

The Effect of Cutting Fluids on Reaming Operation

By

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In order to investigate the effect of cutting fluids on reaming operation, reaming tests were performed with various kinds of cutting fluids, and reaming torque and accuracy of reamed holes were compared for dry and wet cuttings. Tests were also made dry and wet for different cutting conditions, and effects of conditions on reaming torque and accuracy of reamed holes were investigated.

Application of cutting fluids improved the accuracy of reamed holes, though reaming torque was increased. The cutting torque component was scarcely affected by cutting fluids. But cutting fluids increased the burnishing torque component in the order of dry, cutting oils, and soluble oils. Dry reaming and reaming with cutting oils produced oversized holes. Reaming with soluble oils produced smaller holes than the actual size of the reamer. The smaller the amount of enlargement of the reamed hole, the larger the burnishing torque component, and the better the surface finish in the order of dry, cutting oils, and soluble oils.

With increases in cutting speed, feed, and depth of cut, the amount of enlargement increased and the surface finish of the reamed hole became worse for both dry and wet conditions.

The sharp reamer showed a peculiar phenomenon for torque pattern in relation to feed rate. The stable reamer which was used several dozen times produced better reamed holes than the sharp reamer.

1. Introduction

There are many factors which affect the accuracy of reamed holes. Cutting fluid plays an important role in reaming operation. In this paper, in order to investigate the effect of it, reaming tests were performed with various cutting fluids, and reaming torque and accuracy of reamed holes were compared with for dry and wet cuttings. Tests were also made dry and wet for different cutting conditions, and effects of cutting conditions on reaming torque and accuracy of reamed holes were investigated.

2. Experimental Procedure

The test setup is shown in Fig. 1. The test piece was installed in the

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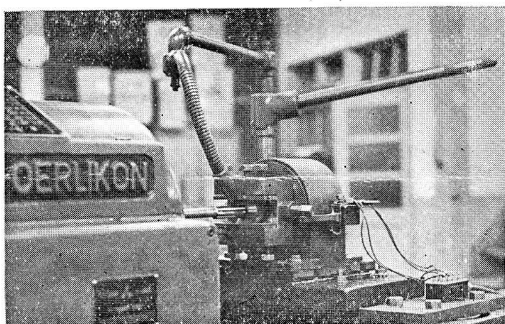


Fig. 1. The test setup.

torque dynamometer set up on the carriage of a lathe. Reamer was fixed in the spindle sleeve. Mitsubishi-Oerlikon DMOa type high speed lathe (swing, 460 mm; center distance, 1500 mm; power, 15 HP) was used for this reaming test.

Test pieces, 22 mm in width, were obtained from S45C steel billets. The chemical composition and mechanical properties of the

test material are shown in Table 1. Before reaming tests, test pieces were drilled and finished with an adjustable reamer to obtain a given depth of cut within error of ± 0.01 mm. The maximum value of surface roughness of holes to be reamed was in 10 to 20 μ . Both the adjustable reamer and the reamer used for the test were installed in the same spindle sleeve of the lathe in order to neglect an eccentricity between the center of the reamer and the center of a hole to be reamed.

Table 1. Chemical composition and mechanical properties of material S45C tested.

Chemical composition (%)								Tensile Strength (kg/mm ²)	Brinell Hardness Number
C	Si	Mn	P	S	Cu	Cr	Fe		
0.41	0.23	0.66	0.015	0.018	0.12	0.04	Bal	76.0	186

The reamer used was a standard taper shank chucking reamer of 20 mm size (material, high-speed steel SKH 9; actual size, 20.016 mm). It was installed in the spindle sleeve so that the total indicated runout was kept less than 0.02 mm for all the tests. As in reaming in practical workshops reamers used for tests were those which had been used several dozen times before test and were stable enough.

Eight kinds of cutting fluid shown in Table 2 were used for the test. It was supplied continuously through the nozzle for cutting fluid at the rate of about 8 l/min.

Dry reaming tests were also made to compare the results with those for wet reaming.

Cutting conditions were kept constant; that is, cutting speed, 5 m/min.; feed, 0.40 mm/rev.; depth of cut in diameter, 0.30 mm. Each test was repeated three times to ascertain reliability.

Table 2. Kinds of cutting fluid used.

Cutting oils	Soluble oils
Mineral oil	Emulsion (Dilutoin) 10
Compound oil	Soluble 20
Extreme pressure oil (active sulpho-chlorinated oil)	Soluble 20 (containing sulphurized extreme pressure additive)
Extreme pressure oil (chlorinated oil)	Chemical solution 40

Next, choosing one kind of cutting fluid, i.e., extreme pressure oil (chemically active, sulpho-chlorinated oil), effects of cutting conditions on reaming torque and accuracy of reamed holes were investigated and compared with those in dry reaming. Cutting conditions were: cutting speed, 2 to 40 m/min.; feed rate, 0.10 to 1.03 mm/rev.; depth of cut in diameter, 0.10 to 0.60 mm. For each cutting condition three times of tests were made in the case of dry reaming and twice in the case of wet reaming.

