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Progress Report No. 1

DEVELOPMENT OF TEST METHODS TO EVALUATE "MM" GRINDING WHEELS

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Project 2190-1

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DEVELOPMENT OF TEST METHODS TO EVALUATE "MM" GRINDING WHEELS

This report covers the results of tests on the rough-grinding of sintered carbide, bit-type tools, obtained from the Carboloy Department of General Electric. The purpose of this program was to evaluate the performance of "MM" grinding wheels and competitive "Precision" wheels by using a positive feed mechanism to plunge-cut the end of 1/2" square tool bit against the face of a grinding wheel. The type of test used in this program represents more severe conditions, i.e., feed rate and area contact than would ever be encountered in industrial practice.

The report is divided into five main parts, i.e., (1) conditions of test-machine, wheel speed, work material, work feed, special tool dynamometer, wattmeter, and surface finish measurement, (2) testing procedures, (3) definition of terms, (4) discussion of results, and (5) conclusions.

I. CONDITIONS OF TEST

Machine: Excello No. 49 (Carboloy) tool grinder equipped with a special, 2-component, tool dynamometer to measure cutting and normal forces on the tool bit being ground.

Wheel Speed: The machine spindle speed was 1395 rpm, representing 5100 surface feet per minute on a 14 inch diameter wheel at no-load. Under load conditions, the speed averaged 1375 rpm or 4930 feet per minute.

Work Material: The three grades of carbide used in the tests were Carboloy 78B, 883, and 831 and the tools were in the form of 1/2" square, solid bits.

The 78B is a steel cutting grade with a characteristic of toughness.

The 883 is a cast iron and nonferrous grade of carbide that gives high wear resistance combined with toughness.

The 831 grade is used in light, high speed machining where close tolerance is required. Some additional tests were run on 18-4-1 HSS tools and SAE 1020 steel specimens. These results are included in the report.

Work Feed: The feed of the tool into the wheel face provided a plunge cut at a defined rate in inches per minute. The rates of feed were as follows:

0.001 inch/min	.73 x 10^{-6} inch/rev. of wheel
0.004 inch/min	2.91 x 10^{-6} inch/rev. of wheel
0.058 inch/min	42.2 x 10^{-6} inch/rev. of wheel*

*Used on low carbon steel only.

At the start of the program the feed of 0.004 inch/min-0.000003 inch per revolution of the wheel was used but it was decided, after conference with Messrs. Franklin and Lane, to run a series of tests using a smaller feed rate of 0.001 inch/min.-0.00000073 inch/rev. in an effort to obtain lesser wheel breakdown and damage to the carbide tools.

Tool Dynamometer: The special tool dynamometer makes use of SR-4 strain gages to measure the values of cutting or tangential force and normal or feeding force. The cutting force was measured tangential to the wheel and the normal force as thrust-feed force, on the tool as it was forced against the wheel. The values of the two components of force were recorded on a twin-viso, Sanborn recorder-oscillograph to an accuracy of 2 pounds per millimeter.

Wattmeter: The Esterline Angus, recording type wattmeter was connected to the power supply of the wheel motor to give a record of input power during cutting. Net horsepower is directly proportional to cutting force and hence this type of measurement provides a check on the dynamometer accuracy and gives an indication of total power.

Surface Finish Measurement: The values of surface finish in microinches, rms represent the averages of a number of readings on the ground face of the tool. The measurements were taken from a Micrometrical Company profilometer which indicates surface roughness by diamond-exploration of the ground specimen across the feed marks.

II. TESTING PROCEDURES

The wheels were mounted on the machine and trend with a .25 wgt octahedron diamond tool at a cross feed rate of 0.004 inch per revolution of the wheel. Depths of cut for the final passes were 0.0005 in. The 1/2 inch square tool bits were mounted in a vise attached to the dynamometer and plunge-fed into the wheel at a positive rate of feed.

Coolant was forced onto the tool bit from nozzles above and below the tool bit at a rate of 5 gpm. A 2% solution of Standard Oil's Superla Soluble oil was used.

Tests were run on the carbide tool bits for 10 minutes at a feed rate of .004 ipm. The tests were stopped at 2-1/2 min. intervals to check the condition of the tool bit and to measure wheel wear and the amount of metal removed. At the .001 ipm feed, the test was run for 20 minutes, halting at 10 minutes to check the tool bit and measure the wheel. The HSS tool bits were tested in 10 minute runs and then measured. The 1020 CRS tests were run 4 minutes at the 0.058 ipm feed rate and 10 minutes at the .004 ipm feed rate.

Measurement of the tool length was observed to an accuracy of .0001 inch before and after the test to determine the volume of metal removed. The amount of wheel wear was obtained by measuring the wheel surface under cut before and after the test to an accuracy of 0.0001 inch. The depth, as measured, was multiplied by the area of the wheel surface under cut to obtain the volume of wheel wear during the test.

While the tests were running, the power required to rotate the grinder motor was recorded on the wattmeter graph. Continuous force measurements (both cutting force and normal force) were recorded on the Sanborn recorder. By the use of a planimeter, the average net readings from the charts were obtained and these figures are used in the graphs.

III. DEFINITION OF TERMS

Volume of Metal Removal (V_m) - Cubic inches of metal removed during the grinding operation.

Volume of Wheel Wear (V_w) - Cubic inches of wheel wear. Obtained by multiplying the depth of the groove in the wheel times the area of the groove on the wheel face.

Volume Ratio (V_m/V_w) - The ratio of metal removal to wheel wear is an index to efficiency of the operation. It is desirable to obtain high metal removal with low wheel wear.

Surface Finish - The value of microinches, rms, as obtained by a diamond stylus passing over the work and originating an electric current proportional to the roughness of the work. This current is indicated on a milliammeter calibrated in microinches.

Cutting Force - The average tangential force required to move the wheel past the tool bit while the tool bit is being fed into the wheel.

Normal Force - The average pressure at which the tool bit is being forced against the grinding wheel.

Coefficient of Friction (μ_a) - The ratio of cutting force to normal force (F_c/F_n). It is an indication of the sharpness of the grit of the grinding wheel during the cut and indicates whether or not the wheel is breaking down properly.

Net Horsepower - The average power required to rotate the grinding wheel against the tool bit. Power used in overcoming machine friction is not included.

IV. DISCUSSION OF RESULTS

A. Machine Setup

Figure 1 shows the Excello No. 49 (Carboloy) tool grinder, equipped with the power feed mechanism; special 2 component, force dynamometer, twin-channel, recorder-oscillograph; and recording, AC wattmeter. The power feed mechanism consists of a lead screw driven by a 16:1 ratio, "Speed-Ranger", transmission and Master electric motor. The dynamometer, twin-channel recorder, and wattmeter were explained under "test conditions".

Figure 2 shows a closeup view of the dynamometer and tool holder. These were fastened to a heavy surface plate, which was driven by the positive lead screw.

B. Volume Ratio

Figures 3, 4, 5, and 6 show the volume ratio for each of the six wheels tested. Although fracture of the tool bits prevents showing a complete picture, the following significant facts were noted;

Figure 3, with carbide 78B shows that the Macklin C60H8 has the highest volume ratio, and thus the best at both .001 and .004 ipm feed rates. The Macklin C46G8 is considered second in this criteria.

Figure 4, using carbide 883 gives inconclusive results due to the early failure of the tool bits in practically all cases.

Figure 5, using 1020 CRS, indicates the Macklin C46G8 is best with the other wheels showing about the same volume ratios on the .004 ipm feed. At .058 ipm the Precision BC60J Wheel was outstanding, while two Macklin Wheels, the C46G8 and the C60H8 overloaded the motor during the test.

Figure 6, using HSS tool bits at .004 ipm feed shows that the volume ratios for the C46G8 and the C60H5 are highest with Precision BC60I and BC60J similar in performance to the C60H5. The Macklin C60H8 and Precision BC60K are lowest of the six wheels in this factor.

C. Surface Finish

Figure 7, 8, 9, and 10 show the surface finish for each of the six wheels. Again, tool breakage prevents conclusive interpretations of results. In general, the surface finish for the several wheels do not vary appreciably.

Figure 7, showing test results of 78B tool bits, indicates that the Macklin C46G8 gives the best surface finish (22 μ in. rms) at .001 ipm feed. The rest of the tests are in a range from 35 to 55 μ in. rms.

Figure 8, showing surface finishes of the 883 tool bits, indicates that the Precision BC60I wheel gives the worst quality-surface finish (60 μ in. rms) at .004 ipm feed. The other tests show a surface finish range between 33 to 48 rms μ in.

Figure 9, using the 1020 CRS tool bits, shows that the C46G8 has the poorest quality surface finish (30 μ in. rms at .004 ipm infeed) while the Macklin C60H8 has the best (11 μ in. rms at .004 ipm infeed.) The others range from 13 to 27 μ in. rms. The length of test was 10 minutes for the .004 inch/minute feed and 4 minutes for the 0.058 inch/minute feed.

Figure 10, showing results from test on the HSS tool bits indicates that the Macklin C46G8 wheel gave the best surface finish (9.5 μ in. rms). The range of the rest of the tests was from 11 to 13 μ in. rms, thus little difference in the wheels can be shown for the hard steel (18-4-1 HSS.)

D. Net Horsepower

Figures 11, 12, 13, and 14 show the average net horsepower requirements for the various tests. The tests are not exactly comparable because their durations vary due to tool bit breakage. Since horsepower requirements tend to rise as a test continues, fracture before the completion of a test will give a lower average net horsepower reading than a complete test with little or no tool chipping.

Figure 11, with 78B carbide tool bits under test, show that the Precision BC60J has the lowest horsepower requirements and the Macklin C46G8 the highest, on the tests with .001 ipm infeed. At .004 infeed, horsepower requirements range from 1.12 to 1.37 net horsepower, the Macklin C46G8 using the least, and the Macklin C60H8 using the greatest amount of net horsepower.

Figure 12, with 883 carbide tool bits under test show that the Macklin C46G8 wheel requires the most horsepower, and the Macklin C60H5 uses the least; an average between the two tests at the range is .001 and .004 ipm infeed. The high value of 1.15 horsepower for the C46G8 wheel at .001 ipm is an indication of wheel loading or glazing.

Figure 13, testing 1020 CRS tool bits, shows a range of horsepower (from .35 to .72 horsepower) at .004 ipm infeed with the Macklin C60H8 and Precision BC60K using 60 to 100% more than the C46G8. The tests at .058 ipm infeed has a wide range, varying from 1.12 horsepower for the Macklin C46G8 and the Precision BC60I to 2.3 horsepower for the Macklin C60H8 and the Precision BC60J wheels.

Figure 14, using HSS tool bits shows a small range of horsepower requirements (from .55 to .87 horsepower), with the Precision BC60J wheel using the least and the Macklin C60H5 using the largest average net horsepower.

Figure 15 shows typical graphs of power and forces recorded by the Wattmeter and the Sanborn Recorder. The irregularity of the carbide tool bit test curves are caused by the intermittent breakdown of the grinding wheel. As the particles dull, they cause an increase in force and power comsumption which is followed by a breakdown of the wheel causing new sharp abrasive particles to do the cutting and thus lower forces and power.

The steadily increasing power and forces recorded in the HSS tool bit tests show a gradual dulling of the abrasive particles and/or wheel loading causing higher forces and power requirements without any breakdown of the wheel evidenced during the test.

The 0-min values on each chart represent tare power and force readings that are subtracted from the average gross values to determine the net values. The planimeter used in these measurements measures the area of the curve between the tare and gross values.

E. Cutting and Normal Forces

Figures 16, 17, 18, and 19 show the normal and cutting forces when different tool materials are used.

Figure 16 shows that the BC60I and C60H5 require the least normal force at the slower infeed (.001 ipm). The C46G8 shows the least normal force required at the faster infeed, however, at the slower infeed (.001 ipm) it shows the highest normal force of the Macklin wheels. The cutting forces for all the wheels tend to vary between two (2) and nine (9) pounds with the BC60J requiring the least of the slow infeed and the C46G8 and BC60I at the faster infeed.

Figure 17 shows rather close performance for all the wheels when using the 883 carbide tool. The normal forces vary between 48 and 62 pounds with the BC60I requiring the least force (48 pounds) at .001 ipm feed. The BC60K requires the least cutting force of all the wheels and the C60H5 the least for the Macklin wheels.

Figure 18 shows large variations in normal forces when using the 1020 steel tool material. The C46G8 and BC60I require the least normal (feeding) force at the higher infeeds (.058 ipm). The BC60I requires the least normal force at the slower infeed (.004 ipm). Both the C60H5 and BC60K required high normal force. The C46G8 and BC60I required the least cutting force at both the slow and fast infeeds.

Figure 19 shows that the C60H8 wheel required the least normal force (30 pounds) while the BC60J the most (75 pounds). Cutting forces remained fairly constant for all wheels at approximately 5 pounds.

F. Coefficient of Friction

Figures 20, 21, 22, and 23 show the coefficient of friction (F_c/F_n) with the different tool materials.

Figure 20 shows that as the infeed was increased (from .001 to .004 ipm), the coefficient of friction increased. The BC60J gave the lowest coefficient of friction at the slow infeed and the BC60K and C60H5 gave the lowest coefficient of friction for the higher infeed.

Figure 21 shows the BC60K had the lowest coefficient of friction at show infeed when using the 883 carbide tool. The C46G8 and BC60I had the highest friction coefficient. The BC60J showed the lowest coefficient of friction when using the fast infeed (.004 ipm). The BC60K had the highest coefficient of friction in this case.

Figure 22 shows the C60H5 to have the lowest coefficient of friction at the fast infeed (.058 ipm) will a 1020 steel tool. The C46G8 wheel had the lowest friction coefficient at the slow infeed (.004 ipm).

Figure 23 shows the BC60J to have the lowest coefficient of friction when using the HSS tool. The C60H8 had the highest friction coefficient indicating a lower value of normal force in relation to the cutting force as compared to those showing lower coefficients.

V. CONCLUSIONS

Volume ratio, average net power, and surface finish are used in establishing a final rating of the six wheels as shown in Table 1.

