THE INFLUENCE OF DESIGN FACTORS ON THE PERFORMANCE OF THE INVERTED CONE BUR

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INTRODUCTION

THE advent of cavity-shaping technics, which utilize high rotational speeds and a light hand pressure to remove a large amount of tooth material, has resulted in an acute awareness by dental operators that certain burs are superior to others. This situation has caused an obvious desire by the dentist, the dental researcher and the manufacturer for knowledge which will explain these differences in cutting ability. This report is a partial result of a program to determine the influence of various design factors on the performance of dental burs.

The actual cutting ability of a bur depends on two qualities, (1) the true cutting ability and (2) any clogging tendencies. This program was designed to study the first quality while eliminating the second as much as possible. For this reason the inverted cone bur with its short length of engagement has been chosen for specific study.

Dental bur manufacturers are faced with a very difficult problem; namely, the inexpensive production of a bur with keen sharp flutes. They can produce better burs than are available at the dental supply stores. However, the cost would be considerably higher than the present market price, so as to be economically unfeasible. This is particularly true in the production of steel burs. It is, therefore, the intent of this program to help them, in conjunction with these research departments, produce for the dental operator as good a bur as possible, while remaining within economic limits.

LITERATURE REVIEW AND PURPOSE

Henry and Peyton[1] have reported on the effect of variation in speed and pressure on the cutting ability of dental burs. We[2] have also compared burs by various manufacturers and related their findings to significant differences in bur design. Lammie[3] studied the rosehead or spherical bur constructed in tungsten carbide. Staunt[4] studied the cutting of enamel by tungsten carbide burs and diamond stones. One of the most enlightening advances in dental bur testing is the use of high speed photography by Hudson and Hartley[5] and their associates at the National Bureau of Standards to photograph a bur

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during the actual cutting of tooth material. The photographs show that only a few bur flutes actually do the cutting and show very dramatically the effects of eccentricity in the bur shaft. Bryton, Skinner, Lindenmeyer, and Lasater[6] have studied bur design and reported on the use of various materials for testing purposes. They reported that ivorene, one of the materials used in this program, cuts 5 times as fast as dentin; without, however, any increase in the clogging tendency. They suggested the use of a "standard ivory" as a testing material.

Specifically, the purpose of this program is to study the effect of 6 variables on the cutting ability of the bur. These variables are: (1) the finish, (2) heat treatment, (3) end flutes, (4) changes in bur diameter, (5) changes in length of engagement, and (6) changes in the number of flutes.

THE EFFECT OF FINISH

The dental bur is formed by cutting each flute into the bur blank with a preformed rotating cutter that is progressing nearly parallel to the axis of the bur. Some machines cut the side and end flutes in one continuous operation while other machines only perform one operation; it being necessary to use 2 machines to cut both flutes. During the first cut or pass of the cutter the flute is roughly formed. The second cut places a cutting edge on the bur flute. However, considerable roughness along the flute either in the form of depressions (''nicks'') or excess material (''fins'') still remains. This excess material may be removed by making subsequent passes or cuts of the bur flutes. It is said that the fins break off the first time that the bur is used and are of no importance to the performance of the bur.

In order to study the effects of subsequent cuttings, 3 groups of burs of 6 dozen each were cut on a bur machine which had been given to the laboratory, on a loan basis, by a commercial bur manufacturer. These burs were sent to the manufacturer and received the commercial heat treatment. The flutes of the first group were cut twice; the second group, 4 times; and the third group, 6 times. The flutes of the burs in the first group had some fins present, while the second and third groups were composed of well-formed burs when they were examined under low-power magnification.