Further, tests were made in order to investigate the difference between reaming operations with sharp reamer (just sharpened) and dull reamer (after used several dozen times).

During tests the reaming torque was measured with the strain gage type torque dynamometer and recorded on oscillograph paper. After tests, the surface roughness of reamed holes was measured with Model 3 Talysurf surface measuring instrument. The diameter at the central position of reamed holes was measured with Imicro internal tri-point micrometer.

3. Test Results on Effect of Cutting Fluids

Reaming tests for S45C steel were performed dry and wet with a reamer of 20 mm nominal diameter. Results of measurements of the reaming torque, the amount of enlargement in diameter, and the surface finish of reamed holes are shown in Figs. 2, 3, and 4, respectively. Cutting conditions were: cutting speed, 5 m/min.; feed, 0.40 mm/rev.; depth of cut in diameter, 0.30 mm.

The variation of reaming torque with time is shown in Fig. 5. Thus, the reaming torque consists of two components, namely, the cutting torque component (T_1) acting on the chamfer and the burnishing torque component (T_2) acting on the margin. In Fig. 2, which shows the relationship between reaming torque and cutting fluids, the black portion represents the cutting torque component and the white portion the burnishing torque component. The total (sum of the cutting and burnishing torque components) is the resultant

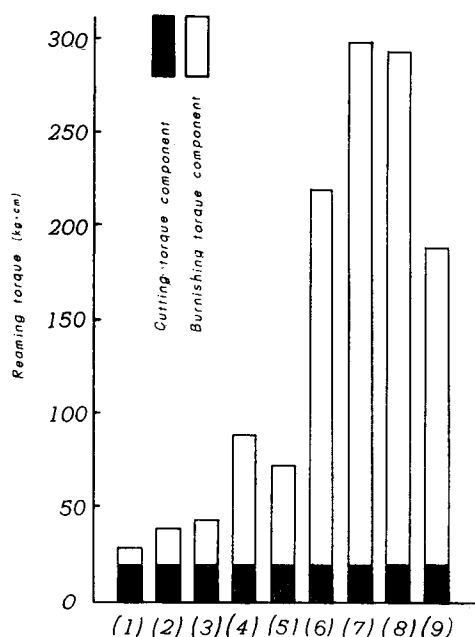


Fig. 2. Effect of cutting fluids on reaming torque [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; feed, 0.40 mm/rev.; depth of cut in diameter, 0.30 mm].

Note for Figs. 2 to 4:

- (1) Dry
- (2) Mineral oil
- (3) Compound oil
- (4) Extreme pressure oil
(active sulpho-chlorinated oil)
- (5) Extreme pressure oil (chlorinated oil)
- (6) Emulsion
- (7) Soluble
- (8) Soluble (containing sulphurized extreme pressure additive)
- (9) Chemical solution

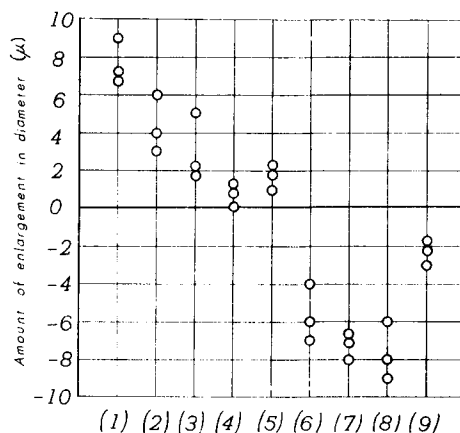


Fig. 3. Effect of cutting fluids on amount of enlargement in hole diameter [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; feed, 0.40 mm/rev.; depth of cut in diameter, 0.30 mm].

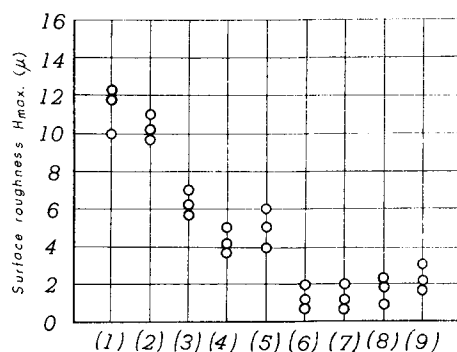


Fig. 4. Effect of cutting fluids on surface roughness [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; feed, 0.40 mm/rev.; depth of cut in diameter, 0.30 mm].

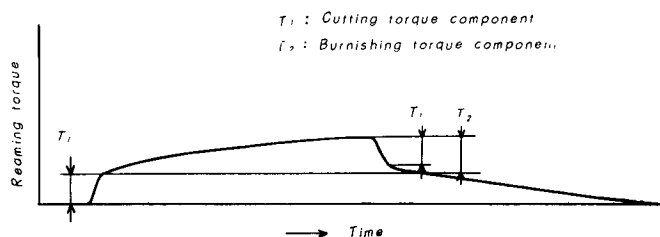


Fig. 5. Variation of reaming torque with time.

reaming torque required in reaming operation. It is found from Fig. 2 that the cutting torque component is almost constant for both dry and wet cuttings. It appears that cutting fluids do not affect the cutting torque component. On the other hand, the burnishing torque component is affected by cutting fluids. Dry reaming showed the smallest burnishing torque component. The burnishing torque component was increased when cutting fluids were used, in the order of mineral oil, compound oil, extreme pressure oil, chemical solution, emulsion, and soluble. Generally, soluble oils showed larger burnishing torque component than cutting oils.

