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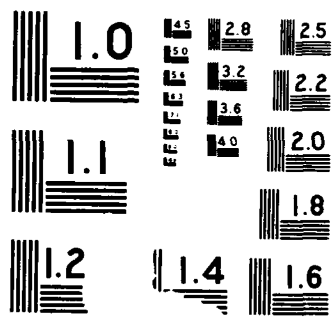
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MANUFACTURING OF TITANIUM ALLOY CANNON COMPONENTS

ALEX WAKULENKO

FEBRUARY 1988

US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
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This report contains the results of the first phase of a multi-year Manufacturing Methods and Technology project which addresses the manufacturing approach of new materials under consideration for cannon tube components. Activities concentrated on the assemblage of preliminary machinability data for a Beta-C, 3Al-8V-6Cr-4Zr-4Mo, titanium (Ti) alloy to support in-house machining requirements. In addition, machinability tests were performed by an

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20. ABSTRACT (CONT'D)

independent laboratory to develop a substantial database for optimizing the manufacture of Ti alloy production components. (Keywords)

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BACKGROUND AND INTRODUCTION

The introduction of lightweight reinforcing jackets on large caliber gun tubes is a relatively new application in cannon designs. Materials, such as titanium alloys and newer iron-based alloys are being considered and tested for this application. These new materials will require special and different manufacturing approaches.

Our production facility historically has machined Nickel Chromium Molybdenum Vanadium (NiCrMoV) steel alloy and has developed a comprehensive experience background in processing this material. However, our production facility's experience base is somewhat limited regarding the machining of new non-ferrous materials. Therefore, an extensive effort is necessary to acquire an applicable manufacturing database in preparation for production manufacture of any new weapon designs employing such new materials.

This program is tailored to address the machining of the various materials as they are introduced for consideration and evaluation as weapon components (reinforcing jackets). The material this project has scrutinized is a Beta-C titanium alloy. Other materials, such as the high strength, high fracture toughness AF1410 iron-based alloy will be included in the next areas of investigation during the follow-up efforts of this program.

PROBLEM

Existing machining methods for titanium alloys are basically those practiced for more than 20 years. The machinability database now in use allows the selection of operating conditions for specific machining operations on aircraft type titanium, typically Ti 6Al-4V, components which require extensive turning, end milling, face milling, drilling, reaming, tapping, sawing and grinding operations. A machinability and processing database for turning, deep hole boring, and bore finishing of hollow cylinders made of high specific strength titanium Beta-C alloy (3Al-8V-6Cr-4Zr-4Mo) is virtually nonexistent.

Many characteristics of this titanium material make it expensive and very difficult to machine. Usually, considerable stock must be removed from primary forms such as long hollow cylindrical forgings. Titanium is also chemically reactive and therefore, has a tendency to weld to cutting tools during machining. Tools experience cratering, chipping, notching, premature tool failure, and produce poor surface finish. Additionally, titanium's low heat conductivity and abrasive nature increases the temperature at the tool/workpiece interface, adversely affecting tool life and consequently, component dimensional accuracy.

The introduction of titanium alloy for lightweight reinforcing jackets on gun tubes presents manufacturing problems to a facility that is experienced in mostly steel processing. The problems include the determination of proper tooling and method of manufacture.

PROBLEM APPROACH

The direction this first phase of the overall project took was to establish an immediate machining knowledge foundation on the Beta-C alloy. This provided preliminary machining information which assisted in the manufacture of prototype titanium components for weapon development activities. The other avenue of approach was to prepare a specification (scope of work) to have an independent engineering effort perform a machinability test on boring and turning this material. This involved the investigation, identification, and testing of tools and processes, and then actually proving all results by machining specific component geometries.

