MACHINING AND GRINDING NI-RESIST AND DUCTILE NI-RESIST

A PRACTICAL GUIDE TO THE USE OF NICKEL-CONTAINING ALLOYS

Nº 242

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MACHINING and GRINDING

NI-RESIST Irons
and
NI-RESIST Ductile Irons

CONTENTS

MACHINING and GRINDING

NI-RESIST Irons
and
NI-RESIST Ductile Irons

Ni-Resist austenitic nickel cast iron is a moderately high alloyed iron of dense structure with graphite in flake form. Ni-Resist ductile austenitic nickel cast iron is likewise a moderately high alloyed iron with a chemical composition adjusted to afford an alloy of higher mechanical properties than those of the flake graphite Ni-Resist alloys. Graphite exists in the dense structure of Ni-Resist ductile iron in spheroidal form.

Hereafter in this publication "Ni-Resist iron" refers to the austenitic nickel cast iron containing flake graphite and "Ni-Resist ductile iron" refers to ductile austenitic nickel cast iron containing spheroidal graphite. In addition, a "D" preceeding the number of the Type as for example D-2, shall identify the various types of Ni-Resist ductile iron.

Neither Ni-Resist iron nor Ni-Resist ductile iron is hardenable in the normal sense by thermal treatment. Refer to Tables I to IV inclusive for the ranges of mechanical properties and chemical compositions of these alloys.

Machinability Test Data

Accelerated short time machining tests using single point, cemented carbide tools were conducted at Jones and Lamson Machine Company[1], Springfield, Vermont on Ni-Resist irons Types 2 and 2b and Ni-Resist ductile irons Types D-2 and D-2B to determine their comparative machinability. These test cuts were made on the parent metal of bars approximately 5-3/4 inches in diameter by 24 inches long. Photomicrographs of the metallurgical structure of the test bars are shown in Figures A to D incl.

The tests were run dry (without cutting lubricant) with Grade K-6, Kennametal cemented carbide tools. The cutting tools were ground to 0^{o} back and side rake, 0^{o} side cutting edge angle, 9^{o} side and front relief and 0.030 inch nose radius. The tests were conducted at 0.100 inch depth cut at 0.015 inch feed per revolution. The end point of each test was predicated on 0.010 inch wear land on the side flank of the cutting tool.

(1) The cooperation of Jones and Lamson Machine Co. is gratefully appreciated.

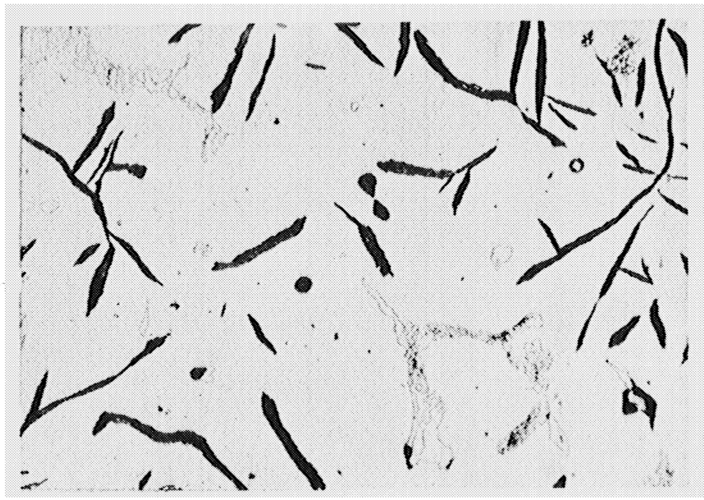


Fig. A - Ni-Resist iron Type 2
(2% Chromium)

Fig. B - Ni-Resist iron Type 2b
(3% Chromium)

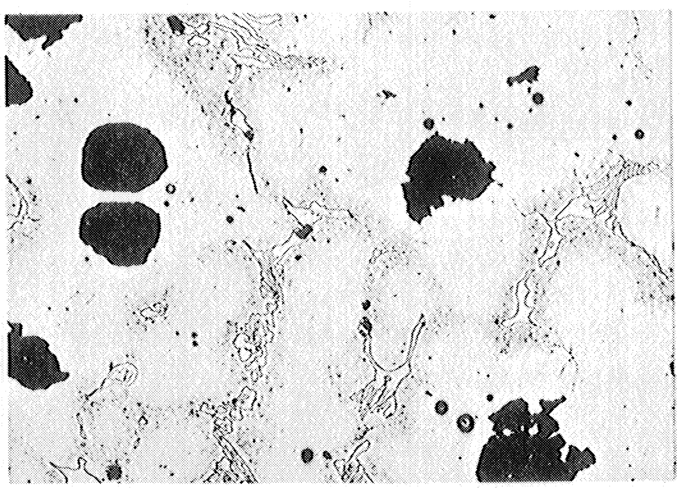


Fig. C - Ni-Resist ductile iron Type D-2
(2% Chromium)

