UNCLASSIFIED

0

CLASSIFICATION CANCELLED	
DATE	FEB 14 1957 <i>ret</i>
For The Atomic Energy Commission	
<i>H. R. Canale</i>	
Chief, Declassification Branch	

Volume 12-B

A-4046

"Machining Graphite and
Special Operations"

This document is
PUBLICLY RELEASABLE

H. Kasser
Authorizing Official

Date: 9-2-71

Photostat Price	<u>3.30</u>
<u>[REDACTED]</u>	
<u>[REDACTED]</u>	
<u>[REDACTED]</u>	
<u>[REDACTED]</u>	
<u>[REDACTED]</u>	
<u>[REDACTED]</u>	

December 1945

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

1-R⁶⁵

UNCLASSIFIED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

~~CONFIDENTIAL~~

~~SECRET~~

1.

MACHINING GRAPHITE AND SPECIAL OPERATIONS

Work done by F. H. Spedding, H. A. Wilhelm and M. Hall

Paper written by C F Gray

With the discovery that graphite is a satisfactory material for
(1)
the melting and casting of uranium, there came an urgent need for
methods of fabricating the graphite into crucibles, molds, and mis-
cellaneous parts. Since a survey of the literature at this time re-
vealed no information on the machining of graphite, Iowa State College
Laboratory undertook to develop the necessary techniques. The rapid
increase in the production of uranium at Iowa State College Laboratory
during this development made the solution of the problem constantly
more urgent. This report will summarize the fabrication of graphite
items and discuss a few of the special operations which have proven
to be definitely important in this laboratory.

All graphite is purchased from the National Carbon Company and
is received in the form of rods. Except for a few rods of Grade AGX
for experimental work, all crucibles, molds, and miscellaneous parts
(2)
are fabricated from Grade AGR graphite. The AGR graphite is made
by thoroughly mixing powdered coke and hot pitch, extruding t is mix-
ture into rods of the desired shape, baking these rods in an oven at
1000°C until they are hard and most of the pitch has been driven off,
then graphitizing the baked rods at 3000°C in a self-resistance fur-
nace. Grade AGX is made in a similar manner except that after the
first baking at 1000°C the rods are reimpregnated with hot pitch under

~~CONFIDENTIAL~~

2. 65
SECRET

successive changes from vacuum to pressure until all voids are filled with pitch. The reimpregnated rods are then rebaked at 1000°C and graphitized as above. Purer raw materials are used in preparing the AGX and consequently a purer product is obtained. The major part of the purification takes place in the graphitizing step, where most impurities are distilled off at 3000°C. In addition to being less pure, the AGR is characterized by its lower density. The average ash content of AGR graphite as reported by National Carbon Company is 1.5%. The ash content has the following analysis:

SiO_2	45%
SiC	14%
Fe_2O_3	22%
Al_2O_3	6%
CaO	12%
MgO	1%

Casting results have proven that there is not enough pickup of any of these impurities in casting uranium to seriously contaminate it.

For the physical properties of the AGR graphite rods, the hardness is about Rockwell 30 on the L scale or 0.5 to 1 on Mohs hardness scale. The tensile strength is 610 psi and the compressive strength, 3420 psi. While pure synthetic graphite acts as a lubricant in the same manner as natural graphite, a bad characteristic of most synthetic graphite is that since the impurities are probably converted to carbides in the graphitizing operation, the synthetic graphite rods are a bonded abrasive with the graphite (bonding agent) in great excess.

~~SECRET~~

In the fabrication of graphite numerous materials for cutting tools were tested, among which were cold rolled steel, hot rolled steel, carbon tool steel, high speed steel, carbide, and stellite. From the standpoint of wear for a given amount of work there is little difference in any of these cutting tools. This can probably be explained by the fact that graphite is much softer than any of these materials and that the small amount of silicon carbide present as an impurity is harder than any of the cutting edges. If the synthetic graphite may be considered as a bonded abrasive, the cutting operation on graphite can be compared to a grinding operation, on the tool, with a very hard abrasive diluted to a very high degree with a bonding agent. Consequently, some of the usual advantages for employing a very hard cutting edge are defeated here. The only advantage for the very hard high speed tools in cutting graphite is that they will maintain a cutting edge at higher working temperatures and over a longer period of time. A comparison of the speeds, the life of a cutting edge, the ease of sharpening, and the ease of making intricate tools from the various cutting materials pointed very definitely to cold rolled steel as the best all around tool material. This is true except in the case of plain turning and drilling, in which cases any metal cutting tool steels are satisfactory.