RESULTS

Initial Tool Material Evaluation

In-house tests were performed to ascertain, initially, the level of difficulty in machining the Beta-C alloy. Early test results showed that conventional steel cutting carbide grades, C-6 through C-8, would not even provide 2 minutes of tool life. These grades appeared to chip, notch, crater, and wear severely during use. Most of the tool failure can be attributed to their titanium carbide (TiC) content, whereby the Ti alloy exhibited a chemical affinity to the high TiC carbide grades and had a tendency to immediately develop built-up-edge (BUE) or chip welding during machining. Typically, the BUE condition may be somewhat minimized by increasing the cutting speed; however, because of titanium's low heat conductivity and abrasive nature, increasing the cutting speed simply accelerated tool failure.

Straight tungsten carbide (WC) cutting tools, typically C-2 grades, performed best since they do not contain similar chemical properties, minimizing the chemical affinity experienced with the TiC grades. Not all C-2 grade equivalents performed equally, and significant performance differences were experienced. This included variances among the C-2 category grades made by the same manufacturer, and from manufacturer to manufacturer. Table 1 shows the preliminary results obtained when conducting milling and facing operations on the Beta-C alloy. For the most part, the data in Table 1 indicate that as the cutting speed is reduced, the tool life increased and also, the tool geometry (insert style) had a significant impact on tool performance. For example, the VC111 grade, round insert had the best performance in milling. The round geometry spread the actual chip load over a larger area, in effect, spreading the cutting forces and the heat over a longer cutting edge surface. In facing, the SNK-43E2, H13A grade milling insert was the best performer. Why it performed better was not exactly obvious; however, its relatively thick cutting edge cross section and unique nose geometry (series of intersecting flats generating a broad nose radius effect) provided cutting edge strength and chip load reduction, respectively. One significant drawback was that this insert did not break the chips while the other insert types did.

The aforementioned testing involved operations that were needed to manufacture material property specimens. Therefore, as a result of these preliminary carbide screening efforts, it was possible to optimize the machining operations involved and produce the required parts on schedule.

Lathe Turning Evaluation

The next stage of in-house activities impacted on the manufacturing operations which will allow the end item (long cylindrical, hollow sleeve) to be produced. Lathe turning and boring are the two major operations of concern, and since outside diameter (OD) and inside diameter (ID) machining are essentially similar, all of the subsequent tests concentrated on OD turning for the ease of operation. Obviously, inside machining or boring requires special tooling and other considerations such as chip control and coolant delivery; however, these

OD turning tests are representative of how a tool performs in respect to tool life. The objective is to identify cutting tools and a set of parameters that will produce the optimum machining conditions, tool life, chip control and workpiece accuracy, in a minimum amount of time and tool changes.

DISCUSSION

The data presented in Table 2 are the aggregate of results obtained during the OD turning trials, whereby both carbide and high speed steel (HSS) tools were evaluated. As a result, a variety of tools was identified which assisted in the ultimate manufacture of a full size prototype titanium jacket. Although these cutting tools enhanced the machining of the Beta-C alloy, they performed somewhat marginally in respect to tool life and machining time.

Two best performers were identified: one was an HSS material and the other was a relatively new carbide grade developed for aerospace alloys. The HSS material (Braecut brand) is a M44 tool steel which lasted 214 minutes during actual boring. Table 3 shows that this HSS was used with a wood packed reamer assembly to machine a 63-inch long bore. Two tools were used and therefore, each cutting edge was subjected to a 0.007 inch per revolution feed rate at 21 RPM. When the feed rate was increased to 0.015 inch per revolution, tool life decreased to 49 minutes or by 77 percent. Logically, it may have been more advantageous to compromise and use the lower tool life parameters to complete the workpiece in 98 minutes instead of 214 minutes. However, 4 hours are required to resharpen the reamer and it turned out that the slower feed rate or longer tool life was more economical. The life was 214 minutes versus 339 minutes, including 4 hours to recondition. Furthermore, it was advantageous to use the slower rate to maintain bore size. By accelerating feed rate, tool wear accelerated and consequently jeopardized bore size.