According to these overall ratings, based on all materials, i.e.; carbides, high-speed steel, and cold-rolled steel, the Macklin "MM" wheels are as good or better than any of the "Precision" wheels tested in the rough grinding of 1/2 inch square tool bits. The final ratings are shown in the column to the right of the table.

Tests using the 78B carbide tools showed the Macklin C46G8 to have the best overall results and the Macklin C60H8 and Precision BC60I as second choices.

Although results of the tests on the 883 carbide tools are not conclusive because of tool fracture, the Precision BC60J gave the best overall results on this material with the Macklin C60H5 as a close second.

The 831 carbide tools were not successfully ground at either of the two feeds used in this series, due to the sensitivity to thermal shock, thus there are no results to be reported on this material.

Tests on the cold-rolled steel specimens show the Macklin C46G8 to be best with the C60H5 second in rating.

Using the high speed steel tool bits, the overall results favor the C46G8 wheel with the Precision BC60J wheel second in performance.

Although in the preliminary work it appeared that the Marklin C60H8 wheel gave the best performance at the high feed rate (.004 ipm), we found in combining those results with the results of the low feed test (.001 ipm) indications that the Macklin C46G8 wheel is the better of the two.

In general, the results shown in this report indicate that one particular wheel, which might be rated high for one carbide material, might not give the best results on other types of carbides. It seems to become necessary to select a type of wheel for each grade of carbide.

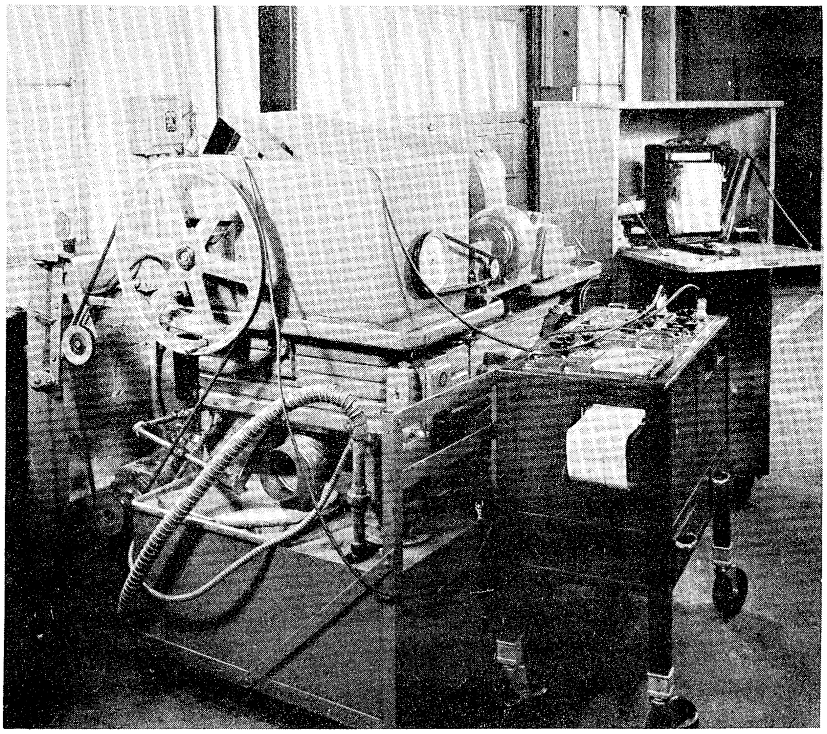
Table I

Comparison of Wheels

	V_R	HP_N	Surf. Fin.	Coef. Fric.	F_N	Rating*
Macklin						
C46G8	3	3	3	-	-	1
C60H8	1	-	2	-	2	2
C60H5	2	1	-	3	1	2
Precision						
BC60I	-	2	-	-	2	3
BC60J	-	1	1	3	1	6
BC60K	-	2	-	2	-	3

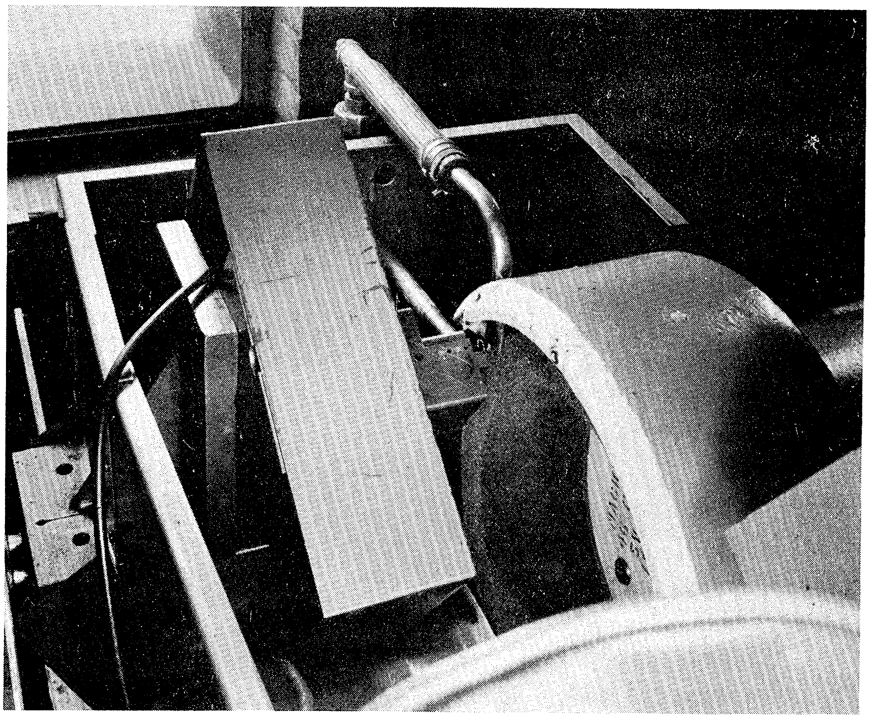
*Rating based on equal weight of Volume Ratio, average net horsepower (averaged for both feed rates), and and Surface Finish.

Figures indicate number of times the wheel was best and next best in the various tests.



Excello No. 49 (Carboloy) grinder equipped with special 2-component dynamometer, Sanborn recorder and Wattmeter. A special, positive variable feed mechanism feeds the tool bit into the wheel face.

Fig. 1



A close up of the tool holder, and dynamometer that are fastened to positive feed mechanism.

Fig. 2

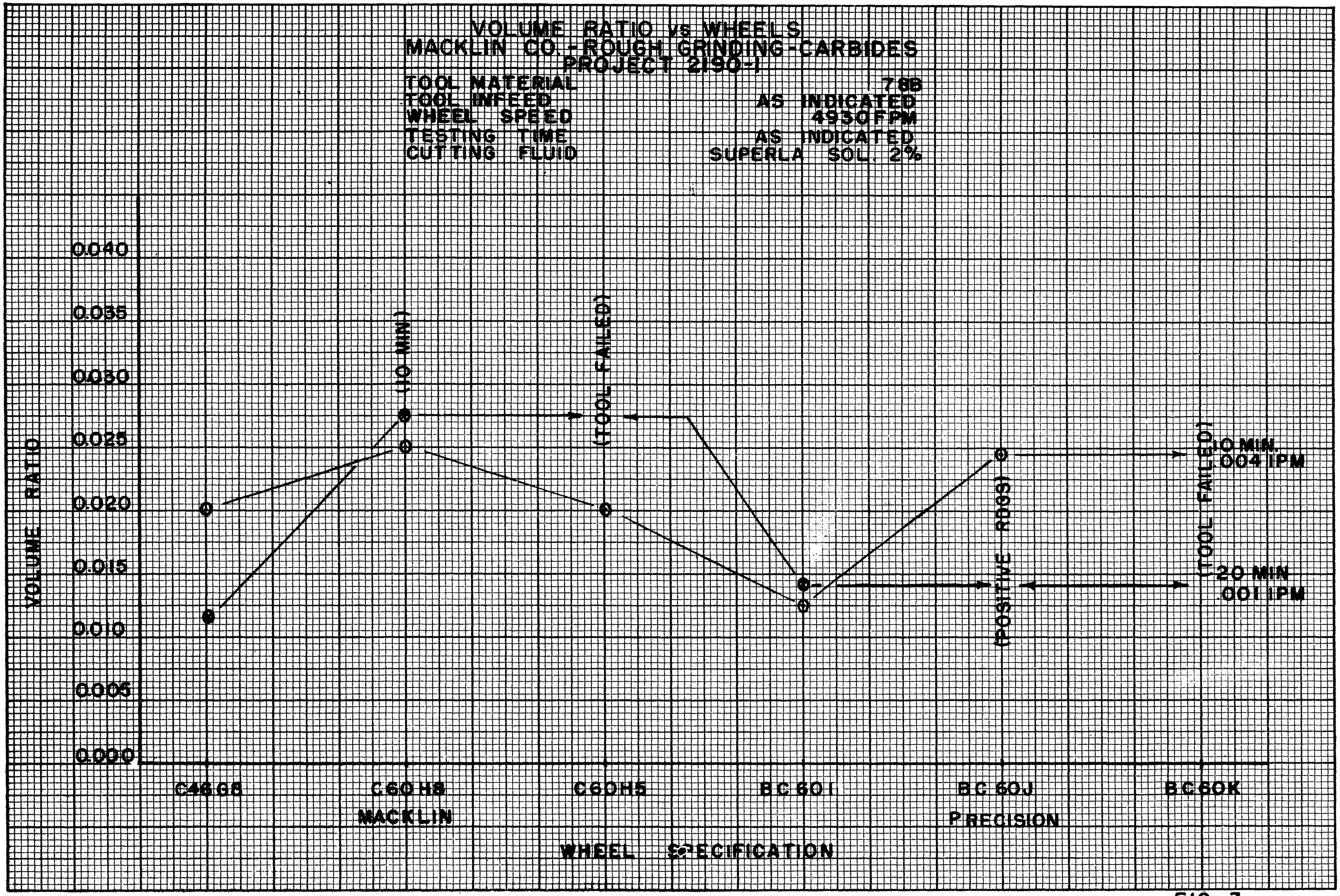
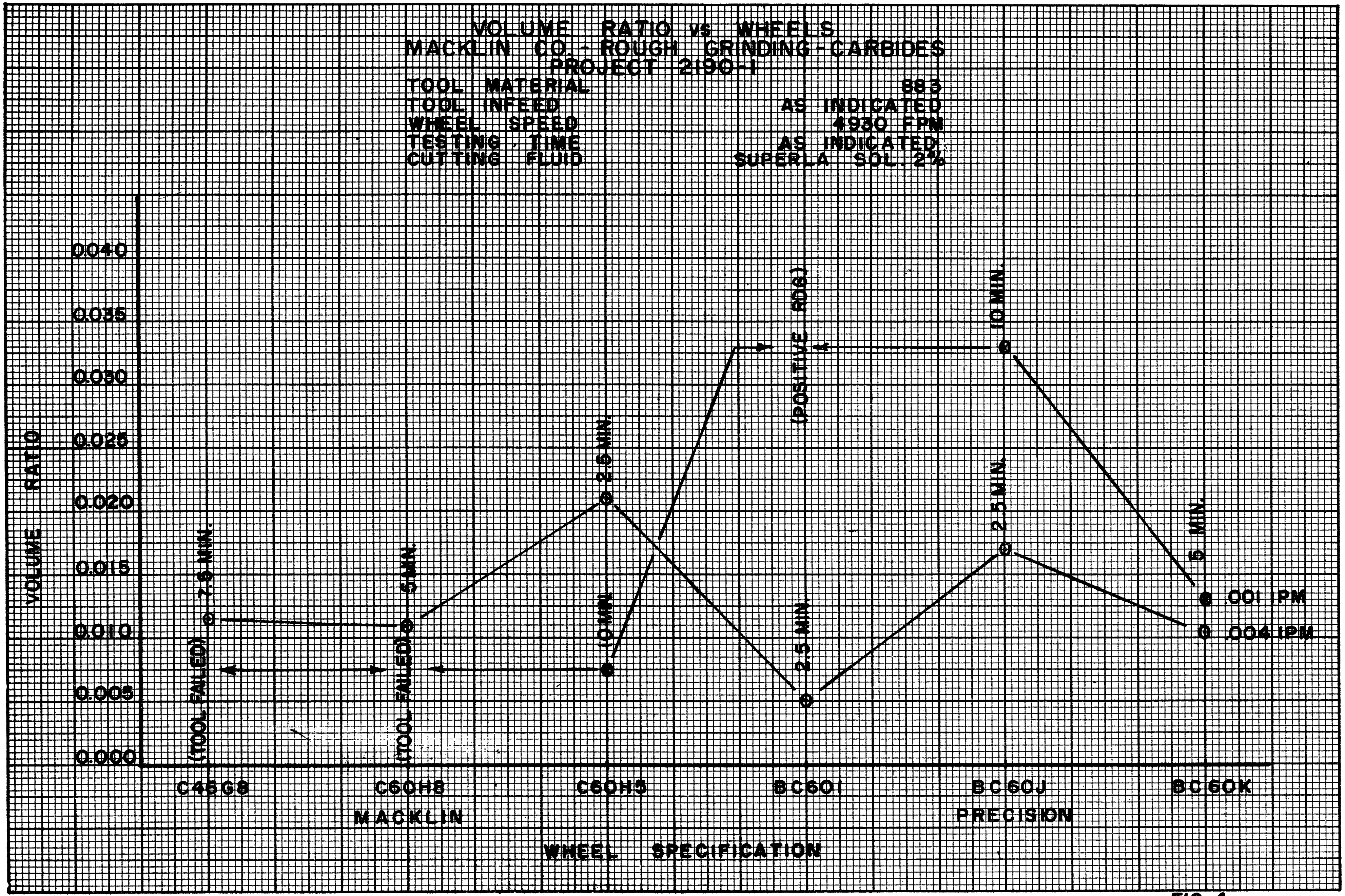