For hand tools, the common wood chisel, coarse wood rasp, file, knife, and abrasive paper and cloth are effective in shaping graphite. Since cold rolled steel holds a good cutting edge, for a reasonable working time, intricate tools are easy to fabricate. No heat treating is necessary. Graphite can be removed very rapidly with a

4765

~~SECRET~~

RECEIVED

coarse wood rasp. On account of the softness of graphite any ordinary knife can be used for rough beveling and similar work. A high polish is given to graphite surfaces with abrasive cloth, paper or common canvas.

Graphite is very easily sawed. For small rods, 2 in. or less in diameter any hand saw is satisfactory. Saw blades with the fewest teeth per inch are the best. For hand cutting medium size rods a common 8 point hand saw is satisfactory. A two-man cross cut saw proves to be very good for sawing large rods by hand. The most efficient means of sawing graphite is a horizontal band saw. A Wells Metal band saw, with a saw blade having 6 teeth per inch, cuts through a 6 1/4 in. rod in about 30 seconds. Saw blades having fewer teeth per inch and more space for saw chips would be better; however, such blades are not ordinarily available. A jig saw is valuable for inside forming, such as the work of making square holes. A blade 14 in. long was made for the jigsaw at Iowa State College Laboratory, and the upper arm blocked up to allow 12 in. work to pass under it. With every second group of set teeth removed, this blade did fair work in 12 in. lengths. Here again, blades with coarse teeth and a large capacity for saw filings are important.

The drill press is indispensable in shaping graphite. All holes up to 2 in. in diameter are drilled with ordinary carbon steel drills. The relationship between the straightness and depth of a hole depends on the rigidity of the drill. The main difficulty in drilling operations is striking small hard carbide particles which can deflect the

5 f 65

~~SECRET~~

drill from its center line. The smaller and also the more flexible the drill, the larger this error becomes. The speed of drilling is not important and is governed only by the maximum working temperature of the drill. The friction of the sides of the drills on the hole seems to generate the major part of the heat. The rate of feed for drilling is fast. No coolant, of course, can be used. The flutes in conventional type twist drills fill rapidly with graphite chips, which necessitates frequent removal and cleaning of the drill in drilling long holes. The best arrangement for this is to use hollow drills connected to a large head, low capacity vacuum blower. This suction removes the chips and greatly aids in cooling the drill. Special two-blade cutters are made from flat cold rolled steel stock for shaping intricate parts, and for boring flat bottomed holes. Since the heat generated at the cutting edge is not too severe, the advantages of harder tool materials are offset by the cost of sharpening them. Cutters of this type are very satisfactory and very accurate work is done with them if a pilot point is inserted into their centers. No rake angle is necessary on the cutting edges; however, a clearance angle of about 15° is used. An important advantage of the drill press is that end mills and router tools can be used in it. Because of the softness of graphite irregular mortises and bevels are cut by merely pushing the graphite piece by hand against the rotating cutter. For many operations this is immeasurably faster than the use of a milling machine since set-up time is virtually eliminated. For stock that machines as readily as graphite, setting up can often take much longer than the actual machining. Conventional end mills have too many

676⁶⁵~~SECRET~~

DECLASSIFIED

cutting edges and too little clearance space for chips. A good end mill for graphite can be made out of a common twist drill by grinding the cutting lips flat and grinding the side clearances into cutting edges.

The lathe is the most useful machine tool for shaping graphite. The chucking operation is in some ways more difficult than in the case of metals. A universal three jaw chuck is handicapped since practically all graphite rods are out of round and practically all are warped to some extent. The smaller they are, the worse the warp. Again on account of the softness of graphite, a four jaw chuck will hold it better than will a three jaw chuck. At Iowa State College Laboratory, production operations on 2.5 in. and 3 in. work are held in the regular 16 in. 4-jaw chucks. The chucking of tubes with thin walls is very difficult. Since they cannot be chucked tightly, very light cuts are taken on them. When graphite is worked between centers, a smooth, clean tailstock center is required because of the softness of the material. Constant adjustment of the tailstock center is necessary because the graphite counterbore wears away from the center point badly. A good lubricant for graphite centers is Ivory soap.