These burs were tested by cutting ivorene and brass under 250 and 500 gram loads with a length of engagement equal to 0.035 inch. Eighteen burs were used for each test run; 2 at each of 9 speeds between 1,000 and 12,000 r.p.m. The blocks of test material were weighed before and after each test on a chemical balance and the weight loss was calculated. These data were plotted as a function of the speed of rotation and the best graphical relationship was determined by the mathematical ''method of least squares.'' From this relationship, the diameter of the bur, and the density of the material, the average linear displacement of the bur per flute revolution was calculated. The results are presented in the form of graphs, which show the average linear displacement per flute revolution, plotted as a function of the peripheral velocity. The results are shown in Fig. 1 for ivorene tests. This quantity, the average linear displacement per flute revolution, represents the average amount that the axis of the bur moves along the cut per revolution of each flute. If the flute were to remove the material in a single chip, this quantity would be the thickness of the chip removed by each flute during each revolu-

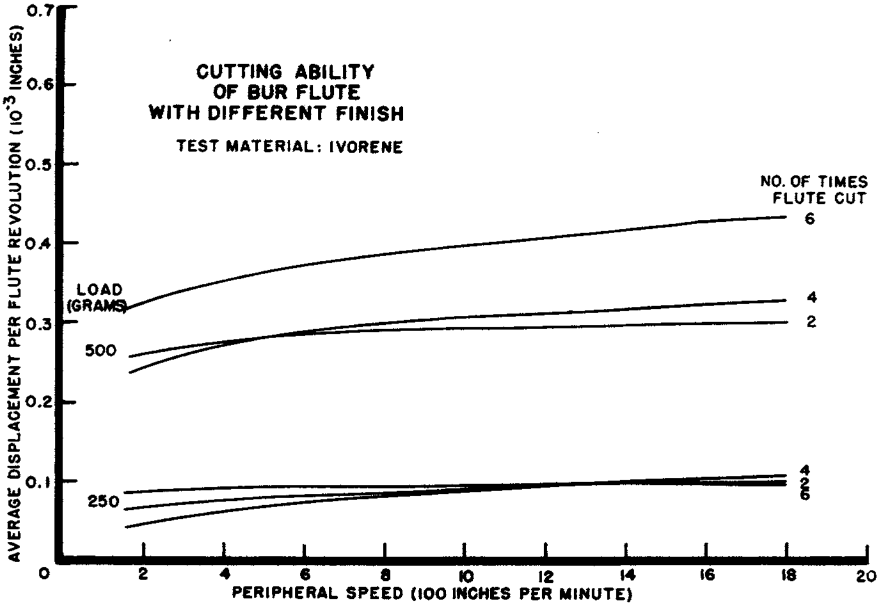

Fig. 1.

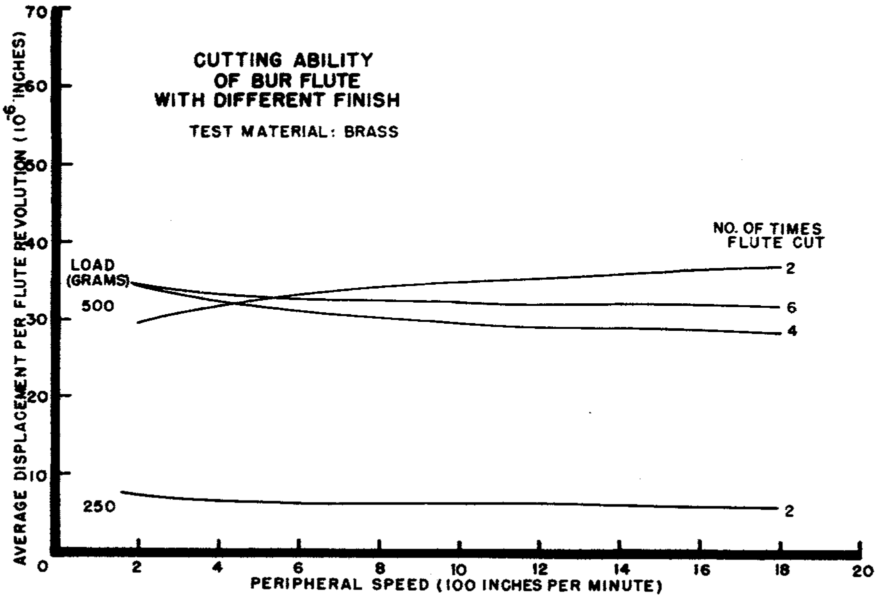

Fig. 2.

tion. When this quantity is plotted against the peripheral speed of the bur, the result is a very good representation of the cutting ability of the flute.