Regarding the amount of enlargement in diameter which indicates the difference between diameters of the reamed hole and the actual reamer size, as shown in Fig. 3, it was positive for dry reaming and for wet reaming supplied with cutting oils, and negative for wet reaming supplied with soluble oils. This means that dry reaming and reaming with cutting oils produced oversized holes and reaming with soluble oils produced undersized holes. It is considered that oversized holes were produced due to the eccentric rotation of the reamer, the occurrence of the so-called built-up edge, etc. On the other hand, it is unusual that undersized holes were practically obtained when reaming with soluble oils. A similar result was reported by Colwell and Branders¹⁾ and Ten Horn, Schuermann, and Slaats²⁾. This phenomenon may be explained by a fact that the

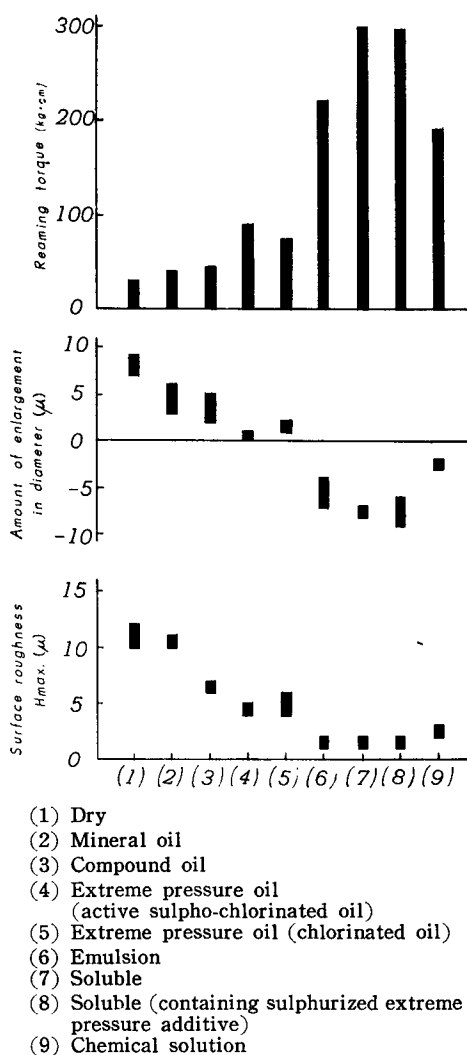


Fig. 6. Effect of cutting fluids on reaming torque, amount of enlargement, and surface roughness [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; feed, 0.40 mm/rev.; depth of cut in diameter, 0.30 mm].

reamer employed in the test had been used several dozen times before test and, hence, owing to wear of cutting edges the diameter of the reamer was slightly smaller than the actual size when it was sharp. The amount of enlargement (which is defined as the difference between the hole diameter and the original actual size of the reamer) appeared to be negative even if the hole diameter was the same as or smaller than the actual size of the dull reamer. Further investigation should be made to clearly explain this phenomenon.

The relationship between surface roughness and cutting fluids is shown in Fig. 4. It is found that the surface finish was improved by using cutting fluids in the order of mineral oil, compound oil, extreme pressure oil, chemical solution, emulsion, and soluble. This trend is related to that of the increase in the burnishing torque component when cutting fluids are supplied (compare Fig. 2 and Fig. 4). Thus, the larger the burnishing torque component, the better the surface finish.

Combining all data of Figs. 2, 3, and 4, Fig. 6 shows the relationship among torque, amount of enlargement, and surface finish in the dry and wet reamings. The smaller the amount of enlargement, the larger the reaming torque (especially the burnishing torque component), and the better the surface finish, in the order of dry, cutting oils, and soluble oils.

4. Test Results on Effect of Cutting Conditions

a. Effect of Cutting Speed

The variation of reaming torque, amount of enlargement, and surface roughness with cutting speed is shown in Figs. 7, 8, and 9, respectively. Feed and depth of cut in diameter were kept constant, i.e., 0.40 mm/rev. and 0.30 mm, respectively.

It is found from Fig. 7 that reaming torque decreases with an increase in cutting speed for both dry and wet cuttings. The rate of decrease is steep specially in low speeds. Reaming torque is larger in the case of wet cutting than in the case of dry cutting. This is remarkable in low speeds. Cutting torque component is almost constant in spite of the change of cutting speed for both dry and wet cuttings. Therefore, with an increase in cutting speed the burnishing torque component decreases and lastly vanishes.