The aforementioned is an ideal situation, but in actuality, the boring operation did not transpire that smoothly. The wood packing on the reamer (which serves as a bearing surface between the machined bore and the tool body itself) wore severely and had to be reconditioned every 20 inches of boring depth. Since the cutting edges were still sharp, only the wood packing was reworked to save time (2 hours). Normally, in steel, the wood packing would last the entire operation, but in this case, the titanium's surface finish apparently degraded the wood size. This type of reamer style was used because it was the only tool available at that time to machine the prototype part. New tooling has been ordered and will be tested during this project's follow-up efforts.

The KZ313 carbide grade exhibited the most promising results among the carbides tested. This KZ313, made by Kennametal, is a new uncoated grade of carbide that has been developed specifically to machine titanium, typically Ti 6Al-4V. The manufacturer's literature states that the substrate is a specially processed fine grain carbide with virtually a porosity-free structure that provides a high-density and high-strength cutting tool without sacrificing edge wear resistance.

In Table 2, the KZ313 carbide allowed up to 322 minutes of tool life or as much as 80 inches of linear machining. During testing, an interesting result happened. The nose of the cutting tool exhibited almost no detectable wear while most of the cutting edge damage was concentrated at the depth-of-cut zone.

Also, as the tool accumulated some time-in-cut, an inspection of the edge indicated considerable cratering and notching (at the depth-of-cut zone). However, the tool still continued to cut, producing good chip control and workpiece size. It appeared that the cutting edge cratered and notched in such a manner that it produced a self-sharpening effect. This, in conjunction with the minimal nose wear, dramatically increased the tool's ability to cut longer compared to the other carbides tested.

One significant point that must be stressed, and is true throughout all tests performed, is that the titanium's surface or skin prior to machining contained an oxidized layer (scale) which drastically impacted on the longevity of all tools. In addition, after machining, the machined outside surface still deteriorated the cutting edge, but to a much lesser degree, at the depth-of-cut zone. Also, references made to tool life within this text refer to the tool's ability to remove material, similarly time-in-cut. Each tool was tested until flank wear, chipping, notching and cratering together rendered the insert edge unusable. Flank wear, which is normally used as a tool life monitor, was not solely used because all of the other tool edge destructive mechanisms propagated simultaneously. It was concluded that this Beta-C titanium alloy reacted somewhat unconventionally with most carbide cutting tools tested.

Titanium nitride (TiN) coated inserts were also briefly tested and resulted in poor surface finish and minimal tool life. The TiN coating exhibited a chemical affinity with the Beta-C titanium and immediately developed a BUE condition which accounted for the poor surface finish on the workpiece. The surface finish was rough and "hairy" to the touch, typical of severe chip welding during machining.

SUPPLEMENTAL MACHINABILITY TEST

In-house activities confirmed that the Beta-C titanium alloy is a significant machining problem and therefore, in an effort to supplement the in-house findings, a procurement document (scope of work) was prepared to have an independent engineering effort perform additional machinability tests. The objective of this procurement action is to conduct an extensive machining and processing evaluation in deep hole boring, finishing, and OD turning of hollow Ti 3Al-8V-6Cr-4Zr-4Mo cylinders.

Since there are numerous parameters that must be investigated, it was decided that it would be beneficial to test this material in a controlled laboratory environment to develop a comprehensive database that will represent and encompass the state-of-the-art cutting tool materials, tooling applications and optimum processing parameters. The results of this research will be used as a process planning database to plan the manufacture of full length (approximately 9 foot) titanium alloy workpieces in a production operation.

The scope of work requires the contractor to plan and perform turning (OD machining) and deep hole boring and finishing (ID machining) operations on titanium tubes supplied by Benet Laboratories. The contractor must record all test data and develop a comprehensive formal technical report which will be used as a guidance for planning the production processing of 9-foot titanium alloy parts.