It is shown in Fig. 1 that at a 250 gram load, there is little difference between the performance of any of the burs. At a 500 gram load, the bur flute which was cut 6 times was superior to the flute cut twice and 4 times, the flute cut 4 times being very slightly superior to the flute that was cut twice.

The same relationship is shown in Fig. 2 when the burs were used to cut brass with a load of 500 grams. It was found that for these cuts the bur cut twice is the best cutter, the bur cut 6 times, the medium cutter, and the bur cut 4 times, the poorest cutter. The over-all differences between the 3 are very small and vary from zero to 25 per cent.

The most significant information offered in these figures is the order of magnitude of the average displacement per flute revolution. When cutting ivorene with a load of 500 grams this quantity is approximately 300 to 400 micro-inches (millionths of an inch). If the load is decreased to 250 grams, the quantity is approximately equal to 100 micro-inches. When the hardness of the material is increased, for example, brass, the quantity is approximately 35 micro-inches when testing with a 500 gram load and approximately 10 micro-inches when testing at a 250 gram load. These results correlate qualitatively with the N.B.S. films where it is shown that the cut material comes from the bur in the form of a dust cloud.

These graphs show very effectively the complex problem faced by bur manufacturers for it is evident that it is within the outer one-thousandth of an inch that the cutting properties of the flute are effective. Thus, any irregularties along the flute edge that are evident to the eye must show up as irregularities on the cut surface. If any excess fins are present, the flute proper never reaches the material, and if they break off from the flute, the cutting properties of the remaining bur flute determine whether or not the bur is a good cutter.

The results indicate that on a performance basis alone subsequent recuttings of the bur flutes form a better bur macroscopically but there is little difference at a few micro-inches from the very edge of the flute. Manufacturers say that most of the production cost occurs in the cutting process, and, if a bur is recut a subsequent number of times, the production cost increases directly without a corresponding increase in cutting ability.

THE EFFECT OF HEAT TREATMENT

Heat treatment is used to harden the bur that has been formed in soft steel. This operation must perform 2 tasks: (1) it must preserve the edge placed on the bur flute by the cutter and (2) it must harden the bur to increase its cutting life. Even though the cutter places a sharp edge on each flute, if the heat treatment process rounds that edge and destroys the sharpness, the bur will cut poorly.

Eighteen burs were formed on the bur machine and samples were photographed before and after heat treatment. The burs were also tested by cutting ivorene with a 250 gram load before and after the heat treatment process. It was felt that testing in a soft material with light load would not destroy the edge placed on the bur flute before heat treating.

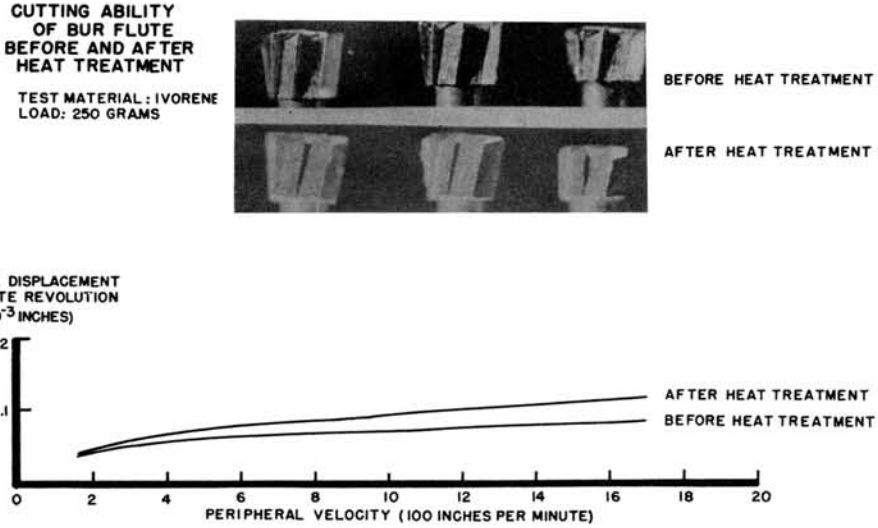

Fig. 3.