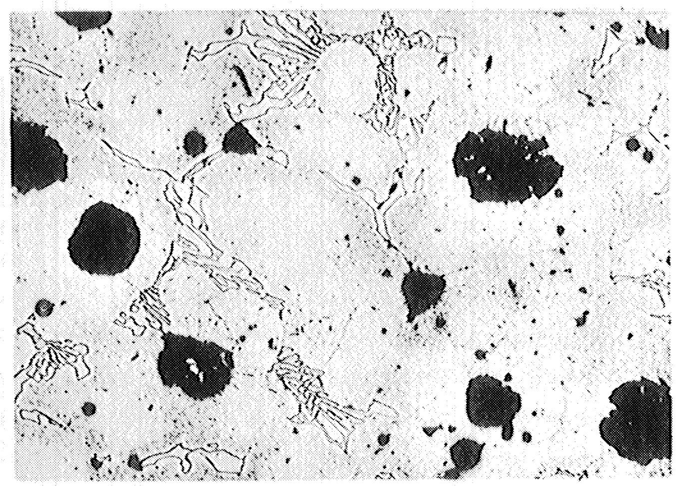


Fig. D - Ni-Resist ductile iron Type D-2B
(3% Chromium)

Microstructures of test bars cast of NI-RESIST irons. 100X magnification, 2% nital etch.
Types 2 and 2b: as cast
Types D-2 and D-2B: heat treated, 5 hours at 1800 F, air cooled

Note: The increase in carbides between the types containing 2% chromium (left) and 3% chromium (right). The effect of magnesium additions in Types D-2 and D-2B in producing spheroidal graphite.

TABLE I

MECHANICAL PROPERTIES OF NI-RESIST IRONS[1]

	Type 1	Type 1b Erosion Resisting	Type 2 20% Nickel	Type 2b Heat Resisting	Type 3 30% Nickel	Type 4 Heat & Stain Resisting	Type 5
Tensile Strength, psi	25-30,000	25-35,000	25-30,000	25-35,000	25-35,000	25-30,000	20-25,000
Elongation, % in 2 in.	1/2% to 2% for all types.						
Hardness BHN	130-170	150-210	125-170	170-250	120-160	150-210	100-125

TABLE II

MECHANICAL PROPERTIES OF NI-RESIST DUCTILE IRONS[1]

	Type D-2[4]	Type D-2B	Type D-2C	Type D-3	Type D-4	Type D-5
Tensile Strength psi	55-69000	58-70000	55-65000	55-67000	60-72000	55-60000
Yield Str. psi (.2% offset)	32-36000	33-37000	30-35000	33-37000	38-44000	30-35000
Elong. % in 2 in.	8-20	7-15	20-40	7-18[2]	1.5-4.0	20-40[3]
Hardness BHN	140-200	150-210	130-170	140-200[2]	170-240	130-180[3]

TABLE III

COMPOSITION RANGE OF NI-RESIST IRONS

	Type 1	Type 1b Erosion Resisting	Type 2 20% Nickel	Type 2b Heat Resisting	Type 3 30% Nickel	Type 4 Heat & Stain Resisting	Type 5
Total Carbon	3.00 max.	3.00 max.	3.00 max.	3.00 max.	2.60 max.	2.60 max.	2.40 max.
Silicon	1.00-2.80	1.00-2.80	1.00-2.80	1.00-2.80	1.00-2.00	5.00-6.00	1.00-2.00
Manganese	1.00-1.50	1.00-1.50	0.80-1.50	0.80-1.50	0.40-0.80	0.40-0.80	0.40-0.80
Nickel	13.50-17.50	13.50-17.50	18.00-22.00	18.00-22.00	28.00-32.00	29.00-32.00	34.00-36.00
Copper	5.50-7.50	5.50-7.50	0.50 max.	0.50 max.	0.50 max.	0.50 max.	0.50 max.
Chromium	1.75-2.50	2.75-3.50	1.75-2.50	3.00-6.00	2.50-3.50	4.50-5.50	0.10 max.

