implies that inches drilled is not improved by ion implantation. This in conjunction with the previous comparison, for the cryogenic treatment, tends to support the contention that additional treatment of the drills is unwarranted.

The wear standard deviation for the subset is different. This indicates that the variation in wear o. ion treated dril s is greater than for untreated drills. This could be due to the ion implantation process.

(9) PERFORMANCE-118, 120, 122 DEGREE POINT ANGLE DRILLS

The correlation coefficients, Table 16.0, imply that workpieces and drill wear are not related to point angle. It is possible to investigate this relationship further by determining if the means and standard deviation of inches drilled and drill wear are equal for drill groupings based on poin angle, Tables 18.0 - 20.0.

TABLE 18.0

TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS
TOOL LIFE-INCHES DRILLED AND MILLIMETERS OF WEAR
118 AND 120 DEGREE POINT ANGLES

VARIABLE	SAMPLE 1 118 DEG. PT. ANGLE	SAMPLE 2 120 DEG. PT. ANGLE	MEAN 1	MEAN 2	STD DEV 1	STD DEV 2	P-LEVEL MEAN*	P-LEV STD DE
LIFE INCHES DRILLED	8	7	258.1	304.2	88.2	90.3	.335	.938
LIFE MM WEAR	8	7	.2913	.3029	045	.044	.623	.959

* RISK OF REJECTING A TRUE NULL HYPOTHESIS

TABLE 19.0

TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS
TOOL LIFE-INCHES DRILLED AND MILLIMETERS OF WEAR
118 AND 122 DEGREE POINT ANGLES

VARIABLE	SAMPLE 1 118 DEG. PT. ANGLE	SAMPLE 2 122 DEG. PT. ANGLE	MEAN 1	MEAN 2	STD DEV 1	STD DEV 2	P-LEVEL MEAN*	P-LEV STD DE
LIFE INCHES DRILLED	8	5	258.1	234.4	88.2	99.2	.661	.73
LIFE MM WEAR	8	5	.2913	.2880	.045	.041	.898	.89

* RISK OF REJECTING A TRUE NULL HYPOTHESIS

TABLE 20.0

TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS
TOOL LIFE-INCHES DRILLED AND MILLIMETERS OF WEAR
120 AND 122 DEGREE POINT ANGLES

VARIABLE	SAMPLE 1 120 DEG. PT. ANGLE	SAMPLE 2 122 DEG. PT. ANGLE	MEAN 1	MEAN 2	STD DEV 1	STD DEV 2	P-LEVEL MEAN*	P-LEV STD DE
LIFE INCHES DRILLED	7	5	304.2	234.4	90.3	99.2	.233	.796
LIFE MM WEAR	7	5	.3029	.2880	.044	.041	.565	.933

* RISK OF REJECTING A TRUE NULL HYPOTHESIS

The hypothesis of equal means and standard deviations for inches drilled and wear for point angles of 118, 120, 122 degrees cannot be rejected. This result supports the correlation coefficient result that there isn't a correlation between point angle and performance. This is an especially significant fact because these subsets include cryogenically treated, ion treated, and untreated drills. The 118 degree subset includes all three cryogenically treated drills, both the 120 and 122 degree subsets include three of the ion implanted drills.

(10) PERFORMANCE DATA-NEW DRILLS AND REGROUND DRILLS:

The preceding work was limited to new drills, generally manufacturer 'A' drills. But, data was also collected on other drills. In fact all the data can be partitioned into the following subsets: 'A' new drills, 'B' new drills, 'A' reground drills-conventional grind, 'B' reground drills-conventional grind, 'A' reground drills-four facet grind, 'A' reground drills-helical grind. Subset statistics are listed in Tables 21.0 - 23.0.

TABLE 21.0

DESCRIPTIVE STATISTICS
'A' NEW DRILLS

VARIABLE	SAMPLE SIZE	MIN VALUE	MAX VALUE	MEAN	STD DEV	95 PERCENT CONFIDENCE INTERVAL FOR MEAN
LIFE INCHES DRILLED	22	139.5	474.3	267.6	88.55	228.14 - 307.03
LIFE MM WEAR	21	.21	.39	.2938	.0409	.2751 - .3125
'A' + 'B' NEW DRILLS						
LIFE INCHES DRILLED	24	139.5	474.3	267.4	84.63	231.48 - 303.26
LIFE MM WEAR	23	.21	.39	.2926	.0392	.2756 - .3096

TABLE 22.0

DESCRIPTIVE STATISTICS
'A' REGROUND-CONVENTIONAL GRIND

VARIABLE	SAMPLE SIZE	MIN VALUE	MAX VALUE	MEAN	STD DEV	95 PERCENT CONFIDEN(INTERVAL FOR ME,
LIFE INCHES DRILLED	22	46.5	353.4	140.8	81.85	104.31 - 177.2:
LIFE MM WEAR	18	.13	.39	.25[illegible]	.0859	.2165 - .3023
'A' + 'B' REGROUN-CONVENTIONAL GRIND						
LIFE INCHES DRILLED	27	46.5	353.4	152.2	89.17	116.97 - 187.5:
LIFE MM WEAR	23	.13	.39	.2591	.0838	.2228 - .2955