It is evident from Fig. 8 that the amount of enlargement increases with cutting speed for both dry and wet cuttings. Only small and fairly consistent data were obtained in the case of wet cutting, compared with in the case of dry cutting.

The surface roughness of reamed holes became worse with an increase in

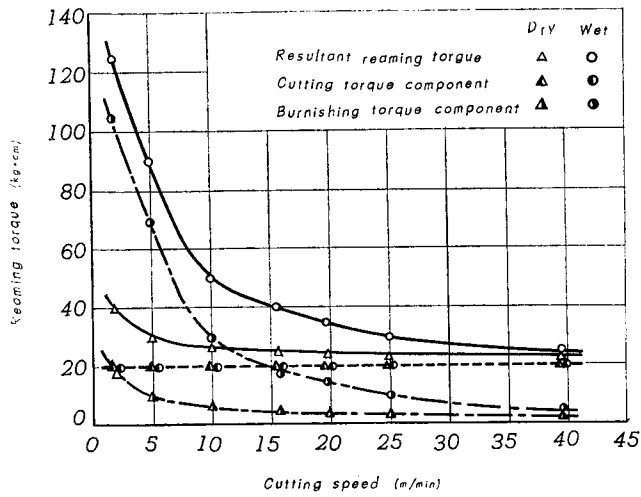


Fig. 7. Relationship between cutting speed and reaming torque [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); feed, 0.40 mm/rev.; depth of cut in diameter, 0.30 mm; dry and wet (supplying extreme pressure oil)].

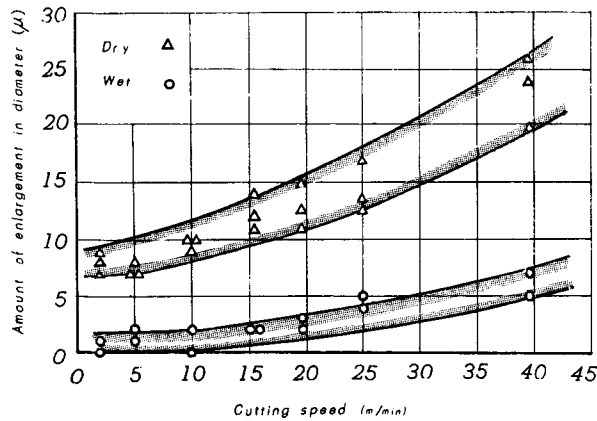


Fig. 8. Relationship between cutting speed and amount of enlargement in diameter [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); feed, 0.40 mm/rev.; depth of cut in diameter, 0.30 mm; dry and wet (supplying extreme pressure oil)].

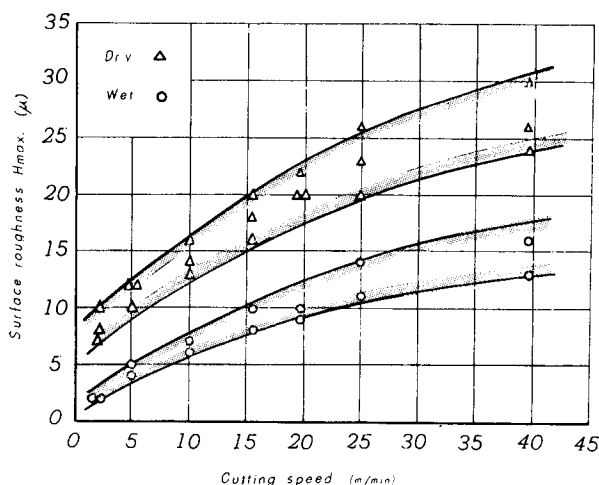


Fig. 9. Relationship between cutting speed and surface roughness [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); feed, 0.40 mm/rev.; depth of cut in diameter, 0.30 mm; dry and wet (supplying extreme pressure oil)].

cutting speed as shown in Fig. 9. Better surface was obtained in the case of wet cutting than in the case of dry cutting.

A summary of the results mentioned above is as follows: With an increase in cutting speed, reaming torque decreases, amount of enlargement increases, and surface finish becomes worse. It is effective to supply cutting fluids; that is, cutting fluids decrease the amount of enlargement of reamed holes and improve surface finish, though they increase reaming torque.

b. Effect of Feed Rate

The variation of reaming torque, amount of enlargement, and surface roughness with an increase in feed rate in a range of 0.10 to 1.03 mm/rev. is shown in Figs. 10, 11, and 12, respectively. Cutting speed and depth of cut in diameter were kept constant: 5 m/min. and 0.30 mm.

It is found from Fig. 10 that the reaming torque increased with feed rate for both dry and wet cuttings. Generally it was larger in the case of wet cutting than in the case of dry cutting. The cutting torque component was almost the same for both dry and wet cuttings, and increased in linear relationship with feed rate. On the other hand, the burnishing torque component was almost constant in the case of dry cutting, but in the case of wet cutting it increased with feed rate.