TABLE IV

COMPOSITION RANGE OF NI-RESIST DUCTILE IRONS

	Type D-2[4]	Type D-2B	Type D-2C	Type D-3	Type D-4	Type D-5
Total Carbon	3.00 max.	3.00 max.	2.90 max.	2.60 max.	2.60 max.	2.40 max.
Silicon	1.75-3.0	1.75-3.0	2.0-3.0	1.5-2.8	5.0-6.0	1.5-2.75
Manganese	0.70-1.0	0.70-1.0	1.8-2.4	.50 max.	.50 max.	.50 max.
Phosphorus	.08 max.	.08 max.	.08 max.	.08 max.	.08 max.	.08 max.
Nickel	18.0-22.0	18.0-22.0	21.0-24.0	28.0-32.0	29.0-32.0	34.0-36.0
Chromium	1.75-2.5	2.75-4.0	.50 max.	2.5-3.5[2]	4.5-5.5	.10 max.[3]

(1) Complete details on mechanical properties are given in (a) "Engineering Properties and Applications of Ni-Resist Irons" and (b) "Engineering Properties of Ni-Resist Ductile Irons". These bulletins are available from Inco.

(2) Type D-3 is available as Type D-3A with 1% Cr resulting in slightly higher elongation of 13-18% and slightly lower hardness of 130-190 BHN.

(3) Type D-5 is available as Type D-5B with 2-3% Cr resulting in a higher hardness of 140-190 BHN and a lower elongation of 5-10%.

(4) Ni-Resist austenitic ductile iron Type D-2M of high nickel plus manganese content providing high impact values at subzero temperatures is available for low-temperature applications. The machinability of the alloy is essentially the same as Type D-2 austenitic ductile iron. Complete details on mechanical properties are given in the "Low Temperature Data Sheet – NI-RESIST Austenitic Ductile Iron Type D-2M" available from INCO.

Figure E is a graph of the data resulting from the tests exemplifying the amount of metal removed versus cutting speed for each test run. Data of this nature materially assists on determining operating speeds for machining a material on a production basis. This concludes the remarks relating to the machinability test data.

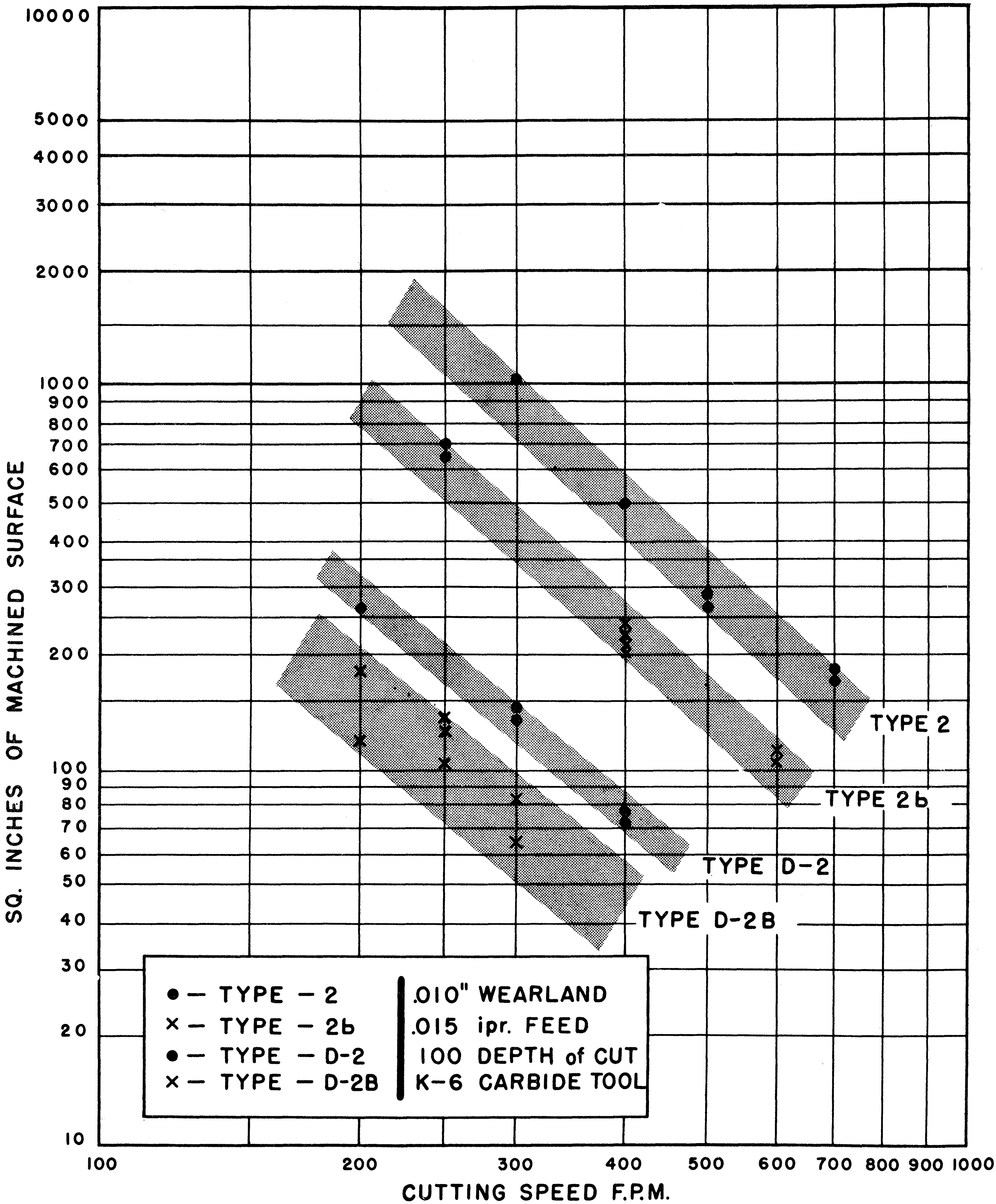
The machinability of these alloys might be lowered by clusters of chromium carbides in their structure; especially in castings of uniform light section and in castings of measurable varying cross-section. These massive carbides lower the machinability, however, they can be withdrawn into the austenitic matrix of the casting and dispersed and some of them decomposed by annealing the castings at 1750°F to 1900°F from one-half hour to five hours, followed by air cooling. Although this treatment may result in some increase to the yield and tensile strength of the castings, the gain in machinability is due to less abrasiveness to the cutting tool by the massive carbides.