VOLUME RATIO vs WHEELS
MACKLIN CO. - ROUGH GRINDING - CARBIDES
PROJECT 2190-1
TOOL MATERIAL 78B
TOOL INFEED AS INDICATED
WHEEL SPEED 4930FPM
TESTING TIME AS INDICATED
CUTTING FLUID SUPERLA SOL. 2%
VOLUME RATIO
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
(10 MIN)
(TOOL FAILED)
(POSITIVE RDGS)
(TOOL FAILED)
10 MIN.
.004 IPM
20 MIN
.001 IPM
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 3



VOLUME RATIO vs WHEELS
MACKLIN CO. - ROUGH GRINDING - CARBIDES
PROJECT 2190-1

TOOL MATERIAL 883
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME AS INDICATED
CUTTING FLUID SUPERLA SOL. 2%

FIG. 4

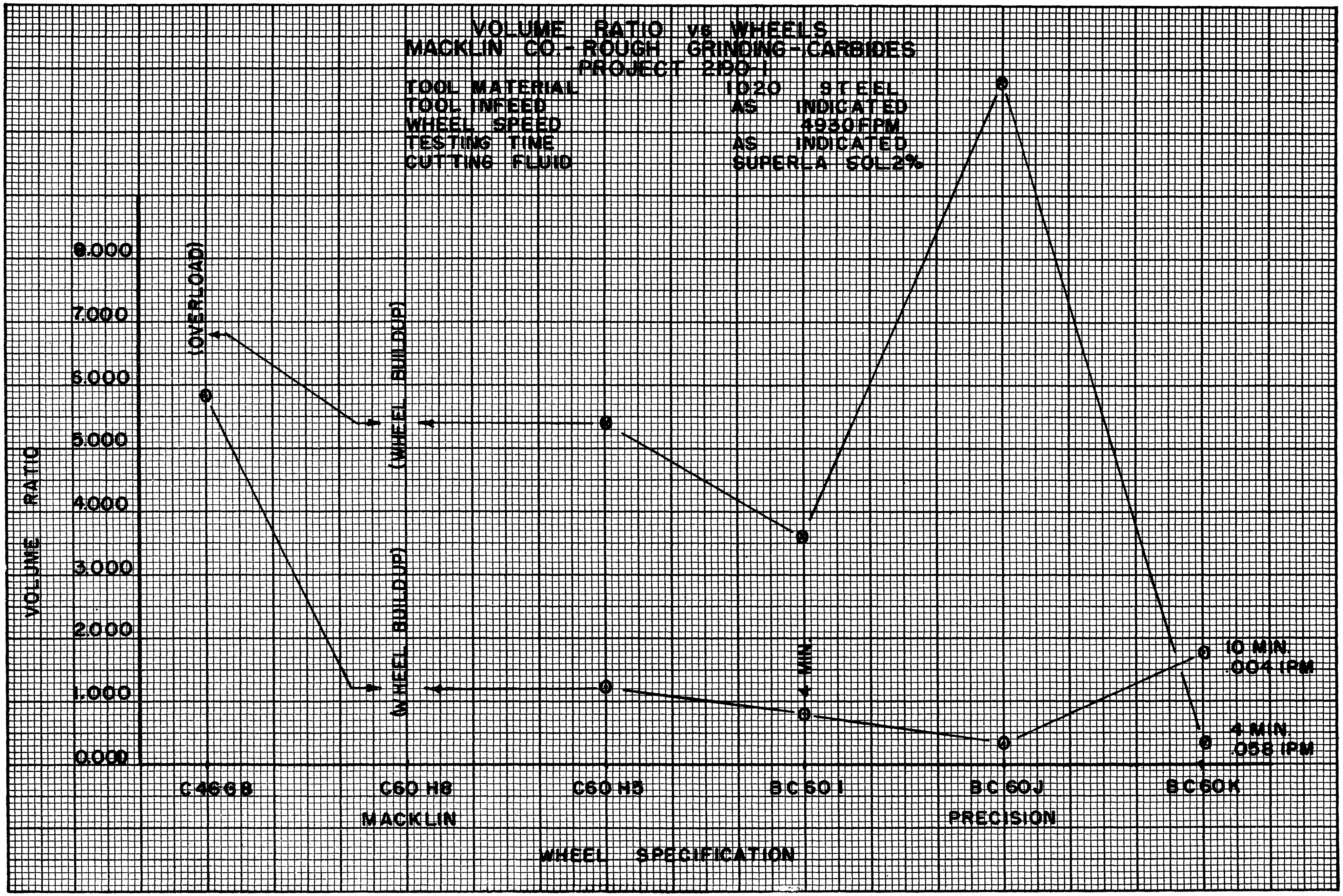

VOLUME RATIO vs WHEELS
MACKLIN CO. - ROUGH GRINDING - CARBIDES
PROJECT 2190-1
TOOL MATERIAL 1020 STEEL
TOOL INFEED AS INDICATED
WHEEL SPEED 4930FPM
TESTING TIME AS INDICATED
CUTTING FLUID SUPERLA SOL.2%
VOLUME RATIO
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
(OVERLOAD)
(WHEEL BUILDUP)
(WHEEL BUILDUP)
4 MIN.
10 MIN. .004 IPM
4 MIN. .058 IPM
C46G8
C60 H8
C60 H5
BC60I
BC 60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 5

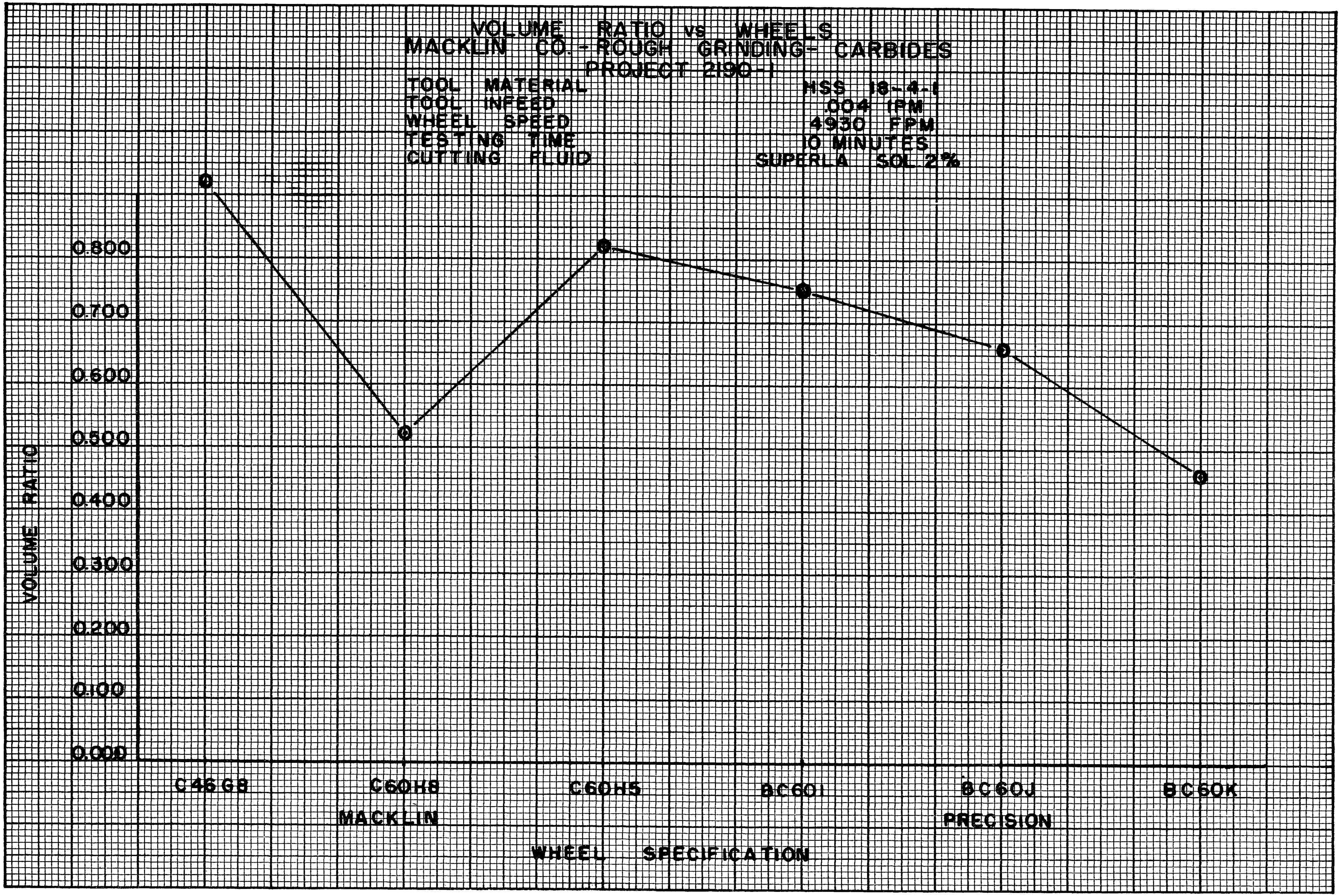

VOLUME RATIO vs WHEELS
MACKLIN CO. - ROUGH GRINDING- CARBIDES
PROJECT 2190-1
TOOL MATERIAL HSS 18-4-1
TOOL INFEED .004 IPM
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL 2%
VOLUME RATIO
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 6

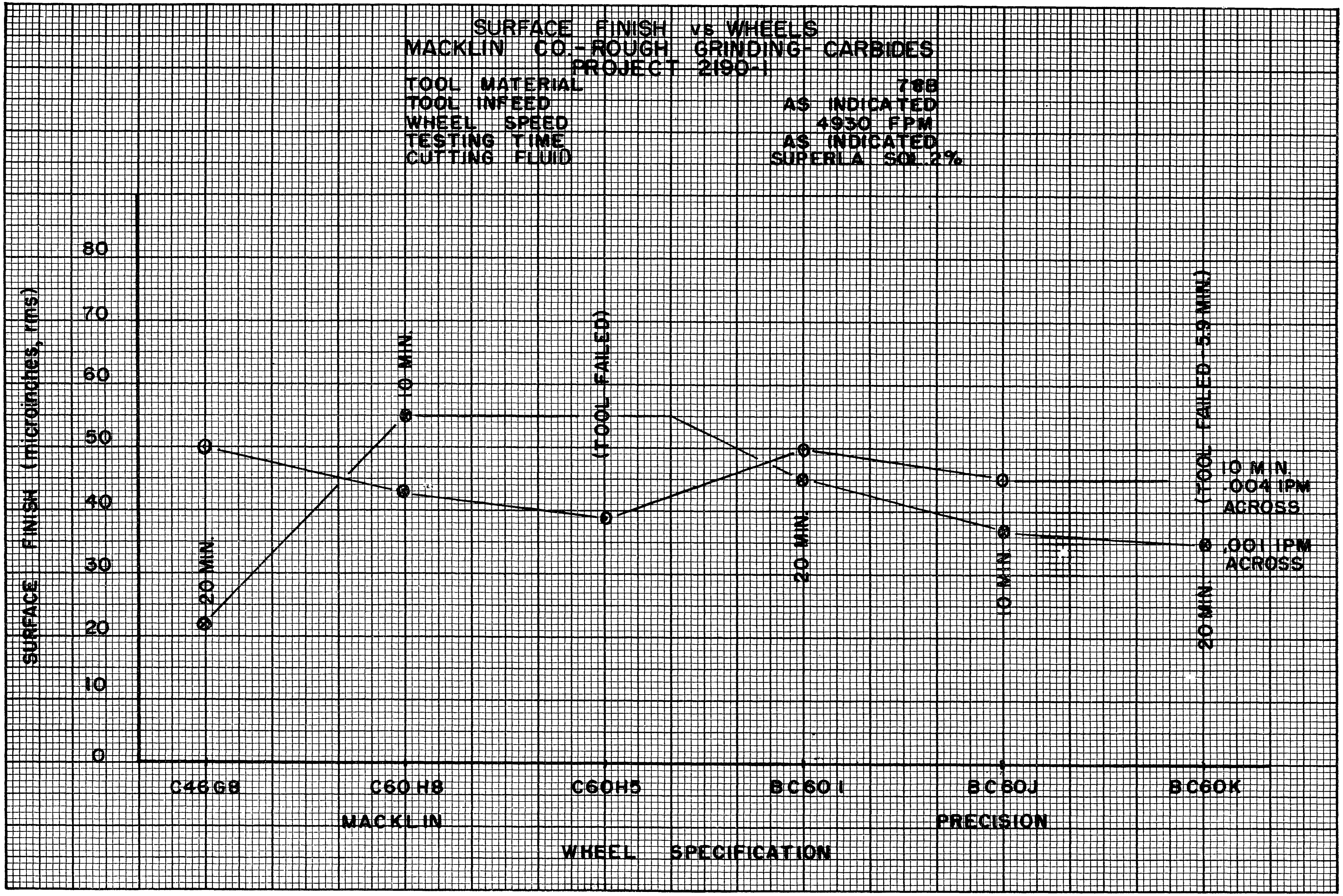

SURFACE FINISH vs WHEELS
MACKLIN CO.-ROUGH GRINDING- CARBIDES
PROJECT 2190-1
TOOL MATERIAL 78B
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME AS INDICATED
CUTTING FLUID SUPERLA SOL.2%
SURFACE FINISH (microinches, rms)
80
70
60
50
40
30
20
10
0
20 MIN.
10 MIN.
(TOOL FAILED)
20 MIN.
10 MIN.
20 MIN.
(TOOL FAILED-5.9 MIN.)
10 MIN.
.004 IPM
ACROSS
.001 IPM
ACROSS
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 7

