THE UNIVERSITY OF MICHIGAN
INDUSTRY PROGRAM OF THE COLLEGE OF ENGINEERING

BEHAVIOUR OF CUTTING FLUIDS IN REAMING STEELS

L. V. Colwell

Henrik Branders

June, 1957

IP-226

Behaviour of Cutting Fluids in Reaming Steels

L. V. Colwell and Henrik Branders

The subject matter of this paper is the result of an initial attempt to develop a combination reamer and burnishing tool. Preliminary calculations indicated that only a very little interference between a burnishing element and the wall of the hole would be required to produce a plastic flow of the metal and thus result in burnishing providing adequate lubrication could be achieved. Preliminary tests were made with improvised burnishing tools; the torques were measured with a range of lubricants and compared with similar torque measurements for reaming the same materials. This information indicated that effective lubricants were very important not only for burnishing but also for reaming. Therefore, it was decided to explore this problem further, particularly in connection with reaming.

The only reference to this topic in the literature involves a Russian research report*. The report makes some reference to torque requirements but deals principally with variations in hole size as related to the reamer size. The principal conclusion of the report is that the "gap" between hole size and reamer size is due to wear by "dust particles of metal" between the wall of the hole and the margin of the reamer. This observation does not appear to be consistent with the preliminary results referred to above. Therefore, it was decided to examine not only the torque requirements but also surface finish and hole size for a range of work materials, lubricants, tool condition, and size of cut.

Program Outline

One-inch diameter by one-inch long test specimens were prepared from hot rolled C-1045 steel, cold drawn C-1020 steel, and cold drawn B-1112

---

* "How Lubrication Affects Deep Hole-Reaming," G. S. Andreev, American Machinist, vol. 100, no. 10, 1. 134, May 7, 1956.

steel. They were drilled and precision bored to selected diameters preparatory to reaming with a standard 3/4-inch machine reamer as supplied by the National Twist Drill and Tool Company. The bored holes were accurate within $\pm$ 0.0005 inch with surface roughness ranging from 80 to 130 microinches rms.

The cutting fluids selected for the study consisted of Carbon Tetrachloride, Chemical Emulsion Concentrate, Butyl Stearate, and dry. Tests were to be made with all fluids on all three work materials at a constant size of cut. Then the cut, in terms of feed rate and thickness of metal removed, was to be varied with one cutting fluid.

The test setup consisted of a sensitive torque dynamometer mounted on a 25-inch, box-column, Fosdick drill press. The work specimens were held in a one-inch collet with the same clamping force used for each test. The reamer was mounted in an adjustable boring head so that the total indicated runout was kept less than 0.002 inches for all tests. The cutting fluid was applied continuously from a pressure container during each test. The torque requirements were recorded continuously on the chart of a carrier-amplifier-recorder. Subsequent to the test, the surface roughness of the reamed hole was measured with a Profilometer. The diameter of the hole was measured with a Sheffield air plug gage, and readings were made to the nearest 0.00005 unit. It was found that the specimens warped upon removal from the collet so that several diameter readings had to be taken so as to determine the minimum and maximum of such readings for each specimen.

Test Results

Torque Requirements

Fig. 1 shows a typical torque curve as produced on the recorder chart. Values of torque increase vertically, and elapsed time increases horizontally to the right. It will be noted that the torque rises very quickly at the beginning of the cut to a value designated as T_1. As the reamer progresses farther into the hole the torque rises further, reaching a peak value just prior to emerging from the other end of the specimen. This increase above the T_1 value is referred to in this paper as "rubbing or burnishing torque" and is designated by T_2. Generally the indicated torque dropped suddenly by the amount T_1 upon emerging from the opposite end of the specimen. The torque then proceeded to decrease gradually as feeding continued, or even if the feed were disengaged and the reamer left to rotate in the hole, it did not decrease to zero until the reamer was completely removed from the hole.

The reproduced torque curve in Fig. 1 is to be considered as a general type exhibiting all the characteristics which were observed in this investigation. In some tests, the torque did not rise above the initial value T_1. This always occurred with dry cutting and in some instances with lubricant as well. In other instances, the torque rose linearly above T_1 until reaming was complete; this occurred primarily in light cuts using either Carbon Tetrachloride or Chemical Emulsion Concentrate as a lubricant. In heavier cuts, particularly with the smaller bored specimens, the torque rose rapidly above T_1 but bent away from a linear trend apparently because of relaxation arising from plastic flow of the metal in the wall of the hole.

Figs. 2, 3, and 4 are bar-graphs of the torque requirements obtained for three different sets of reaming conditions. In Fig. 2, for example, the torque requirements are shown for all three work materials as reamed at the four different lubricant conditions. All of the tests represented in Figs. 2, 3, and 4 were made with a feed 0.015 ipr, 60 rpm, and while increasing the diameter from 0.745 to 0.750 inches.

It will be noted in Fig. 2 that Carbon Tetrachloride generally required the highest torque while Chemical Emulsion Concentrate, Butyl Stearate, and dry cutting generally required less torque in that sequence. The cross-hatched portion of each bar shows the value of T_1 for each condition while the total height of the bar represents the peak torque requirement just prior to completion of cutting. Thus the open portion of each bar represents that additional torque which presumably was caused by rubbing friction between the reamer margins and the wall of the hole. It will be noted that the rubbing torque is frequently more than twenty times that required simply to remove the metal.

The data plotted in Fig. 2 are averages of two to three tests in each case. They were obtained with one reamer in the as-received condition. The same test conditions were repeated in single tests with another reamer. These results are shown in Fig. 3. It will be noted that there is a substantial variation in the total torque requirements where the Chemical Emulsion Concentrate was used as the lubricant. This appeared to be due to small variations between reamers and in alignment between the reamer and test specimen.

The test conditions reported in Figs. 2 and 3 were repeated with a "dull reamer". For this purpose, a new sharp reamer was "dulled" by rubbing the cutting edges adjacent to the margins with fine, metallographic abrasive paper until a visible radius appeared when viewed under the microscope. It was estimated that the radius was the order of magnitude of 0.001 inch. The torque requirements obtained for this reamer are shown in Fig. 4. It will be noted that the pattern of behavior is substantially the same as was obtained with the two sharp reamers. Such variations as occurred compared to the data in Figs. 2 and 3 can be attributed readily to small, uncontrolled variations in test conditions.

Surface Finish

Figs. 5 to 7, inclusive, show the corresponding surface finish data obtained for tests for which the torque requirements are reported in Figs. 2 to 4, inclusive. The bar-graphs indicate the full range of roughness measurements. It will be noted that an inverse relationship exists between torque requirements and surface roughness, that is, the higher the torque requirement the lower the roughness. This condition existed without exception in all tests represented by these figures. The best surface finished were produced with Carbon Tetrachloride and Chemical Emulsion Concentrate as cutting fluids. This was due to almost total removal of any built-up edge or loading accompanied by appreciable burnishing as manifested in the higher torque requirements.

Hole Size

Corresponding data on hole size as measured with the air-plug gage are shown plotted in Figs. 8 to 10, inclusive. The bars indicate the range and extremes of diameter measurements which, of course, represent only the condition of the reamed hole after removal from the collet. Consequently, the actual size of the hole as reamed before removal lies somewhere between the extremes. Regardless of this aspect of the problem, there is no question as to the validity of direct correlation between increasing hole diameter and increasing surface roughness or the converse when related to torque requirements.