TABLE 23.0

DESCRIPTIVE STATISTICS
'A'REGROUND FOUR FACET GRIND

VARIABLE CONFIDENCE	SAMPLE SIZE	MIN. VALUE	MAX. VALUE	MEAN	ST.DEV.	95 PERCENT INTERVAL FOR MEAN
LIFE INCHES DRILLED	15	46.5	455.7	218.2	128.33	146.67 - 289.81
LIFE MM WEAR	15	.13	.44	.3020	.1038	.2441 - .3599

For the reground drills, Tables 22.0 and 23.0, the low minimum values f(inches drilled were due to the fact that some of the drill points chipped o: the drills had to be removed because of rapid excessive wear. It is postulated that this was caused by asymmetrical variations in drill geometr; due to improper regrinding.

(11) PERFORMANCE-MANUFACTURER 'A' NEW AND REGROUND DRILLS, CONVENTIONAL GRIND.

The data for the reground drills, in the following tables, was censored any tool that had drilled less than 93 inches when removed was not consider(in the comparisons. The selection of this value is related to a parallel effort investigating the use of neural networks for tool life forecasting. The network was more accurate when it used nine thrust values to define the input vector, this equates to 83.7 inches. If the life forecast is made at 83.7 inches then the earliest the drill can be removed is one workpiece lat(or 93 drilling inches. Table 24.0 contains data on the comparison of means and standard deviations of 'A' conventional grind new and reground drills. All of the new drills are titanium nitride coated, two of the reground drill

have been recoated. The set of new drills includes treated (cryogenic and ion implanted) and untreated drills. The history of the reground drills wit respect to their membership in the set of new drills is unknown.

TABLE 24.0

TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS
TOOL LIFE-INCHES DRILLED AND MILLIMETERS OF WEAR
"A" NEW AND REGROUND DRILLS-CONVENTIONAL GRIND

VARIABLE	SAMPLE 1 "A" NEW	SAMPLE 2 "B" REGROUND	MEAN 1	MEAN 2	STD DEV 1	STD DEV 2	P-LEVEL MEAN*	P-LEVEL STD DEV*
LIFE INCHES DRILLED	22	15	267.6	176.1	88.6	75.9	.0024	.561
LIFE MM WEAR	21	12	.2938	.3042	.041	.066	.5799	.062

* RISK OF REJECTING A TRUE NULL HYPOTHESIS

Regrinding the "A" drills with an identical conventional grind has resulted in a significant shift in the mean tool life (inches drilled) of approximately minus 90 inches. However, the standard deviation has not changed. Basically the distribution of drill lifetimes has shifted to the left. If the drill life is measured in tool lip wear instead of inches drilled then the hypothesis of equal mean lifes for the two subsets cannot t rejected, but the wear standard deviation has changed. The standard deviation of the reground drills is greater than the one for new drills. These changes might be due to the regrinding operation. However, a second confounding variable is that the new drills are all Titanium Nitride coated and only two of the reground drills had been recoated.

(12) PERFORMANCE-"A" NEW AND REGROUND DRILLS
CONVENTIONAL GRIND:

Table 25.0 is a comparison of untreated new "A" drills with the titanit nitride coating and reground "A" drills without the coating.

TABLE 25.0

TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS
TOOL LIFE-INCHES DRILLED AND MILLIMETERS OF WEAR

VARIABLE	SAMPLE 1 "A" NEW	SAMPLE 2 "A" REGROUND	MEAN 1	MEAN 2	STD DEV 1	STD DEV 2	P-LEVEL MEAN*	P-LEVEL STD DEV*
LIFE INCHES DRILLED	13	13	276.1	150.1	81.2	35.8	.00003	.008
LIFE MM WEAR	12	10	.2983	.2920	.029	.065	.3050	.016

*RISK OF REJECTING A TRUE NULL HYPOTHESIS

Removal of the recoated drills from the set of reground drills and removing treated drills from the set of new drills has changed the statistics. Regrinding without recoating has shifted the mean a minus 126 inches as opposed to a shift of minus 90 inches when the recoated drills are members of the reground set. It has also 'fected the standard deviation comparison the hypothesis of equal standard deviations for inches drilled ca now be rejected where it couldn't be rejected in the previous comparison. However, the total wear characteristics have not changed overly much. What seems to have changed is not the total wear but the way in which the drill wears. Therefore it seems safe to hypothesize that recoating reground drill does improve performance.

(13) PERFORMANCE-"A" REGROUND DRILLS- CONVENTIONAL AND FOUR FACET GRINDS.

Performance data has been gathered on reground drills with conventional four facet, and helical grinds. The number of drills with conventional and four facet grinds is sufficient that statistical tests can be conducted to determine if the mean inches drilled and mean wear for the two groups are equal. The data for these groups is shown in Table 26.0. Neither group has any recoated members.