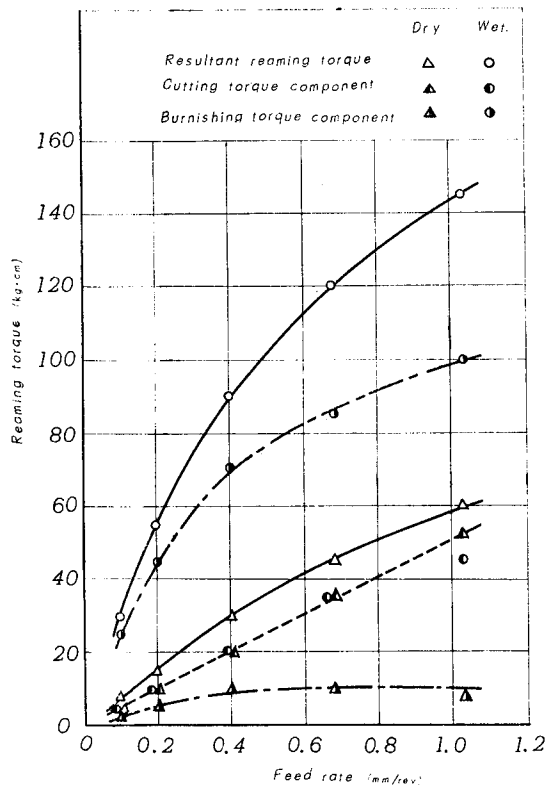


Fig. 10. Relationship between feed rate and reaming torque [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; depth of cut in diameter, 0.30 mm; dry and wet (supplying extreme pressure oil)].

As shown in Fig. 11, the amount of enlargement increased with feed rate for both dry and wet cuttings. Wet cutting produced smaller amount of enlargement than dry cutting.

The surface finish of reamed holes became worse with an increase in feed rate for both dry and wet cuttings, as shown in Fig. 12. It is reasonable that wet cutting produced better surface finish.

Summarizing above, with an increase in feed rate, reaming torque increases, amount of enlargement increases, and surface finish becomes worse. Cutting fluid supplied decreases amount of enlargement and produces good surface finish, though it increases reaming torque.

c. Effect of Depth of Cut

The variation of reaming torque, amount of enlargement, and surface

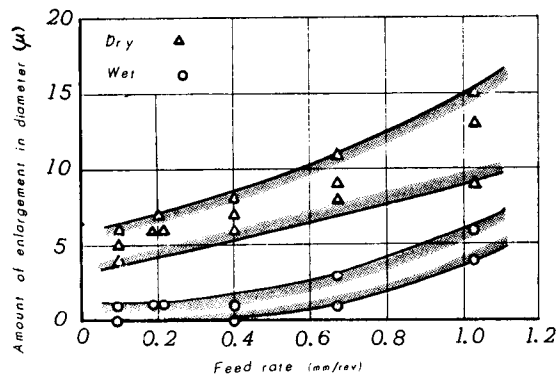


Fig. 11. Relationship between feed rate and amount of enlargement in diameter [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min; depth of cut in diameter, 0.30 mm; dry and wet (supplying extreme pressure oil)].

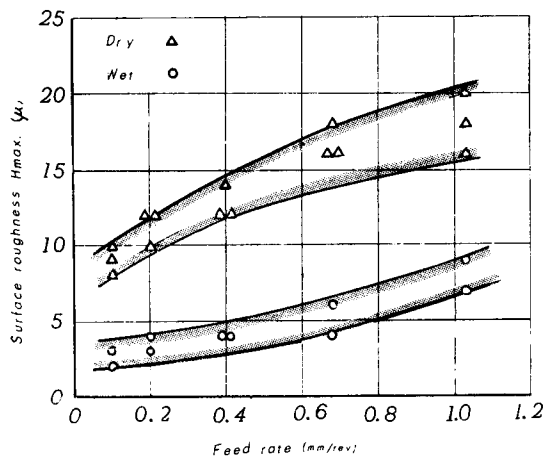


Fig. 12. Relationship between feed rate and surface roughness [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; depth of cut in diameter, 0.30 mm; dry and wet (supplying extreme pressure oil)].

roughness in relation to depth of cut in diameter is shown in Figs. 13, 14, and 15, respectively. In this case, cutting speed and feed rate were kept constant: 5 m/min. and 0.40 mm/rev.

As shown in Fig. 13, the reaming torque was larger in the case of wet cutting than in the case of dry cutting. The cutting torque component was almost the same for both cases and increased in linear relationship with depth of cut. On the other hand, with an increase in depth of cut, the burnishing torque component was constant in the case of dry cutting, but increased gradually in the case of wet cutting.

It is obvious from Figs. 14 and 15 that both the amount of enlargement and the surface roughness of reamed holes increased with depth of cut, and were smaller for wet cutting than for dry cutting.

Thus, the effect of depth of cut in diameter on reaming torque, amount of enlargement, and surface finish is almost the same as that of feed rate.