The hole size data appear to furnish further support for the suggestion that different cutting fluids or lubricants affect the size of the built-up edge. Thus a large built-up edge can be expected to produce a larger reamed hole whereas the minimum could be expected for a combination of no built-up edge and an effective lubricant. The reamers were measured before the tests and found to be from 0.7503 to 0.7504 inches diameter. Therefore, it is quite possible that some of the reamed holes, particularly those obtained with the Carbon Tetrachloride as a cutting fluid, were actually smaller in diameter than the reamer used.

Effect of Size of Cut

Further tests were made wherein both the feed and the thickness of metal removed were varied. The results of these tests are plotted in Figs. 11 through 13.

Fig. 11 shows the torque requirements for reaming the C-1020 steel with Chemical Emulsion Concentrate and a "dull" reamer while removing 0.005, 0.010, and 0.015 inches on the diameter. Both the cutting torque and the rubbing torque increase continually with increase in the amount of metal removed. A similar result was obtained for increasing feed as shown in Fig. 12. A "dull" reamer was used on C-1020 steel. The feed in inches per revolution was varied while diameter increase was held constant at 0.005 inches. Again both the cutting and rubbing torques increased continually with increased size of cut.

In contrast, Fig. 13 shows similar torque requirements for reaming C-1045 steel with a sharp reamer at three different feeds and constant diameter increase of 0.005 inches. Here a quite different result was obtained. The rubbing torque was greatest at the 0.005 feed and decreased very rapidly to almost zero at a feed rate 0.015 ipr while at the same time the cutting torque increased steadily with increased feed as would be expected. Thus it would appear that total torque requirements for sharp reamers can actually decrease with increased size of cut, providing built-up edges are small enough at the light cuts.

It is significant that both the surface finish and hole size varied rather little for the tests made with the dull reamer. On the other hand, the sharp reamer tests represented in Fig. 13 demonstrated substantial increase in both surface roughness and hole size with increased feed or size of cut.

Conclusions

1. The presence of a built-up edge at the outer corner of end-cutting reamers affects hole size, surface finish, and torque required for reaming.
2. Some lubricants may reduce the size of built-up edges on reamers to such an extent that substantial rubbing occurs between the wall of the hole and the reamer margin.
3. A dull reamer in the presence of a good lubricant can continue

to produce good surface finish and close control of diameter. The same lubricant with a sharp reamer might fail to prevent significant loading, thus resulting in poor finish and size control.

4. Higher torque in reaming is not necessarily bad since it may be the result of burnishing which can produce better finish and closer control of hole size.

ACKNOWLEDGEMENT

Grateful acknowledgement is extended to the National Twist Drill and Tool Company for supplying the reamers used in these tests, and to Mr. Harold Sullivan of the Production Laboratories for his patience and skill in preparing the test specimens and for his assistance in running the tests.

TYPICAL REAMING TORQUE CHART

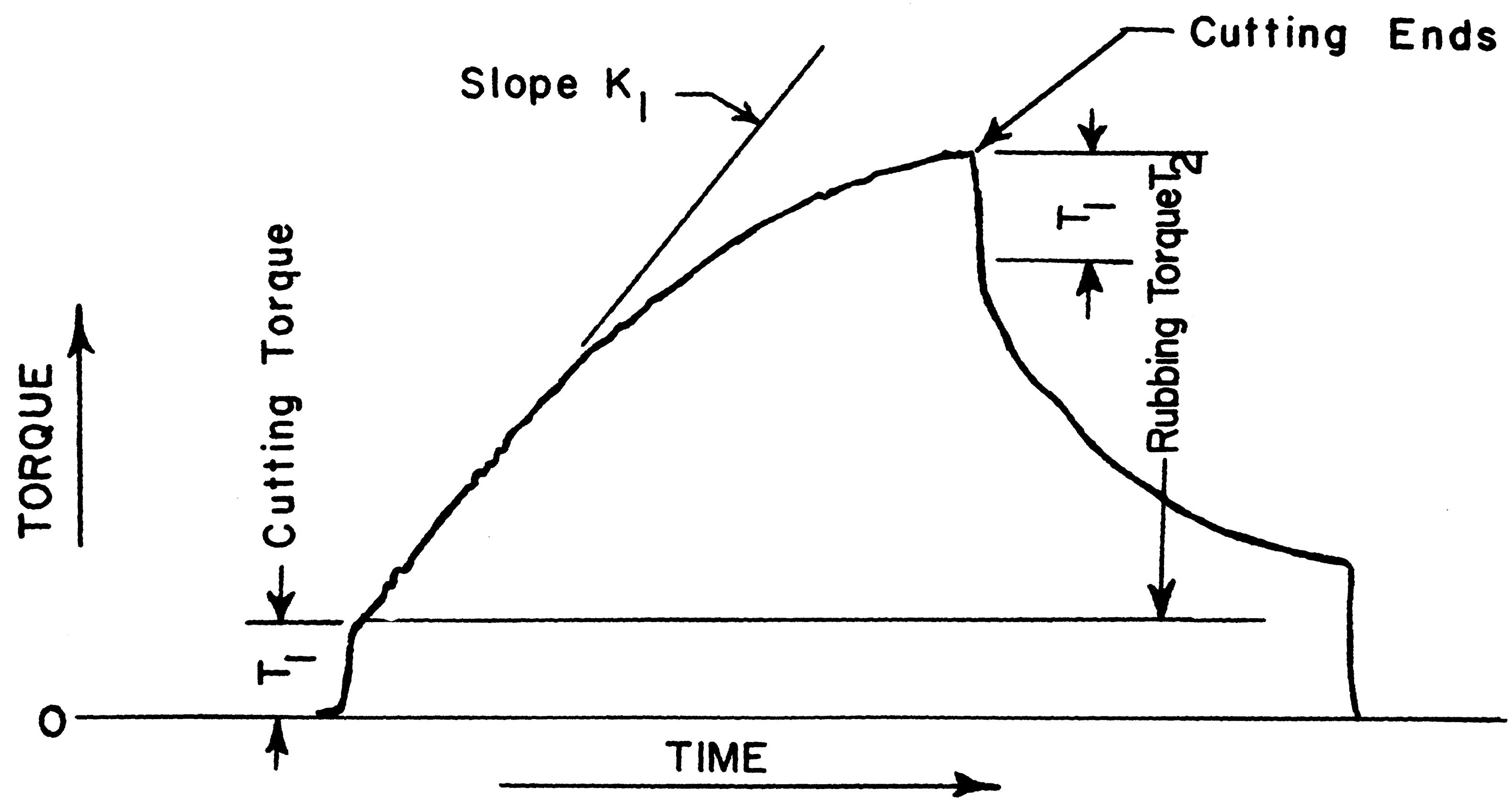

Figure 1: Typical torque-time chart for reaming when rubbing occurs. Deviation from linear trend is due to plastic flow or burnishing. Torque for dry cutting remains constant at T_1 level.