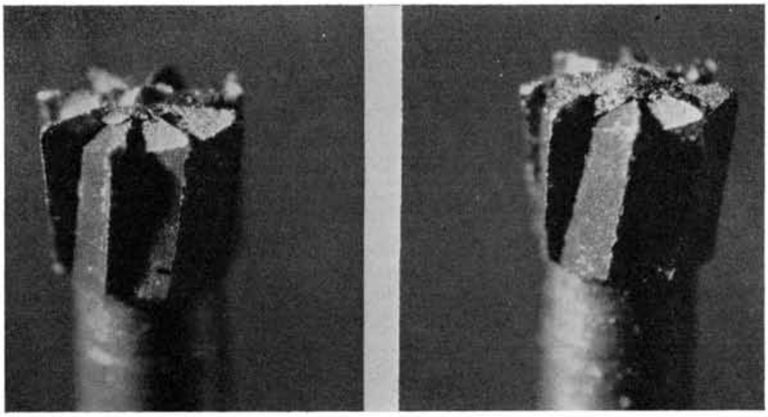

Fig. 4.

The results are shown in Fig. 3. The top half of the figure shows the photographic comparison and the bottom half shows the comparison of cutting results. The photographs show that, for the burs photographed, the flutes before heat treatment do not contain as many small irregularities as the same flutes after heat treatment. However, the cutting results indicate that the burs are as effective after, as they were before the heat treatment, for these test conditions.

THE EFFECT OF END FLUTES

Dental burs are formed with 2 different styles of end flutes: (1) the "Revelation" cut and (2) the "Star" cut. The end flutes of a "Star" cut head come together in a common junction at the axis of the bur, while the flutes of the "Revelation" cut bur come together at two junctions near a diametral cutting edge. This arrangement eliminates the noncutting center junction. For experimental purposes, burs may be formed without end flutes also. This entire study has been conducted with peripheral cutting and it is felt that the end flutes are inoperative.