To accomplish this, 12 feet (four 3-foot long cylinders) of material were supplied to enable the contractor to do preliminary machining and processing evaluations. Once acceptable parameters are developed, the contractor will actually manufacture three (3-foot long) additional workpieces to specific drawing requirements to substantiate their findings and recommendations.

The contractor is Metcut Research Associates Inc., in Cincinnati, Ohio. Metcut has done similar work for other DOD departments for various other materials and applications. The contract was awarded on 9 September 1986 and final results will be discussed in the FY87 phase of this project.

CONCLUSIONS

Based on the tests performed to date, the Beta-C, 3Al-8V-6Cr-4Zr-4Mo titanium alloy is very difficult to machine and will present a manufacturing bottleneck if this alloy does become the requirement of a production component. Its chemical composition and mechanical properties are detrimental to all tool material tested. The few HSS and carbide tools that enhanced its machinability will not, at this time, provide suitable performance in production conditions without further refinement of pertinent manufacturing methods and technologies.

Slow cutting speeds, ranging between 25 and 45 surface feet per minute, dictate that machining operations will be lengthy and consequently expensive. Since there was no significant difference between the performance of HSS and carbide, there is little economic advantage in using one over the other at this time. Ideally, a carbide insert which is purchased formed and ready to use would offer more economy in lieu of HSS. HSS is customarily machined by the end user, at a premium, to specific tool geometries. The availability of HSS pre-made inserts are limited and not widely used. However, the search for a cutting tool material that offers the best performance is the first priority, and the cost, although important, is secondary at this stage. Economics will be evaluated once all manufacturing processes are determined and tested.

The results of this first project phase, which developed preliminary in-house background and initiated a machinability contract, will be used to support and conclude the balance of work remaining in the follow-up efforts. These follow-up activities will address the process needs of full length Ti components, and continue the evaluation of additional unique materials as they are introduced for weapon design consideration.

WORKPIECE DESCRIPTION	MATERIAL	CUTTING TOOL MATERIAL	TYPE OF OPER.	TOOL DESCRIPTION	FEED	RPM	DEPTH OF CUT	sfm / TOOL LIFE nim.	COMMENTS
3/4" sq. 6-1/2" lg.	Ti-38644	V1N grade coated (Valenite) SNMG-434	Milling	4" Dia. Face Mill	1/2 IPM	99	.200"	104 / 26	2 Passes (13" machined) Poor surface finish Good for roughing only
3/4" sq. 6-1/2" lg.	Ti-38644	VC111 grade RNEA-32 Round (Valenite)	Milling	1" Dia. End Mill	1.5 IPM	217	.125"	58 / 21.7	5 Passes (32.5" mach.) Good surface finish
1/2" sq. 6-1/2" lg.	Ti-38644	H13A grade SNMG-432-23 (Sandvik)	Milling	4" Dia. Face Mill	1/2 IPM	99	.05"	104 / 52	4 Passes (26" machined) Good surface finish
2-1/2" wide 8" long 1-1/2" thick	Ti-38644	H13A grade SNMG-432-23 (Sandvik)	Milling	4" Dia. Face Mill	1/2 IPM	75	.025" to .05"	79 / 80	5 Passes (40" machined) Good surface finish
2-1/2" wide 8" long 1-1/2" thick	Ti-38644	H13A grade SNMG-432-23 (Sandvik)	Milling	4" Dia. Face Mill	7/8 IPM	44	.250"	46 / 22.9	2-1/2 Passes (20" mach.) Good surface finish
2-1/2" wide 8" long 1-1/1" thick	Ti-38644	V1N grade SNMG-432 coated (Valenite)	Milling	4" Dia. Face Mill	7/8 IPM	44	.250"	46 / 41.1	4-1/2 Passes (36" mach.) Poor surface finish
2-1/2" wide 8" long 1-1/2 thick	Ti-38644	2A5 grade C2 equiv. SNG-432 (Wesson)	Milling	4" Dia. Face Mill	7/8 IPM	44	.250"	46 / 9.1	1 Pass at most