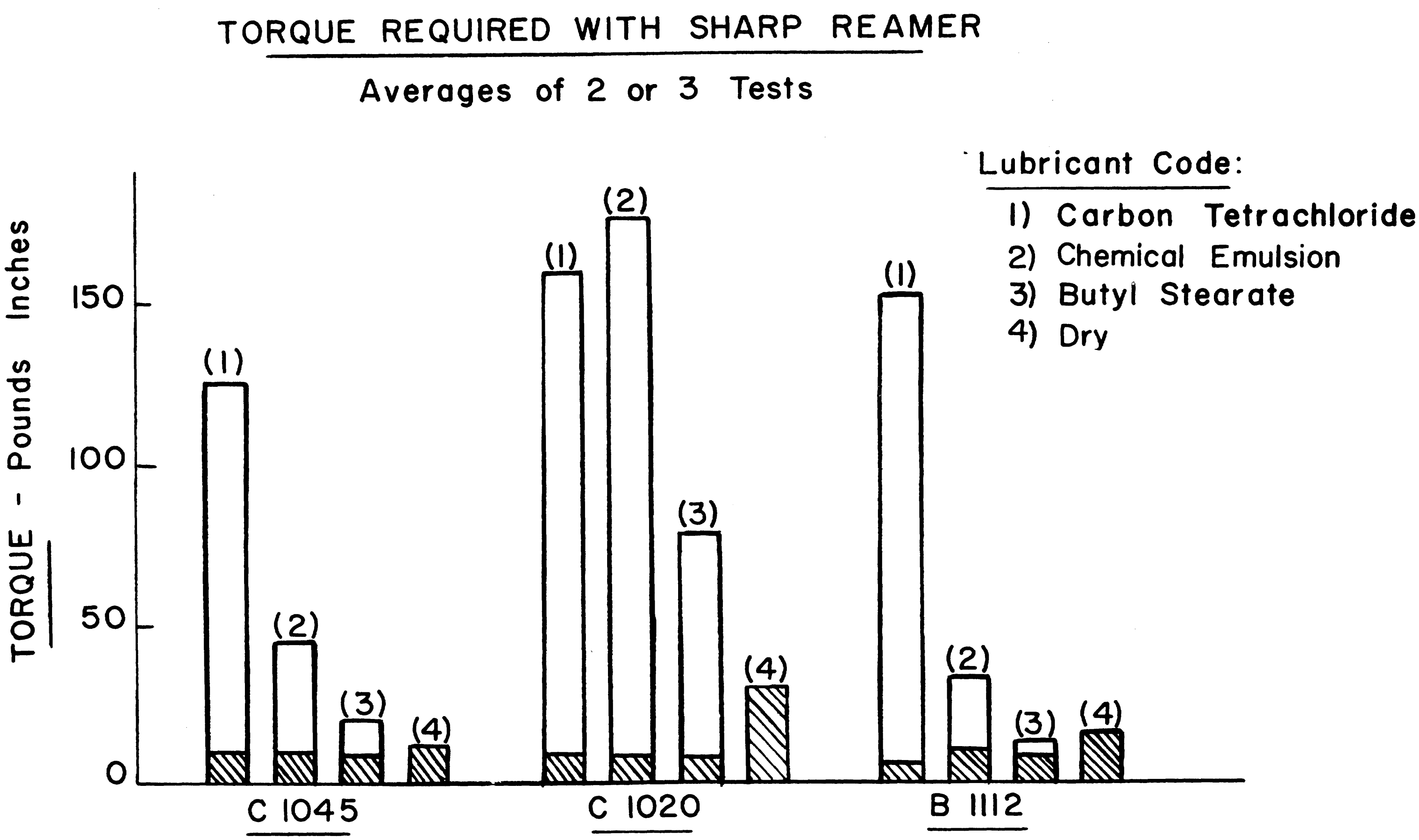

Figure 2: Total height of bars is maximum torque during test run. Cross-hatched portion is cutting torque (T_1); open portion represents rubbing torque (T_2). Feed was 0.015 ipr, speed was 60 rpm; reamer diameter was 0.7504 inches; hole diameter before reaming was 0.745 inches.

SECOND RUN WITH SHARP REAMER

Results for One Hole at Each Condition

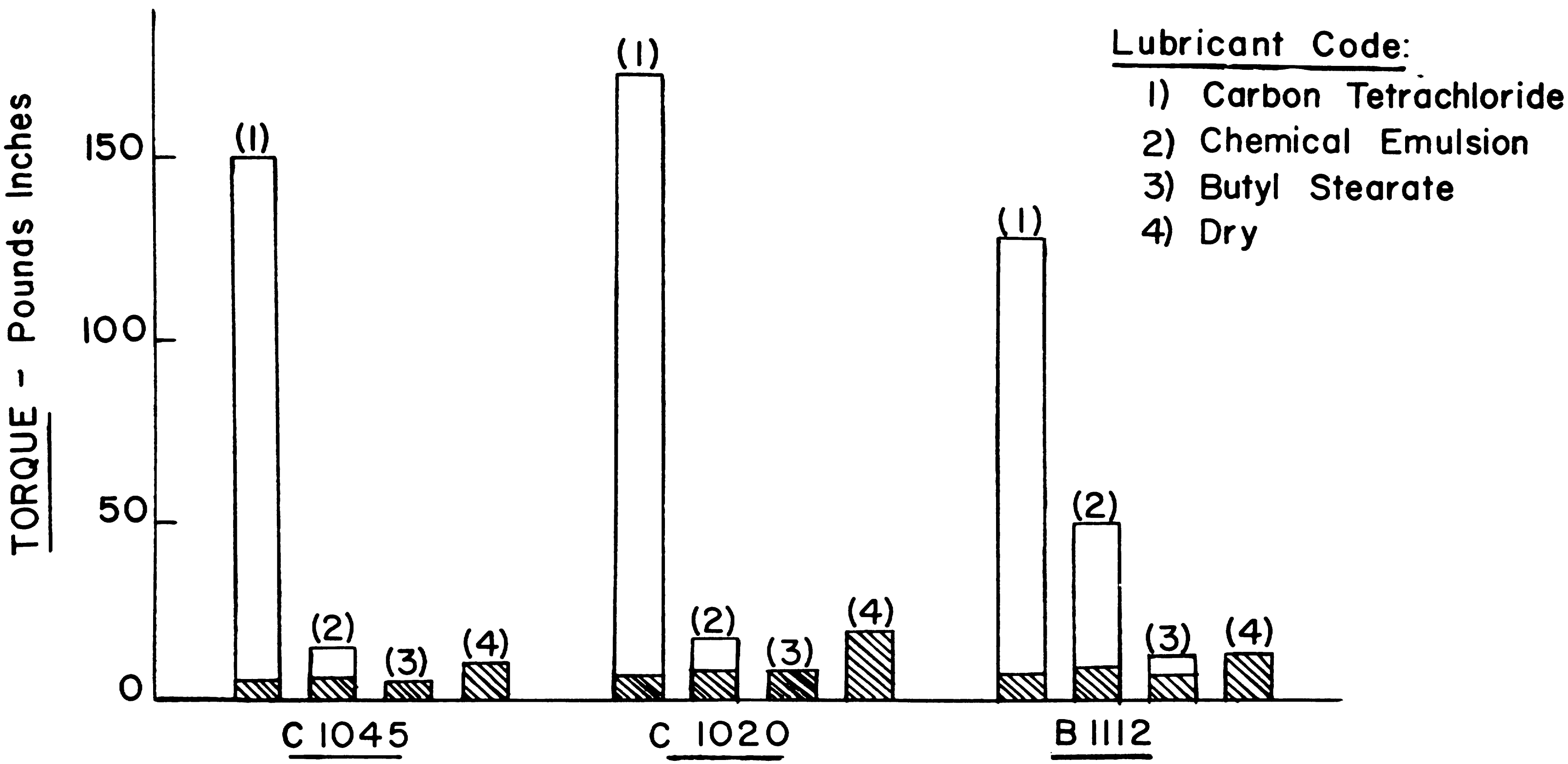

Figure 3: Tests were repeated with another reamer. Cutting conditions same as for Fig. 2. Small variations in reamer runout may cause considerable change in rubbing torque.