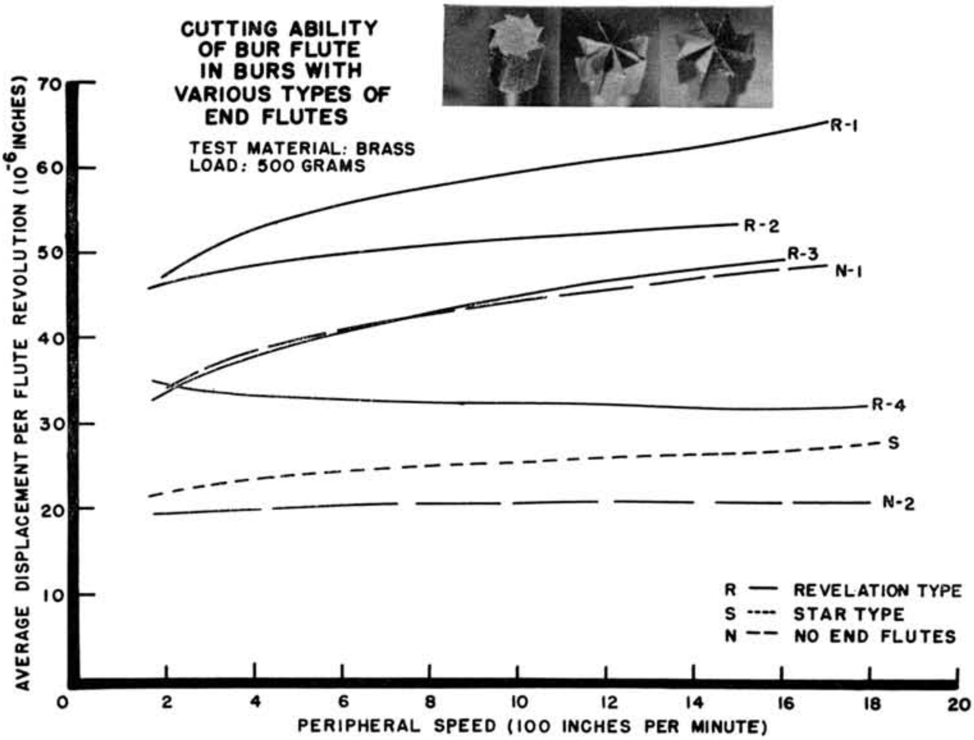

Fig. 5.

It is sometimes found when cutting brass that a "bearing" is formed at the end of the rotational axis of the bur, as shown in Fig. 4. This condition is more prevalent when testing burs with smaller diameters at the higher rotational speeds. Needless to say, the results should be questioned.

All test results, obtained from cutting brass with a 500 gram load by eight-fluted burs, the flutes of which were cut six times, are shown in Fig. 5. The results indicate that the "Revelation" type bur shows some superiority; however, there is considerable discrepancy between all curves, indicating that the ability to form equally effective side flutes on all burs is more important than the type of end flute utilized.

Emphasis must again be made that the tests were made by cutting peripherally. Plunge or oblique cutting tests, where the end flutes are directly involved, may not produce the same results. This should be the object of another study.

THE EFFECT OF CHANGING BUR DIAMETER

General theory indicates that the forces on each bur flute, when determined from the external load, do not depend on the diameter of the bur, but rather on the number of flutes and their rotational position. Thus, the average linear displacement per revolution and the length of cut under identical test conditions do not depend on the diameter of the bur. It follows that, because length of cut is constant, the volume of material removed will vary directly with the bur diameter as will the torque and the amount of mechanical energy that the engine is required to supply.

This same reasoning is substantiated experimentally. The curves of Figs. 1, 2, 3, and 5 show that the average displacement per flute revolution is nearly constant and does not depend to a great degree on the peripheral velocity. This quantity does increase slightly as the peripheral velocity is increased. This increase is felt to be due to increasing inertia forces, for in the test instrument the specimen is held in a rather heavy car while the bur is attached directly to the armature of a dental engine.

THE EFFECT OF CHANGING THE LENGTH OF ENGAGEMENT (DEPTH OF CUTTING)

Theory indicates that the external load (250 and 500 grams for these tests) is divided among the bur flutes that are actively cutting, resulting in certain forces on each flute. As the length of engagement is decreased, the force intensity on each small portion of the flute still cutting is correspondingly increased and the average displacement per flute revolution should also increase. This increase is so great that the volume of material removed by a shallow cut often exceeds that of a deeper cut.

Burs of standard design, that were formed in the laboratory, were tested by cutting brass with a 500 gram external load at cutting depths of 0.020, 0.030, and 0.040 inch. The results, given in Fig. 6, again show the average displacement per flute revolution as a function of the peripheral velocity. The results agree with theoretical considerations. For example, at a peripheral speed of 1,000 inches per minute (6,000 r.p.m.), it is found that for the particular group of burs tested, the average displacement was equal to 39 micro-inches when tested at a depth of 0.040; 60 micro-inches, at a depth of 0.030; and 110 micro-inches, at a depth of 0.020 inch.