TABLE 26.0

TESTS FOR EQUAL MEANS AND STANDARD DEVIATIONS
TOOL LIFE-INCHES DRILLED AND MILLIMETERS OF WEAR

VARIABLE	SAMPLE 1 "A" REGROUND CONV. FACET	SAMPLE 2 "A" REGROUND FOUR	MEAN 1	MEAN 2	STD DEV 1	STD DEV 2	P-LEVEL MEAN*	P-LEV STD DE
LIFE INCHES DRILLED	13	10	150.2	187.9	35.8	70.2	.108	.03
LIFE MM WEAR	10	10	.2920	.3160	.065	.113	.567	.1

*RISK OF REJECTING A TRUE NULL HYPOTHESIS

The hypothesis that the mean number of inches drilled for the two group: are equal cannot be rejected. But, the hypothesis that the standard deviations are equal can be rejected. The variation in performance for the four facet drills is greater than for the conventional grind drills. The equal means and standard deviations for total wear for the groups cannot be rejected. These comparisons imply that there isn't any gain in performance from four facet grind.

4. DISCUSSION:

This effort was initiated to provide a manufacturing facility with the capability to implemented untended or semi-untended machine tool operations specifically for machining involving twist drill.

Implementation of this strategy is contingent on the capability to forecast tool life. The effort to develop a forecasting capability has bee: oriented to neural networks. However, data was gathered on many tool parameters so this effort also included a statistical analysis of the data. This was included for two reasons; to answer questions such as, does coatin: of the drills improve their performance? and to establish an understanding of the working phenomena. The statistical analysis was conducted prior to the neural network activity. Most of the statistical work and the neural network investigations were carried out on new drill data, even though thre: sets of data were available; new drill, reground conventional grind drills, and reground four facet drills.

Within the new drills category some of the drills in addition to being coated with Titanium Nitride were also given additional treatment namely; cryogenic treatment (-300 F) or ion implantation. Therefore, within this category the drills could be further divided into untreated, cryogenically treated or ion implantation. An analysis of tool life data for these three categories indicates that the additional treatment did not improve the mean life of the drills.

Two drills, one cryogenically treated and the otner untreated had identical values for the descriptive parameters; point angle, relief angle,

angle, web thickness, and chisel edge length. In addition they had the same lip wear when removed by the machinist. However, they did not have the same lifetime measured in inches drilled or workpieces completed. The cryogenically treated drill had a greater lifetime. In conjunction with this greater lifetime the drill also had lower average thrust values per workpiece. It was thought that maybe the trajectory of average thrust vs. workpiece could be a surrogate for a wear trajectory and that a shallow trajectory indicated a lower wear rate and therefore a longer lifetime. This did not prove out because drills with a steeper trajectory and higher thrust values sometimes performed better than drills with shallow trajectory and lower thrust values.

There is a statistically significant correlation between pieces completed and total lip wear, pieces completed and ratio (cel/web), cel and web. The first and last relationships were expected the first because both variables are measures of tool life and the last because both variables are related to the point geometry. The correlation coefficient value of .46644 for the first relationship is lower than might have been expected considering that there should be a strong relationship between lip wear and work completed. The relationship between pieces completed and ratio is a negative one as ratio increases pieces completed decreases. However, this is not a strong relationship and further investigations showed that ratio is not a very good indicator of performance.

Tests were conducted to determine if group means and standard deviations were equal. If they are then in most cases it can be considered that the parameter that defines the groups does not impact tool life, at least for these samples. This hold for ion treatment, cryogenic treatment, point angle, for new drills. There is a difference in performance between new and reground drills with a conventional grind. The new drills are better performers than the reground drills. However, it appears that recoating the reground drills improves their performance; but they are still poorer performers than the new drills. This difference could be the result of quality control in the machining of the new and reground drills.

The new drills all have conventional grinds but when the drills are reground they can be given different grinds; conventional, four facet, helical. The helical grind was not investigated because only two drills were given this grind. The conventional and four facet grinds were compared as to equal means and standard deviations for inches drilled and lip wear. The hypothesis of equal mean inches drilled for the two groups could not be rejected, but the four facet grind group had a greater standard deviation. For lip wear the hypothesis of equal means and standard deviations for the two groups could not be rejected at the .05 level.

5. CONCLUSIONS:

a. The best improver of drill performance is to coat the drills with Titanium Nitride.

b. Additional treatment of the drills either cryogenically or by ion implantation does not seem effective.

c. The shape of the thrust trajectory is not a good indicator of drill performance. A shallow trajectory does not signal a long life time and a steep trajectory does not signal a short one.

d. Reground drills in general do not have life times equivalent to new drills.

e. Four facet reground drills and conventional reground drills are equivalent performers.

f. Recoating reground drills does not make them equivalent to new drills.

g. Recoating reground drills does improve the performance of the reground drill with respect to other reground drills.

h. It does not seem feasible to forecast tool life with standard forecasting techniques.

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