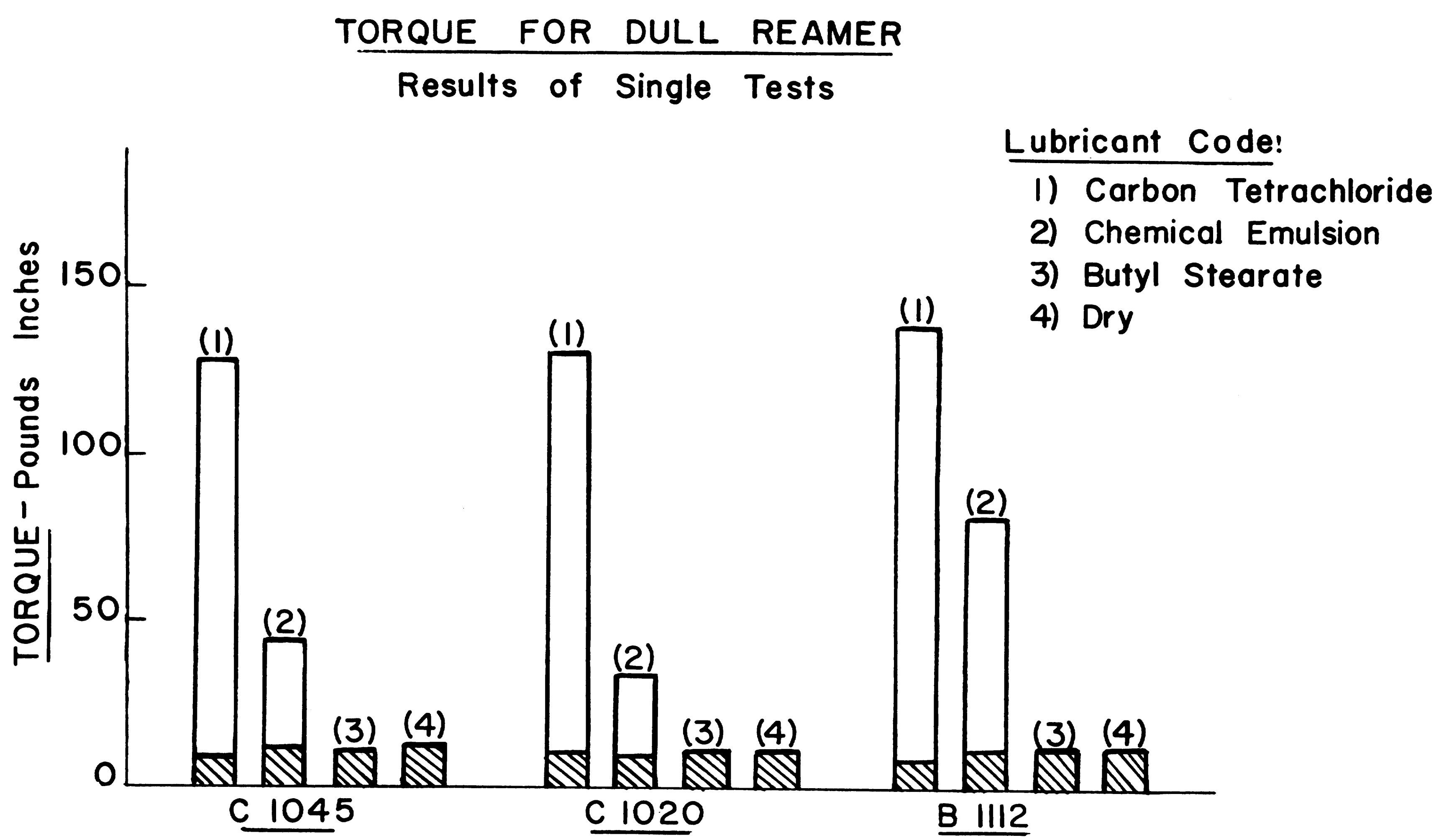

Figure 4: Cutting conditions same as for Figs. 2 and 3 except that a "pre-dulled" reamer was used. Note uniform pattern of behavior between work materials.

