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A note on an investigation of the surface grinding process with examples of wheel and coolant selection and planning data

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SUMMARY

This note deals with an investigation into the establishment of manufacturing techniques, on a production scale, for surface grinding, high tensile heat resistant alloy sheet approximately 7 feet by 5 feet. Rigid manufacturing tolerances are demanded in which surface finish must not exceed 10 micro-inches and the thickness tolerance is plus or minus 0. 0002 inches.

The information contained in this report applies to the surface grinding process in general and can be used to aid production planning, as a correct estimate of wheel life when operating under set conditions can be made, and the necessary time for redressing allowed. Results from the work carried out suggest that it may be beneficial to pass components to be surface ground under a roughing wheel (Lumsden) type machine, which will set the constant metal thickness for final finishing. In this way a correct estimated time could be allowed for the operations roughing and finish grinding at optimum conditions.

CONTENTS

INTRODUCTION

This report deals with an investigation into the establishment of manufacturing techniques, on a production scale, for surface grinding, high tensile heat resistant alloy sheet approximately 7 feet by 5 feet. Rigid manufacturing tolerances are demanded in which surface finish must not exceed 10 microinches and the thickness tolerance is plus or minus 0. 0002 inches.

To meet this specification an analysis of the fundamentals of the grinding process was necessary, the results of which will be found in the text.

SECTION 1.

EQUIPMENT

The surface grinding machine used throughout the Test is a Jones and Shipman Model 540. 18" x 6" hydraulic surface grinding machine, in new condition. The wheel is carried in plain bearings, driven by an endless belt.

The table is hydraulically operated on the longitudinal traverse, with ratchet wheel and paul for cross feed; each ratchet tooth equals 0. 007" cross feed. The work table was an Eclipse magnetic chuck 10" x 5".

Coolant Supply

Unless otherwise stated, the coolant used for all tests was Shell soluble oil M3, in water 1:60 ; delivery was constant at a half gallon per minute. The equipment used to filter and deliver the coolant was a Philips Universal Clarifier Type 7733/25, the filtering medium being Philips 150 medium fine paper.

Wheel Dressing Equipment

The surface grinding machine, used as quoted, has no provision for power traverse wheel dressing, and as this may be a variable factor in wheel performance it was necessary to control this function. A dressing attachment was designed to give a traverse speed to the diamond dressing tool of 5 ins. per minute i. e. 6 seconds for the 0. 500 ins. wheel width.

Dressing Tool

The diamond dressing tool was supplied by Technical Diamonds Limited and was used as advised by the supplier in their Patent location system. Shank size ½" x 4" No. 1763/1 Weight 1.00 carat. Quality Q6.

The Jones and Shipman Model No. 1 Balancing Unit was used throughout, all wheel assemblies being balanced before each test.

C. L. A. surface finish records were taken of each machined test piece in a direction across the longitudinal traverse, and along the direction of traverse.

A Taylor Hobson Talysurf was used for these tests.

Traverse and rotational speeds were measured by a Smiths Tachometer.

SECTION 2

GENERAL LIMITATIONS

Limitations in the machine

The tests carried out with reference to surface finish and wheel life showed that there is a limit to the total load which may be imposed on the machine spindle, above which vibration and deflection in the spindle and structure of the machine considerably reduce the life of the wheel. Surface finish appears to suffer equally, and a deterioration from 10 - 12 micro-inches to 80 - 100 micro-inches was recorded, due to this machine load being exceeded.

Limitations of the Grinding Wheel

The tests suggest there are three main reasons for failure directly attributable to the grinding wheel.

(a) Maximum grit load

The wheel will fail or wear rapidly due to overloading when the rate of penetration of the grit into the surface of the workpiece imposes a stress capable of shearing and crushing the grit or breaking its bond thus displacing the entire grit.

(b) Clearance spaces between the grits

The chip produced during the cutting period of each grit must be carried before the leading face of the grit until the surface of the workpiece is cleared; the swarf or chip is then free to be washed or thrown out of the wheel, hence the structure of the wheel must incorporate adequate chip space, i. e. porosity.

Failures arising from inadequate chip space may be attributed to two distinct causes:-

(1) In which chip space becomes filled with removed stock (swarf), causing pressure to be exerted between the grits, thereby displacing them and causing failure.

(2) In which the swarf contained in the chip space is carried under pressure across and in contact with the surface of the workpiece creating elevated temperatures between swarf and work surface. Under this condition, welding takes place between chip and work surface, the increased effort necessary to shear the welds causing grit fracture or displacement

Figure 1a showing the surface of a wheel which carries a weld failure, will be seen to be clean and open when compared with the darker wheel surface shown in Fig. 2a. This is due to the continuous grit displacement (Wheel failure).

The surfaces produced from the wheels in Figs. 1a and 2a are shown in Figs. 1b and 2b.

(c) Lower load limit

Work carried out to determine life between redressing of the grinding wheel face showed there may be a lower load limit. This appears to be when working conditions produce a very small chip at high speeds. Samples of the swarf were found to contain very little metal; the majority of the sample appeared as an ash. Separation was achieved by immersing the sample in water, and removal of the metallic portion by a magnet.

Results from tests which produced this swarf condition proved less satisfactory. The volume of metal removed before redressing became necessary was less than half the expected volume.

From close observation it was found that the wheel work contact area was incandescent and it is assumed that the rise in temperature given by the oxidisation of the chip results in a shorter and unpredictable wheel face life.

SECTION 3.

CHARACTERISTICS AND PROGRESS OF GRINDING WHEEL WEAR

Theory of Wheel Wear

Taking an ideal case, a grinding wheel is assumed to be composed of:

(a) Grits which do the metal cutting
(b) The bond holding the grits in the wheel
(c) The spaces or porosity of the wheel.

In the ideal wheel each grit is of similar size, and is secured in the wheel by its bond, the amount and strength of which is assumed to be identical for each grit. The total volume of space (porosity) is also assumed to be shared by each grit equally, i. e. each grit has its allotted chip clearance and may be considered as a separate unit, or cutting tool.

Each grit can do equal work and is capable of withstanding a certain maximum load before being displaced from its setting (bond). The load imposed on the grit by the workpiece may cause grit failure due to the limitations (as set out in Section 2a and 2b) being exceeded.

Progress of Wheel Wear

Considering the ideal case, in which each grit is presented with an equal task, all grits being sharp and the load imposed by the task insufficient to dislodge the grit, then cutting action takes place and continues until every applied grit becomes worn. Due to this wear the increase in force necessary to drive the grit, against the set task, exceeds the strength of the bond, and the grit is displaced. All active grits would be simultaneously displaced.

The Practical Case

In practice the wheel is dressed and set to work, conditions of wheel speed, cross feed, depth of stock to be removed, table speed and coolant being constant.

The work is cross traversed under the wheel surface by one cross feed increment and ideally the wheel should remove that section of the work along the length of the workpiece. However the limitations are usually exceeded and a large number of grits are removed from the wheel whence it is found that an angle has been produced on the leading edge of the wheel with a corresponding angle on the workpiece. On continuing the process the angle (α) becomes less steep at each pass, until after a short time it becomes almost constant.

During the initial period (formation of the approach angle α) wheel wear is very rapid, and work to wheel ratio was between ten and fifteen to one for the test conditions. Progress of this wear is shown in Fig. 3 in which length B is the loss of wheel surface due to approach angle .

Fig. 4a shows the progress of wear after the approach angle α is formed. Once formed, this angle remains almost constant and recedes across the wheel face at a constant rate for constant surface area and/ volume produced or removed by the wheel. Ref. wheel life test results, A zone).

Fig. 4b shows the change in angle α when table speed is increased (Ref. Test Result Sheet on wheel face life).

Approach Angle α

The approach angle α which is formed on the wheel is the angle through the wheel leading edge which will present the required number of grits to the working area such that each grit has a task within its limitations. By continued use, wear increases the force on the grits and the whole working row of grits on the approach angle are displaced, leaving the next row to proceed with the task.

Observed in this way an increase in table speed or cross traverse will increase the task, and since each grit is restricted to a limited effort, a greater number of grits will be required to carry out the increased task. Hence the angle α is reduced, the active face width is increased and more grits are presented to the cutting face, each performing its limited effort.

Fig. 5 refers to the form of the approach angle. From the results given on wheel life between redress (Section 4) it will be seen that in the progression of the approach angle across the wheel face in Zone A, length A is at first not constant for constant surface area or volume produced. To find a reason for this the ideal wheel must be considered.

In the ideal wheel it is assumed that each grit is held in the wheel in identical circumstances. Fig. 5 shows that at areas X, a and b this is not so. Grits in the region of the side edge of the wheel are not so well supported as the grits some distance in from the side of the wheel. This produces wear length X at which position the support is equal to other grits.

This support theory also explains the initial variation in the length of wear on A for unit surface area produced. In Fig. 5, areas a and b, it will be seen that at the intersection of the approach angle with the worn face of the wheel, (position b), the immediate grits have more support than the grits on approach angle. This causes a radius to develop in that area since, being better supported, the grits can do more work before being displaced.

The intersection of the approach angle with the wheel surface (position a), presents the opposite case. Grits in this position are not so well supported, hence the convex radius automatically produced to equalise the work and stabilise cutting conditions (see rate of wear per surface area produced in life test, Section 4).

<u>Variation in the approach angle α</u>

It can be seen that the approach angle will change if the rate of metal removal is increased either by an increase in the rate of cross feed or in table speed. This decrease in α creates an increase in the number of grits in action so that each works within its limitations. Fig. 6 shows the change in α schematically.

When the rate of metal removal is so great that it requires a greater number of grits to be present in action than can be achieved by an angle extending the whole width across the wheel face, the stable conditions are never reached, and metal to wheel wear is in the order of ten to one, surface finish is not at its best and dimensional accuracy is not achieved (i. e. the work is tapered in the cross traverse direction).

Figure 7 shows that the angle α is not changed by increase in depth of cut. An increase in metal removal rate is achieved by an increase in the depth of active face; equal depths of this face perform equal tasks.

Referring to wheel life, (Section 4) for . 0005 and . 001 depth angle α remains constant, length A is reduced to the increased proportions of the sides bounding the angle α , thus for a wheel of constant width life is reduced.

Effect on wheel wear of variation in grit size (Fig. 8)

The result of an increase in grit size shows that, over a constant length of active wheel face on the α angle, fewer grits are presented to the work. In the ideal wheel, if the larger grit were secured in position as strongly as the small grit, the increase in grit size would necessitate an increase in the active face length in order to bring an equal number of grits into action for each to perform its limited task.

In the practical case, usually the larger grit is more strongly held (for a given bond and structure) and each grit is capable of an increased maximum effort, therefore the actual length of the wheel face on angle α is proportionally reduced. A counterbalancing factor is that a large grit will have larger facets and will cut a wider chip, thus increasing the load on the grit and subtracting from the expected life. The results of an increase in grit size may be summarised as follows:-

Advantages (giving greater life)	Disadvantages (reducing life)
Stronger Grit	Larger Chip per Grit
Stronger Bond	Fewer Grits per Unit Length on Active Face
Greater Chip Space (Porosity)	

The effect of variation in the wheel diameter

Assuming other conditions constant, an increase in wheel diameter will increase the arc of contact between the wheel and work piece, resulting in a greater chip length and heavier chip load (see calculation for chip load, Section 5, wheel life in B zone).

The result of this increase in chip length and thickness, is to increase the load on each grit; this will result in a readjustment i. e. increase the active face width on the approach angle α and so bring the task of each grit back to its limited maximum effort. Rate of wear in the constant Zone A will be reduced in proportion to the increase in number of grits round the active face of the wheel.

SECTION 4.

GRINDING WHEEL LIFE

In this section the life of the grinding wheel face is considered, as obviously the total life of the wheel will be very appreciably influenced by the amount of wheel removed when redressing the face after it becomes worn, and on initial mounting and remounting if changes of wheel are necessary.

Section 3 analyses wheel wear and shows there are two distinct zones referred to as Zone A and Zone B. The rate of wear in these zones is very different. In B it is rapid giving a work to wheel ratio of approximately ten volumes of stock removed to one volume of wheel loss (for the wheel and work material tested). Zone A shows a very low rate of wear which is almost constant for constant worling conditions. The work to wheel ratio is very high. Tests results sheets 1 and 2 and Figs. 9 and 10 show 147 and 185 volumes of stock removed to one volume of wheel loss in Zone A.

Figure 11 shows schematically the Zones A and B. The effect on wheel face life between redress (the change in angle α) is also shown in Fig. 11 when the metal removal rate is increased by an increase in table speed.

It will be seen that the life of the wheel face is reduced by the decrease in length A on the wheel face and volume in Zone A. Although the time to form length B and Zone B is increased, the sum of these changes on life is negative due to the very much greater wheel to work ratio volume for volume of wheel in Zone A than in Zone B.

However when the approach angle α is established, the loss on length A in both cases of metal removal rate will be identical, i. e. equal volume of metal removed produces equal loss in length A until the active face of the wheel reaches a point approximately equal to the distance (X) from the trailing edge of the wheel, (discussed in wheel theory), when failure will occur due to lack of support as previously outlined.

The life of the wheel face will be affected by an increase in cross feed rate in a similar manner to that brought about by a change in table speed. For an increase in cross feed there will be a loss in A and a gain in B, the net result being a loss in metal removed per wheel face redress.

Test Result Sheets 4, 5 and 6 show that after the initial adjustment period , which includes loss in Zone B and the settling down on points (a) and (b) (see fig. 19), the volume of metal removed relative to the loss on length A is again identical for any other set of conditions. This is illustrated by the analogy of an ideal wheel, i. e. each grit being capable of a limited maximum effort.

SECTION 5

DETAILED ANALYSIS OF TESTS CARRIED OUT

During the early work in this investigation a large number of tests were carried out, but many failed to give acceptable practical results which agreed with theoretical calculations. Eventually, techniques were developed which allowed the necessary rigid control of the many variables to be achieved. For example Test 3 for .0015 depth of cut shows the deviation from the results which were obtained in life tests at .0005 and .001 depth of cut (Test Result Sheets 1 and 2); the wear on the active face failed to settle down at .050" to .060". This incorrect test result was due to vibration in the wheel, as is shown in Fig. 12. When the active cutting face reached the position indicated in Fig. 12, a distinct change in the sound produced by the wheel/work action developed similar to the hollow sound made when grinding an unsupported workpiece.

In the later stages of the investigation it was possible to analyse the early results and find the reason for these errors.

All tests which were completed without error were repeated at least once, the shorter tests being repeated three or four times. The following sample of tests, adequate to prove each point are included in this report.

(1) The wheel limitations (Section 2)
(2) Wheel face wear, determination of approach angle α and Zones A and B and wear on A (Section 3)
(3) The effect of varying grit size (Section 3)
(4) Grinding wheel face life in relation to metal removed (Section 4)
(5) The effect of coolants on wheel face life.

Brief analysis of tests carried out

Test No. 1. Wheel limitations (Section 2)

During this series of tests the progress of wheel wear was closely observed. It is difficult to distinguish between grit overload and chip space crowding failures. Fig. 1a shows a weld failure; the wheel surface is clean and open due to continued grit displacement. A quantity of swarf may be seen adhering to the clean wheel, the surface of this swarf exhibiting shear marks.