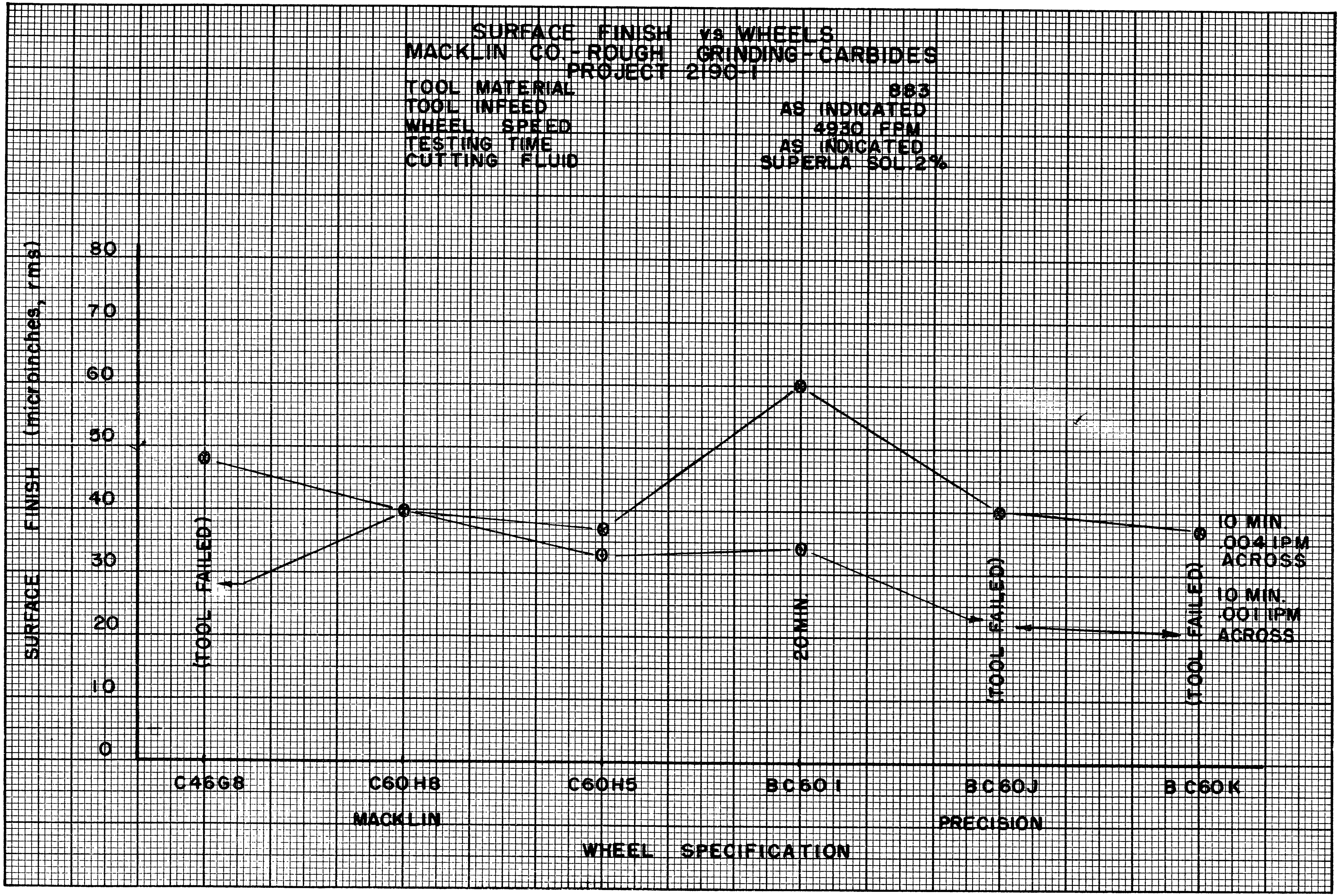

SURFACE FINISH vs WHEELS
MACKLIN CO. - ROUGH GRINDING - CARBIDES
PROJECT 2190-1
TOOL MATERIAL 883
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME AS INDICATED
CUTTING FLUID SUPERLA SOL. 2%
SURFACE FINISH (microinches, rms)
80
70
60
50
40
30
20
10
0
(TOOL FAILED)
20 MIN
(TOOL FAILED)
(TOOL FAILED)
10 MIN.
.004 IPM
ACROSS
10 MIN.
.001 IPM
ACROSS
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 8

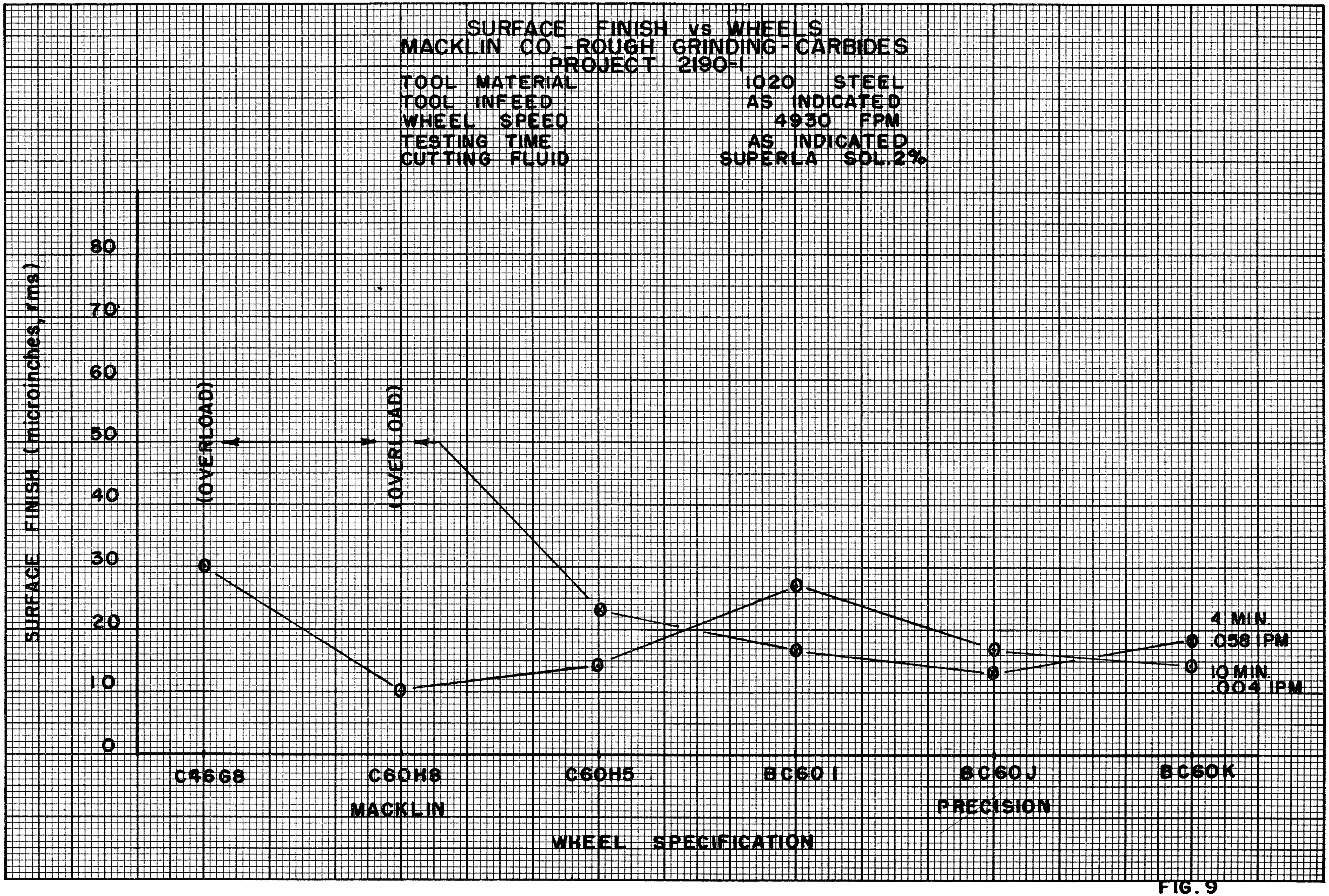
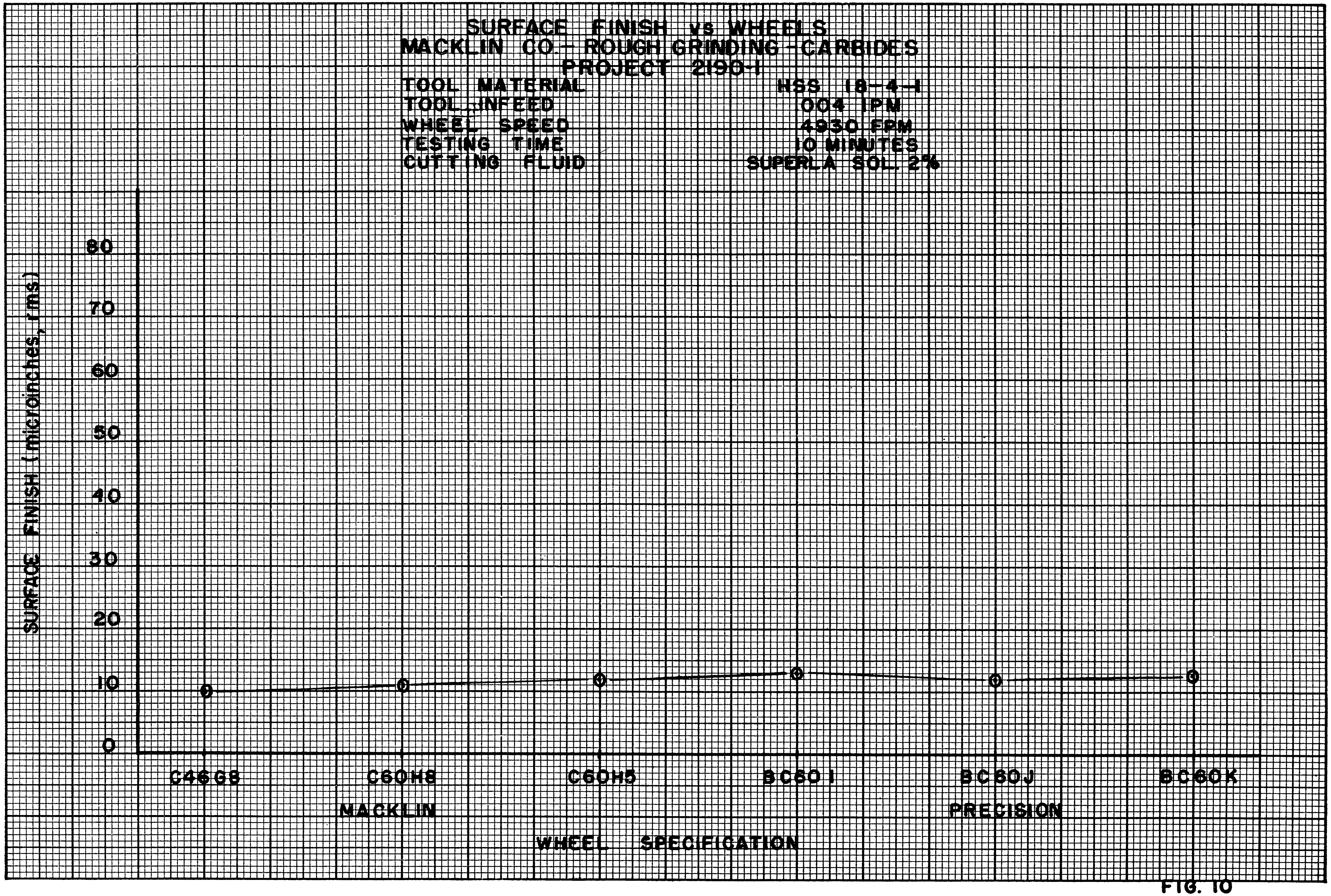

SURFACE FINISH vs WHEELS
MACKLIN CO. - ROUGH GRINDING - CARBIDES
PROJECT 2190-I
TOOL MATERIAL 1020 STEEL
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME AS INDICATED
CUTTING FLUID SUPERLA SOL. 2%
SURFACE FINISH (microinches, rms)
80
70
60
50
40
30
20
10
0
(OVERLOAD)
(OVERLOAD)
4 MIN.
.058 IPM
10 MIN.
.004 IPM
C46G8
C60H8
C60H5
BC60 I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 9



SURFACE FINISH vs WHEELS
MACKLIN CO - ROUGH GRINDING - CARBIDES
PROJECT 2190-1

TOOL MATERIAL HSS 18-4-1
TOOL INFEED .004 IPM
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL. 2%