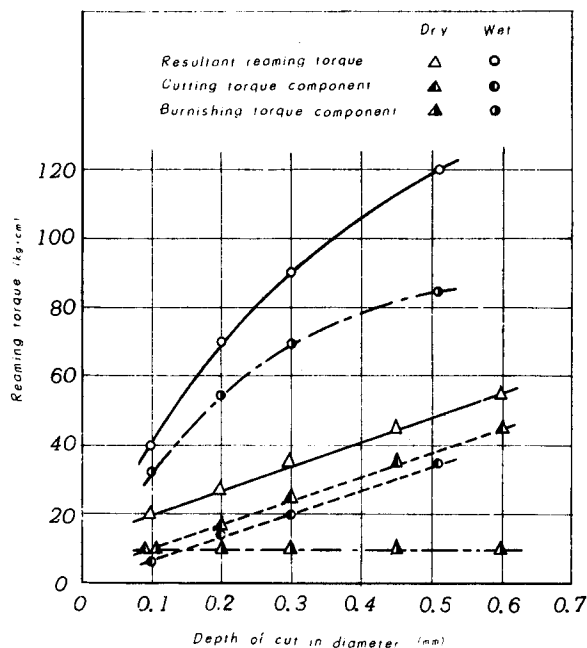


Fig. 13. Relationship between depth of cut in diameter and reaming torque [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; feed, 0.40 mm/rev.; dry and wet (supplying extreme pressure oil)].

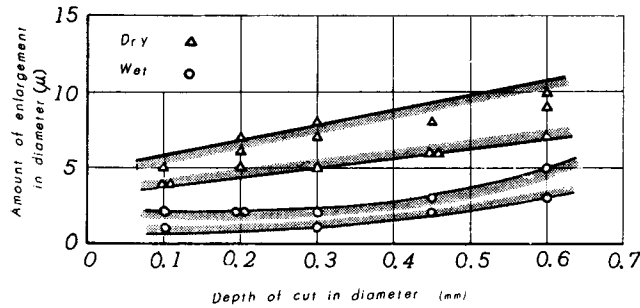


Fig. 14. Relationship between depth of cut in diameter and amount of enlargement in diameter [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; feed, 0.40 mm/rev.; dry and wet (supplying extreme pressure oil)].

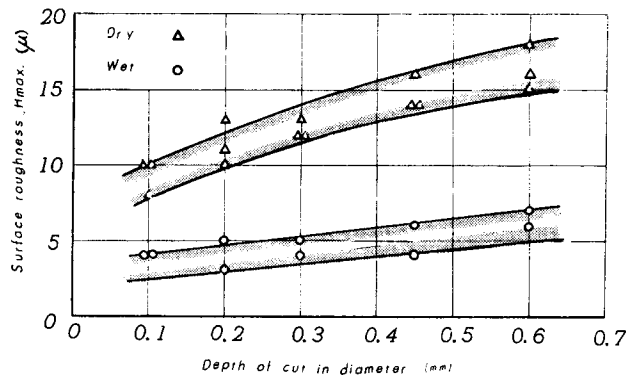
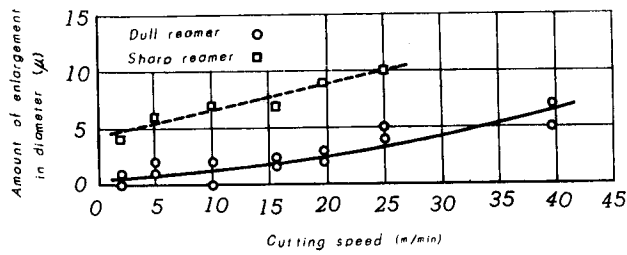


Fig. 15. Relationship between depth of cut in diameter and surface roughness [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; feed, 0.40 mm/rev.; dry and wet (supplying extreme pressure oil)].

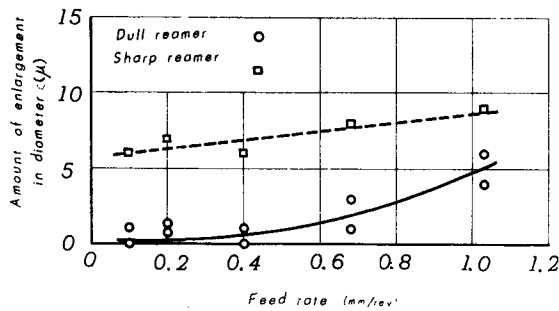
d. Reaming Characteristics of a Sharp Reamer

Reamers used in previous tests were those which had been used several dozen times before the test and were stable enough. Compared with these dull reamers, sharp reamers (just sharpened) produced different results as follows. Tests were performed with sharp and dull reamers, supplying extreme pressure oil, and the results were compared.