THE EFFECT OF CHANGING THE NUMBER OF BLADES

As mentioned previously, the external load is distributed among the blades actively cutting. As the number of blades is decreased, the magnitude of the forces at each blade increases and the thickness of chip removed by each flute should correspondingly increase. It is interesting that, under cer-

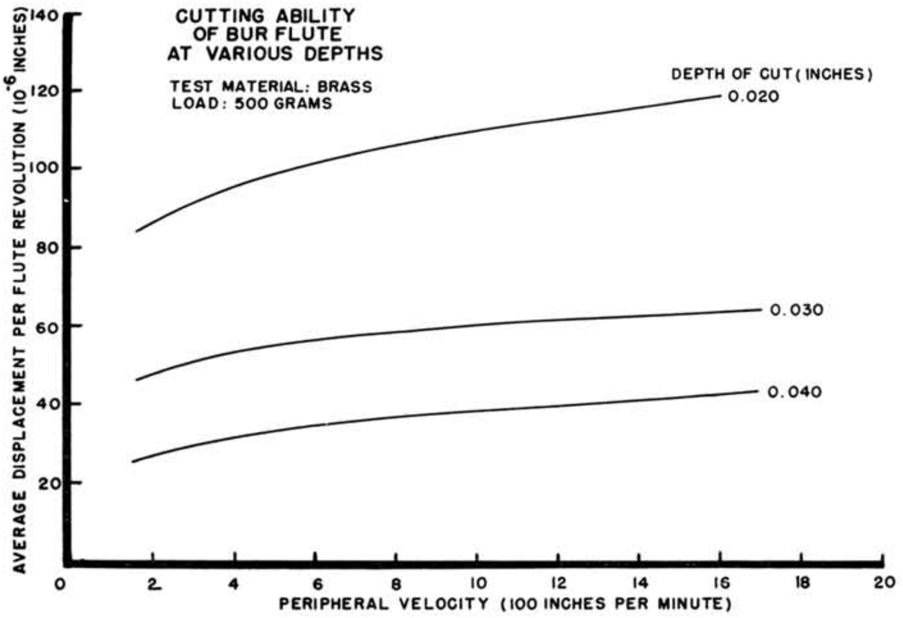
CUTTING ABILITY
OF BUR FLUTE
AT VARIOUS DEPTHS
TEST MATERIAL: BRASS
LOAD: 500 GRAMS
DEPTH OF CUT (INCHES)
0.020
0.030
0.040
AVERAGE DISPLACEMENT PER FLUTE REVOLUTION (10^-6 INCHES)
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
PERIPHERAL VELOCITY (100 INCHES PER MINUTE)

Fig. 6.

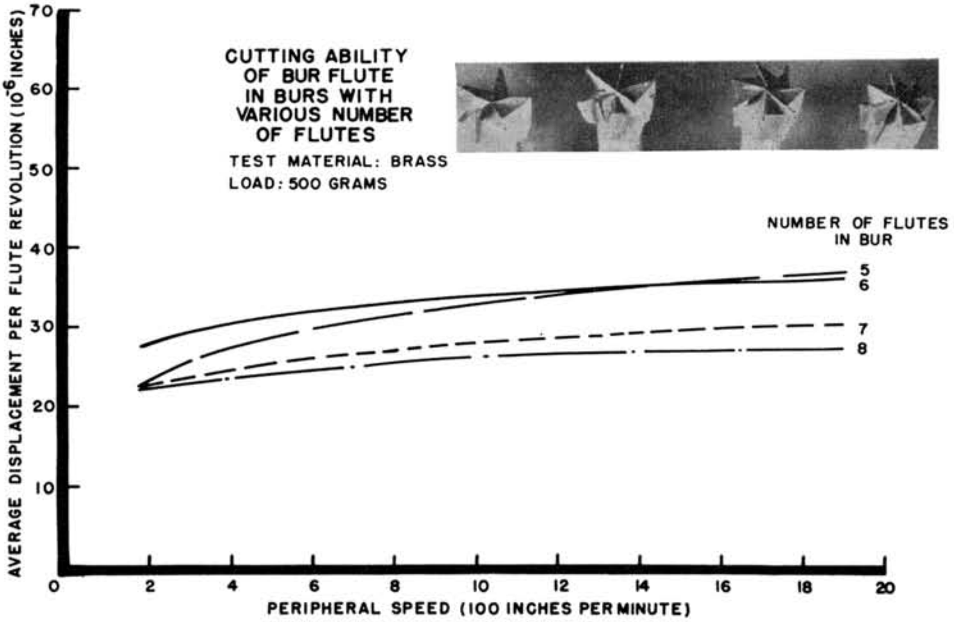
CUTTING ABILITY
OF BUR FLUTE
IN BURS WITH
VARIOUS NUMBER
OF FLUTES
TEST MATERIAL: BRASS
LOAD: 500 GRAMS
NUMBER OF FLUTES
IN BUR
5
6
7
8
AVERAGE DISPLACEMENT PER FLUTE REVOLUTION (10^-6 INCHES)
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
18
20
PERIPHERAL SPEED (100 INCHES PER MINUTE)