Castings that are to be finished to close dimensional tolerances ought to be stress relief annealed to remove residual casting and machining stresses or strains. This is accomplished by holding the castings at 1250°F for one hour per inch of section, followed by furnace or uniform air cooling. This treatment does not affect the structure or properties of the cast alloys. Obviously, the preferred interval in the production sequence for stress relieving would be after rough machining. Usually, castings that have been annealed as described above for improved machinability, need not be stress relief annealed. However, it is prudent to set the rough machined casting aside for several hours to stabilize before proceeding to finish it to close tolerances.

General Operating Conditions

The prerequisites for satisfactory and economical machining call for the use of sturdy machines and cutting tools as well as a rigid work setup. The carry-over of vibrations to cutting tools is a major factor towards tool failure.

The abrasive characteristic of the as-cast surface of the castings causes high rate of wear to cutting tools. Consequently avoid, wherever possible, plunge cuts on the as-cast surface. Using the principle of down milling on as-cast surfaces with plain or slab millers, permits initial tool contact with the surface and can result in



10000
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500
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300
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100
90
80
70
60
50
40
30
20
10
SQ. INCHES OF MACHINED SURFACE
TYPE 2
TYPE 2b
TYPE D-2
TYPE D-2B
● – TYPE – 2
× – TYPE – 2b
● – TYPE – D-2
× – TYPE – D-2B
.010" WEARLAND
.015 ipr. FEED
100 DEPTH of CUT
K-6 CARBIDE TOOL
100
200
300
400
500
600
700
800
900
1000
CUTTING SPEED F.P.M.

Figure E

rapid tool wear. When removing the as-cast surface, endeavor to maintain the point of the cutting tool well under this surface.

The cutting speeds noted later on are intended to cover general conditions encountered when machining Ni-Resist irons and Ni-Resist ductile irons. These speeds should be adjusted within their indicated range to suit the geometry of the work, the cutting tool and the severity of the machining operation. Several factors to consider are:-

(1) The surface speed should, in general, be in inverse proportion to the mechanical properties of the workpiece.

(2) Maximum life of the cutting tool exists at speeds below the suggested maximum cutting speed.

(3) Maximum metal removal is accomplished at lower speeds (fpm), greater depth cut and high feed (ipr) rates.

(4) Surface finish improves with higher speeds (fpm), lower depth cut and lower feed (ipr) rates.

Cutting Lubricants

Every machining operation on these alloys should be supplied with a continuous stream of a force fed cutting lubricant. Make every effort to get the lubricant to the cutting point of the tool. Constantly maintain the lubricant (coolant) at the lowest possible temperature.

High temperatures are developed at the interface of tool and chip upon machining these alloys which, if not dissipated to the best extent, leads to premature tool failure, rough finish and dimensional inaccuracy of the workpiece.

Type Lubricants:-

(1) Chemical active water base solutions have high cooling ability and contain additives that reduce friction between the chip and tool. These are quite suitable for all machining operations. These solutions are preferred for medium to fine machining. However, they do not produce as good a machined finish as petroleum oil.