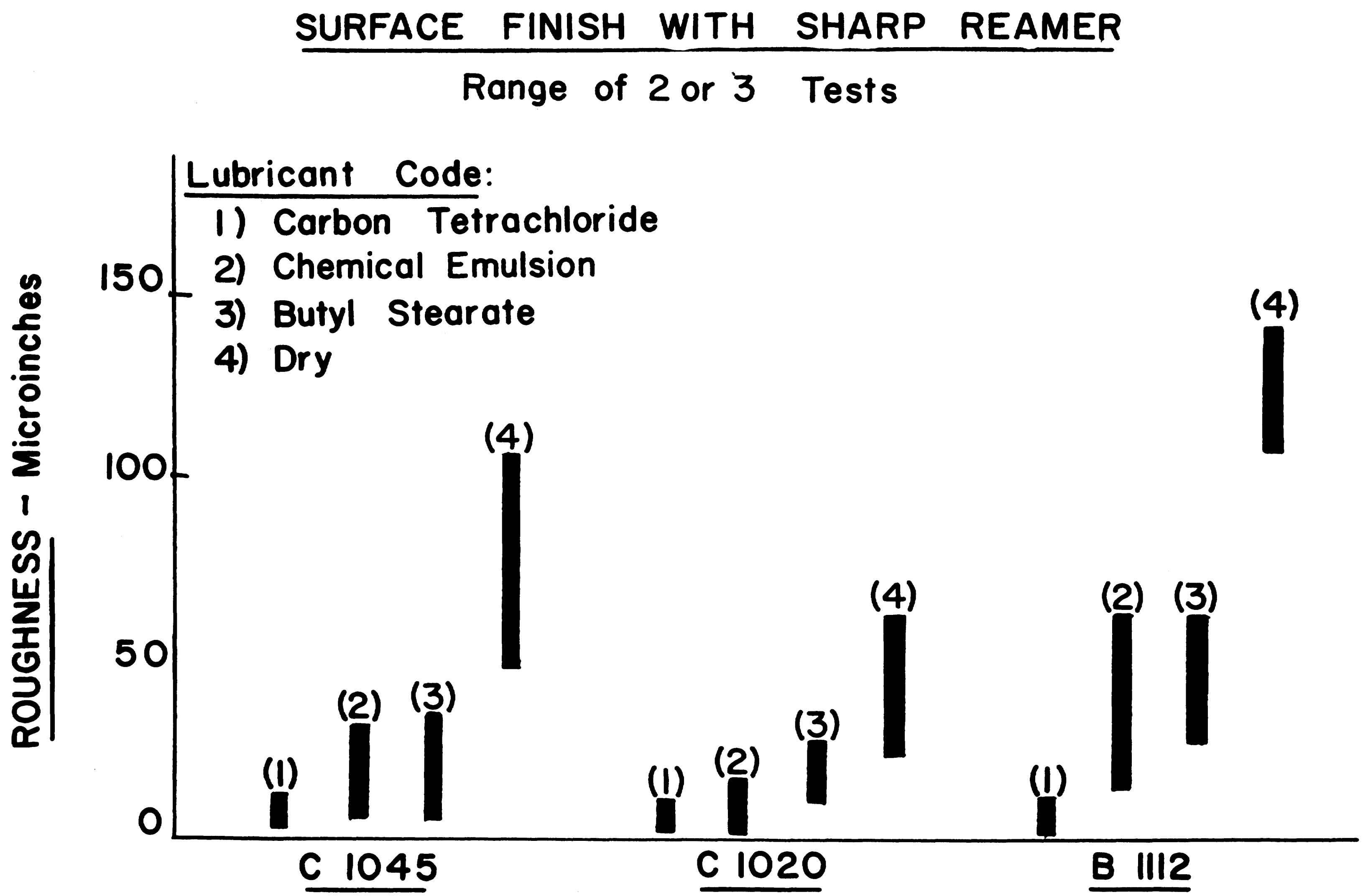

Figure 5: Bars represent full range of measurements for all tests. Cutting conditions same as for Fig. 2.

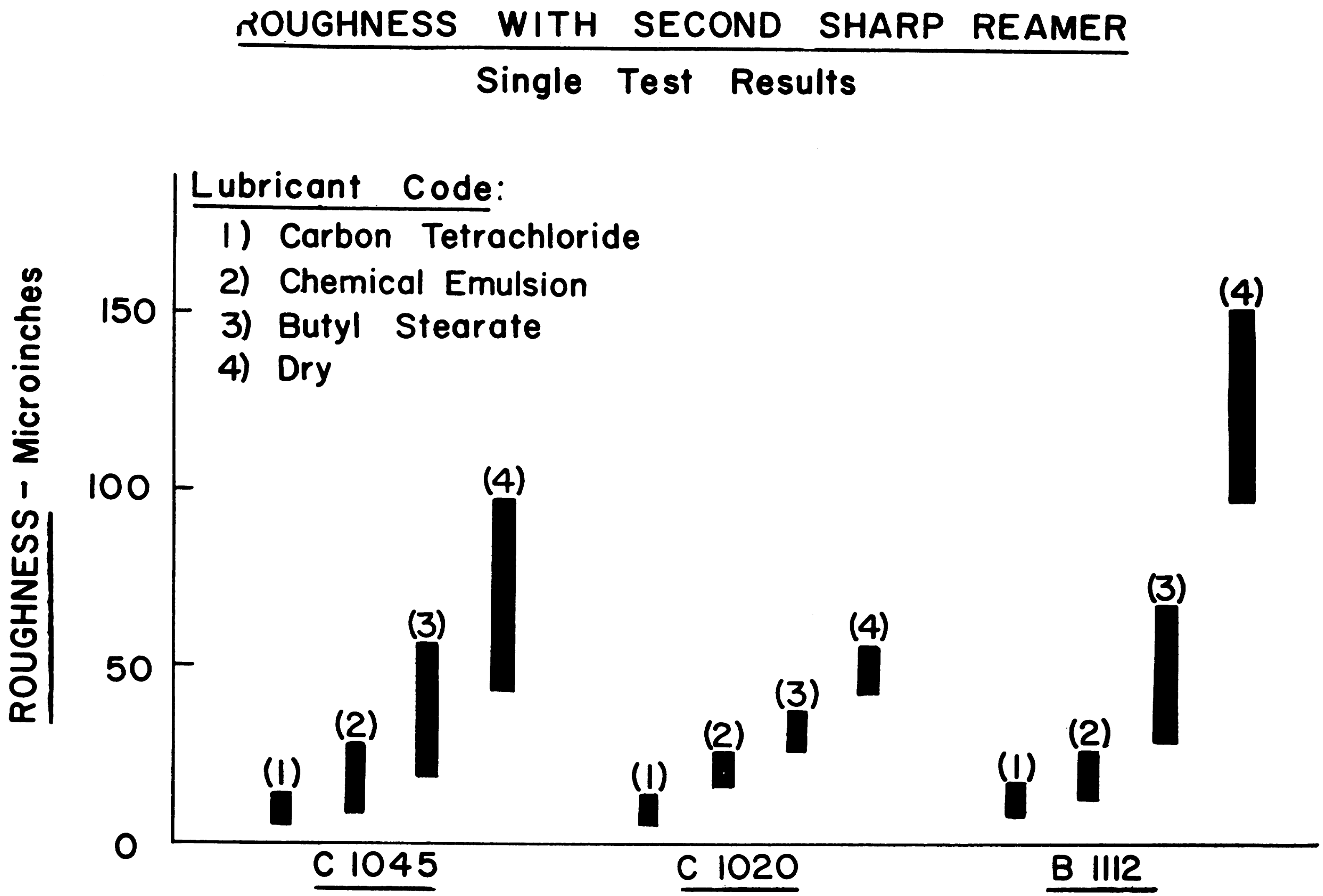

Figure 6: Roughness level appears to depend on size of built-up edge and amount of burnishing. Cutting conditions same as Fig. 3.