FIG. 10

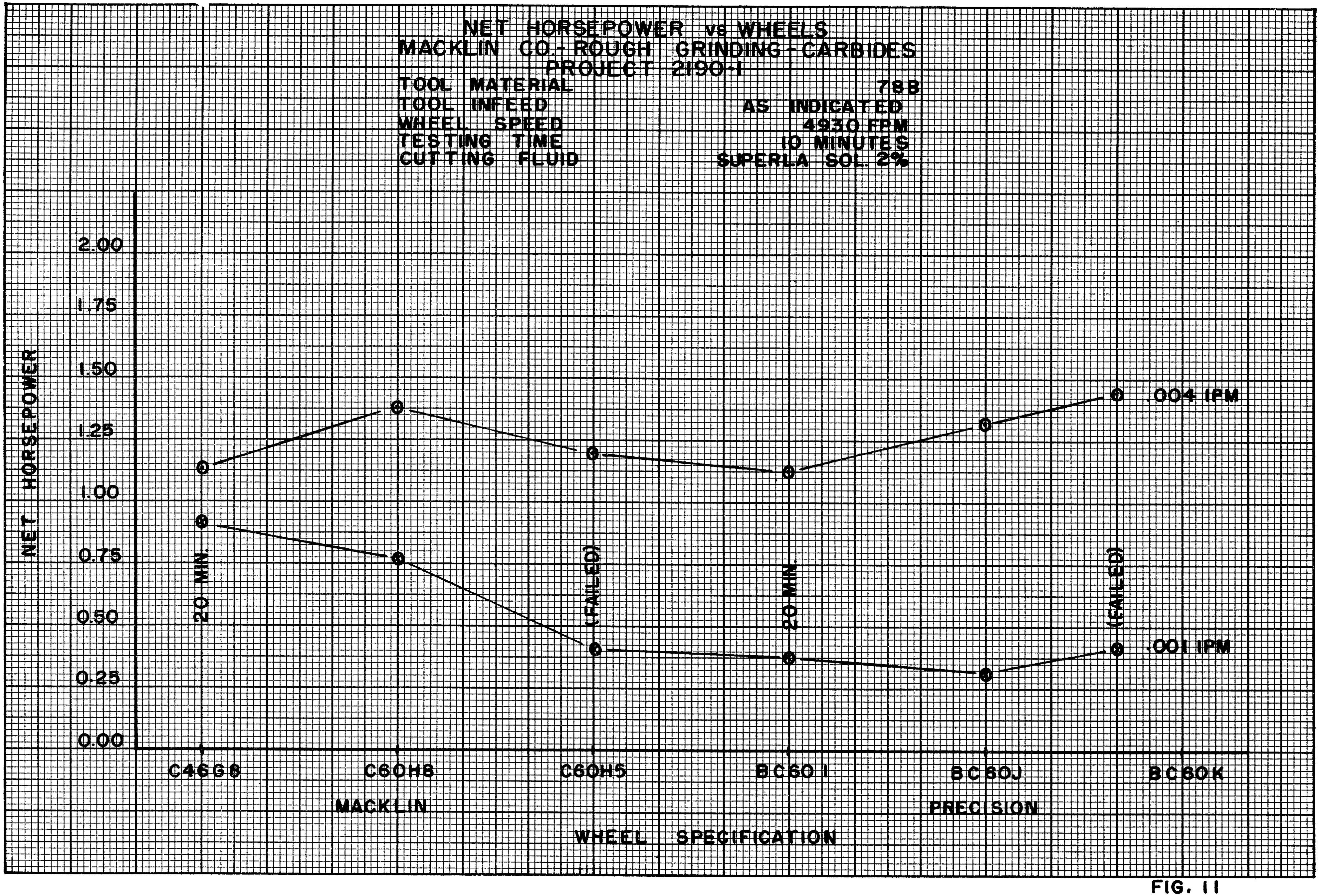

NET HORSEPOWER vs WHEELS
MACKLIN CO.- ROUGH GRINDING - CARBIDES
PROJECT 2190-1
TOOL MATERIAL 78B
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL. 2%
NET HORSEPOWER
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
.004 IPM
.001 IPM
20 MIN.
(FAILED)
20 MIN.
(FAILED)
C46G8
C60H8
C60H5
BC60I
BC80J
BC80K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 11

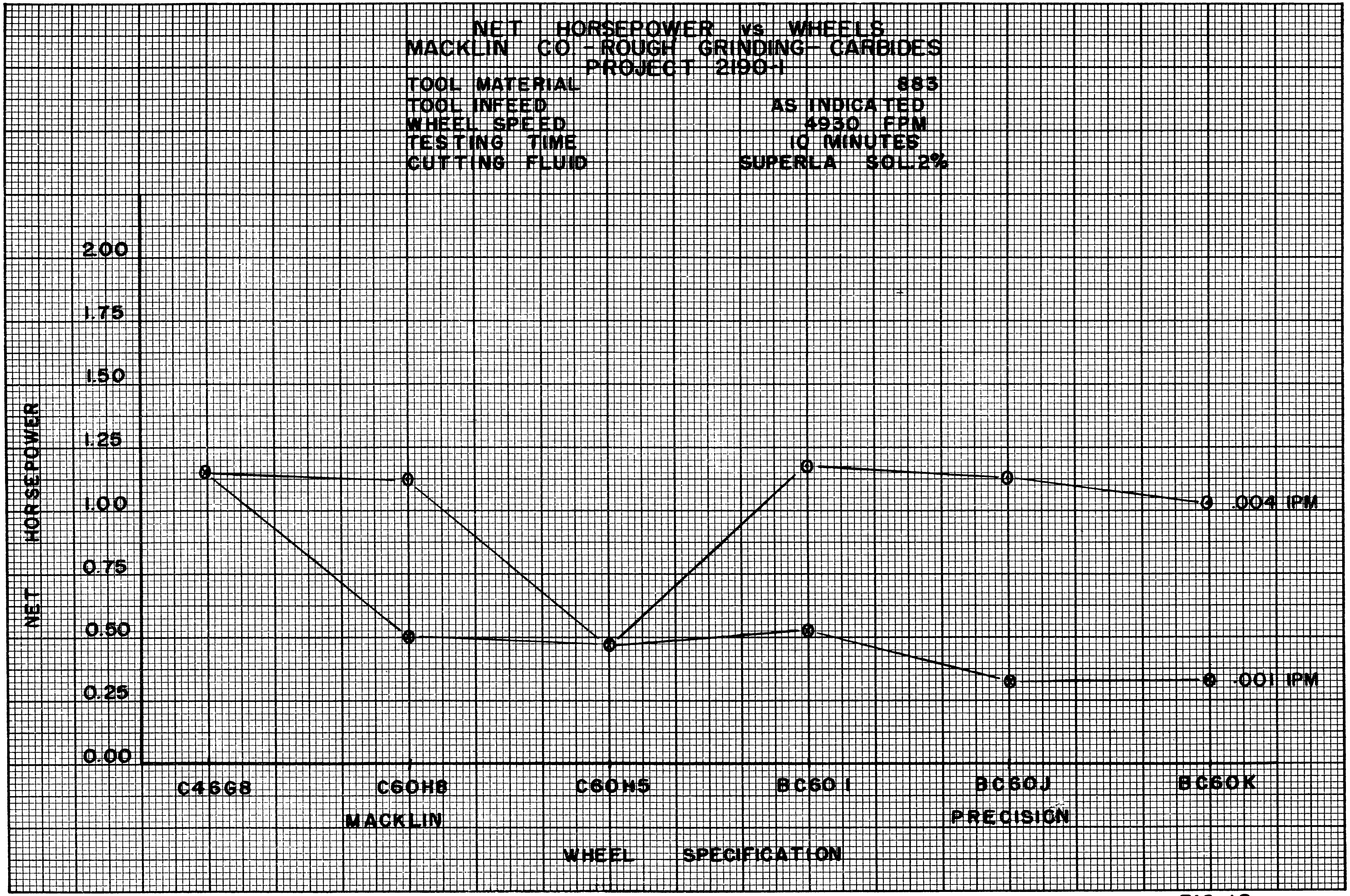

NET HORSEPOWER vs WHEELS
MACKLIN CO - ROUGH GRINDING- CARBIDES
PROJECT 2190-1
TOOL MATERIAL 883
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL.2%
NET HORSEPOWER
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
.004 IPM
.001 IPM
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 12

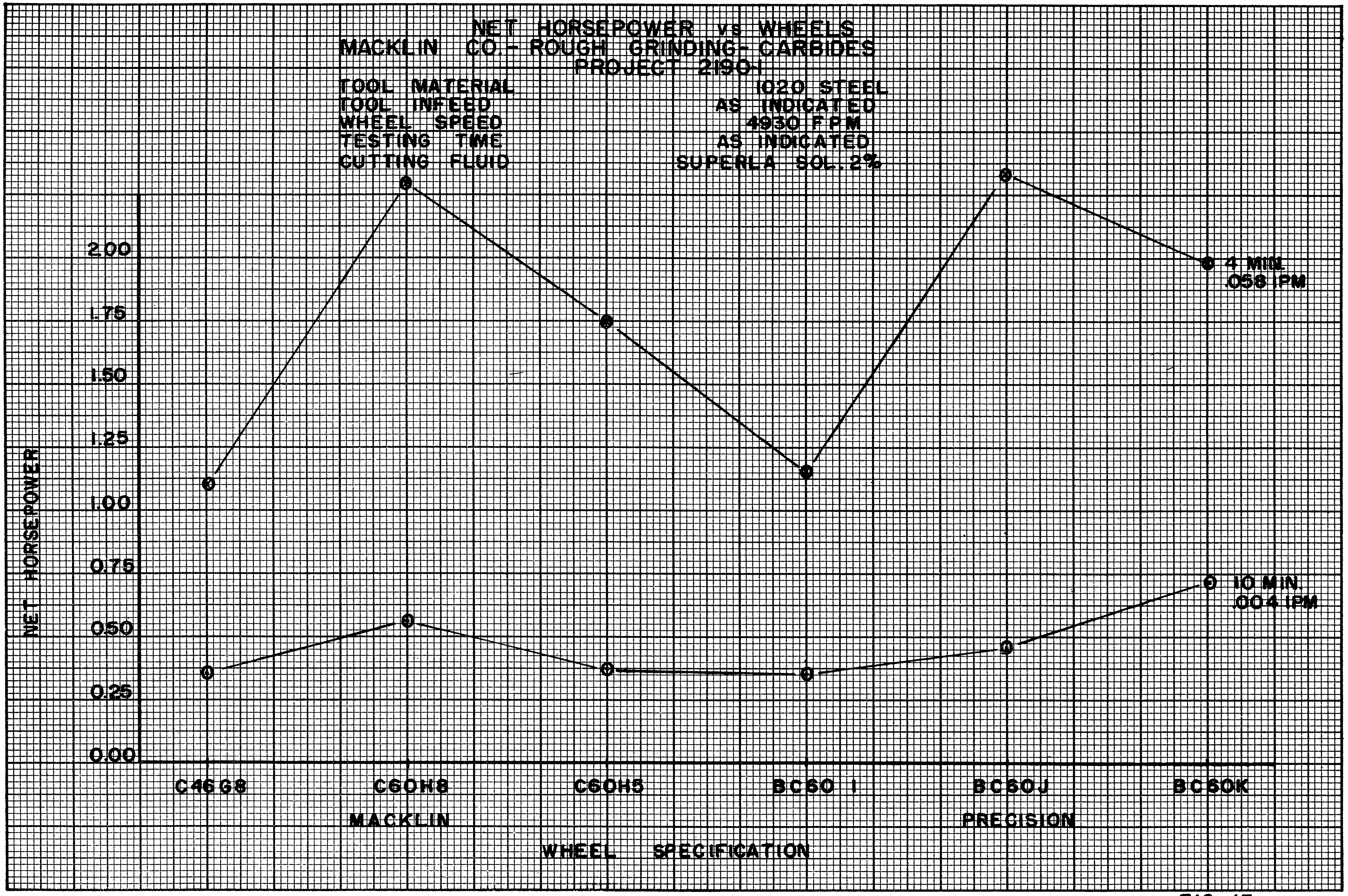

NET HORSEPOWER vs WHEELS
MACKLIN CO. - ROUGH GRINDING - CARBIDES
PROJECT 21901
TOOL MATERIAL 1020 STEEL
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME AS INDICATED
CUTTING FLUID SUPERLA SOL. 2%
NET HORSEPOWER
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
4 MIN.
.058 IPM
10 MIN.
.004 IPM
C46G8
C60H8
C60H5
BC60 I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 13