Fig. 7.

tain conditions, theory indicates that nearly the same amount of material can be removed by either an 8-, 7-, 6-, or 5-fluted bur; i.e., the product of the chip thickness removed by each flute and the number of flutes may be nearly a constant. The reason for constructing burs with a smaller number of flutes arises from the increased space between the flutes which decreases the clogging tendency. Inasmuch as each flute is removing more material, the tendency for flute wear should be greater and the cutting life should be decreased.

It has been shown that in the fissure burs a bur with straight flutes produces less temperature rise than one with spiral flutes.[7] It has been reasoned that this may be due to the formation of a larger chip by the straight-fluted bur. The chip then carries some heat energy with it. Similar reasoning indicates that a bur with less flutes would be cooler operating. Again, there is a need for further study. A bur with a smaller number of flutes has also been shown to be more vibratory.

Four groups of 6 dozen burs each were formed and hardened. The first group was composed of burs with 8 flutes; the second group, 7 flutes; the third group, 6 flutes; and the fourth group, 5 flutes. These burs were tested and the results obtained when cutting brass with a load of 500 grams are shown in Fig. 7. In general, the results agree with theory. The 5-fluted bur was not as much superior to the 6-fluted bur as would be expected; in fact, at the lower values of peripheral velocity, the 5-fluted burs tested are inferior to the 6-fluted burs tested. This situation further confirms the supposition that it is very difficult to produce bur flutes of identical sharpness consistently.

SUMMARY

This report has presented briefly some results obtained during a testing program designed to show the effects of different design parameters on the performance of the inverted cone bur. These parameters are (1) flute finish, (2) heat treatment, (3) end flutes, (4) diameter of bur, (5) length of engagement or cutting depth, and (6) the number of flutes in the bur. The results have been expressed as graphs showing the average linear displacement per flute revolution as a function of the peripheral velocity. The average linear displacement per flute revolution is equivalent to the average distance that the bur advances into the cut per flute revolution. It has been found that this manner of data presentation demonstrates changes in edge-cutting ability very effectively.

It has been found that only the last one-thousandth of an inch of flute edge is effective for cutting a soft material. This distance decreases as the material hardness increases until only a few micro-inches of blade edge are effective in some cases. The largest manufacturing difficulty lies in producing equally sharp edges consistently; i.e., bur flutes that are identical within the outer one-thousandth of an inch.

The flutes of commercial burs usually have some fins or excess material. It may be removed by subsequent cuttings of the bur flutes; however, it has been found that the small increase in the effectiveness of the bur does not warrant the extra cost. Heat treatment must retain the sharp edge placed on the flute by the cutter as well as harden the bur and increase its cutting life.

During peripheral cutting it is felt that the end flutes are inoperative. Test results indicate that the "Revelation" type flute is superior to the "Star" type end flute and the bur without end flutes. However, the results are not conclusive.

It has been found experimentally, as well as theoretically, that the average linear displacement per flute revolution does not depend markedly on velocity, indicating that the length of cut is nearly constant irrespective of reasonable changes in bur diameter. It is assumed in this statement that the edge conditions at the flutes as well as the test conditions are the same.

Changing the length of engagement as well as the number of flutes changes the manner in which the external load is distributed among the flutes of the burs. If the force on the flute is increased, the average displacement per flute revolution is increased. This occurs when either the length of engagement or the number of flutes is decreased.

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