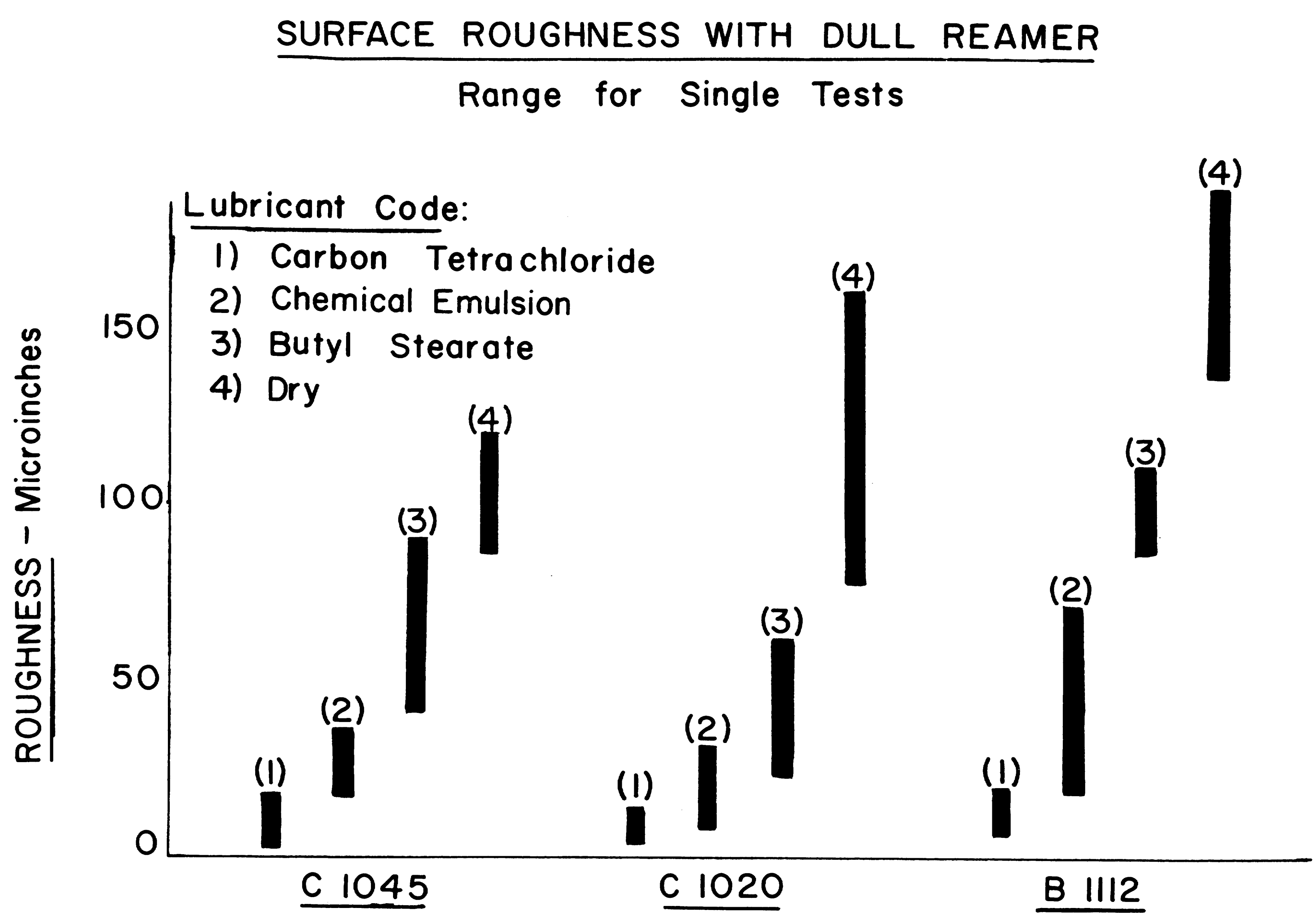

Figure 7: Cutting conditions same as Fig. 4. Roughness appears to be more sensitive to lubrication with dull reamer.

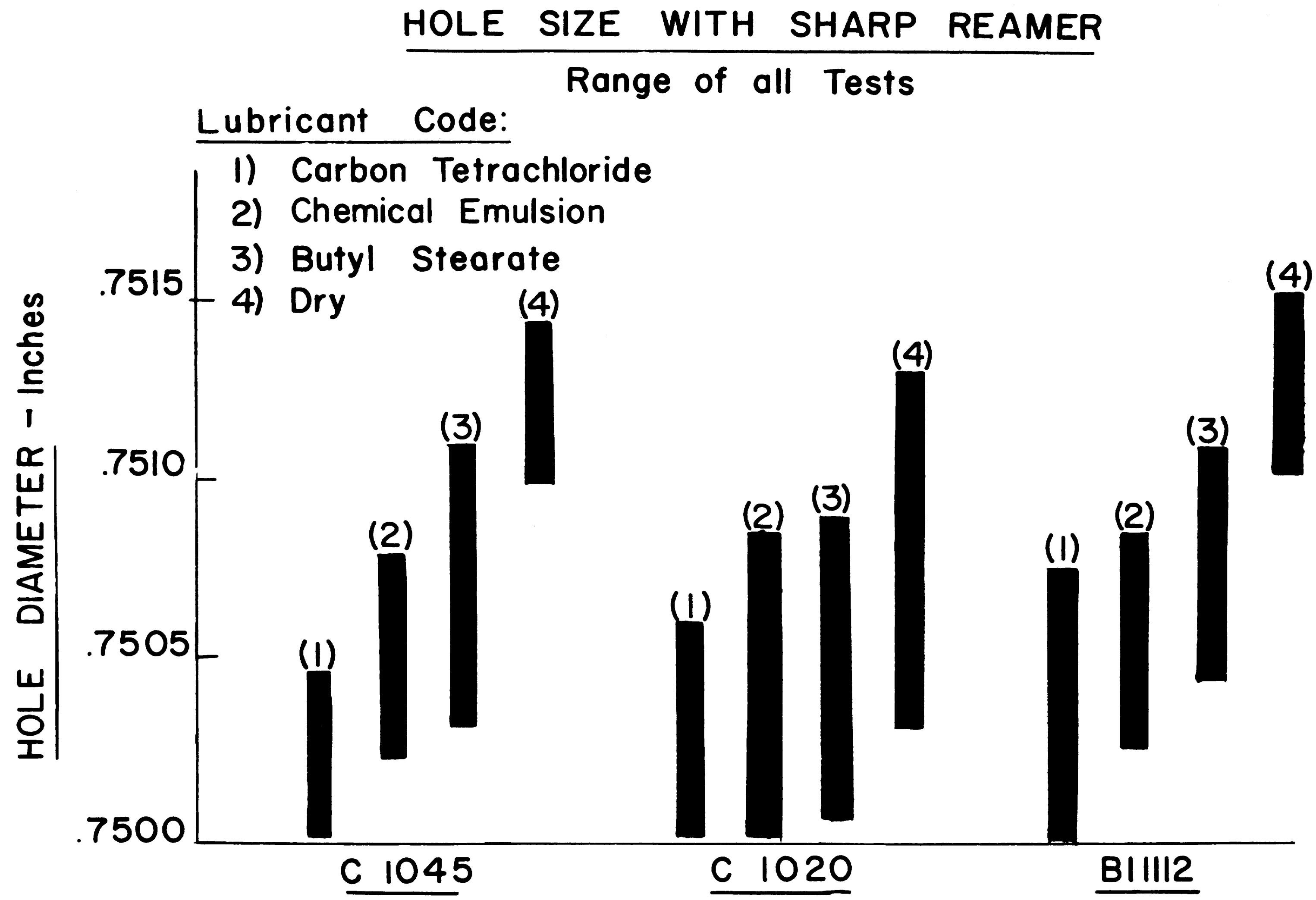

Figure 8: Cutting conditions same as Fig. 2. Full range of measurements is shown. Warping after removal from collet is responsible for part of the range.