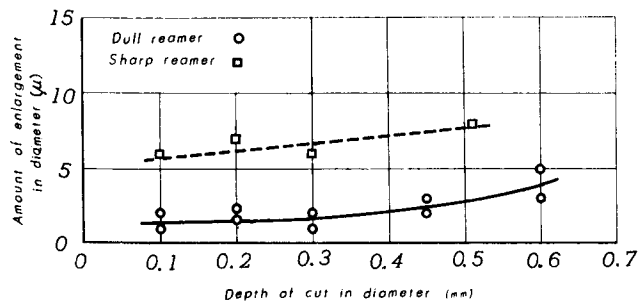
The amount of enlargement and the surface roughness of reamed holes in relation to cutting speed, feed rate, and depth of cut in diameter are shown in Figs. 16 and 17. It is found from these figures that both the amount of enlarge-



(a)

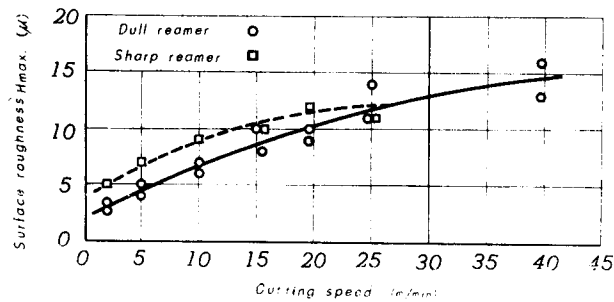


(b)

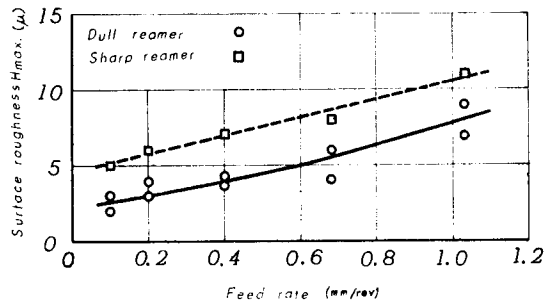


(c)

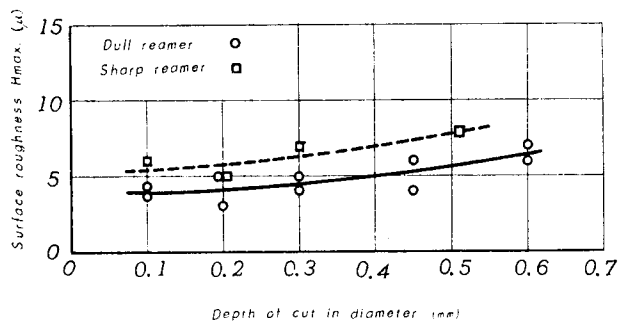
Fig. 16. Comparison of reaming characteristics with sharp and dull reamers (1) Amount of enlargement in diameter in relation to cutting conditions [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; feed, 0.40 mm/rev.; wet (supplying extreme pressure oil)].



(a)

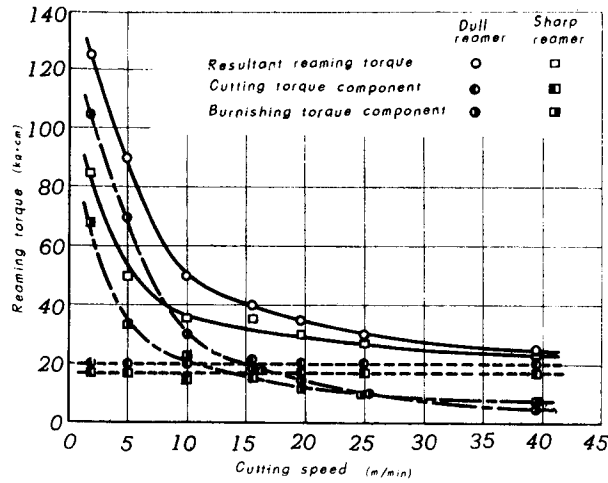


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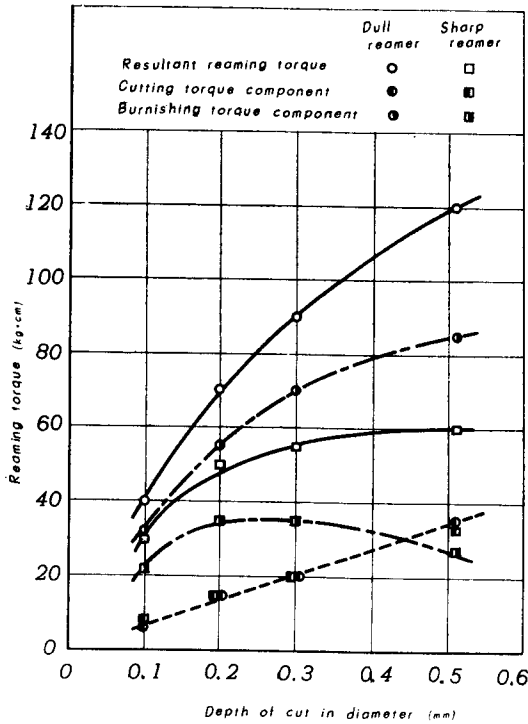