To reduce welding a heavily sulphurised soluble oil was applied to a wheel working under similar conditions, this reduced the rate of wheel wear and improved the finish on the workpiece, suggesting that the more active coolant did reduce the welding between the swarf and the workpiece surface.

Test No. 2 Wheel face wear, determination of approach angle, wear in Zones A and B.

The initial wear on the wheel face is very rapid but a progressive decrease in this wear rate is found to take place. The nature of the wear rate may be presented graphically as in Fig. 13 which shows that during the first few seconds of wheel work contact, after redress, the wheel contact area suffers almost complete loss. The proportion of wheel to work loss rapidly improves until at the intersection of Zone A and Zone B the curve became almost asymptotic.

The method used to determine the position of Point A was to commence the cut and stop the operation at each table stroke. The wear on the wheel may be found by measuring the width of the form produced on the workpiece, a pair of dividers being used for pricking the boundaries of the wear. This procedure is continued, until the measured wear length on the workpiece becomes constant for four or five table strokes. (The dimension of the workpiece is shown in Fig. 10 i. e. 6 ins. long by $4\frac{1}{2}$ ins. wide and was constant for all tests.)

The results of these tests showed the conditions reported in Figs. 3, 7, 9 and 10. From the wear stage which gave the intersection of A and B (Fig. 3) the work was continued, records of the wear width from A being taken as follows:-

After a predetermined volume (referred to as unit volume) of metal is removed, the work surface is smeared with a light film of engineers blue, the wheel is allowed to pass over the surface, with the cross feed disengaged and without alteration to spindle setting. In this way the deflection of the wheel spindle etc. under the load of the previous cut is removed and the wheel removes a width of marking blue approximately equal to the unworn width of the wheel face; this width is then measured.

The results recorded in Section 4 show that after the approach angle α is established, wear of length A Figure 9 is constant for constant metal removal. The reference to grit support section (Fig. 5) shows the reason for the gradual diminishing of the wear Length A in the initial stages of the constant wear period.

Calculation of the approach angle formed on the wheel active face may be made from the dimension of wheel wear recorded as above and the depth of cut used.

The wheel to work ratio, recorded in Section 4, is calculated from the wheel wear records and the work loss from the test piece measured by micrometer. Figure 14 shows schematically the above method of wheel work ratio calculation.

Test No. 3 The effect of varying the wheel grit size.

The effect on wheel life when grit size is changed will only be found by test; there is a limitation to the maximum and minimum sizes which would work efficiently under each set of conditions. Remarks in Section 3 will give guidance on the choice of grit size. The results of other than the optimum grit size will be an increase in length B and a decrease in length A, with a corresponding reduction in volume of stock removed per wheel face redress.

Test No. 4 Grinding wheel face life in relationship to volume of metal removed (Section 4)

There are two distinct parts in the total life of a wheel face:- Part 1, extending over length A (except for a length on the trailing edge of the wheel approximately equal to X in the figure on wheel wear) and Part 2, extending over length B.

Part 1 It has been shown in the test result sheets on wheel life and in the figures related to these sheets that, other conditions remaining constant, an increase in metal removal rate by increasing depth of cut, cross feed or table speed will not effect the rate of wear of length A (Figs. 6 and 7) after the approach angle and points (a) and (b) of Fig. 5 are established. When metal removal rate is increased by an increase in the depth of cut, the additional grits are provided by an extension of the active face at the same α angle, towards the centre of the wheel, resulting in a shorter length A. The effect of increased metal removed rate by increase in cross feed or table speed is to change the angle α ; this increases the active face of the wheel and presents the greater number of grits necessary to remove the increased volume of metal, with the net result that length A is decreased.

Part 2 In length B and Zone B there is no constant state; initially rapid, the rate of wear is continuously reduced. The volume of metal presented to the wheel dictates the characteristics of wear cr wheel breakdown, i. e. the greater the grit load the steeper the wear curve.

The nature of this curve is shown in Figure 15a. Test Results Sheet 7 gives the actual experimental results from which the curve is plotted, on Log-Log bases. This curve becomes a straight line from which wheel life under B conditions may be predicted (see Section 6).

Test No. 5 The effect of coolants on wheel face life.

The effect of a more efficient coolant on wheel face life will be to reduce length B and increase length A with a net increase in volume of metal removed per redress. Improvement is also found in the loss on length A per unit of volume of metal removed. The reason for these gains is the decrease in force necessary to do unit work; a slight improvement in surface finish is also observed.

Surface finish and dimensional accuracy

In the tests carried out with wheel, Carborundum GC. 80 JX5 V. G. the surface finish from length A was constant at 7 to 8 micro-inches, under all conditions of depth of cut, surface speed and cross feed, (example 70 passes over the work-piece at . 001 inches per pass), until the trailing edge of the wheel was approached by the active face (distance X), when surface finish deteriorated progressively. Finish from length B was 18 to 20 micro-inches initially gradually improving to 7 to 8 micro-inches at the intersection with length A.

Dimensional accuracy

The work surface produced from wheel face length B was tapered in the cross traverse direction; the amount of taper varied with the load on the wheel. Work produced from wheel face length A was level, and it was found (Test Result Sheets 1 and 2) that after taking 70 passes at . 001 ins. depth of cut and 80 passes at . 0005 depth of cut, . 069 ins. and . 040 ins. of stock thickness respectively had been removed from the workpiece and that the two faces, i. e. base and new face, were parallel as far as could be determined by a one-tenth thou. micrometer. (The loss of . 001 on the results was due to expansion in the machine during the test period).

The change in surface finish produced by a change in grit size was very small for the sizes tested. Numerical results are as follows:

100 grit	5 to 6	micro	inches
80 "	7 to 8	"	"
60 "	7 to 9	"	"
46 "	8 to 11	"	"

Metal removal rate at constant wheel wear conditions made no change in surface finish recorded.

The wheel was dressed by taking one pass at .003 ins., one pass at .0005 ins. and one pass with no down feed.

This was adopted as standard practice for all tests. Rate of diamond traverse was 5 inches per minute. The diamond/wheel position for wheel dressing was constant for all tests.

SECTION 6

SUGGESTED USE OF THE INFORMATION GAINED FROM THE INVESTIGATION

Grinding Wheel Selection

The procedure for life tests Section 4, would be carried out.

The wheel showing shortest length B and least wear on length A per unit volume of stock removed under standardised test conditions would be the best wheel for the set of conditions presented for the test (surface finish being acceptable).

Selection of Coolants

Similar procedure as for wheel selection, all conditions other than the coolants remaining constant.

The value of the knowledge of events in length A and B

In many cases the rate of metal removal when operating under conditions which give the greatest wheel face life (i. e. least loss on length A for unit volume of stock removed) is too slow and conditions in B are used, (see Conclusions, Section 7). However, in other cases, due to loss in dimensional accuracy, depreciation of surface finish and large surface areas to be covered, before redress of the wheel face is possible, the length A conditions must be used. For example, finish grinding of steel sheet mill rolls or sections of aircraft skins, especially in possible future high speed aircraft, using alloy skins.

Procedure for use of a wheel selected to operate under 'A' condition

Find the wear to produce 'B' length and for 'A' to become stable Proceed with wear/volume removed test and find wheel work ratio on A.

Two units of wear on A results are adequate for reliable estimate. The length of wheel left on A minus X multiplied by the unit volume per loss on A will be the remaining life volume, and the total volume removed per redress may be found. Alternatively the area of surface produced per unti volume of wheel lost multiplied by unit length left on A minus X will be the total area of surface remaining, and total surface obtainable per redress at the test conditions may be found from the volume or surface figures. It is possible in this way to show the total area of a sheet which may be ground before redressing the wheel.

(Charts can be prepared for planning office use showing the condition of operation A or B and area/volume removed. See Fig. 16 for graph of B operation condition).

Procedure for use when wheel is to operate on length B conditions

The following method of calculating grit load was used throughout the tests reported in life versus volume of stock removed, Section 4, and was found to be sufficiently accurate for practical use.

Approximately 20 life curves have been drawn. About 50 of the results were predetermined and the tests proved these calculated results to be 85% to 95% correct.

PROCEDURE

The grit enters the work surface at the bottom dead centre of the wheel and progresses radially until emerging at the uncut work surface. During this time a continuous chip similar in form to that removed by the tooth of a milling cutter is assumed to be removed from the work-piece. The dimensions of the chip will be proportional to the wheel diameter, the size of grit, the depth of cut and table speed.

Grit size is neglected in the calculation used to determine grit load. The benefits of large or small grit size are evident from the life curves produced by varying grit size in test wheels.

Formulae used to determine grit load.

(1) Arc of contact $= \frac{\Pi r}{180} \cos^{-1} \left(\frac{r - h}{r}\right)$

h = depth of cut

r = radius of wheel

$$\frac{\text{arc of contact in inches}}{\text{surface speed of wheel in ins./min.}} = \text{minutes for a grit to travel the arc distance.}$$

Time to travel arc distance x table speed ins. /min. = feed rate per grit (ins.)

$$\cos^{-1}\left(\frac{r-h}{r}\right) \times \frac{T}{360n \pm T} = \text{Feed rate per grit (ins.)}$$

where

h = depth of cut in inches
r = radius of wheel in inches
T = table speed in inches per minute
n = revolution of spindle per minute
The value $\pm$ T is ignored and a mean speed found.

The results of calculations made for various depths of cut and table speeds may be presented on a simple graph as shown in Fig. 16 together with the life of the wheel in cubic inches of metal per redress.

METHOD

The wheel is trued and balanced, the test conditions are set, standard wheel dressing is carried out, and the surface of the work piece is given a 10 micro-inch finish.

The surface produced by the wheel is recorded by the Taylor Hobson Talysurf at each pass, and the metal removed is checked by micrometer measurement. The test is continued until the surface finish has deteriorated to 20 micro-inches.

It is found from test results that the surface finish improves from the initial 16 - 20 micro-inches throughout the useful life of the wheel surface to approximately 8 - 10 micro-inches.

The volume of metal taken as the end of the useful life is that removed before a depreciation of finish is recorded i. e. the last pass producing 10 to 12 micro-inches.

Each life test was repeated twice, the shorter ones were repeated three times. No significant variation in results was found in any test within the limitation of the particular wheel on test. The standard coolant was used throughout.

Wheel speed was calculated for loss in diameter due to redress.

Procedure when lengths A and B are to be used to obtain highest production efficiency with maintained quality of product

When the stock to be removed is of irregular thickness, or is an amount which cannot be removed at one finishing pass, it may be found possible to remove the amount exceeding the finishing cut, at the length B conditions, and to finish at length A conditions (a wheel which is best at one condition will operate satisfactorily at both conditions).

There is one point to watch in this change over method as it may be necessary to redress the wheel face several times during the roughing operation, which is permissible. However when the finishing cut is to be taken the wheel surface is redressed, but instead of being set on the finishing cut and producing the initial irregularities due to angle formation, it is set to remove a suitable small area of the roughing cut left for the purpose. This stabilises the wheel and on making the finishing pass the whole area will have equally good surface finish and dimensional accuracy will be achieved.

SECTION 7

CONCLUSIONS

A grinding wheel cannot be better than the machine on which it is used. The machine must have adequate power and rigidity also wheel speeds and table speeds must be constant when under load. Any change in speed will be detrimental to the wheel, e.g. wheel speed falling under cut has a similar effect to an increase in table speed, and α angle cannot become stable.

The performance of the grinding wheels tested showed them to be efficient and reliable. The wheel should be as wide as possible as this gives proportional increase in life of A and more than proportional in B.

Maximum metal removal rate to give greatest wheel/work volume per redress may be calculated as shown in Fig. 17, from which, with similar calculations made for various wheel widths, it is found that the metal removal rates at optimum (A) conditions are as high or even higher than volumes at other than optimum (B) conditions. The limitations lie only in the power of the machine and wheel width.

The information contained in this report can be used to aid production planning, as a correct estimate of wheel life when operating under set conditions can be made, and the necessary time for redressing allowed. Results from the work carried out suggest that it may be beneficial to pass components to be surface ground under a roughing wheel (Lumsden) type machine, which will set the constant metal thickness for final finishing. In this way a correct estimated time could be allowed for the operations roughing and finish grinding at optimum conditions.

The products supplied by the Companies in the list of appreciation were found to be excellent in every respect.

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Manchester Oil Refinery Limited
Shell-Mex & B. P. Limited
Regent Oil Company Limited
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The Carbon Dioxide Company Limited Ce-dee cut cooling equipment.
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EXPERIMENT: To find approach angle α
and the ratio:- $\frac{\text{volume of metal removed}}{\text{volume of wheel lost}}$
for various depths of cut

TEST CONDITIONS

Depth of Cut	0. 0005 ins.
Table Speed	60 ft/min.
Cross Feed	0. 042 ins. /pass
Wheel	Carborundum GC. 80 J. X. 5 V. G. 1" wide

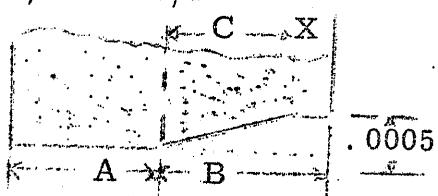
RESULTS

Surface Area Ground sq. ins.	Start	36	300	600	900	1200	1500	1800	2100
Width of Wheel lost ins.	none	0.080*	0.070	0.080	0.090	0.110	0.035	0.040	0.050
Width of Wheel left ins.	0.960	0.880	0.790	0.710	0.620	0.510	0.475	0.435	0.380

Total measured volume of metal removed = 1.0395 cu. ins.
Total volume of wheel lost = 0.00682 cu. ins.

	Overall	Zone A	Zone B
Ratio:- $\frac{\text{volume of metal removed}}{\text{volume of wheel lost}}$	$= \frac{1.0395}{0.00682}$		
	= 152/1	185/1	8/1

Approach flat X = 0.060"
Stabilised length C = 0.110"
Angle = $0^{\circ}\ 15'$
Estimated full life of wheel before redress necessary = 1.93 cu. ins. of metal removed



* Initial high wear rate while Zone A is 'stabilised' (See Figure 5)

TEST RESULT SHEET 2

EXPERIMENT:

To find approach angle α
and the ratio:- $\dfrac{\text{volume of metal removed}}{\text{volume of wheel lost}}$
for various depths of cut

TEST CONDITIONS

Depth of Cut	0.001 ins.
Table Speed	60 ft/min.
Cross Feed	0.042 ins/pass
Wheel	Carborundum GC. 80 J. X. 5 V. G. 1" wide

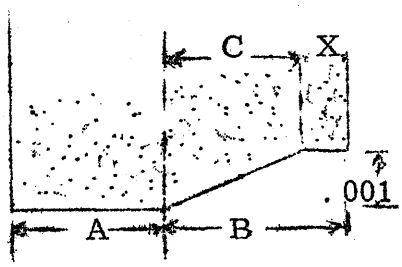
RESULTS

Surface Area Ground sq. ins.	Start	36	81	300	600	900	1200	1500	1800
Width of Wheel lost ins.	none	B *=	0.250	0.130	0.120	0.070	0.040	0.070	0.050
Width of Wheel left ins.	0.960		0.710	0.580	0.460	0.390	0.350	0.280	0.230

Total measured volume of metal removed = 1.836 cu. ins.
Total volume of wheel lost = 0.01606 cu. ins.