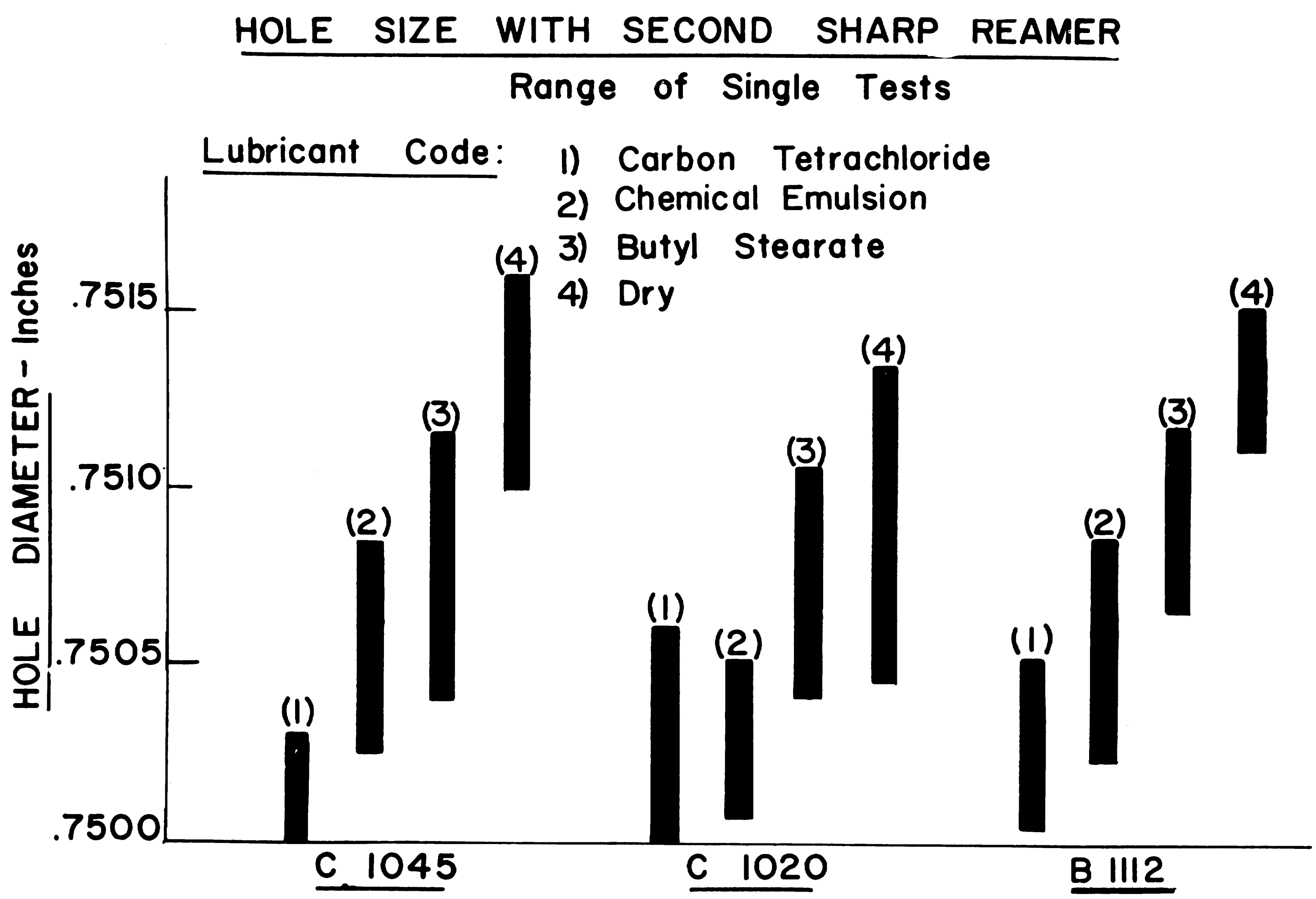

Figure 9: Cutting conditions same as Fig. 3. Repeat run with second reamer confirms size trend.

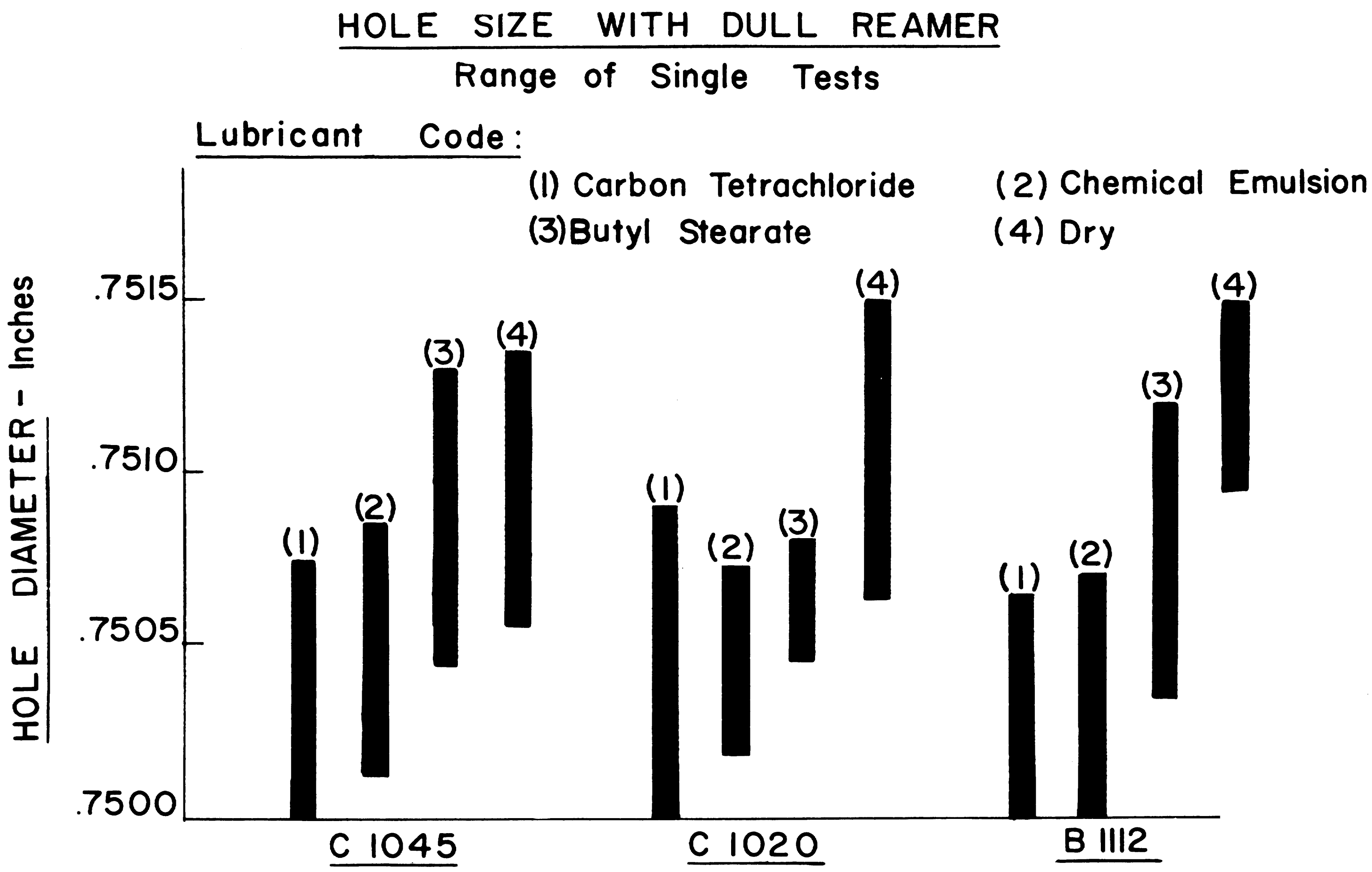

Figure 10: Cutting conditions same as Fig. 4. Dull reamer produces somewhat smaller holes.