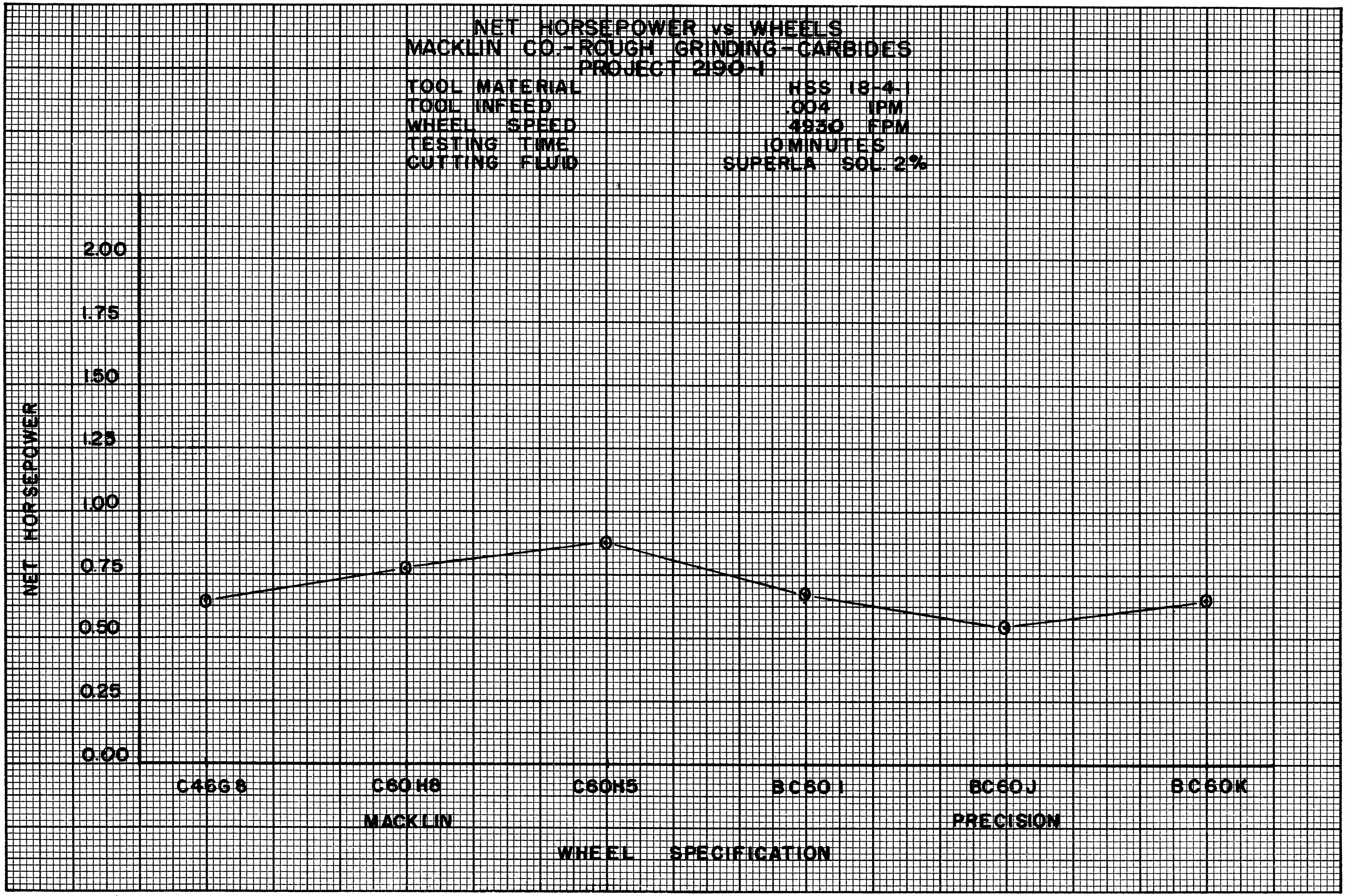
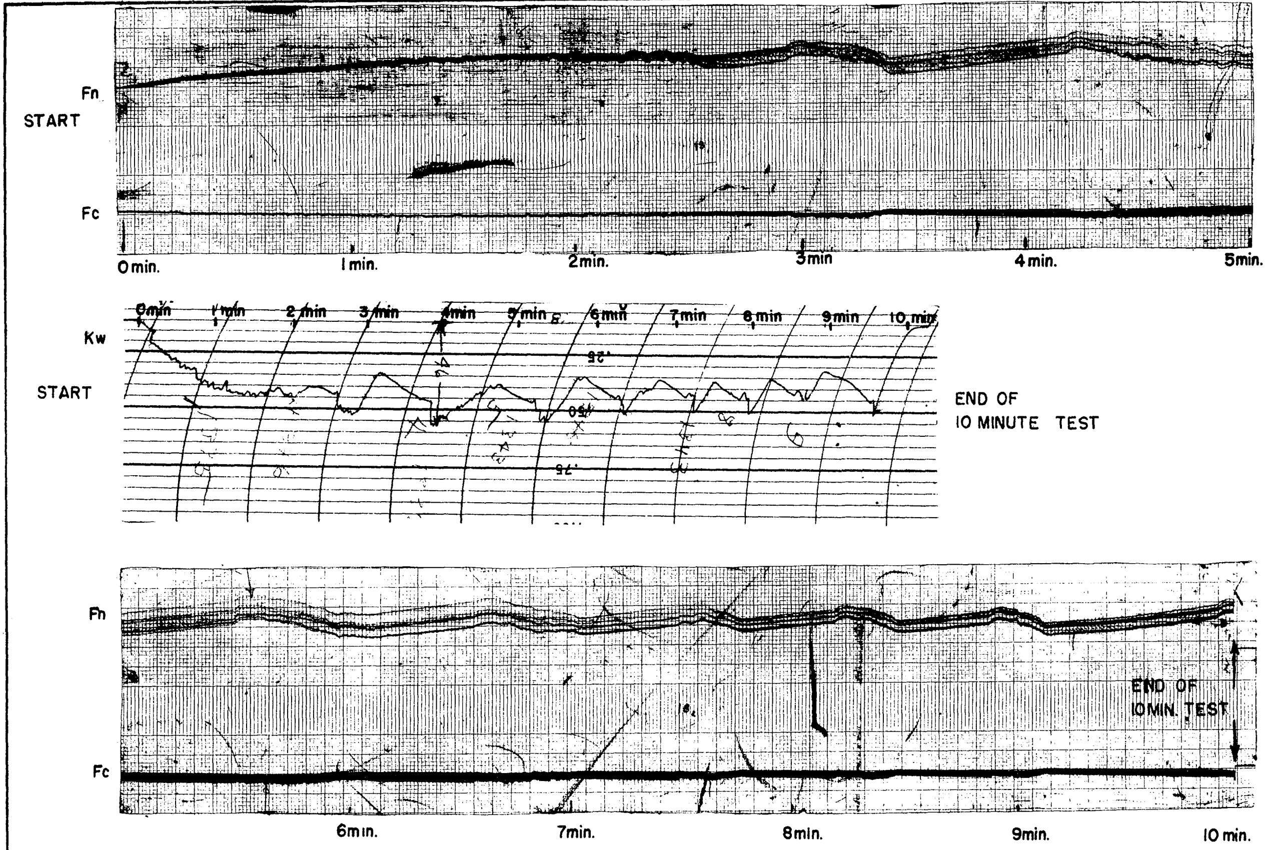
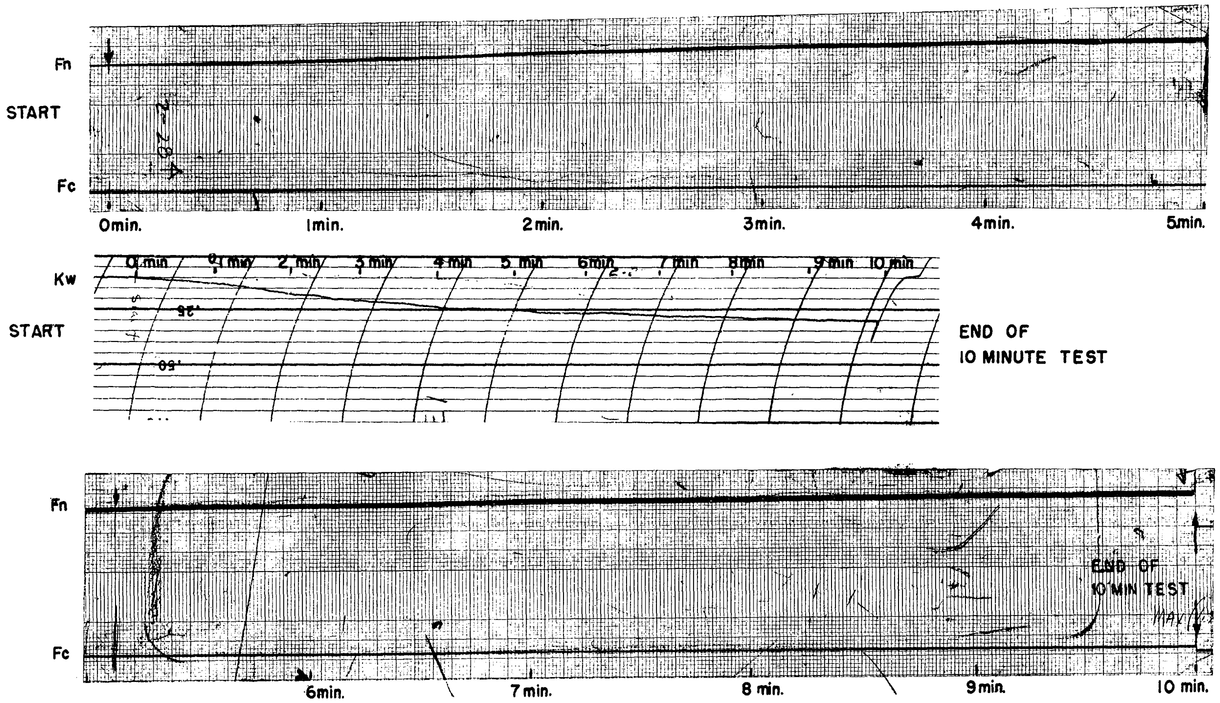

NET HORSEPOWER vs WHEELS
MACKLIN CO.-ROUGH GRINDING-CARBIDES
PROJECT 2190-1
TOOL MATERIAL HSS 18-4-1
TOOL INFEED .004 IPM
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL. 2%
NET HORSEPOWER
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 14

TYPICAL GRAPHS OF POWER, TANGENTIAL FORCE, and NORMAL FORCE FOR CARBIDE, HSS, and CRS TOOL BITS



CARBIDE TOOL BIT (78B)
GROUND WITH MACKLIN C46G8



HSS or CRS TOOL BIT
GROUND WITH MACKLIN C60H8

FIG. 15

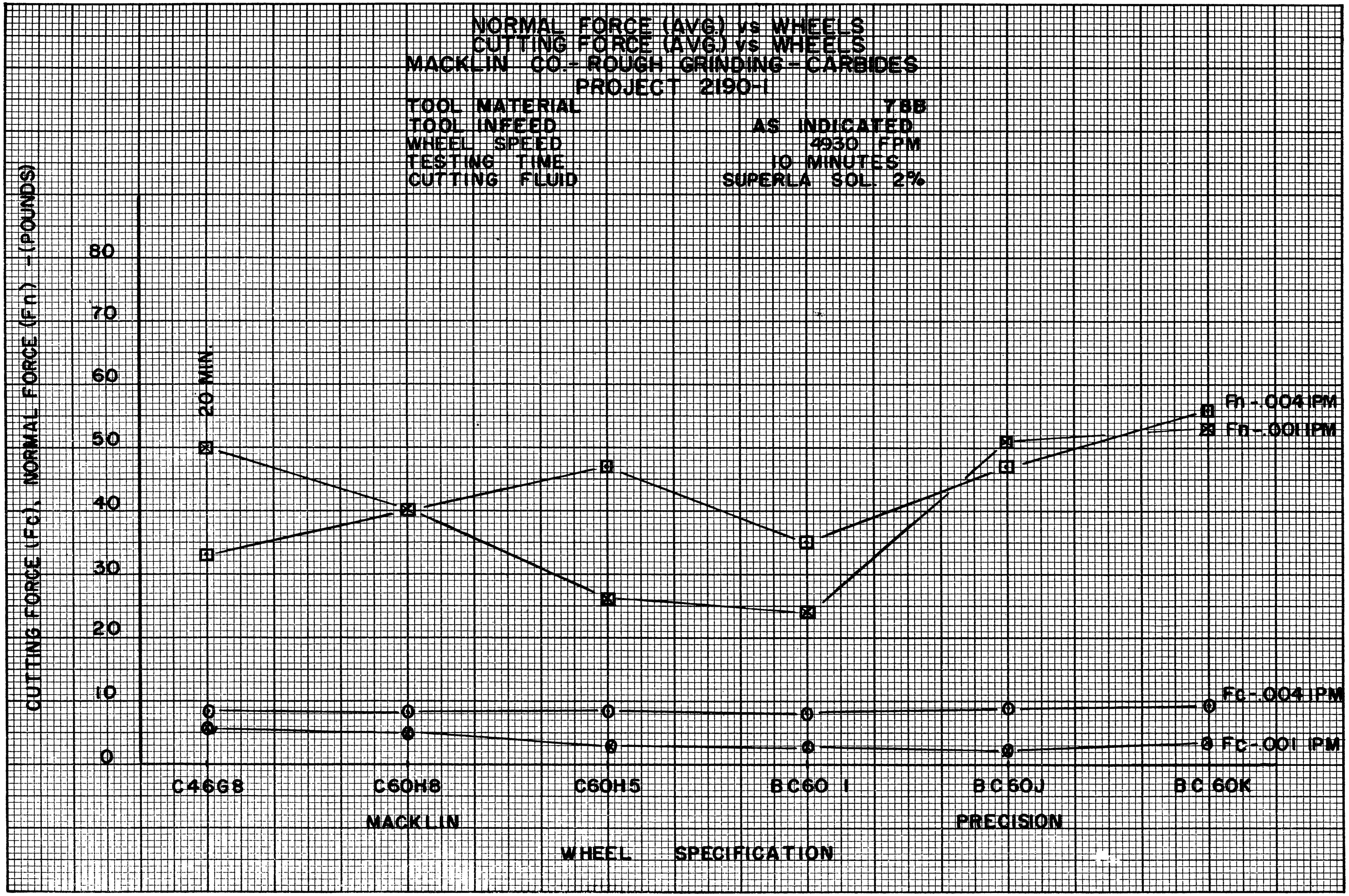

NORMAL FORCE (AVG.) vs WHEELS
CUTTING FORCE (AVG.) vs WHEELS
MACKLIN CO.- ROUGH GRINDING - CARBIDES
PROJECT 2190-1
TOOL MATERIAL 78B
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL. 2%
CUTTING FORCE (Fc), NORMAL FORCE (Fn) -(POUNDS)
80
70
60
50
40
30
20
10
0
20 MIN.
Fn-.004 IPM
Fn-.001 IPM
Fc-.004 IPM
Fc-.001 IPM
C46G8
C60H8
C60H5
BC60 I
BC60J
BC 60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 16