	Overall	Zone A	Zone B
Ratio:- $\dfrac{\text{volume of metal removed}}{\text{volume of wheel lost}}$	$= \dfrac{1.836}{0.01606}$		
	= 114/1	147/1	14/1

Approach flat X = .030"
Stabilised length C = 0.220"
Angle = $0^{\circ}15'$
Estimated full life of wheel before redress = 2.330 cu. ins. of metal removed



* Initial high wear rate while Zone A is stabilising

EXPERIMENT:

To find approach angle α
and the ratio:- $\frac{\text{volume of metal removed}}{\text{volume of wheel lost}}$
for various depths of cut

TEST CONDITIONS

Depth of Cut	.0015 ins.
Table Speed	35 ft/min.
Cross Feed	0.042 ins. /pass
Wheel	Carborundum GC. 80 J. X. 5 V. G. 1" wide

RESULTS

Surface Area Ground sq. ins.	Start	81	300	600	900	1200
Width of Wheel lost ins.	none	0.290*	0.150	0.120	0.100	0.140
Width of Wheel left ins.	0.990	0.700	0.550	0.430	0.330	0.190+

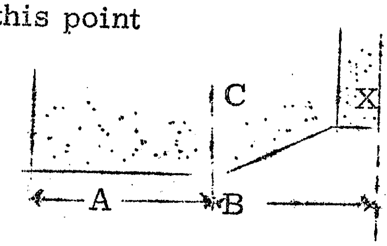
\+ Test discontinued at this point due to lack of rigidity in wheel structure. See Section 5, 5.1, and Figure

The test was satisfactory up to this point

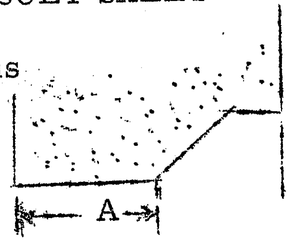
* The stabilised length C was formed at this point

Stabilised length C = 0.290

See analysis of tests. Section 5



EXPERIMENT: To find wear rate in Zone A for various rates of cross feed



TEST CONDITIONS

Depth of Cut	.001 ins.
Table Speed	50 ft/min.
Cross Feed	0.028 ins/pass
Wheel	Carborundum GC. 80 J. X. 5 V. G. 1" wide

RESULTS

Surface Area Ground sq. ins.	Width of Wheel lost ins.	Width of Wheel left ins.
Start	None	0.990
12	0.05	0.940
24	0.035	0.905
36	0.010*	0.890
300	0.190	0.70
600	0.090	0.610
900	0.090	0.520
1200	0.040	0.480
1500	0.050	0.430
1800	0.050	0.380

* Initial high wear rate while Zone A is stabilised

EXPERIMENT:

To find wear rate in Zone A for various rates of cross feed

TEST CONDITIONS

Depth of Cut	. 001 ins.
Table Speed	50 ft/min.
Cross feed	0.042 ins. /pass
Wheel	Carborundum GC. 80 J. X. 5 V. G. 1" wide

RESULTS

Surface Area Ground sq. ins.	Width of Wheel lost ins.	Width of Wheel left ins.
Start	None	0.990
12	0.08	0.910
24	0.04	0.870
36	0.03	0.840
48	0.02	0.820
60	0.01*	0.810
300	0.230	0.580
600	0.050	0.530
900	0.055	0.475
1200	0.050	0.425

* Initial high wear rate while Zone A is stabilised

EXPERIMENT :

To find wear rate in Zone A for various rates of cross feed

TEST CONDITIONS

Depth of Cut	. 001 ins.
Table Speed	50 ft.
Cross Feed	. 056 ins. /pass
Wheel width	Carborundum GC. 80 J. X. 5 V. G. 1" wide

RESULTS

Surface Area Ground sq. ins.	Width of Wheel lost ins.	Width of Wheel left ins.
Start	None	0.960
24	0.140	0.820
36	0.010	0.810
48	0.005	0.805
60	0.003	0.802
72	0.002*	0.800
300	0.200	0.600
600	0.080	0.520
900	0.100	0.420
1200	0.050	0.370
1500	0.060	0.310

* Initial high wear rate while Zone A is stabilised

EXPERIMENT:

To find life in volume removed against metal removal rate

TEST CONDITIONS

Depth of Cut	see below
Table Speed	" "
Cross Feed	.042 ins/pass
Wheel	Carborundum GC. 80 J. X. 5 V. G. 1" wide

Depth	Table	Cross Feed	Feed Rate per grit	Volume (removed per redress)
0.0025	65 ft	0.042	0.0016	0.015
0.0015	65 ft	"	0.00125	0.108
0.0005	65 ft	"	0.00075	0.460
0.0020	50 ft	"	0.00112	0.144
0.0015	50 ft	"	0.00097	0.150
0.001	55 ft	"	0.00087	0.360

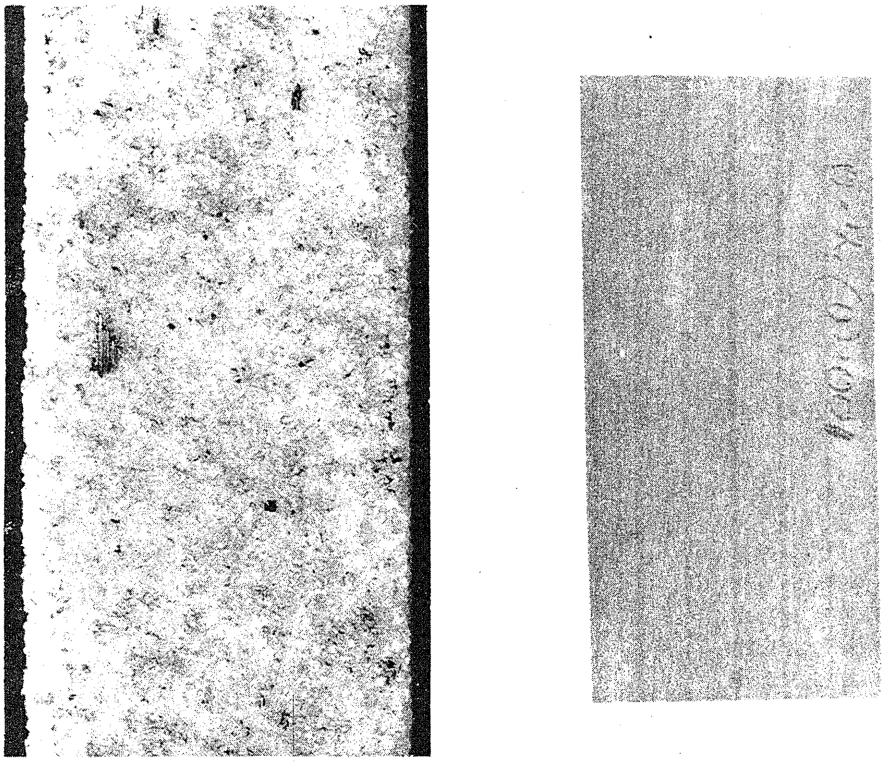


FIGURE 1. INCORRECT WHEEL ACTION

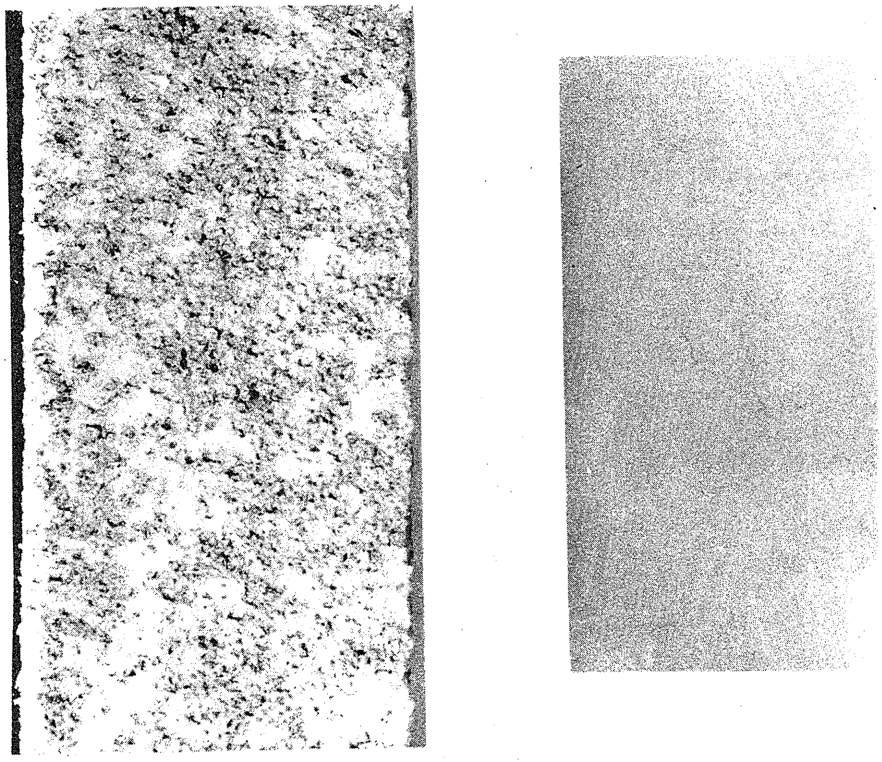


FIGURE 2. CORRECT WHEEL ACTION

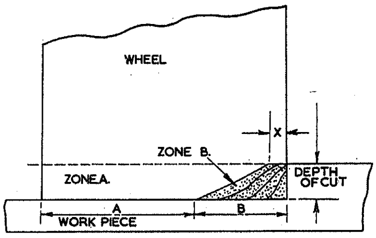
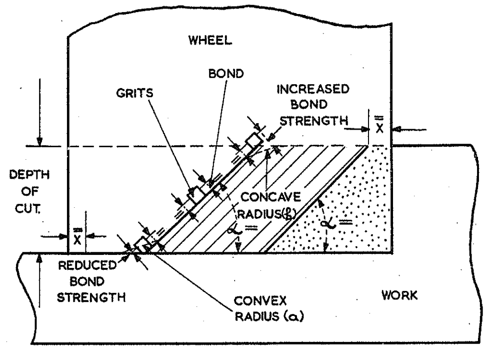


FIG.3. THE PROGRESS OF WHEEL WEAR DURING THE FORMATION OF THE APPROACH ANGLE α.



ACTIVE FACE AND APPROACH ANGLE SELF ADJUSTMENTS.

FIG. 5.

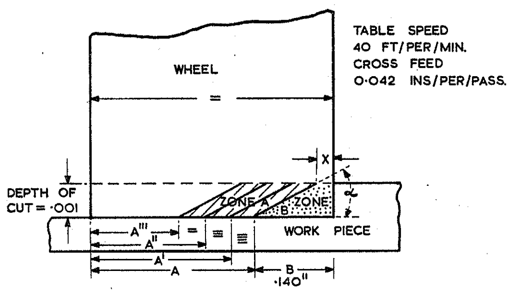


FIG. 4A.

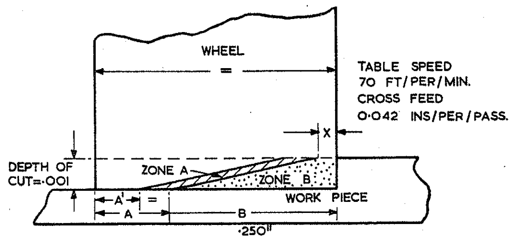
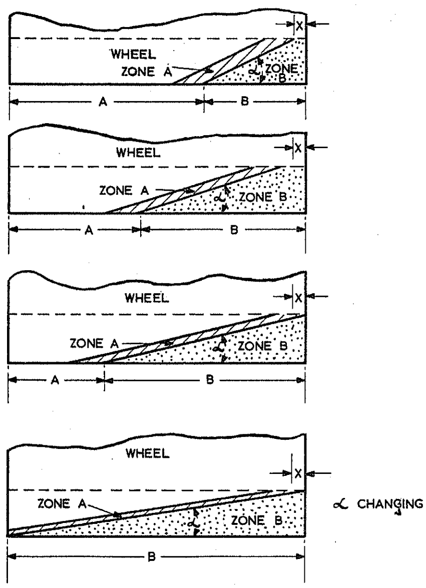


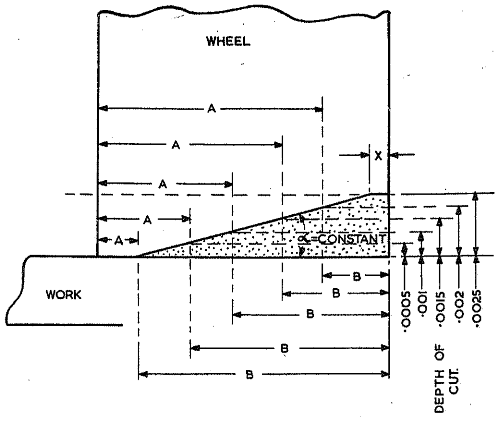
FIG. 4B.

PROGRESS OF WHEEL WEAR AT TWO RATES OF METAL REMOVAL. RATE OF REMOVAL IS INCREASED BY INCREASE IN TABLE SPEED DEPTH OF CUT REMAINING CONSTANT.
FIGS. 4A. & 4B.



RESULTS OF INCREASING METAL REMOVAL RATE BY INCREASING TABLE SPEED OR CROSS FEED. DEPTH REMAINING CONSTANT.

FIG. 6.



CHANGE IN WHEEL FACE DUE TO INCREASED DEPTH OF CUT.

FIG. 7

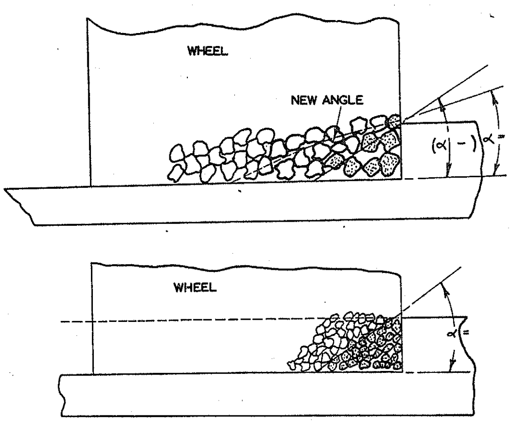
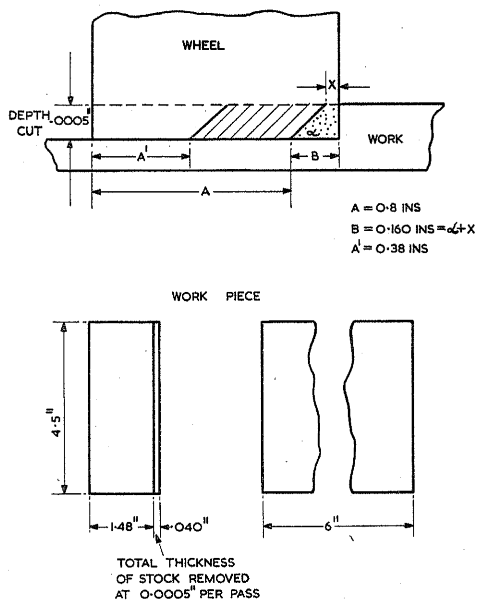
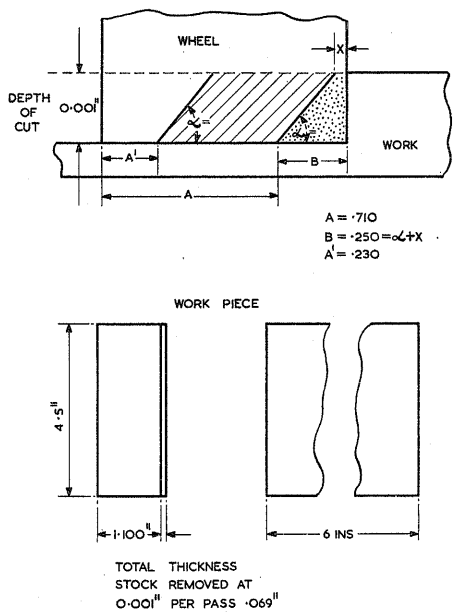


FIG. 8 EFFECT OF VARYING GRIT SIZE



SCHEMATIC PRESENTATION OF TEST AT 0·0005" DEPTH

FIG. 9



SCHEMATIC PRESENTATION OF TEST AT 0·001" DEPTH

FIG. 10.