TABLE 1. PRELIMINARY RESULTS OBTAINED WHEN CONDUCTING MILLING AND FACING OPERATIONS

WORKPIECE DESCRIPTION	MATERIAL	CUTTING TOOL MATERIAL	TYPE OF OPER.	TOOL DESCRIPTION	FEED	RPM	DEPTH OF CUT	sfm / TOOL LIFE min.	COMMENTS
2-1/2" wide 8" long 1-1/2 thick	Ti-38644	V29 grade SNG-432 (Valenite)	Milling	4"Dia. Face Mill	7/8 IPM	44	.250"	46 9.1	1 Pass Carbide too brittle for milling
4.75" ID 7.00" OD	Ti-38644	H13A grade SNK-43E2 (milling insert) (Sandvik)	Facing	15 degree lead No chip bkr.	.004 per rev.	105	.070"	192- 130 32.1	Oil coolant used Machined very well No chip breakage 6 Passes(included interrupted cuts)
4.75" ID 7.00" OD	Ti-38644	V1N grade SNMG-432 coated (Valenite)	Facing	45 degree lead	.015 per rev.	55	.070"	100- 68 2.7	Oil coolant used Cutting edge broke on 1st cut, chips broke Observation-w/broken edge tool cont. to cut
4.75" ID 7.00" OD	Ti-38644	V1N grade SNMG-432 coated (Valenite)	Facing	45 degree lead	.025" per rev.	40	.080"	73- 50 6.75	Oil coolant used 3 Passes, chips broke Poor surface finish
4.75" ID 7.00" OD	Ti-38644	H13A grade SNMG-432-23 (Sandvik)	Facing	45 degree lead	.025" per rev.	40	.080"	73- 50 2.25	Oil coolant 1 Pass, chips broke Cutting edge broke
4.75" ID 7.00" OD	Ti-38644	H29 grade SNG-432 (Valenite)	Facing	45 degree lead	.012 per rev.	83	.060"	103- 152 13.6	Oil coolant used 6 Passes

TABLE 1. (CONT'D) PRELIMINARY RESULTS OBTAINED WHEN CONDUCTING MILLING AND FACING OPERATIONS

WORKPIECE DESCRIPTION	MATERIAL	CUTTING TOOL MATERIAL	TYPE OF OPER.	TOOL DESCRIPTION	FEED	RPM	DEPTH OF CUT	sfm / TOOL LIFE min.	COMMENTS
7.0" OD 20 " long 1st pass scale 2nd no scale 20" ea. pass	Ti-38644	KZ313 grade SNMG-432 (Kennametal)	Turning	45 degree lead	.015" per rev.	19	.200"	43.8 200	Good chip breakage Size w/.002 Tool cratered 1/16 from nose. Still cut w/crater cond.
5.90 OD 20" long No scale	Ti-38644	KZ313 grade SNMG-432 (Kennametal)	Turning	45 degree lead	.015 per rev.	41	.200"	63 23	Stringy chips Wear on nose 10" l.o.c.
1st pass 5.90D 2nd pass 5.50D 3rd pass 5.10D 4th pass 7.00D 5th pass 6.60D	Ti-38644 No scale	KZ313 grade SNMG-432 (Kennametal)	Turning	45 degree lead	.015 per rev.	19	.200"	34.8 to 25.3 280	1st pass 10" l.o.c. 2nd pass 19" l.o.c. 3rd pass 19" l.o.c. 4th pass 16" l.o.c. 5th pass 16" l.o.c.
7.0" OD Scale on OD	Ti-38644	KZ313 grade SNMG-432 (Kennametal)	Turning	15 degree lead	.0088 per rev.	25	.200" to .300"	46 18	4" l.o.c. Scale destroyed edge
1st pass 7.00D w/scale 2nd pass 6.50D no scale	Ti-38644	KZ313 grade SNMG-432 (Kennametal)	Turning	15 degree lead	.0088 per rev.	25	.200"	46-42 73	1st pass 1-1/2 l.o.c. finished scale. 2nd pass 14-1/2 l.o.c. edge failed where scale notched edge
1st pass 6.50D 2nd pass 6.10D 3rd pass 5.70D 4th pass 5.30D 5th pass 7.00D	Ti-38644 -scale	KZ313 grade SNMG-432 (Kennametal)	Turning	15 degree lead	.0088 per rev.	25	.200"	42-34 322	1st pass 6-1/2" l.o.c. 2nd pass 21" l.o.c. 3rd pass 21" l.o.c. 4th pass 21" l.o.c. 5th pass 1-1/2" l.o.c.