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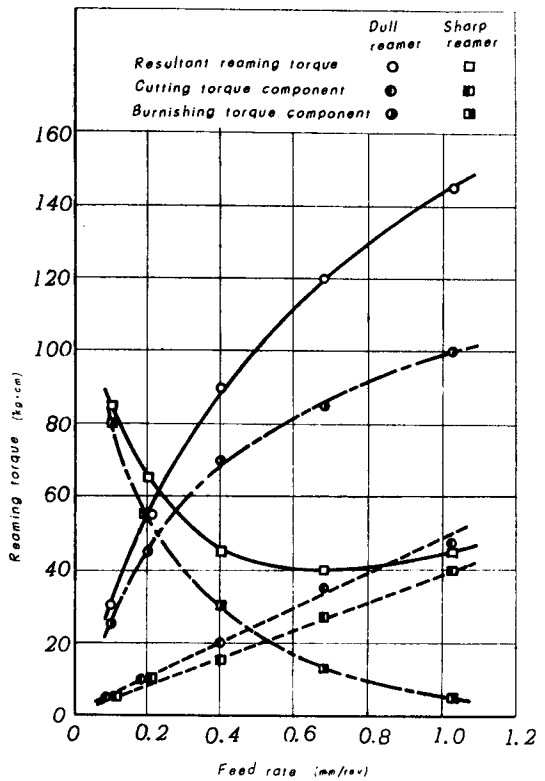
Fig. 17. Comparison of reaming characteristics with sharp and dull reamers (2) Surface roughness in relation to cutting conditions [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; feed, 0.40 mm/rev.; wet (supplying extreme pressure oil)].



(a)



(b)



(c)

Fig. 18. Comparison of reaming characteristics with sharp and dull reamers (3) Reaming torque in relation to cutting conditions [Reamer, high-speed steel (SKH 9); actual reamer size, 20.016 mm; work material, carbon steel (S45C); cutting speed, 5 m/min.; depth of cut in diameter, 0.30 mm; wet (supplying extreme pressure oil)].

ment and the surface finish of reamed holes show the same tendency as in figures explained in the previous section. That is, with increases in cutting speed, feed rate, and depth of cut, the amount of enlargement increased and the surface finish became worse. It is a noteworthy fact that the sharp reamer produced a greater amount of enlargement and poorer surface finish than the stable dull reamer. Thus, reamers which have been used several dozen times are preferable from the viewpoint of the accuracy of reamed holes.

The reaming torque in relation to cutting speed is shown in Fig. 18(a). It is found from this figure that reaming torque decreased gradually with an increase in cutting speed for both sharp and dull reamers. The sharp reamer produced smaller torque than the stable dull reamer. This is because larger burnishing torque component is produced for stable reamer due to dullness of cutting edges.

The reaming torque in relation to depth of cut is shown in Fig. 18(b). Thus, torque components increased gradually with depth of cut, except the burnishing torque component in the case of sharp reamer. The reaming torque is slightly smaller with sharp reamer than with stable dull reamer.

The reaming torque in relation to feed rate is shown in Fig. 18(c). This torque pattern is quite different from one obtained before (Fig. 10). With stable dull reamer, both cutting and burnishing torque components increased gradually with feed rate as mentioned previously. With sharp reamer, however, the cutting torque component increased in linear proportion, but the burnishing torque component decreased with an increase in feed rate. A similar result has been reported by Colwell and Branders¹⁾. It is difficult to explain this unusual phenomenon of reaming operation by sharp reamer.

5. Conclusions

Reaming tests for carbon steel were performed dry and wet with high-speed steel reamers. These lead to the following conclusions.

(i) The reaming torque consists of two components, namely, the cutting torque component acting on the chamfer and burnishing torque component acting on the margin. The cutting torque component is scarcely affected by cutting fluids. But cutting fluids increase the burnishing torque component in the order of dry, cutting oils, and soluble oils.

(ii) Dry reaming and reaming with cutting oils produce oversized holes. Smaller holes than the actual size of the reamer used are produced with soluble oils.

(iii) The surface finish of reamed holes is improved by reaming with cutting fluids. Soluble oils produce better surface finish than cutting oils.

(iv) The smaller the amount of enlargement, the larger the burnishing torque component, and the better the surface finish, in the order of dry, cutting oils, and soluble oils.

(v) Application of cutting fluid improves the accuracy of reamed holes, though it increases reaming torque.

(vi) With an increase in cutting speed, for both dry and wet conditions, reaming torque decreases, amount of enlargement increases, and surface finish becomes worse.

(vii) With increases in feed rate and depth of cut, reaming torque and amount of enlargement increase, and surface finish becomes worse for both dry and wet cuttings.

(viii) Sharp reamer showed an unusual phenomenon for torque pattern in relation to feed rate. Stable reamer which has been used several dozen times produced better reamed holes than sharp reamer.

References

- 1) L. V. Colwell and H. Branders: Behavior of Cutting Fluids in Reaming Steel; Trans. ASME, Vol. 80, 1958, pp. 1073-1078.
- 2) B. L. Ten Horn, R. A. Schuermann, and J. Slaats: Reaming Accuracy Improved with Coolants; The Tool Engineer, Vol. 42, No. 3, 1959, pp. 93-99.