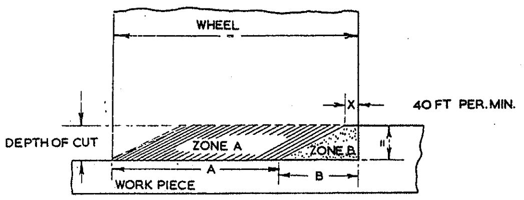


FIG.11A.

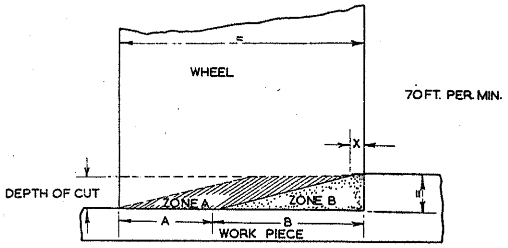


FIG.11B.

SHOWING EFFECTIVE WHEEL VOLUME BETWEEN REDRESS AT TWO RATES OF METAL REMOVAL RATE BEING INCREASED BY INCREASING TABLE SPEED.

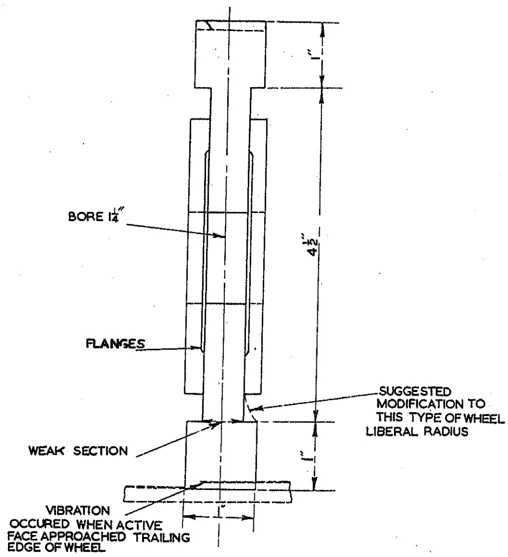
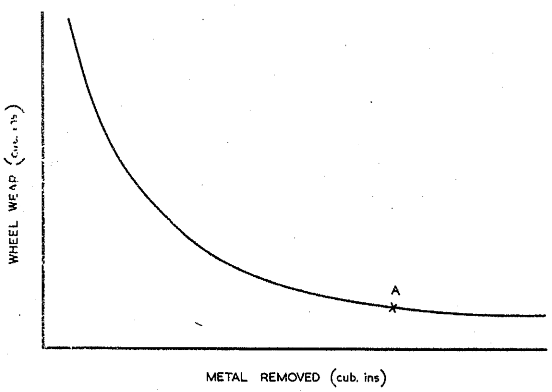
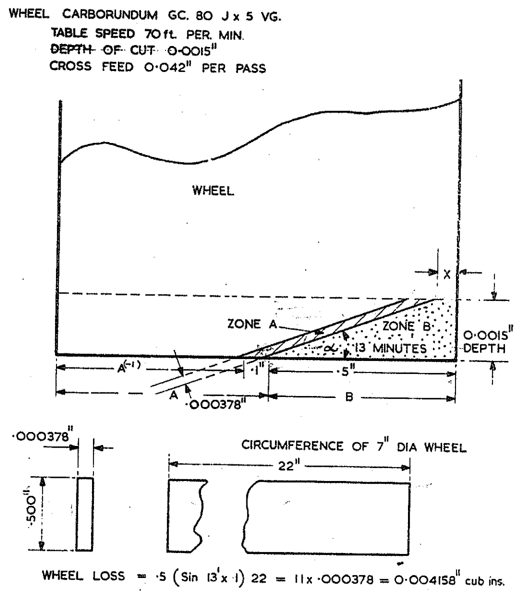


FIG.12 RESULTS OF FAULTY WHEEL DESIGN



GRAPH SHOWING PROGRESS OF WHEEL FACE WEAR PLOTTED AGAINST VOLUME OF METAL REMOVED.

FIG. 13.



METHOD USED TO CALCULATE VOLUME OF WHEEL LOSS IN ZONE A.

FIG. 14.

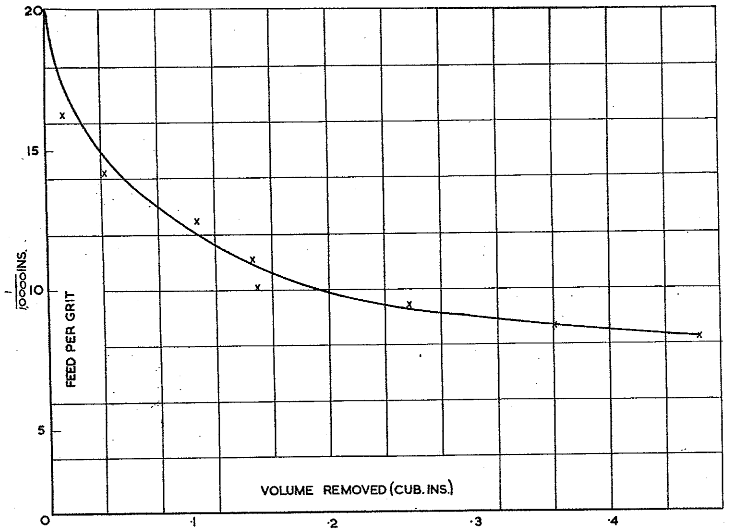
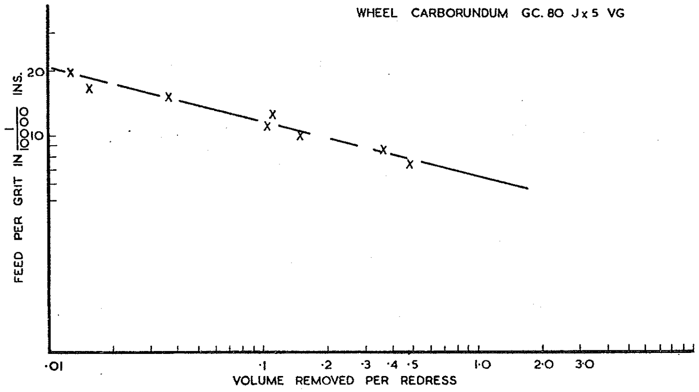


FIG.15A. LIFE OF WHEEL FACE IN CUBIC INS. OF METAL REMOVED AT VARIOUS CHIP THICKNESS OR GRIT LOAD.



DATA ON FIG. 15. A. PLOTTED LOG – LOG.

FIG. 15. B.

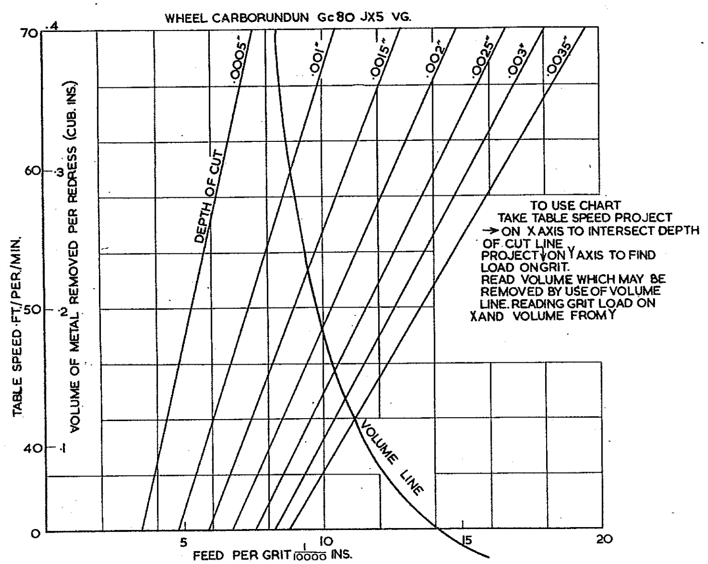
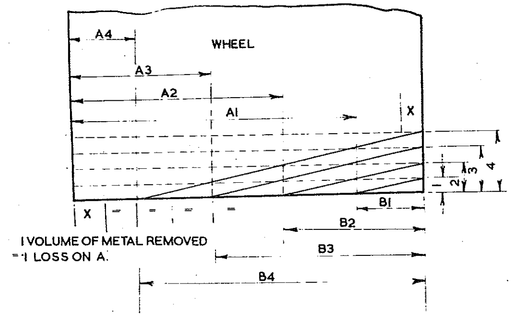


FIG.16 VOLUME PER REDRESS AND DEPTH OF CUT AS VARIABLES PRESENTED FOR PLANNING REFERENCE.



PLANNING DATA

TOTAL	WHEEL	WIDTH = 1 INS. (B)		VOLUME LIFE (A)
LOSS ON A1	AT DEPTH	·001 = ·2	LEAVING	·8 = ·8X100 SQ. INS. ·8 CUB. INS
" " A2	" "	·002 = ·4	"	·6 = ·6 X 100 SQ. INS. X2 = 1·200 CUB. INS.
" " A3	" "	·003 = ·6	"	·4 = ·4 X 100X3 = 1·200 CUB. INS.
" " A4	" "	·004 = ·8	"	·2 = 2 X 100 X4 = ·8 CUB. INS.

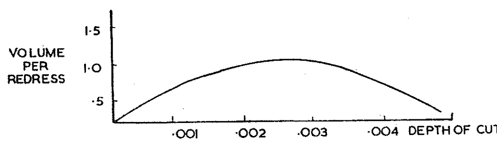


FIG.17 OPTIMUM METAL REMOVAL RATE WITH REFERENCE TO DEPTH OF CUT.

APPENDIX A

INTRODUCTION

This appendix reports in detail the data obtained from a test programme designed to provide information from which the best grinding wheel and an efficient coolant can be selected for surface grinding Rex 448 stainless steel sheet in the hardness and tempered condition to 75 tons tensile strength.

The methods and techniques used to obtain the data are suggested in Note 38. The arrangement of data obtained from standard tests enables a mathematical or graphical presentation of the important factors of wheel life to be made. It is intended that the method of presentation and comments in Note 38 and in this Appendix will assist in introducing the methods and techniques onto the shop floor and will familiarise the operator with the basic fundamentals of the surface grinding process.

CONTENTS

1. Data required for selection of the best grinding wheel

There are two conditions to be met by the wheel.

1. The wheel should be capable of removing maximum volume of stock from the workpiece, for minimum loss from the grinding wheel.

2. The surface finish produced from the grinding wheel must be acceptable.

The data to be obtained is the volume of grinding wheel loss per volume of stock removed and the surface finish produced on the workpiece, when the wheel is operating under conditions which will be met in practice.

2. Methods and techniques used to obtain the required data

The methods are proposed in Section 5, Test No. 2, of Note 38. It is not necessary when testing a wheel to continue the tests to complete wheel face life. The test should be continued until the approach angle and conditions in Zone A are stabilised. This will give the form of the approach angle and loss on the wheel face to this stage of wear, referred to as length B.

From this stabilised condition the life test is continued until a predetermined volume of stock is removed from the workpiece and a measure of wheel wear on length A (ref. Note 38, Section 5, Test No. 2) is taken. A further volume of stock is then removed (unit volume) and wear on A is again measured, this stock removal and measurement of wear should be repeated three or four times and the test results tabulated as shown in Test Sheets Nos. 1 to 16 of this Appendix.

Any wheel which wears rapidly during the selection tests, and fails to stabilise (Note 38) will be eliminated from further test.

Surface finish records should be taken during the test. Any wheel which fails to settle down and produce acceptable finish will be eliminated from further test.

3. Examples of data taken from a wheel selection test programme and its arrangement for ease of interpretation

Test Sheets Nos. 1 to 16 show the test results obtained from a wheel selection test programme and data arrangement for ease of interpretation.

The small diagram and summary of the important values greatly assists final evaluation and quick reference.
Detailed results of tests to select the best grinding wheel specification for use when surface grinding REX 448 stainless steel sheet, hardened and tempered to 75 tons tensile strength.

Constants for all tests recorded on test result sheets nos. 1 to 16

Size of wheel	7 ins. dia., 1 in. wide, $1\frac{1}{4}$ in. bore
Surface speed of wheel	5,500 ft. /min.
Depth of cut	0.001 in.
Cross feed (in one direction only)	0.042 in. /pass
Table speed	50 ft. /min.
Coolant	M. 3 Sheel Mex Soluble Oil 1 vol in 60 vols water
Wheel dressing and balancing	Constant

The estimate of wheel face life is made for a wheel 0.970 in. face width, this estimation is made as follows. Take the total wheel face width remaining after the approach angle α is stabilised (ref. Note 38 as Length A) this value is divided by the length lost on A per unit volume of stock removed, the figure obtained being multiplied by the unit volume.
Example - taken from data on Result Sheet No. 1.
Loss on wheel to point B = 0.120 in.
Loss on wheel per unit volume of stock removed 0.065 in.
Total width of wheel = 0.970 in.

Therefore $\frac{0.970 - 0.120 + 0.65}{0.065}$ = 12 unit volumes = 0.132 x 12 = 1.584 cubic in.

Add to this the volume of metal removed in Zone B to arrive at the total life of the wheel face
= Zone A + Zone B
= 1.584 + 0.072 = 1.656 cubic in.

4. The interpretation of the data and its use in suggesting wheel development

An example

On completion of the wheel selection test programme the resulting data is calculated as shown on Test Result Sheet Nos. 1 to 16 these may then be analysed by simple comparison of the important values i. e. wear rate in Zone A and Zone B and surface finish.

The tabulated data may be used to suggest changes in the wheel structure and further tests of a similar nature made on the modified wheel this will confirm if the suggested change in structure has been beneficial or otherwise.

The following data on three different wheels will serve to explain this suggested procedure.

TABLE A

Wheel	Manufacturer	Specification	Loss on B length = angle	Loss on A length per unit volume removed	Surface finish
1	Carborundum	70-A-60-15. VFBLU	0.120"	0.065	6 micro ins.
2	"	70-A-60-15. VF8	0.200"	0.053	6 micro ins.
3	"	70-A-60-J5. VF8	0.150"	0.100	11 micro ins.