TABLE 2. AGGREGATE RESULTS OBTAINED DURING OD TURNING TRIALS

WORKPIECE DESCRIPTION	MATERIAL	CUTTING TOOL MATERIAL	TYPE OF OPER.	TOOL DESCRIPTION	FEED	RPM	DEPTH OF CUT	sfm / TOOL LIFE min.	COMMENTS
7.00 in. OD Scale	Ti-38644	HSS - T15 Sandvik	Turning	1/2 in. Radius	.007" per rev.	19	.200" to .100"	34.8 / 0.9	Length of cut 1/8 in.
7.00 in. OD Scale	Ti-38644	HSS Tantung "G" VR/Wesson	Turning	1/2 in. Radius	.007" per rev.	19	.200" to .300"	34.8 / 15	Length of cut 2 in.
7.00 in. OD Scale	Ti-38644	HSS-Rex 939	Turning	1/2 in. Radius	.007" per rev.	19	.200" to .300"	34.8 / 0.9	Length of cut 1/8 in.
7.00 in. OD Scale	Ti-38644	HSS Braecut	Turning	1/2 in. Radius	.007" per rev.	19	.200" to .300"	34.8 / 7.5	Length of cut 1 in.
7.00 in. OD Scale	Ti-38644	HSS Braecut	Turning	1/2 in. Radius	.007" per rev.	16	.300" to .200"	29.3 / 8.9	Length of cut 1 in.
7.00 in. OD Scale	Ti-38644	HSS-Rex 939	Turning	1/2 in. Radius	.007" per rev.	16	.300" to .200"	29.3 / 4.5	Length of cut 1/2 in.
7.00 in. OD Scale	Ti-38644	HSS Tantung VR/Wesson	Turning	1/2 in. Radius	.007" per rev.	16	.300" to .200	29.3 / 22.3	Length of cut 2-1/2 in.

TABLE 2. (CONT'D) AGGREGATE RESULTS OBTAINED DURING OD TURNING TRIALS

WORKPIECE DESCRIPTION	MATERIAL	CUTTING TOOL MATERIAL	TYPE OF OPER.	TOOL DESCRIPTION	FEED	RPM	DEPTH OF CUT	sfm / TOOL LIFE min.	COMMENTS
7.00 in. OD Scale	Ti-38644	HSS-Rex 939	Turning	1/2 in. Radius	.007" per rev.	13.5	.300" to .200"	24.7 / 10.5	Length of cut 1.0 in.
7.00 in. OD Scale	Ti-38644	HSS Braecut	Turning	1/2 in. Radius	.007" per rev.	13.5	.300" to .200"	24.7 / 7.9	Length of cut 3/4 in.
7.00 in. OD Scale	Ti-38644	Hss Tantung VR/Wesson	Turning	1/2 in. Radius	.007" per rev.	13.5	.300" to .200"	24.7 / 106+	Length of cut 10 in. Cutting edge still good.
7.00 in. OD Scale	Ti-38644	HSS Braecut	Turning	23 degree lead	.007" per rev.	13.5	.300" to .200"	24.7 / 52.9	Length of cut 5 in.
7.00 in. OD Scale	Ti-38644	HSS-Rex 939	Turning	23 degree lead	.007" per rev.	13.5	.300" to .200"	24.7 / 5.3	Length of cut 1/2 in.
7.00 in. OD Scale	Ti-38644	HSS Tantung "G" VR/Wesson	Turning	23 degree lead	.007" per rev.	13.5	.300" to .200"	24.7 / 1.7	Length of cut 1/16 in.