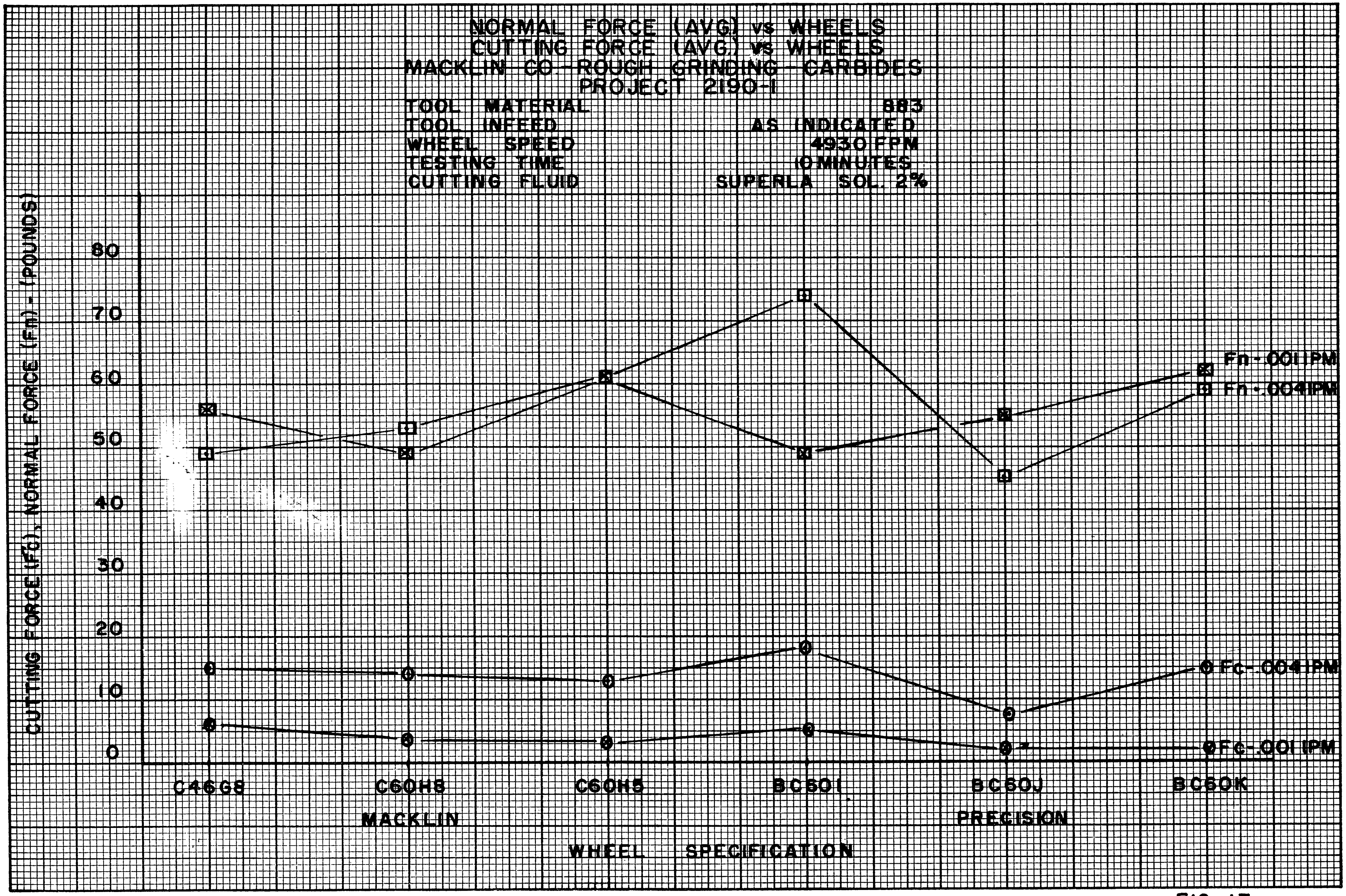

NORMAL FORCE (AVG) vs WHEELS
CUTTING FORCE (AVG) vs WHEELS
MACKLIN CO - ROUGH GRINDING CARBIDES
PROJECT 2190-1
TOOL MATERIAL 883
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL. 2%
CUTTING FORCE (Fc), NORMAL FORCE (Fn) - (POUNDS)
80
70
60
50
40
30
20
10
0
Fn-.001IPM
Fn-.004IPM
Fc-.004IPM
Fc-.001IPM
C46G8
C60H8
C60H5
BC50I
BC50J
BC50K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 17

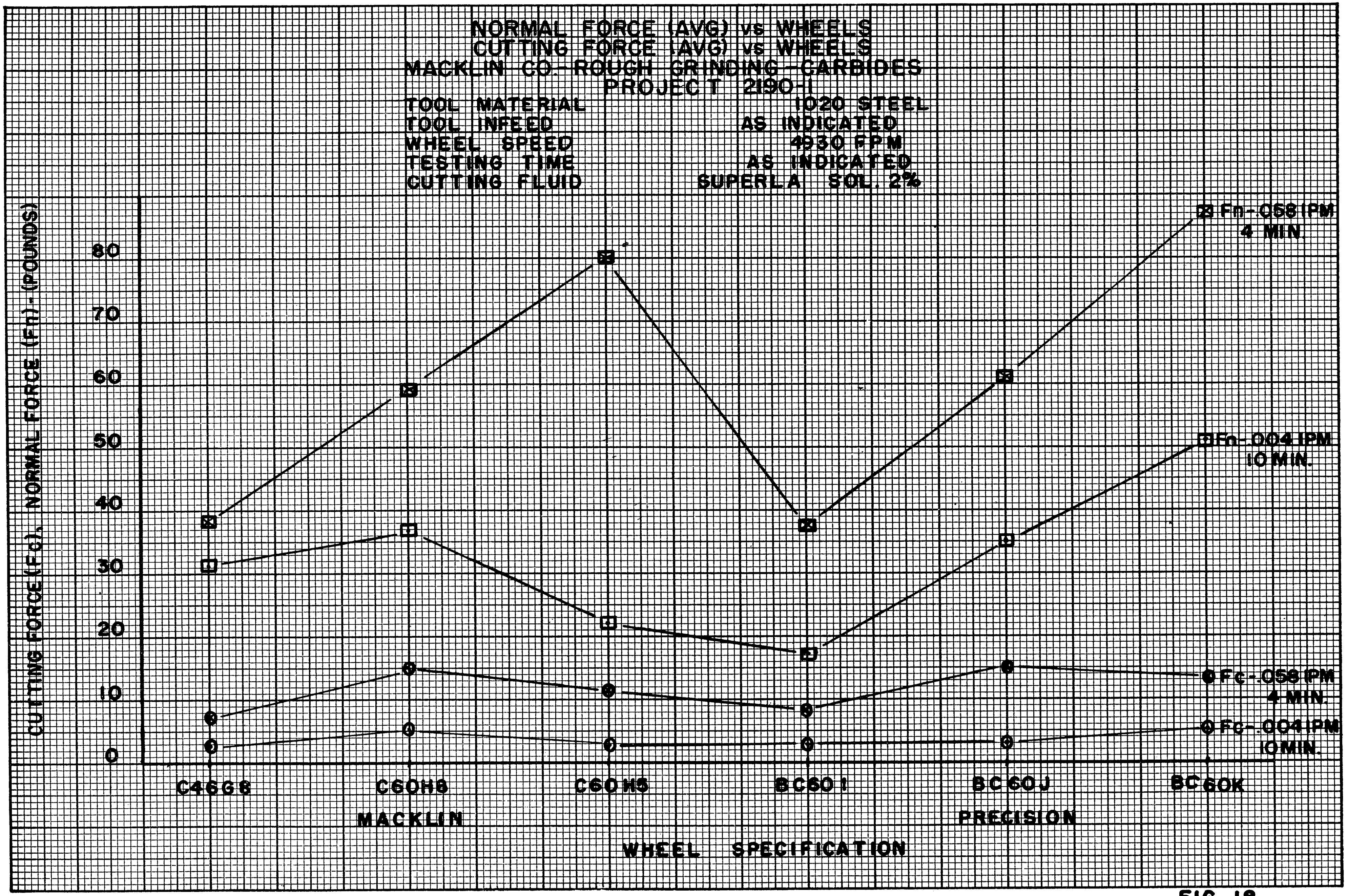

NORMAL FORCE (AVG) vs WHEELS
CUTTING FORCE (AVG) vs WHEELS
MACKLIN CO.-ROUGH GRINDING-CARBIDES
PROJECT 2190-1
TOOL MATERIAL 1020 STEEL
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME AS INDICATED
CUTTING FLUID SUPERLA SOL. 2%
CUTTING FORCE (Fc), NORMAL FORCE (Fn) - (POUNDS)
80
70
60
50
40
30
20
10
0
☒ Fn-.058 IPM 4 MIN.
□ Fn-.004 IPM 10 MIN.
● Fc-.058 IPM 4 MIN.
○ Fc-.004 IPM 10 MIN.
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 18

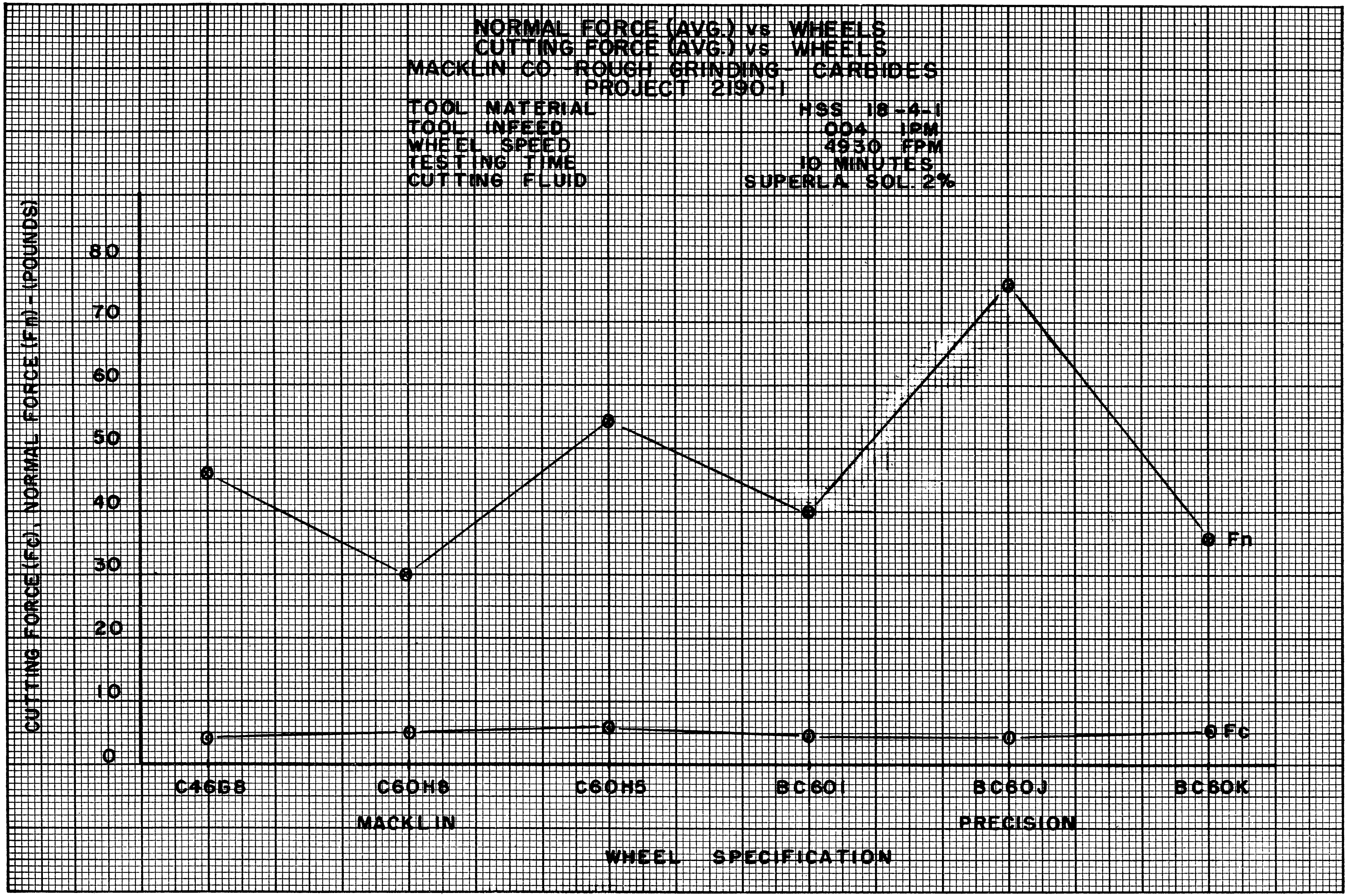

NORMAL FORCE (AVG.) vs WHEELS
CUTTING FORCE (AVG.) vs WHEELS
MACKLIN CO.-ROUGH GRINDING- CARBIDES
PROJECT 2190-1
TOOL MATERIAL HSS 18-4-1
TOOL INFEED .004 IPM
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL. 2%
CUTTING FORCE (Fc), NORMAL FORCE (Fn) - (POUNDS)
80
70
60
50
40
30
20
10
0
Fn
Fc
C46B8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 19

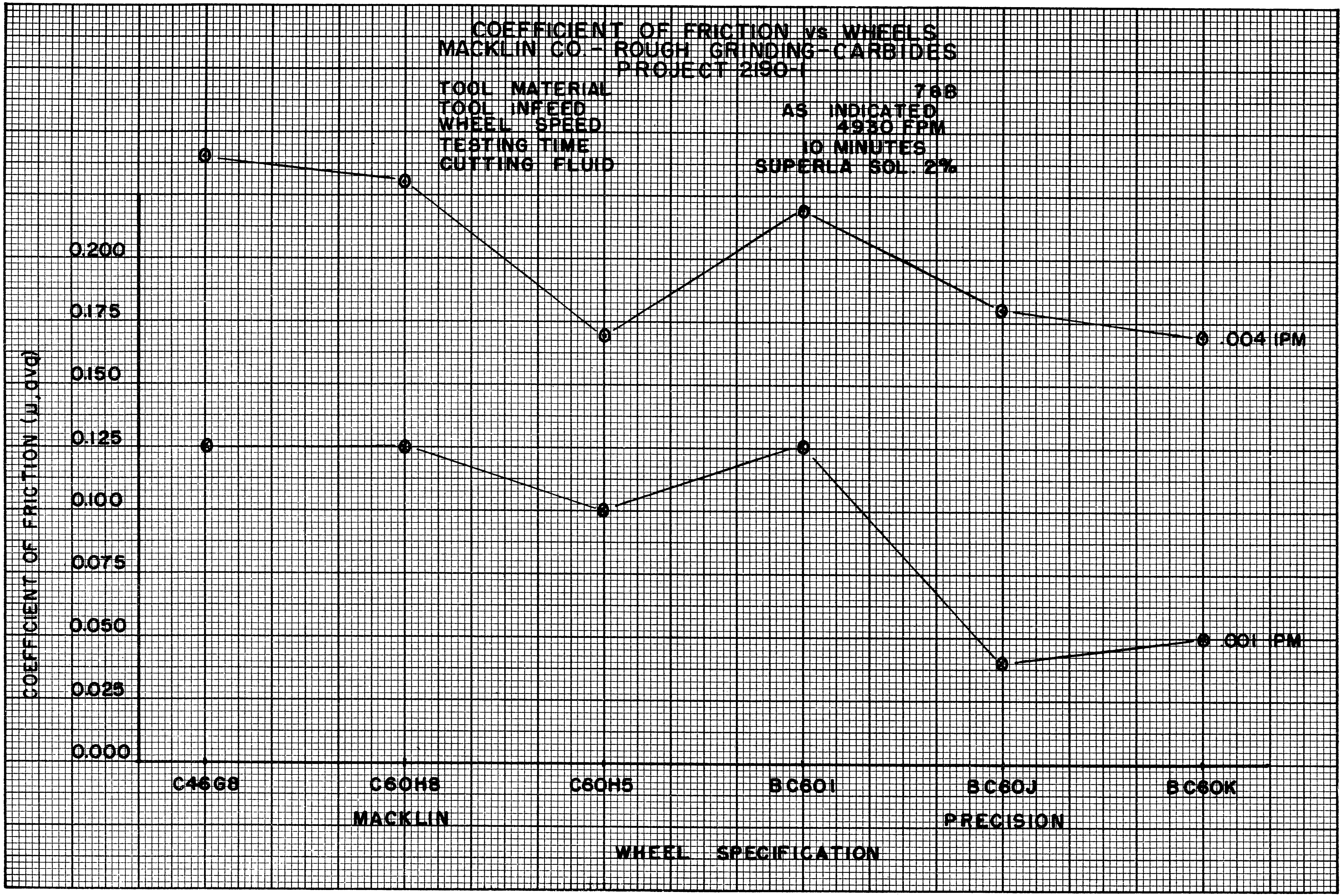

COEFFICIENT OF FRICTION vs WHEELS
MACKLIN CO. - ROUGH GRINDING-CARBIDES
PROJECT 2190-I
TOOL MATERIAL 78B
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL. 2%
COEFFICIENT OF FRICTION (μ, avg)
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
.004 IPM
.001 IPM
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 20