Table A clearly shows that wheel No. 1 is best for loss on length B. The wear per unit volume of stock removed i. e. on length A (ref. Note 38, Section 5, Test No. 2) is less favourable than that recorded from wheel No. 2. From the table wheel 3 is down on B compared with wheel no. 1 and is far less effective than any on length A per unit volume removed hence wheel no. 3 would be eliminated. The choice is between wheels no. 1 and 2 and since the wear rate is almost equal per unit volume of stock removed, the best wheel is no. 1 since it has least initial wear in Zone B.

On inspection of loss on B for both wheels nos. 1 and 2 it is found that wheel no. 2 has lost 0.200 inches, while the loss on B from no. 1 is 0.120 inches, this would suggest no. 2 is a softer wheel but when wear on length A per unit volume of stock removed is considered, it is seen that in no. 1 loss on A is 0.065 inches and in no. 2 loss on A is 0.053 inches once the approach angle α is established no. 2 will do more work than no. 1 hence it cannot be softer, the interpretation here is lack of chip space (porosity) no. 2 wheel being too dense is broken down due to chip crowding (see general limitation, Note 38, Section 2, b1 and 2).

For a wheel to be soft the loss on B, and the wear on A, must inevitably both be greater. In this way the reason for failure is easily found.

In the Test Sheets Nos. 1 to 16 attached many examples of both soft wheels and wheels with density faults may be found.

The records of surface finish show that in the sample of three wheels tabulated in Table A as the example there is similarity in wheels Nos. 1 and 2 while wheel No. 3 is again less efficient.

5. Data necessary for the selection of an efficient coolant

When the best wheel has been selected this is kept constant, together with table speed, depth of cut, and cross traverse rate, only the coolant being varied.

The data required is similar to that for wheel selection i. e. wheel wear rate against metal removed, and surface finish the data is obtained by the same method as wheel selection.

The coolant is changed, after 2 to 4, unit volume of stock removed results are obtained, the results are tabulated as for wheel selection, and a simple comparison is made the smallest loss on length B and A, will be the best coolant, for wheel wear. (See Test Result Sheets Nos. 17 to 28).

Many of the coolants tested in this programme showed a marked improvement in wear rate, the thicker oil type coolants stood out in this respect, but surface finish often deteriorated, when these these thicker oils were used.

The deterioration was found to be due to the swarf, and wheel particles which had been broken from the wheel, being held on to the surface of the workpiece by the thick oil film, when the wheel passed over these particles they were rolled over the surface of the workpiece and caused depreciation in surface finish.

It is quite easy to check this condition, by taking a small sample of oil from the surface of the workpiece. Examination will show the inclusions, if they are present, also it is possible to feel these with the finger when it is passed over the finished oily surface of the work piece.

It was found that the lighter (low viscosity) type oils, and the soluble oil coolants, swilled the surface of the work piece clear of inclusions, and with these types no loss in surface finish was suffered.

The oils suggested in this Appendix as being the most efficient of those tested, were capable of this swilling action, and gave appreciable increase in wheel face life recorded on Result Sheets Nos. 17 to 28.

Detailed results of tests to select an efficient coolant for use when surface grinding REX 448 stainless steel sheet

Hardened and Tempered to 75 tons tensile strength.

Constants for all tests recorded on tests. Sheets Nos. 17 to 28.
Grinding wheel specification Carborundum 70. A. 60. I. 5. VF. BLU
Size 7 ins. diameter, 1 ins. thick, $1\frac{1}{4}$ ins. bore.

Surface speed of wheel	5, 500 ft. per min.
Depth of cut	0.001 ins.
Cross feed	0.042 ins. /pass
(feed in one (cross wise) direction only)	
Table speed	50 ft. /min.

The coolant is the only variable and all are delivered at a constant rate of $\frac{1}{2}$ gal. per minute.

Estimated wheel face life is given for a wheel 0.970 in. wide calculated in a similar manner as for wheel selection tests nos. 1 to 16.

6. Planning Data

By the use of the methods and techniques suggested in Note 38 it is possible to lay down standard procedure for the surface grinding process. Once these standards are in force the forward planning and estimating of surface grinding work may be accomplished with reasonable accuracy.

In Note 38, Section 3, the theory of wheel wear is discussed and reference is made to an ideal wheel. In practice the word 'ideal' is replaced by 'average' and results obtained in practice are for the average grit etc. Considered in this way, it is found that for a set task, the wheel face will adjust itself to an angle α in order to present that number of grits to the working zone which is required to perform the task. A short series of tests are reported in Results Sheet No. 1. which were designed to verify the theory. From these results it is found that the proportion of the wear triangle is proportional to the metal removal rate and that the average number of grits present on the working face is increased by this adjustment of the approach angle α . When the metal removal rate is increased by an increase in table speed or rate of cross feed, i. e. the working face length increased and approach angle α is reduced (ref. Note 38, figs. IIA,).

Test No. 1 shows the effect on the approach angle when metal removal rate is increased by an increase in depth of cut, it is found that angle is not changed. Each unit length of working face on the approach angle performed a similar task, the increase in number of grits is provided in depth by an extension of the working face towards the centre of the wheel (ref. Note 38, fig. 7).

The result of this self adjustment on wheel life does not affect the wear in Zone A or on Length A.

Obviously, once the number of grits is presented on the working face, for the constant conditions of test, each grit will perform a set task and rate of wear on the wheel face width will be constant and independent of metal removal rate (ref. Note 38, Test Result Sheet Nos. 1 - 6). The loss in wheel face life suffered by an increase in metal removal rate is strictly confined to the loss in Zone B and on Length B.

Hence it is possible to estimate the wheel face life at various metal removal rates from the following known values:-

1. the proportions of the approach triangle at one metal removal rate
2. the wear on Length A for one unit volume of stock removed
3. the total width of the wheel to be used
4. similarity of machine to the test machine
5. the task is within the capacity of the machine.

An estimate of the work done during wear in Zone B Length B may be made from graphs as shown (Note 38, Section 6, figs. 15B and 16). The volume of metal removed in Zone B is small. It is suggested that for estimating the life of the wheel face per redress that this Zone B work be ignored and the calculated volume obtained from Zone A solely be utilised. (Zone B volume will provide a safety margin).

It should be noted that cross feed increments are made in <u>one</u> direction only. The work is returned to starting position on completion of the cross wise pass, otherwise the allowance for wear in Zone B and on Length B must be made from both edges of the wheel face.

The only condition necessary to achieve the results reported in Note 38 and this Appendix are

Machine rigidity - and <u>constant</u> table and wheel surface speeds.

Tests to determine specific cutting capacity of the most efficient wheel when cooled/lubricated. With the most efficient coolant tested, (grinding REX 448 H/T to 75 tons T/S) show, that for the operating conditions of the test, approaximately 27 horse power would be required to remove the metal at a rate of one cubic inch per minute.

Grinding Wheel
Specification CARBORUNDUM 70. A60. I. 5. VF. BLU.
Coolant STERNOL TAPOYL 514

Test Results

Depth of cut ins.	Cross feed ins.	Table Speed ft.	Electrical Input K. watts: Machine of load	Machine in cut	Difference K. watts
0. 001	0. 056	50	0. 750	1. 400	0. 650
0. 002	0. 056	50	0. 750	2. 000	1. 250
0. 003	0. 056	50	0. 750	2. 700	2. 050

SUMMARY OF TEST RESULTS

Test No. 1 shows that within the limits of practical measurement angle α remains constant when metal removal rate is varied by a variation of depth of cut the increase in the number of grits presented on the working face (approach angle) is provided by an extension of the working face in depth i. e. towards the centre of the wheel at the constant angle.

Tests No. 2 and 3 - it is found from these results that when the metal removal rate is varied by an increase in table speed or cross feed angle α changes. This is due to the increase in number of grits on the working face being provided at a constant depth of wheel radius, hence, the angle α is changed it being increased when the metal removal rate is reduced and vice versa. These results are independently verified by test results sheets shown in (Note 38, Sheets No. 3, 4 and 5).

CONCLUSION

The data and methods described in Note 38 and Appendix 1 show that the following useful information may be obtained from short standard tests.

1. Wheel to work ratios
2. Dimensional accuracy equivalent to that of the slides and rigidity of the machine
3. Constant surface finish during the wheel face lift
4. A reliable estimate of the volume of metal which may be removed between redress of the wheel face.
5. The estimation of wheel face life may be made for any metal removal rate from the data found at one metal removal rate.

6. That many of the variables in the surface grinding process may be controlled and held at optimum values.
7. The evaluation of a series of wheels may be made from short standard tests.
8. Coolants may be compared by short standard tests.
9. Grinding wheels and coolants may be developed from standard test data.
10. The life in volume of metal removed per redress may be presented graphically for planning and estimating.

TEST RESULT SHEET No. 1

Tests to determine the proportions of the approach triangle, or boundaries of Zone B and angle α at various metal removed rates.

CONSTANTS

The grinding wheel specification:

Carborundum 70. A. 60. I. 5. VF. BLU Size 7 ins. dia., 1 in. wide $1\frac{1}{4}$" bore.

Coolant: Sternol tapoyl delivered at the rate of 4 pints per minute

Test results for various depths of cut (values are average of three runs)

Test No.	Depth of cut ins.	Table Speed ft/min.	Cross Feed ins.	Length B	Approach angle	Metal removal rate cu. ins/min.
1	0.001	70	0.056	0.050	1° 9'	0.047
	0.0015	70	0.056	0.080	1° 4'	0.0705
	0.002	70	0.056	0.100	1° 9'	0.0940
	0.0025	70	0.056	0.124	1° 9'	0.1175
2	Results for various Table Speeds					
	0.001	70	0.056	0.050	1° 9'	0.047
		50	0.056	0.040	1° 26'	0.0325
		30	0.056	0.023	1° 53'	0.0201
	0.002	70	0.056	0.100	1° 9'	0.094
		50	0.056	0.074	1° 32'	0.0630
		30	0.056	0.045	2° 32'	0.0402
3	Results for various cross feed rates					
	0.001	70	0.028	0.022	2° 36'	0.0296
	0.001	70	0.042	0.038	1° 31'	0.0355
	0.001	70	0.056	0.050	1° 9'	0.047
	0.002	70	0.028	0.051	2° 18'	0.0472
	0.002	70	0.042	0.074	1° 31'	0.0710
	0.002	70	0.056	0.100	1° 9'	0.0950

Quick Reference tabulation of wheel selection test results

Wheel No.	Specification	Surface finish micro ins. CLA	wear on B	wear on A	Estimated life or 0.970" wide wheel	Comments
1	Carborundum 70.A.60.I.5.VF.BLU	5	0.120	0.065	1.656 cu. ins.	Good
2	Carborundum 7. A60. I. 5. VF. 8	5	0.200	0.053	1.854 " "	Wheel lacks porosity
3	Carborundum 7. A60. J. 5. VF. 8	11	0.150	0.140	Test discontinued	Soft
4	Carborundum C. 80. I. 5. B. R.	8	0.320	0.120	" "	"
5	Carborundum GC. 80JX. 5. VG	7	0.130	0.060	1.788 cu. ins.	Good
6	Carborundum 7. A60. I. 5. VF. 8	6	0.150	0.0625	1.699 " "	Good
7	Carborundum 70. A. 60. J. 5. VF. BLU	5 - 6	0.120	0.071	1.55 " "	Slightly soft
8	Carborundum GC. 80. J. 11. V. B.	8	0.200	0.048	2.052 " "	Very good wheel could be improved by increased porosity
9	Norton 38. A. 46. J. 8. V. BE	9	0.180	0.170	Test discontinued	Soft
10	Norton 38. A. 60. I. 8. VBE	7	0.160	0.060	1.722 cu. ins.	Would be good if porosity increased
11	Universal W. A. 60. J. V.	8	0.140	0.0625	1.55 " "	Slightly soft

(Continued)

Wheel No.	Specification	Surface finish micro ins. CLA	wear on B	A	Estimated life or 0. 970" wide wheel	Comments
12	Universal W. A. 80. I. V.	12	0. 160	0. 050	Finish too rough	Slightly hard
13	Abrafact A. 80. N. B. 930	5	0. 150	0. 0725	1. 418 cu. ins.	Good but slightly soft
14	Abrafact A. 80. NB. 919	7	0. 200	0. 065	1. 516 " "	Too dense increase porosity
15	Abrafact A. 80. OB. 919. 3/194	7	0. 190	0. 085	Test discontinued	Soft
16	Abrafact A. 80. PB. 919. 3/194	8 - 9	0. 180	0. 080	Test discontinued	Soft and too dense

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: CARBORUNDUM 70.A.60.I.5V.F.BLU.

Surface area ground sq. ins.	Start	48	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.120	0.120	0.50	0.08	0.05	0.08
Width of wheel left in ins.	0.970	0.850	0.850	0.800	0.720	0.670	0.590
Surface finish micro ins. CLA	-	7	6	5	5	5	5

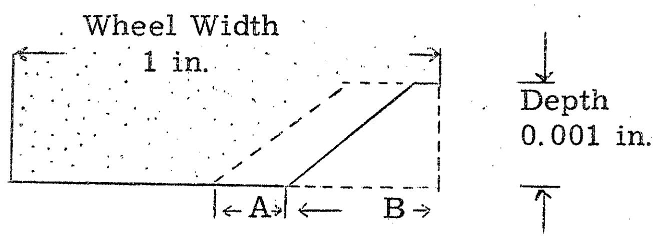
* = work done to stabilise approach angle and wear in Zone B

+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	= 0.120 in.
Loss on A per unit volume of stock removed	= 0.065 in.
Total volume of stock removed for tests	= 0.600 cub. in.
Loss of wheel in Zone B	= 0.0013 cub. in.
Stock removed for loss in Zone B	= 0.072 cub. in.
Loss of wheel in Zone A	= 0.0057 cub. in.
Stock removed for loss in Zone A	= 0.528 cub. in.
Ratio of work loss to wheel loss Zone B	= 55.5 to 1
Ratio of work loss to wheel loss Zone A	= 93 to 1
Number of unit volume lengths on A	= 12
Estimated life of wheel face in Zone B	= 0.072 cub. in
Estimated life of wheel face in Zone A	= 1.584 cub. in.
Total estimated life = Zone A + Zone B	= 1.656 cub. in.

Surface finish micro ins. = 5



A = 0.065 in. B = 0.120 in.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: CARBORUNDUM 7 A.60.I.5 VF.8

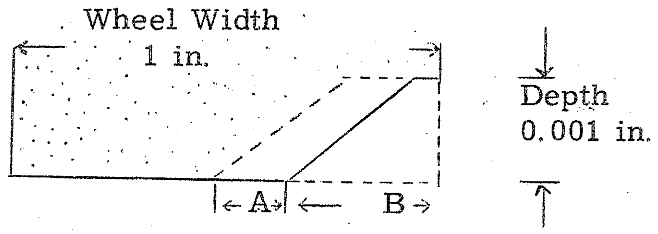
Surface area ground sq.ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.200	0.200	0.060	0.040	0.060	0.050
Width of wheel left in ins.	1.020	0.820	0.820	0.760	0.720	0.660	0.610
Surface finish micro ins.CLA	-	10	7	5	5	5	5

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	=	0.200 ins.
Loss on A per unit volume of stock removed	=	0.053 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.0022 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.0042 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	33 TO1
Ratio of work loss to wheel loss Zone A	=	110 TO.1.
Number of unit volume lengths on A	=	13.5
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.782 cu.ins.
Total estimated life = Zone A + Zone B	=	1.854 cu.ins.