TABLE 2. (CONT'D) AGGREGATE RESULTS OBTAINED DURING OD TURNING TRIALS

WORKPIECE DESCRIPTION	MATERIAL	CUTTING TOOL MATERIAL	TYPE OF OPER.	TOOL DESCRIPTION	FEED	RPM	DEPTH OF CUT	sfm / TOOL LIFE min.	COMMENTS
7.0 in. OD Scale	Ti-38644	HSS-Rex 76 (Crucible)	Turning	.015" nose radius. 23 degree lead. Chip breaker	.0105 in. per rev.	19	.200"	34.8 / 0.5	Length of cut .10 in. Used coolant.
7.0 in. OD Scale	Ti-38644	HSS-Rex 76 (Crucible)	Turning	No radius on nose. Chip breaker 23 degree lead	.0105 in. per rev.	19	.200"	34.8 / 0.5	Used coolant. Length of cut .10 in.
7.0 in. OD Scale	Ti-38644	HSS-Rex 20 (Crucible)	Turning	.015" nose radius. Chip breaker 23 degree lead.	.0105 in. per rev.	19	.200"	34.8 / 0.5	Used coolant. Length of cut .10 in. 3 tests w/ same results
7.0 in. OD	Ti-38644	HSS-Rex T15 (Crucible)	Turning	No nose radius. Chip breaker 23 degree lead.	.0105 in. per rev.	19	.200"	34.8 / 0.5	Used coolant. Length of cut .10 in. 4 tests w/same results
7.0 in. OD Scale	Ti-38644	HSS-Rex 76	Turning	45 degree lead. Chip breaker .015 nose radius.	.007" per rev.	19	.200"	34.8 / 7.5	Length of cut 1.00 in. Used coolant.
7.0 in. OD Scale	Ti-38644	HSS-Rex 76	Turning	45 degree lead. Chip breaker .015"nose radius.	.0052 in. per rev.	19	.200"	34.8 / 35.4	Length of cut 3-1/2 in. Used coolant. Stringy chips.
6.6 in. OD	Ti-38644	HSS-Rex 76	Turning	45 degree lead. Chip breaker	.0052 in. per rev.	19	.200"	32.8 / 40.5	Length of cut 4.0 in. Used coolant. Stringy chips.

TABLE 2. (CONT'D) AGGREGATE RESULTS OBTAINED DURING OD TURNING TRIALS

WORKPIECE DESCRIPTION	MATERIAL	CUTTING TOOL MATERIAL	TYPE OF OPER.	TOOL DESCRIPTION	FEED	RPM	DEPTH OF CUT	sfm / TOOL LIFE min.	COMMENTS
6.6 in. OD	Ti-38644	HSS-Rex 76 (Crucible)	Turning	.015" nose radius. 45 degree lead. Chip breaker	.0052 in.	19	.200" per rev.	32.8 / 68	Length of cut 6-3/4 in. Used coolant. Stringy chips.
6.6 in. OD No scale	Ti-38644	HSS-Rex 20 (Crucible)	Turning	.015" radius on nose. Chip breaker 45 degree lead	.0052 in.	19	.200" per rev.	32.8 / 40.5	Used coolant. Length of cut 4.0 in.
6.6 in. OD No scale	Ti-38644	HSS-Rex 76 (Crucible)	Turning	.015" nose R Honed edge. Chip breaker 45 degree lead.	.007"	19	.200" per rev.	32.8 / 22.6	Used coolant. Length of cut 3.0 in. Stringy chips Nose held up but edge notched .125 back.
1st pass 6.0" OD 2nd pass 6.2" OD NO scale	Ti-38644	SNG-433 AN-2 grade	Turning	15 degree lead	.0105 in.	19	.200" per rev.	32.8 & 30.8 / 139	Used coolant. 1st pass l.o.c. 18-1/2" 2nd pass l.o.c. 9-1/4"
6.2 in. OD No scale	Ti-38644	SNMG-432A AN-23 grade	Turning	15 degree lead.	.0105 in.	19	.200" per rev.	30.8 / 133	Length of cut 26-1/2 in. chips broke. Used coolant.
5.8 in. OD No scale	Ti-38644	SPG 432 AN-23 grade	Turning	15 degree lead.	.0105 in.	19	.200" per rev.	28.8 / 0.5	Length of cut .10 in. Used coolant. Nose snapped off.
5.8 in. OD	Ti-38644	SPG 432 AN-23 grade	Turning	15 degree lead.	.0084 in.	19	.200" per rev.	28.8 / 98.7	Length of cut 15-3/4 in. Used coolant.