All of the metal machining operations common to an engine lathe are feasible with graphite; however, in the case of graphite there is a great deal more flexibility in the speed of machining than for metals. One important limiting factor for graphite machining is the maximum working temperature of the cutting tool since no coolant can be used. At high speeds on outside or facing cuts the chips will

~~SECRET~~

7.

leave the cutting tool at high enough velocities to shower the room and operator. At high speeds on internal cuts the chips are held inside of the hole by centrifugal force, so that they interfere with further cutting by binding and plugging the exit.

The finishes on the graphite machined surfaces are classified as rough finish, semi-fine finish, and fine finish. In the production of crucibles, the rough finish is used for the exterior cut on crucibles and molds. Usually graphite rod is selected of such a diameter the exterior turnings is unnecessary. The semi-fine finished surface is used for the interior surface of crucibles, molds, spillways, and other parts which come in contact with molten metal. The lathe cutting tool marks are hardly visible and the surface is smooth to the touch; however, close inspection reveals many small cavities where particles of graphite have broken out of the surface. The semi-fine finish is also used for facing operations where one unit is intended to be set on top of another and the seal between these surfaces is depended upon to prevent the flow of molten uranium between them. The fine-finished surface is used for mandrels and shapes for forming ceramic powders into crucibles for sintering. The fine finished surface is very smooth.

For the rough finish the cut is taken at a high rate of speed. The depth of cut may be as much as 0.500 in. and the rate of feed from 0.070 to 0.100 in. per rev. In one particular case, in which 7 in. diameter rod was being roughed down to 6.25 in., the depth of cut was 0.375 in., the rate of feed 0.097 in. per rev. and the speed

87-65

~~SECRET~~

~~SECRET~~

e.

533 rpm or about 940 ft. per min. A high speed tool steel bit was used for this operation. With a 2 H.P. motor this rate can be maintained on a production basis. In the semi-fine finish the depth of cut may also be as much as 0.500 in., but the rate of feed is slower, ranging from 0.020 to 0.050 in. per rev., depending on the amount of stock to be removed and the diameter of the stock. For this finish the cutting tool is sharpened so that it leaves barely noticeable toolmarks. One example of this finish is in the machining of a 5.125 in. rod down to 4.250 in. for an egg cup billet. All the excess stock is removed in one cut at a rate of feed of 0.043 in. per rev. and a speed of 450 rpm. A tolerance of ± 0.003 in. is maintained on this operation. For a fine finish the depth of cut varies from .001 to .100 in. and the rate of feed from 0.005 to 0.020 in. One particular mandrel was finished with a cut 0.090 in. deep and a rate of feed of .010 in. per rev. at a speed of 450 rpm. The relation of the size of stock to the maximum speed is unimportant and depends mainly on the lathe. It was found impractical to operate most lathes in excess of 600 to 700 rpm. Tolerances of 0.002 in. can be maintained for the fine finish. For all finishes, tools are sharpened with rake angle of zero and clearance angle of 15° . The above discussion also applies to facing and internal machining except that the speed of the lathe must be reduced for internal work to a point at which the centrifugal force does not hold the chips in the hole, if the hole is small and the cut heavy.

For internal boring, of which there is considerable in the fabrication of crucibles and molds, the common methods used for drilling

9765

~~SECRET~~

large holes in metals were abandoned because of their slowness. Holes up to 2 in. in diameter are drilled in one step with the common carbon twist drill mounted in the tail stock and forced into the work. The relationship between the size of hole, the depth of hole, and the tolerance on center line to be expected is given in Table 1. For the usual work the lathe is operated at about 500 rpm and the drill forced in at about 20 to 40 in. per min. Three production examples of carbon twist drilling are given in Table 2. In the one case where the lathe speed is given as 1265 rpm, the graphite rod was very small and the lathe a 9 in. bench model.

Table 1 - approximate relationship between size of drill, depth of hole, and tolerance to be expected.

<u>Size of drill,</u> <u>in.</u>	<u>Tolerance on center line,</u> <u>in.</u>	<u>Depth of</u> <u>hole, in.</u>
1/4	1/8	12
5/16	1/8	16
5/16	1/16	12
3/8	1/8	20
3/8	1/16	16
1/2	1/8	24
1/2	1/16	18
3/4	1/16	24
1	1/16	30
1 1/2	0.010	30

Table 2 - Three typical examples of carbon twist drill boring.