Surface finish micro ins. = 5



A = 0.053 ins. B = 0.200 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: CARBORUNDUM 7.A.60.J.5 VF.8.

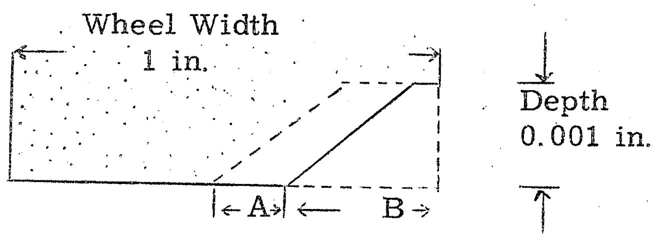
Surface area ground sq.ins.	Start	60	72*	+132 =204	+132 =336		
Width of wheel lost in ins.	None	0.150	0.150	0.180	0.110		
Width of wheel left in ins.	0.850	0.700	0.700	0.520	0.410		
Surface finish micro ins.CLA	-	12	11	11	11		

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	=	0.150 ins.
Loss on A per unit volume of stock removed	=	0.140 ins.
Total volume of stock removed for tests	=	
Loss of wheel in Zone B	=	Test discontinued
Stock removed for loss in Zone B	=	finish two course
Loss of wheel in Zone A	=	wear rate too high
Stock removed for loss in Zone A	=	
Ratio of work loss to wheel loss Zone B	=	
Ratio of work loss to wheel loss Zone A	=	
Number of unit volume lengths on A	=	
Estimated life of wheel face in Zone B	=	
Estimated life of wheel face in Zone A	=	
Total estimated life = Zone A + Zone B	=	

Surface finish micro ins. =



A = 0.140 ins. B = 0.150 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: CARBORUNDUM C.80.I.5.BR.

Surface area ground sq. ins.	Start	84*	+132 =216				
Width of wheel lost in ins.	None	0.320	0.120				
Width of wheel left in ins.	1.040	0.720	0.600				
Surface finish micro ins. CLA	-	9	8				

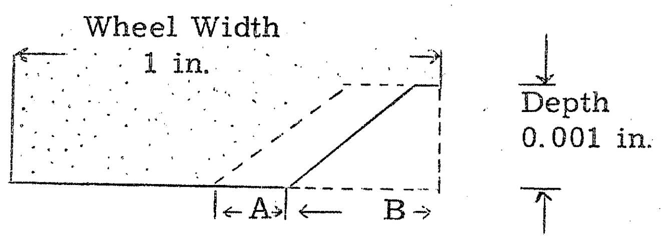
* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point * =
Loss on A per unit volume of stock removed =
Total volume of stock removed for tests =
Loss of wheel in Zone B =
Stock removed for loss in Zone B =
Loss of wheel in Zone A =
Stock removed for loss in Zone A =
Ratio of work loss to wheel loss Zone B =
Ratio of work loss to wheel loss Zone A =
Number of unit volume lengths on A =
Estimated life of wheel face in Zone B =
Estimated life of wheel face in Zone A =
Total estimated life = Zone A + Zone B =

Test discontinued due to high initial wear on B, and high rate of wear on A per unit volume removed.

Surface finish micro ins. = 8



A = 0.120 ins. B = 0.320 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: CARBORUNDUM GC.80.J.X.5.VG.

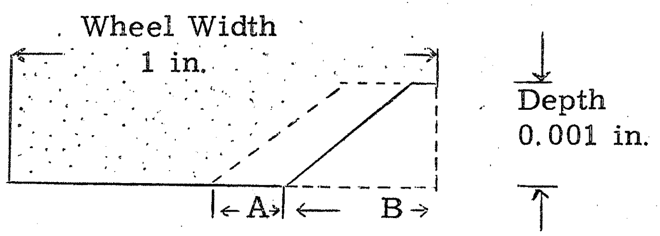
Surface area ground sq.ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.130	0.130	0.070	0.080	0.050	0.040
Width of wheel left in ins.	1,000	0.870	0.870	0.800	0.720	0.670	0.630
Surface finish micro ins.CLA	-	10	9	7	7	7	7

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	=	0.130 ins.
Loss on A per unit volume of stock removed	=	0.060 ins.
Total volume of stock removed for tests	=	0.600
Loss of wheel in Zone B	=	0.00143 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.00528 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	51.4 to 1
Ratio of work loss to wheel loss Zone A	=	100 to 1
Number of unit volume lengths on A	=	13
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.716 cu.ins.
Total estimated life = Zone A + Zone B	=	1.788 cu.ins.

Surface finish micro ins. = 7



A = 0.060 ins. B = 0.130 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: CARBORUNDUM 7.A.60.I.5.VF.8.

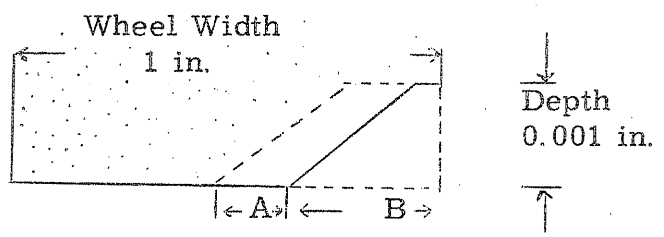
Surface area ground sq. ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.150	0.150	0.090	0.090	0.030	0.040
Width of wheel left in ins.	1.000	0.850	0.850	0.760	0.670	0.640	0.600
Surface finish micro ins. CLA	-	7	6	6	6	6	6

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	=	0.150 ins.
Loss on A per unit volume of stock removed	=	0.0625 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.00165 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.0055 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	45 to 1
Ratio of work loss to wheel loss Zone A	=	96 to 1
Number of unit volume lengths on A	=	12.4
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.627 cu.ins.
Total estimated life = Zone A + Zone B	=	1.699 cu.ins.

Surface finish micro ins. = 6



A = 0.0625 ins. B = 0.150 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: CARBORUNDUM 70.A.60.J.5.VF.BLU

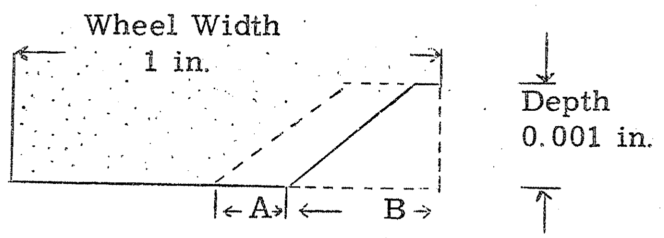
Surface area ground sq.ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.120	0.120	0.045	0.070	0.110	0.060
Width of wheel left in ins.	0.985	0.865	0.865	0.820	0.750	0.640	0.580
Surface finish micro ins.CLA	-	9	8	6	5	6	5

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	=	0.120 ins.
Loss on A per unit volume of stock removed	=	0.071 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.0013 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.0063 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	55.4 to 1
Ratio of work loss to wheel loss Zone A	=	83.8 to 1
Number of unit volume lengths on A	=	11.2
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.478 cu.ins.
Total estimated life = Zone A + Zone B	=	1.55 cu. ins.

Surface finish micro ins. = 5 to 6



A = 0.071 ins. B = 0.120 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: CARBORUNDUM GC.80.J.11.V.B.

Surface area ground sq.ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.160	0.160	0.120	0.030	0.040	0.040
Width of wheel left in ins.	1.000	0.840	0.840	0.720	0.690	0.650	0.610
Surface finish micro ins.CLA	-	9	9	8	8	8	8

* = work done to stabilise approach angle and wear in Zone B

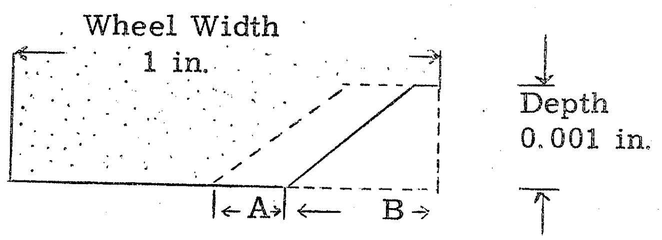
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Note: B point * adjusted from 0.16 to 0.200. for unstable wear on * volume records

Summary of results

Loss on B to point *	* =	0.200 ins
Loss on A per unit volume of stock removed	=	0.048 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.0022 cu. ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.0042 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	32.7 to 1
Ratio of work loss to wheel loss Zone A	=	125.7 to 1
Number of unit volume lengths on A	=	15
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.98
Total estimated life = Zone A + Zone B	=	2.052

Surface finish micro ins. = 8



A = 0.048 ins. B = 0.200 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: NORTON 38A.46.J.8.VBE

Surface area ground sq. ins.	Start	60	72*	+132 =204	+132 =336		
Width of wheel lost in ins.	None	0.180	0.180	0.180	0.160		
Width of wheel left in ins.	1.000	0.820	0.820	0.640	0.480		
Surface finish micro ins.CLA	-	9	9	9	9		

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

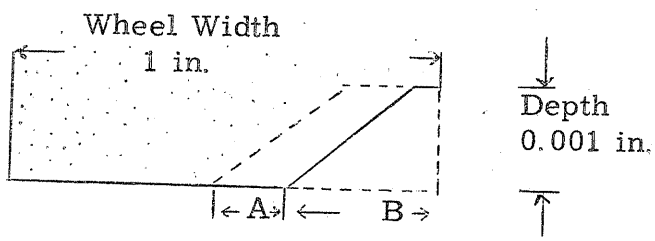
Summary of results

Loss on B to point * =
Loss on A per unit volume of stock removed =
Total volume of stock removed for tests =
Loss of wheel in Zone B =
Stock removed for loss in Zone B =
Loss of wheel in Zone A =
Stock removed for loss in Zone A =
Ratio of work loss to wheel loss Zone B =
Ratio of work loss to wheel loss Zone A =
Number of unit volume lengths on A =
Estimated life of wheel face in Zone B =
Estimated life of wheel face in Zone A =
Total estimated life = Zone A + Zone B =

Test discontinued due to failure to stabilise on B, and high wear rate per unit volume removed.

Grit size too large.

Surface finish micro ins. = 9



A = 0.170 ins. B = 0.180 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: NORTON 38.A.60.I.8.VBE.

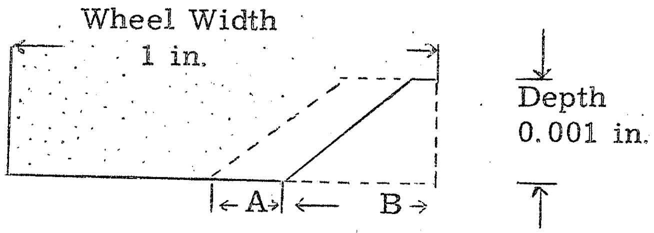
Surface area ground sq.ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.160	0.160	0.080	0.060	0.050	0.050
Width of wheel left in ins.	0.990	0.830	0.830	0.750	0.690	0.640	0.590
Surface finish micro ins.CLA	-	10	8	7	7	7	7

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	=	0.160 ins.
Loss on A per unit volume of stock removed	=	0.060 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.00176
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.0053 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	40 to 1
Ratio of work loss to wheel loss Zone A	=	99.6 to 1
Number of unit volume lengths on A	=	12.5
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.65 cu.ins.
Total estimated life = Zone A + Zone B	=	1.722 cu.ins.

Surface finish micro ins. = 7



A = 0.060 ins. B = 0.160 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: UNIVEESAL W.A.60.J.V.

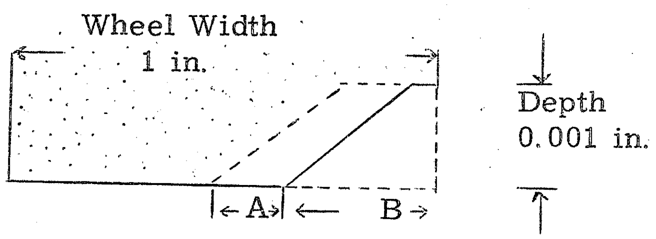
Surface area ground sq. ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.140	0.140	0.090	0.060	0.050	0.050
Width of wheel left in ins.	1.000	0.860	0.860	0.770	0.710	0.660	0.610
Surface finish micro ins.CLA	-	11	10	9	8	8	8

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	=	0.140 ins.
Loss on A per unit volume of stock removed	=	0.0625 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.00154 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.0055 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	48 to 1
Ratio of work loss to wheel loss Zone A	=	96.to1
Number of unit volume lengths on A	=	11.7
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.478 cu.ins.
Total estimated life = Zone A + Zone B	=	1.55 cu.ins.

Surface finish micro ins. = 8



A = 0.0625 B = 0.140 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: UNIVERSAL WA.80.I.V.

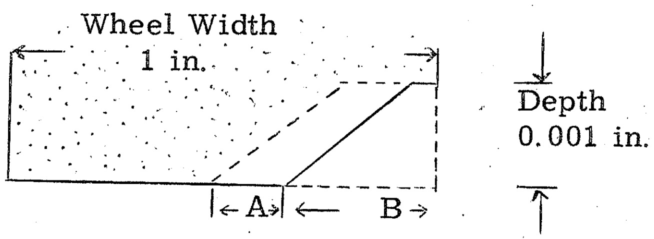
Surface area ground sq.ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.160	0.160	0.060	0.050	0.040	0.050
Width of wheel left in ins.	1.020	0.860	0.860	0.800	0.750	0.710	0.660
Surface finish micro ins.CLA	-	16	14	12	12	12	12

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	=	0.160 ins.
Loss on A per unit volume of stock removed	=	0.050 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.00176 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.0044 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	40 to 1
Ratio of work loss to wheel loss Zone A	=	120 to 1
Number of unit volume lengths on A	=	
Estimated life of wheel face in Zone B	=	
Estimated life of wheel face in Zone A	=	
Total estimated life = Zone A + Zone B	=	

Surface finish micro ins. = 12 too rough



A = 0.050 ins. B = 0.160 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: ABRAFACT A.80.NB.930

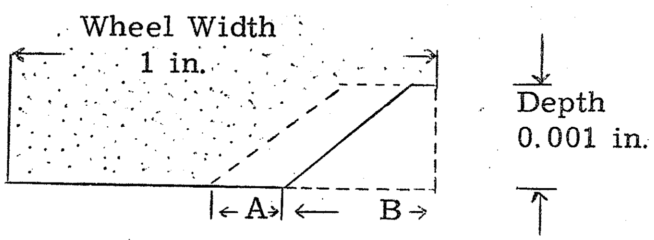
Surface area ground sq. ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.150	0.150	0.070	0.090	0.070	0.060
Width of wheel left in ins.	1.000	0.850	0.850	0.780	0.690	0.620	0.560
Surface finish micro ins. CLA	-	7	6	5	5	5	5

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point *	=	0.150 ins.
Loss on A per unit volume of stock removed	=	0.0725 ins.
Total volume of stock removed for tests	=	0.600 cu. ins.
Loss of wheel in Zone B	=	0.00165 cu. ins.
Stock removed for loss in Zone B	=	0.072 cu. ins.
Loss of wheel in Zone A	=	0.00638 cu. ins.
Stock removed for loss in Zone A	=	0.528 cu. ins.
Ratio of work loss to wheel loss Zone B	=	45 to 1
Ratio of work loss to wheel loss Zone A	=	82.5 to 1
Number of unit volume lengths on A	=	10.4
Estimated life of wheel face in Zone B	=	0.072 cu. ins.
Estimated life of wheel face in Zone A	=	1.346 cu. ins.
Total estimated life = Zone A + Zone B	=	1.418 cu. ins.