TABLE 2. (CONT'D) AGGREGATE RESULTS OBTAINED DURING OD TURNING TRIALS

WORKPIECE DESCRIPTION	MATERIAL	CUTTING TOOL MATERIAL	TYPE OF OPER.	TOOL DESCRIPTION	FEED	RPM	DEPTH OF CUT	sfm / TOOL LIFE min.	COMMENTS
5.8 in. OD No scale	Ti-38644	SPG-422-JA AN-23 grade	Turning	15 degree lead.	.0105 in.	19	.200" per rev.	28.8 / 98	Length of cut 19-1/2 in. Used coolant. Chatter. Nose broke down.
5.4 in. OD No scale	Ti-38644	SNPG 543 KZ313 grade	Turning	15 degree lead	.0052 in.	14	.200" per rev.	26.9 / 481	Used coolant. Length of cut 35 in. Stringy chips. Nose held up but side of tool wore out.

TABLE 2. (CONT'D) AGGREGATE RESULTS OBTAINED DURING OD TURNING TRIALS

WORKPIECE DESCRIPTION	MATERIAL	CUTTING TOOL MATERIAL	TYPE OF OPER.	TOOL DESCRIPTION	FEED	RPM	DEPTH OF CUT	sfm / TOOL LIFE min.	COMMENTS
4.75" ID 63" Long(bore) Ending ID 5.152"	Ti-38644	HSS (Breacut)	BORING	Wood packed reamer Tow cutters 23 degree lead	.014" per rev.	21	.201"	26 / 214	Machined entire bore (63" machined)
4.75" ID 63" Long(bore) Ending ID 5.152"	Ti-38644	HSS (Breacut) M-44 cobalt	BORING	Wood packed reamer Two cutters 23 degree lead	.03" per rev.	21	.201	26 / 49	Machined 31" deep
5.152" ID 63" Long(bore) Ending ID 5.310"	Ti-38644	HSS (Breacut) M-44 cobalt	BORING	Wood packed reamer two cutters 23 degree lead	.014" per rev.	21	.079	28 / 214	Machined entire bore (63" machined)
5.310" ID 74" Long(bore) Ending ID 5.320"	Ti-38644	A180-J8-V2X Hone stone (Superior Hone)	HONING	Hone head with 15 stones 5 banks of 3	#3 strk. set.	75	300 lb prs.	104 /	*15 to 20 min. cutting time. Removed approx. .001 of mtl. per set of stones.
5.310" ID 74" Long bore	Ti-38644	A220-J8-V4X Hone stone (Superior Hone)	HONING	Hone head with 15 stones 5 banks of 3	#3 stkr. set.	75	300 lb prs.	104 /	Same as above. *Approx. 60 strokes per min.
5.310" ID 74" bore	Ti-38644	A240-V6S Hone stone (Arsenal stones)	HONING	Hone head with 15 stones 5 banks of 3	#3 strk. set.	75	300 lb prs.		Same as above.

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