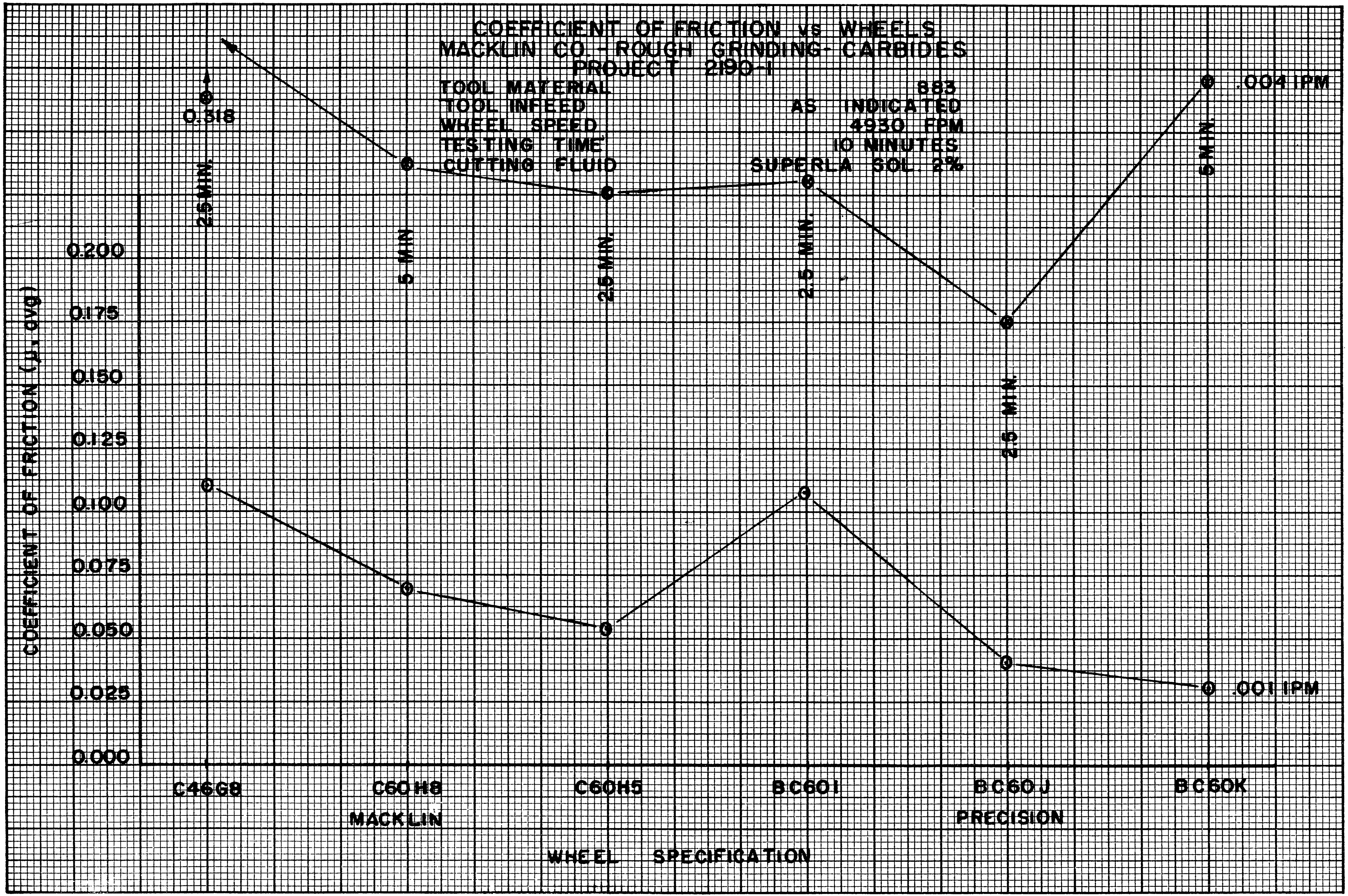

COEFFICIENT OF FRICTION vs WHEELS
MACKLIN CO. - ROUGH GRINDING - CARBIDES
PROJECT 2190-1
TOOL MATERIAL 883
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL. 2%
COEFFICIENT OF FRICTION (μ, avg)
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0.318
2.5 MIN.
5 MIN.
2.5 MIN.
2.5 MIN.
2.5 MIN.
5 MIN.
.004 IPM
.001 IPM
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 21

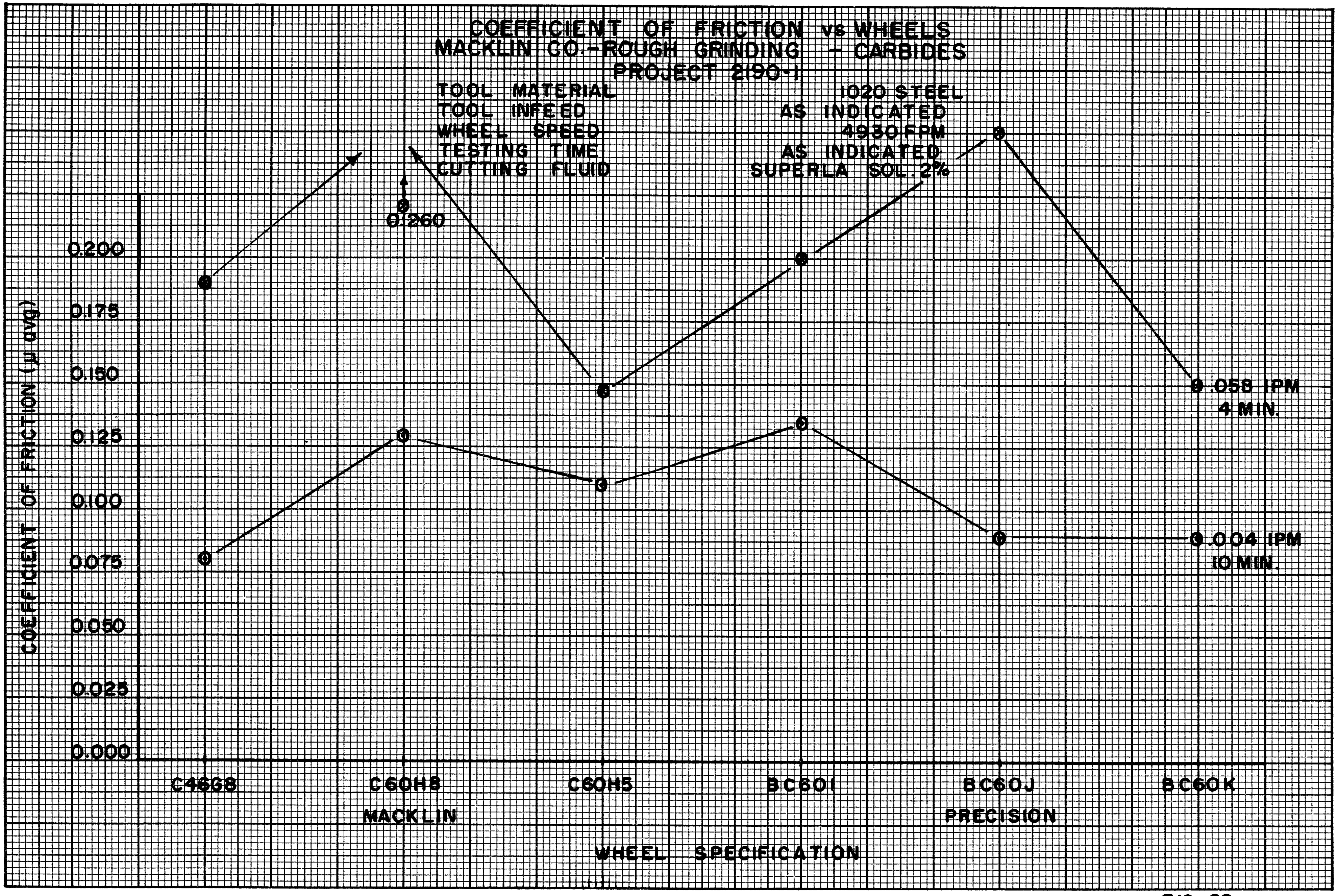

COEFFICIENT OF FRICTION vs WHEELS
MACKLIN CO.-ROUGH GRINDING - CARBIDES
PROJECT 2190-1
TOOL MATERIAL 1020 STEEL
TOOL INFEED AS INDICATED
WHEEL SPEED 4930 FPM
TESTING TIME AS INDICATED
CUTTING FLUID SUPERLA SOL. 2%
0.260
.058 IPM
4 MIN.
.004 IPM
10 MIN.
COEFFICIENT OF FRICTION (μ avg)
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 22

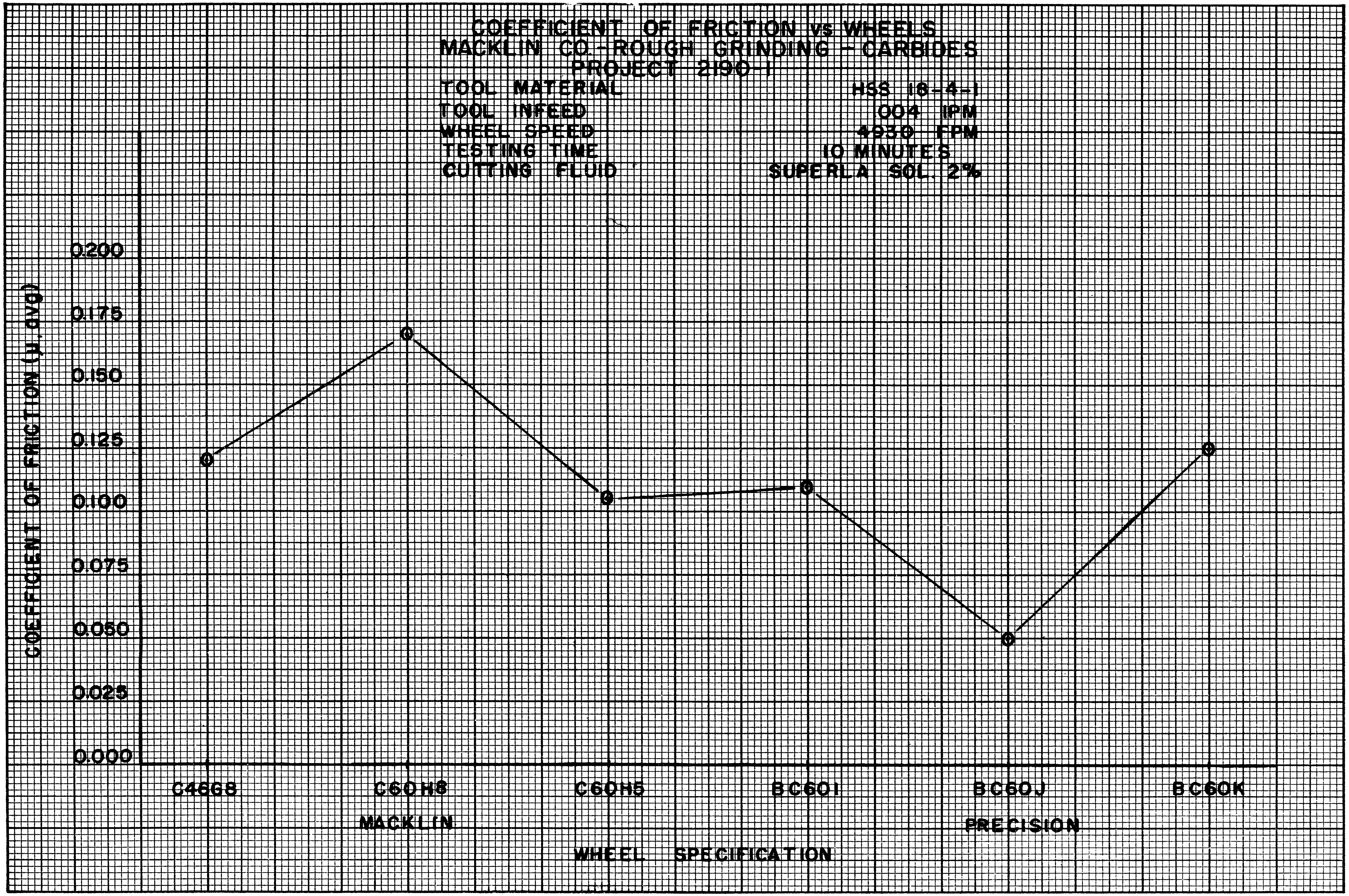

COEFFICIENT OF FRICTION vs WHEELS
MACKLIN CO.-ROUGH GRINDING - CARBIDES
PROJECT 2190-1
TOOL MATERIAL HSS 18-4-1
TOOL INFEED 004 IPM
WHEEL SPEED 4930 FPM
TESTING TIME 10 MINUTES
CUTTING FLUID SUPERLA SOL. 2%
COEFFICIENT OF FRICTION (μ, avg)
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
C46G8
C60H8
C60H5
BC60I
BC60J
BC60K
MACKLIN
PRECISION
WHEEL SPECIFICATION

FIG. 23