Surface finish micro ins. = 5



A = 0.0725 ins. B = 0.150 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: ABRAFACT A.80.NB.919

Surface area ground sq. ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	+132 =600
Width of wheel lost in ins.	None	0.150	0.150	0.140	0.090	0.030	0.050
Width of wheel left in ins.	0.990	0.840	0.840	0.700	0.610	0.580	0.530
Surface finish micro ins.CLA	-	8	7	7	7	7	7

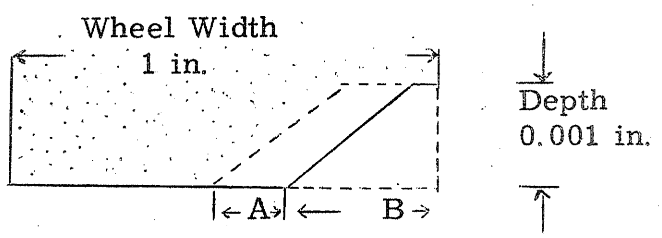
* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Note: Adjustment on first unit volume value to allow for unstable α angle from 0.015 to 0.200 ins.

Summary of results

Loss on B to point *	= 0.200 ins.
Loss on A per unit volume of stock removed	= 0.060 ins.
Total volume of stock removed for tests	= 0.600 cu.ins.
Loss of wheel in Zone B	= 0.0022 cu.ins.
Stock removed for loss in Zone B	= 0.090 cu.ins.
Loss of wheel in Zone A	= 0.0057 cu.ins.
Stock removed for loss in Zone A	= 0.510 cu.ins.
Ratio of work loss to wheel loss Zone B	= 42 to 1
Ratio of work loss to wheel loss Zone A	= 89.5 to 1
Number of unit volume lengths on A	= 10.8
Estimated life of wheel face in Zone B	= 0.090 cu.ins.
Estimated life of wheel face in Zone A	= 1.426 cu.ins.
Total estimated life = Zone A + Zone B	= 1.516 cu.ins.

Surface finish micro ins. = 7



A = 0.065 ins. B = 0.200 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: ABRAFACT A.80.0.B.919. 3/194

Surface area ground sq.ins.	Start	60	72*	+132 =204	+132 =336		
Width of wheel lost in ins.	None	0.190	0.190	0.090	0.080		
Width of wheel left in ins.	0.960	0.770	0.770	0.680	0.600		
Surface finish micro ins.CLA	-	7	7	7	7		

* = work done to stabilise approach angle and wear in Zone B
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

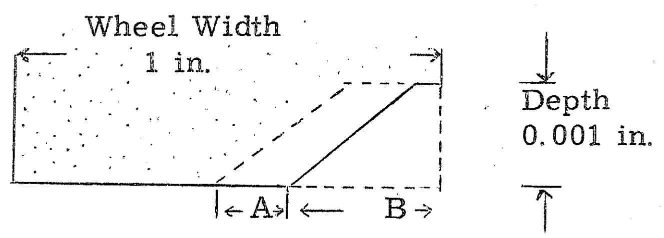
Summary of results

Loss on B to point * = 0.190 ins.
Loss on A per unit volume of stock removed = 0.085 ins.
Total volume of stock removed for tests =
Loss of wheel in Zone B =
Stock removed for loss in Zone B =
Loss of wheel in Zone A =
Stock removed for loss in Zone A =
Ratio of work loss to wheel loss Zone B =
Ratio of work loss to wheel loss Zone A =
Number of unit volume lengths on A =
Estimated life of wheel face in Zone B =
Estimated life of wheel face in Zone A =
Total estimated life = Zone A + Zone B =

Test discontinued due to high initial loss on B and wear on unit volume

Density at fault

Surface finish micro ins. = 7



A = 0.085 ins. B = 0.190 ins.

GRINDING WHEEL SELECTION TEST

WHEEL SPECIFICATION: ABRAFACT A.80 P.B. 919/3/194

Surface area ground sq.ins.	Start	60	72*	+132 =204	+132 =336	+132 =468	
Width of wheel lost in ins.	None	0.180	0.180	0.140	0.080	0.080	
Width of wheel left in ins.	0.960	0.780	0.780	0.640	0.560	0.480	
Surface finish micro ins.CLA	-	11	10	9	8	9	

* = work done to stabilise approach angle and wear in Zone B

+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

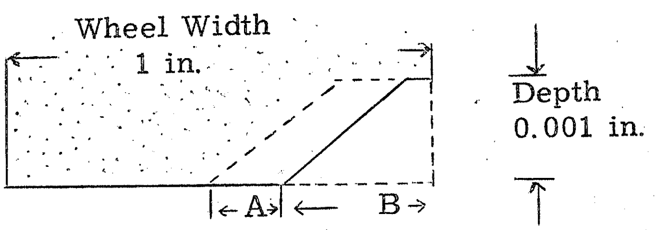
Summary of results

Loss on B to point * =
Loss on A per unit volume of stock removed =
Total volume of stock removed for tests =
Loss of wheel in Zone B =
Stock removed for loss in Zone B =
Loss of wheel in Zone A =
Stock removed for loss in Zone A =
Ratio of work loss to wheel loss Zone B =
Ratio of work loss to wheel loss Zone A =
Number of unit volume lengths on A =
Estimated life of wheel face in Zone B =
Estimated life of wheel face in Zone A =
Total estimated life = Zone A + Zone B =

Test discontinued due to high initial wear on α angle and high wear rate per unit volume removed

Wheel too dense

Surface finish micro ins. = 8 to 9



A = .080 ins. B = 0.180 ins.

Quick reference tabulation of coolant test results

Coolant Test No.	Coolant Supplier	Reference	Dilution	Surface finish CLA micro ins.	Wheel wear B	Wheel wear A	Estimated wheel face life for 0.970" width wheel
17	Shell Mex B. P.	S. 4377 Soluble oil	1 vol in 100 water	7	0.150	0.0875	1.181 cu. ins.
18	Sternol	Soluble cutting oil	1 vol in 70 water	10	0.120	0.095	1.272 " "
19	Fletcher Miller	Almarine Grinding fluid	1 vol in 90 water	6	0.160	0.0725	1.600 " "
20	Shell Mex B. P.	Dromus oil D. soluble	1 vol in 80 water	7	0.140	0.057	1.867 " "
21	Regent	Caltex E. P. soluble oil	1 vol in 20 water	10	0.080	0.045	2.250 " "
22	Manchester Oil Refinery	Diaphanol H soluble	1 vol in 30 water	7	0.120	0.075	1.432 " "
23	C. C. Wake-field Dick	Solubriol Clear Dixol	1 vol in 50 water	5 - 6	0.120	0.0625	1.748 " "
24	Shell Mex B. P.	Drumas Cil B soluble	1 vol in 50 water	9	0.100	0.070	1.656 " "
25	Manchester Oil Refinery	Primor M. C.	As supplied	7	0.040	0.030	20 " "
26	Fletcher Miller	Swift H	As supplied	7	0.050	0.045	12.872 " "
27	Stenol	Tapoyl 514	As supplied	7	0.050	0.032	18.00 " "
28	Wakefield	Clear grinding fluid	1 vol in 60 water	7	0.140	0.057	1.867 " "

COOLANT SELECTION TEST

COOLANT: SHELL-MEX S. 4377 Soluble oil 1 vol. in 100 water

Surface area ground sq. ins.	Start	72*	+132 =204	+132 =336	+132 =468	+132 =600	
Width of wheel lost in ins.	None	0.150	0.100	0.07	0.100	0.08	
Width of wheel left in ins.	0.990	0.840	0.740	0.670	0.570	0.490	
Surface finish micro ins. CLA	-	14 to 7	7	7	7	7	

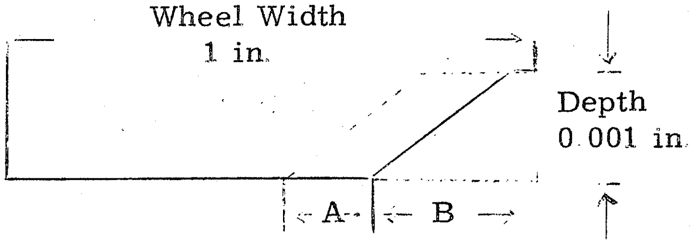
* = work done to stabilise approach angle α and wear in Zone B

+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point = 0.150 ins.
Loss on A per unit volume of stock removed = 0.0875 ins.
Total volume of stock removed for tests = 0.600 cu.ins.
Loss of wheel in Zone B = 0.00165 cu.ins.
Stock removed for loss in Zone B = 0.072 cu.ins.
Loss of wheel in Zone A = 0.0077 cu.ins.
Stock removed for loss in Zone A = 0.528 cu.ins.
Ratio of work loss to wheel loss Zone B = 45 to 1
Ratio of work loss to wheel loss Zone A = 68.6 to 1
Number of unit volume lengths on A = 8.4
Estimated life of wheel face in Zone B = 0.072 cu.ins.
Estimated life of wheel face in Zone A = 1.109 cu.ins.
Total estimated life = Zone A + Zone B = 1.181 cu.ins.

Surface finish micro ins. = 7



A = 0.0875 ins. B = 0.150 ins.

COOLANT SELECTION TEST

COOLANT

STERNOL CUTTING OIL 1 vol. in 70 vols. water

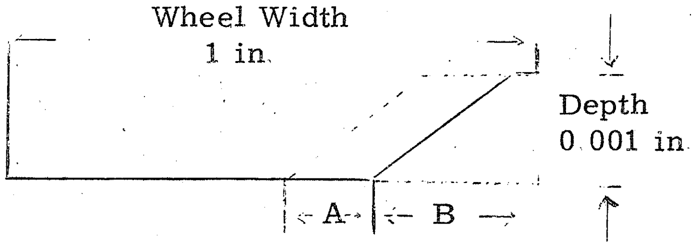
Surface area ground sq. ins.	Start	72*	+132 =204	+132 =336	+132 =468	+132 =600	
Width of wheel lost in ins	None	0.120	0.100	0.110	0.08	0.09	
Width of wheel left in ins.	1.000	0.880	0.780	0.670	0.590	0.500	
Surface finish micro ins. CLA	18 to 12	10	10	10	10	10	

* = work done to stabilise approach angle α and wear in Zone B
+132 = the surface area at constant depth of 0 001 in taken as one unit volume of stock removed.

Summary of results

Loss on B to point	=	0.120 ins.
Loss on A per unit volume of stock removed	=	0.095 ins
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.00132 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.0084 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins
Ratio of work loss to wheel loss Zone B	=	55.5 to 1
Ratio of work loss to wheel loss Zone A	=	63 to 1
Number of unit volume lengths on A	=	9.1
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.20 cu.ins.
Total estimated life = Zone A + Zone B	=	1.272 cu.ins.

Surface finish micro ins. = 10



A = 0.095 ins. B = 0.120 ins.

COOLANT SELECTION TEST

COOLANT: FLETCHER MILLER ALMARINE GRINDING FLUID — 1 vol. in 90 vols. water

Surface area ground sq. ins.	Start	72*	+132 =204	+132 =336	+132 =468	+132 =600	
Width of wheel lost in ins.	None	0.160	0.090	0.050	0.090	0.060	
Width of wheel left in ins.	0.990	0.830	0.740	0.690	0.600	0.540	
Surface finish micro ins. CLA	11 to 8	6	6	6	6	6	

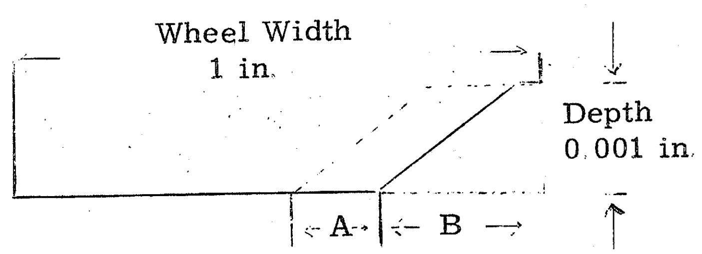
* = work done to stabilise approach angle α and wear in Zone B

+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point	=	0.160 ins
Loss on A per unit volume of stock removed	=	0.0725 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.00176 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.00638 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	40 to 1
Ratio of work loss to wheel loss Zone A	=	82.5 to 1
Number of unit volume lengths on A	=	11.6
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.531 cu.ins.
Total estimated life = Zone A + Zone B	=	1.60 cu.ins.

Surface finish micro ins. = 6



A = 0.0725 ins. B = 0.160 ins.

COOLANT SELECTION TEST

COOLANT: SHELL-MEX DROMUS OIL D. 1 vol in 80 vols water

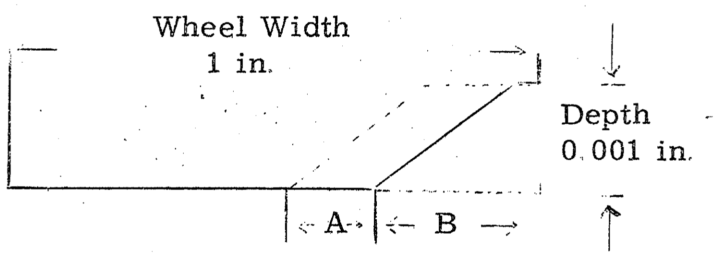
Surface area ground sq. ins.	Start	72*	+132 =204	+132 =336	+132 =468	+132 =600	
Width of wheel lost in ins.	None	0.140	0.03	0.07	0.08	0.05	
Width of wheel left in ins.	1.000	0.860	0.830	0.760	0.680	0.630	
Surface finish micro ins. CLA	-	10 to 7	7	7	7	7	

* = work done to stabilise approach angle α and wear in Zone B
+132 = the surface area at constant depth of 0. 001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point	=	0.140 ins.
Loss on A per unit volume of stock removed	=	0.057
Total volume of stock removed for tests	=	0.600
Loss of wheel in Zone B	=	0.00154 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.005 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	48 to 1
Ratio of work loss to wheel loss Zone A	=	105.6 to 1
Number of unit volume lengths on A	=	13.6
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.795 cu.ins.
Total estimated life = Zone A + Zone B	=	1.867 cu.ins.

Surface finish micro ins. = 7



A = 0.057 ins. B = 0.140 ins.