<u>Size of drill,</u> <u>in.</u>	<u>Speed of lathe,</u> <u>rpm.</u>	<u>Rate of drilling</u> <u>in./min.</u>
0.3125	1265	52
1.0	445	27
1.5	535	31

For holes larger than 2 in. in diameter, or for any hole requiring a flat bottom, special two blade cutters, the same as those discussed

10-K-65

~~SECRET~~10

for the drill press are used. These cutters are sharpened to give any special asymmetrical contour desired on the bottom of the piece being machined. The cutters were made from 0.25 in. cold rolled flat stock with a pilot point in the center between the cutting edges. With such cutters large diameter holes can be bored at a high rate of speed and within close tolerances. These flat faced cutter blades are used at the highest speeds that will allow the loose chips to run out of the hole. The cutters are sharpened as mentioned above, with a rake angle of zero and a 15° cutting edge clearance. The sides of the cutters are machined to the radius of the hole to be bored and have no clearance angle. The boring data for three examples of the use of these boring blades is given in Table 3. All three examples are regular production operations.

Table 3 - Three examples of blade boring.

Size of hole, in.	Item Produced	Speed of lathe, rpm	Rate of boring, in./min.	Tolerance, in.
2.250	egg cup	535	40.0	± 0.005
4.250	mold	115	11.6	± 0.002
8.750	crucible	118	4.1	± 0.015

Well formed threads can be cut on graphite rods by following the common metal cutting rules, except that heavier initial cuts can be taken without the risk of injuring the tool. Practice has shown that good threads can be produced for 0.750 in. 10 threads per in. and 2.250 in. 12 threads per in. with five cuts. Fastenings made by graphite threads are very strong; however, in continued use the threads wear rapidly. Coarse threads give better service under continued use.

11765

~~SECRET~~

~~SECRET~~

11

Other machine tools such as milling machines and shapers are used to produce special research equipment. Most metal shaping operations can be carried out on graphite with these machines in a manner comparable to that described above for lathes.

Machine tools used for shaping graphite require special care in lubrication. Oil and grease must be kept off all surfaces that come in contact with graphite chips and dust. The oil or grease with the graphite and small particles of hard carbides form an abrasive paste which wears and badly scores the metal surfaces and clogged oil lines. The best practice is to oil only those bearing surfaces that are covered; however, this does not eliminate all trouble because fine dust can easily be carried to these bearings. For this reason and a number of others; the common metal cutting lathe does not stand up and retain its accuracy under continuous graphite work. A lathe designed for graphite should be ruggedly built and have all bearing surfaces requiring oil adequately sealed from dust.

Adequate ventilation is absolutely necessary for graphite machining. The most efficient ventilating system is a combination of two types. The fine dust suspended in the atmosphere is removed by a large high capacity-low head blower and circulated through a bag filter to the working room again. The chips and dust are removed by a low capacity-high head blower with the inlet at the source of the chips and dust. This is accomplished by using hollow drills and boring blade shafts and special hoods that fit over the cutting tool.

The success of the bottom-operated valve pouring model is in a

1272
65
~~SECRET~~
DECLASSIFIED

12

large degree dependent upon the accurate fabrication of graphite. The valve itself is an example of this. The two surfaces, one on the valve button and the other on the crucible, which fit together and prevent the molten uranium from leaking into the mold before pouring, are carefully machined perpendicular to the axis of the crucible. After this they are fitted together and the valve button rotated until a mirror-like sealing surface is produced. This operation insures a good fit and also reveals any faulty valves or seats. Another example is the flatness of the bottom of the crucible and the top of the spillway. Unless these surfaces fit, molten uranium will run out between them and be lost. Also definite clearances are maintained between the egg cup and mold, and between the valve rod and spillway bushing. In the first case the outside diameter of the egg cup can not be less than 0.005 in. under the inside diameter of the mold or molten uranium will run between them. For the valve rod and valve rod sleeve, the diameter of the valve rod must be between 0.001 and 0.003 in. smaller than the valve rod sleeve in order to have a good working fit and prevent molten uranium from running down between them.

The technique for fabricating graphite has been developed to the point where any type of crucible or mold desired for production or research at Iowa State College Laboratory can be produced. Metal cutting lathes are satisfactory for graphite; however, a more rugged machine with special oiling features should be developed. Adequate ventilation is very important in the machining operations.

13 12 66

~~CONFIDENTIAL~~

~~SECRET~~

13.

13

Bibliography

- (1) Spedding, F. H., Wilhelm, H. A., and Gray C F, "Early Methods for Casting Uranium at Iowa State College " reported in M.P.R. Volume 12-B.
- (2) Novick, A., and Neubert, T. J., reported in CO-1083 (November 26, 1943)

~~CONFIDENTIAL~~

147265

~~SECRET~~

REF ID: A71111