EFFECT OF INCREASING SIZE OF CUT WITH DULL REAMER

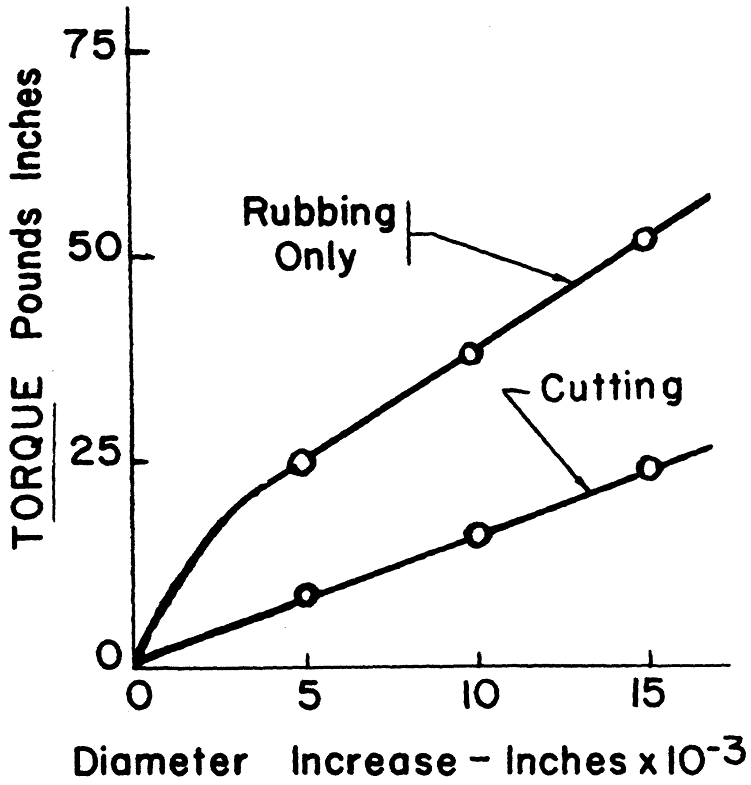

Figure 11: Both cutting torque and rubbing torque increased with thickness of metal removed when dull reamer was used with Chemical Emulsion on C 1020 Steel. Feed was constant at 0.015 ipr.

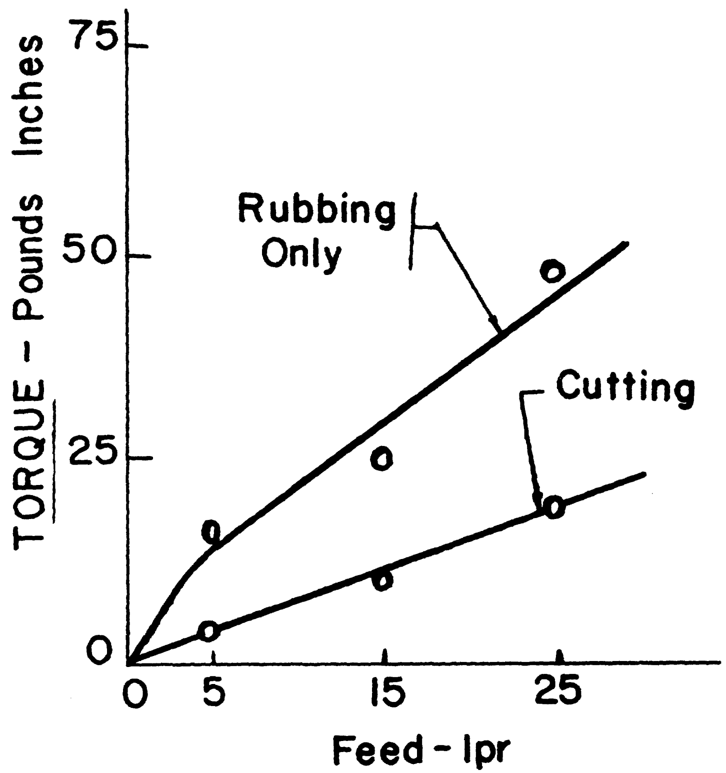

Figure 12: Torque increases with feed for dull reamer on C 1020 Steel with Chemical Emulsion as lubricant. Initial hole diameter was 0.745 inches.

INCREASING SIZE OF CUT WITH SHARP REAMER

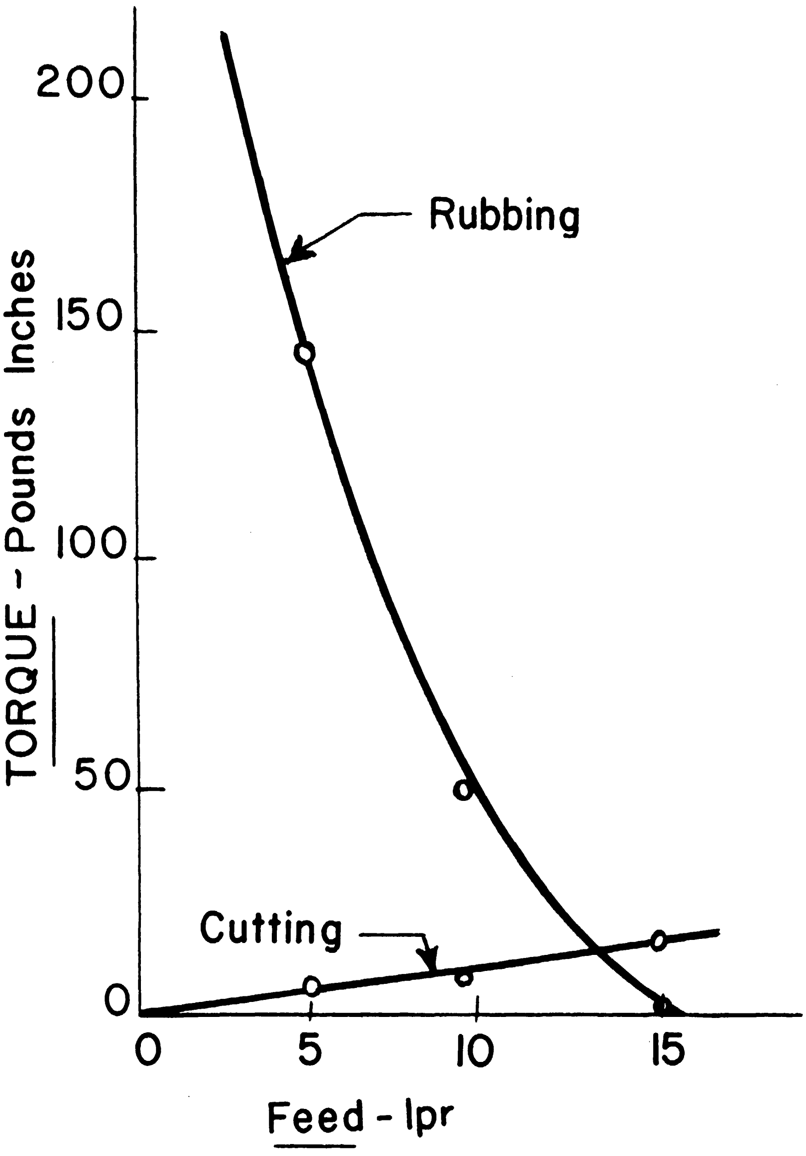

Figure 13: Increased feed with sharp reamer on C 1045 steel resulted in considerable reduction of rubbing torque as size of built-up edge increased. Finish also deteriorated. Lubricant: Chemical Emulsion. Initial Hole Diameter: 0.745 inches.