COOLANT SELECTION TEST

COOLANT:

REGENT. CALTEX E.P. SOLUBLE OIL 1 vol in 20 vols water

Surface area ground sq. ins.	Start	72*	+132 =204	+132 =336	+132 =468	+132 =600	
Width of wheel lost in ins.	None	0.080	0.03	0.05	0.05	0.05	
Width of wheel left in ins.	0.980	0.900	0.870	0.820	0.770	0.720	
Surface finish micro ins. CLA	-	25 to 10	10	10	10	10	

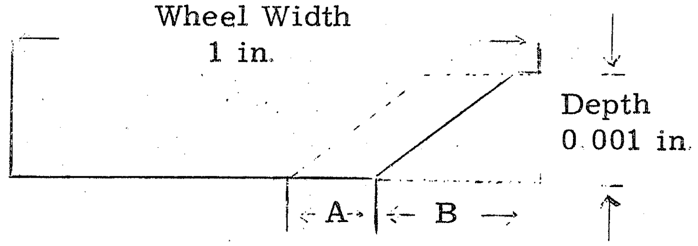
* = work done to stabilise approach angle α and wear in Zone B

+132 = the surface area at constant depth of 0. 001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point	=	0.080 ins.
Loss on A per unit volume of stock removed	=	0.045 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.00088 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.004 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	80 to 1
Ratio of work loss to wheel loss Zone A	=	132 to 1
Number of unit volume lengths on A	=	16.5
Estimated life of wheel face in Zone B	=	0.072
Estimated life of wheel face in Zone A	=	2.178 cu.ins.
Total estimated life = Zone A + Zone B	=	2.25 cu.ins.

Surface finish micro ins. = 10



A = 0.045 ins. B = 0.080 ins.

RESULTS SHEET NO. 22

COOLANT SELECTION TEST

COOLANT: MANCHESTER OIL REFINERY, DIAPHANOL.H. — 1 vol. in 30 vOls water

Surface area ground sq. ins.	Start	72*	+132 =204	+132 =336	+132 =468	+132 =600	
Width of wheel lost in ins.	None	0.120	0.08	0.07	0.100	0.05	
Width of wheel left in ins.	0.990	0.870	0.790	0.720	0.620	0.570	
Surface finish micro ins. CLA	-	11 to 7	7	7	7	7	

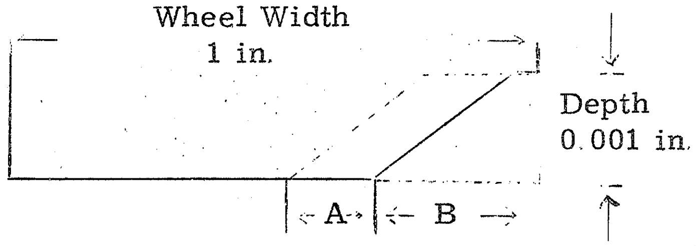
* = work done to stabilise approach angle α and wear in Zone B

+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point	=	0.120 ins.
Loss on A per unit volume of stock removed	=	0.075 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.00132 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.0066 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	55.5 to 1
Ratio of work loss to wheel loss Zone A	=	80 to 1
Number of unit volume lengths on A	=	10.3
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.36 cu.ins.
Total estimated life = Zone A + Zone B	=	1.432 cu.ins.

Surface finish micro ins. = 7



A = 0.075 ins. B = 0.120 ins.

COOLANT SELECTION TEST

COOLANT: C.C. WAKEFIELD SOLUBRIOL CLEAR DIXOL 1 vol. in 50 vols. water

Surface area ground sq. ins.	Start	72*	+132 =204	+132 =336	+132 =468	+132 =600	
Width of wheel lost in ins.	None	0.120	0.070	0.050	0.090	0.040	
Width of wheel left in ins.	0.970	0.850	0.780	0.730	0.640	0.600	
Surface finish micro ins. CLA	-	8 to 6	6	5	5	6	

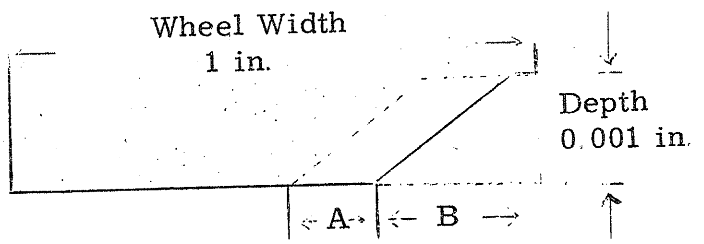
* = work done to stabilise approach angle α and wear in Zone B

+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point = 0.120 ins.
Loss on A per unit volume of stock removed = 0.062 ins.
Total volume of stock removed for tests = 0.600 cu.ins.
Loss of wheel in Zone B = 0.0013 cu.ins.
Stock removed for loss in Zone B = 0.072 cu.ins.
Loss of wheel in Zone A = 0.0055 cu.ins.
Stock removed for loss in Zone A = 0.528 cu.ins.
Ratio of work loss to wheel loss Zone B = 55.5 to 1
Ratio of work loss to wheel loss Zone A = 96.to 1
Number of unit volume lengths on A = 12.7
Estimated life of wheel face in Zone B = 0.072 cu.ins.
Estimated life of wheel face in Zone A = 1.676 cu.ins.
Total estimated life = Zone A + Zone B = 1.748 cu.ins.

Surface finish micro ins. = 5 to 6



A = 0.0625 ins. B = 0.120 ins.

COOLANT SELECTION TEST

COOLANT: SHELL-MEX DROMUS OIL B. 1 vol. in 50 vols. water

Surface area ground sq. ins.	Start	72*	+132 =204	+132 =336	+132 =468	+132 =600	
Width of wheel lost in ins.	None	0.100	0.08	0.06	0.08	0.06	
Width of wheel left in ins.	1.000	0.900	0.820	0.760	0.680	0.620	
Surface finish micro ins. CLA	-	14 to 9	9	9	9	9	

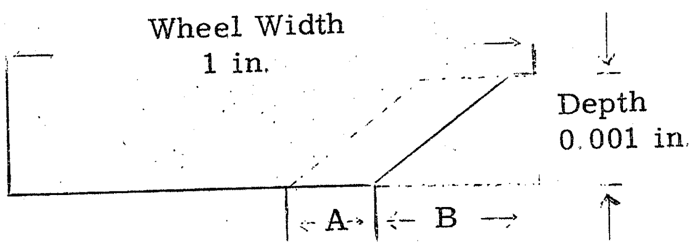
* = work done to stabilise approach angle α and wear in Zone B

+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point	=	0.100 ins.
Loss on A per unit volume of stock removed	=	0.070 ins.
Total volume of stock removed for tests	=	0.600 cu. ins.
Loss of wheel in Zone B	=	0.0011 cu. ims
Stock removed for loss in Zone B	=	0.072 cu. ins.
Loss of wheel in Zone A	=	0.0062 cu. ins.
Stock removed for loss in Zone A	=	0.528 cu. ins.
Ratio of work loss to wheel loss Zone B	=	65.5 to 1
Ratio of work loss to wheel loss Zone A	=	85 to 1
Number of unit volume lengths on A	=	10.2
Estimated life of wheel face in Zone B	=	0.072 cu. ins.
Estimated life of wheel face in Zone A	=	1.584 cu. ins.
Total estimated life = Zone A + Zone B	=	1.656 cu. ins.

Surface finish micro ins. = 9



A = 0.070 ins. B = 0.100 ins.

COOLANT SELECTION TEST

COOLANT: MANCHESTER OIL REFINERY PRIMOR M.C. OIL

Surface area ground sq. ins.	Start	72*	+132x5 = 732	+132x5 =1392	+132x5 =2052	+132x5 =2712	
Width of wheel lost in ins.	None	0.04	0.03	0.03	0.03	0.03	
Width of wheel left in ins.	1.000	0.960	0.930	0.900	0.870	0.840	
Surface finish micro ins. CLA	-	10 to 8	7	8	7	7	

* = work done to stabilise approach angle α and wear in Zone B

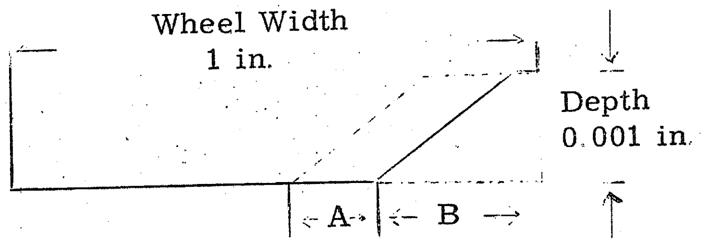
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Note: For this coolant 5 unit volumes of stock are taken at each measured point.

Summary of results

Loss on B to point	=	0.040 ins.
Loss on A per unit volume of stock removed	=	0.030 ins.
Total volume of stock removed for tests	=	2.712 cu.ins.
Loss of wheel in Zone B	=	0.00044 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.00264 cu.ins.
Stock removed for loss in Zone A	=	2.640 cu.ins.
Ratio of work loss to wheel loss Zone B	=	163.6 to 1
Ratio of work loss to wheel loss Zone A	=	1,000 to 1
Number of unit volume lengths on A	=	30
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	19.80 cu.ins.
Total estimated life = Zone A + Zone B	=	20.00 cu.ins.

Surface finish micro ins. = 7



A = 0.03 ins. B = 0.04 ins.

COOLANT SELECTION TEST

COOLANT: FLETCHER MILLER SWIFT H.

Surface area ground sq. ins.	Start	72 *	+132x5 =732	+132x5 =1,392	+132x5 =2,052	+132x5 =2,712	
Width of wheel lost in ins.	None	0.050	0.030	0.060	0.050	0.040	
Width of wheel left in ins.	1.030	0.980	0.950	0.890	0.840	0.800	
Surface finish micro ins. CLA	-	12 to 7	7	7	7	7	

* = work done to stabilise approach angle α and wear in Zone B

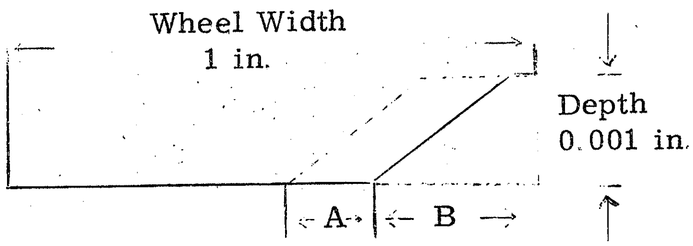
+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Note: For this coolant 5 unit volumes of stock are taken at each measured point

Summary of results

Loss on B to point	=	0.050 ins
Loss on A per unit volume of stock removed	=	0.045 ins
Total volume of stock removed for tests	=	2.712 cu.ins.
Loss of wheel in Zone B	=	0.00055 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.00396 cu.ins.
Stock removed for loss in Zone A	=	2.640 cu.ins.
Ratio of work loss to wheel loss Zone B	=	131 to 1
Ratio of work loss to wheel loss Zone A	=	660 to 1
Number of unit volume lengths on A	=	19.4
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	12.8 cu.ins.
Total estimated life = Zone A + Zone B	=	12.872 cu.ins.

Surface finish micro ins. = 7



A = 0.045 ins. B = 0.05 ins.

COOLANT SELECTION TEST

COOLANT: STERNOL TAPOYL 514

Surface area ground sq. ins.	Start	72*	+132x5 =732	+132x5 =1,392	+132x5 =2052	+132x5 =2,712	
Width of wheel lost in ins.	None	0.050	0.030	0.040	0.020	0.040	
Width of wheel left in ins.	1.010	0.960	0.930	0.890	0.870	0.830	
Surface finish micro ins. CLA	-	8 to 7	7	7	7	7	7

* = work done to stabilise approach angle α and wear in Zone B

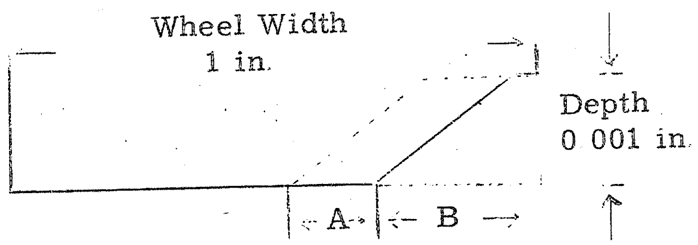
+132 = the surface area at constant depth of 0. 001 in. taken as one unit volume of stock removed.

Note: For this coolant 5 unit vols. of stock are taken at each measured point.

Summary of results

Loss on B to point	=	0.050 ins.
Loss on A per unit volume of stock removed	=	0.032 ins.
Total volume of stock removed for tests	=	2.712 cu. ins.
Loss of wheel in Zone B	=	0.00055 cu. ins.
Stock removed for loss in Zone B	=	0.072 cu. ins.
Loss of wheel in Zone A	=	0.00286 cu. ins.
Stock removed for loss in Zone A	=	2.640 cu. ins.
Ratio of work loss to wheel loss Zone B	=	131 to 1
Ratio of work loss to wheel loss Zone A	=	910 to 1
Number of unit volume lengths on A	=	27
Estimated life of wheel face in Zone B	=	0.072 cu. ins.
Estimated life of wheel face in Zone A	=	17.82 cu. ins.
Total estimated life = Zone A + Zone B	=	18.00 cu. ins.

Surface finish micro ins. = 7



A = 0.0325 ins. B = 0.050 ins.

COOLANT SELECTION TEST

COOLANT:

WAKEFIELD GRINDING FLUID

Surface area ground sq. ins.	Start	72*	+132 =204	+132 =336	+132 =468	+132 =600	
Width of wheel lost in ins.	None	0.140	0.060	0.060	0.070	0.040	
Width of wheel left in ins.	0.990	0.850	0.790	0.730	0.660	0.620	
Surface finish micro ins. CLA	-	11 to 7	7	7	7	7	

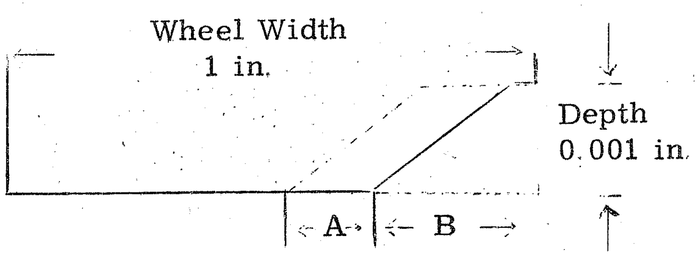
* = work done to stabilise approach angle α and wear in Zone B

+132 = the surface area at constant depth of 0.001 in. taken as one unit volume of stock removed.

Summary of results

Loss on B to point	=	0.140 ins.
Loss on A per unit volume of stock removed	=	0.057 ins.
Total volume of stock removed for tests	=	0.600 cu.ins.
Loss of wheel in Zone B	=	0.00154 cu.ins.
Stock removed for loss in Zone B	=	0.072 cu.ins.
Loss of wheel in Zone A	=	0.005 cu.ins.
Stock removed for loss in Zone A	=	0.528 cu.ins.
Ratio of work loss to wheel loss Zone B	=	48 to 1
Ratio of work loss to wheel loss Zone A	=	105 to 1
Number of unit volume lengths on A	=	13.6
Estimated life of wheel face in Zone B	=	0.072 cu.ins.
Estimated life of wheel face in Zone A	=	1.795 cu.ins.
Total estimated life = Zone A + Zone B	=	1.867 cu.ins.

Surface finish micro ins. = 7



A = 0.057 ins. B = 0.140 ins.