(2) Plain soluble oil and water, mixed 10 parts water to one part soluble oil, exhibits high cooling capacity but lower friction resisting characteristics than chemical active coolants or petrcleum oils. This type of oil is quite suitable for medium to light machining but does not afford as high a machined finish as petroleum oil.

(3) Chlorinated sulfurized fatty mineral oil's cooling capacity is lower than the aforementioned lubricants Nos. 1 or 2, however, it does possess high friction and adhesion resisting characteristics. This oil is preferred for attaining high machined finishes.

It should be noted that if this oil is extremely high in sulfur, especially free sulfur, it will be somewhat abrasive to cutting tools. Consequently, oils of high sulfur content are thinned with straight mineral or paraffin oil.

Tool Materials

These alloys are machined with high speed steel, cast non-ferrous and cemented carbide cutting tools as noted in Tables V and VI.

The straight tungsten carbide tools and that type containing tantalum appear to show preference over other grades of carbides.

Tools should be carefully ground without drawing the temper on H. S. S. tools and without overheating the cast non-ferrous and cemented carbide tools.

Tools should be ground to a smooth high finish and wire edges honed from their keen edges after grinding.

Machined Surface Finish

The smoothest finish expected from finish turning, boring and similar single point cutting tools would be on the order of 45 to 50 Micro Incnes (RMS). The smoothest expected finish from face milling would be 55 to 60 Micro Inches (RMS). Smooth reamed finishes are on the order of 25 to 30 Micro Inches (RMS).

Castings of high hardness and mechanical properties afford better finishes than those of lower corresponding properties.

Usually castings containing coarse flake graphite can not be machine finished to the smoothness of those containing fine flake graphite.

Experience indicates that castings with graphite in spheroidal form finish smoother than those containing flake graphite.

It is possible that graphite might be pulled from the surface of the castings during finishing, leaving microscopic pits.

Cemented carbide tools have afforded the smoothest machined finish. High cutting speeds (fpm) and low feed (ipr) produce a better finish than inverse cutting speeds.

Tool geometry is important. Higher positive back and side rakes than those used for normal machining are preferred for finishing. Increasing the tool nose radius produces a smoother machined finish.

Table V

Some H. S. S. and Cast Non-Ferrous Tool Materials

Type	Tungsten	Molybdenum	Chromium	Vanadium	Cobalt	General Remarks
	Approximate Analysis in Percent					
T-1, Regular Tungsten	18		4	1		Is tough, has high red hardness and abrasion resistance
T-4, Tungsten, Cobalt	18		4	1	5	Essentially the same as T-1 with higher red hardness
T-15, Tungsten, Vanadium, Cobalt	13		4-1/4	5	5	High abrasion resistance and red hardness, low toughness
T-20, Tungsten, High Vanadium	18-1/2		4	4		For high speed and light cuts
M-1, Molybdenum, Tungsten, Vanadium	8	1-1/2	4	1		Comparable to Type T-1
M-3 Type 2, Molybdenum, Tungsten	6	6	4	3		General purpose with high abrasion resistance and strength
M-30, Molybdenum, Tungsten, Cobalt	2	8	4	1	5	Exhibits high red hardness comparable to Type T-4
Cast Non-Ferrous	Cobalt, Chromium, Tungsten, with additions of carbon and minor additions of Tantalum					Superior to carbides in toughness, but of lower abrasion resistance. Higher red hardness than H.S.S. but not as tough.

Table VI

Cemented Carbide Cutting Tools

Designation	
C-1	Severe roughing, interrupted cuts
C-2	Normal roughing cuts, machining the as-cast surface of castings. Suitable also for semi-finishing.
C-3	Normal finishing cuts.
C-4	Fine finishing cuts.

Chlorinated sulfurized fatty mineral oil cut with straight mineral or paraffin oil must be supplied to finish machining to attain a smooth finish.

Relative Machinability of Ni-Resist Irons and Ni-Resist Ductile Irons

Ni-Resist irons Types 1b, 4 and 5 and Ni-Resist ductile irons Types D-2C, D-3, D-4 and D-5 are not specifically listed in the tables that follow. Nevertheless, their machinabilities fall in these categories:-

Ni-Resist iron Type 1b	-	Somewhat lower machinability than Type 1
Ni-Resist iron Type 4	-	Parallels quite evenly Type 2b
Ni-Resist iron Type 5	-	Parallels and is somewhat higher than Type 1
Ni-Resist ductile iron Types D-2M and D-2C	-	Parallels quite evenly Type D-2
Ni-Resist ductile iron Type D-3	-	Parallels and is somewhat higher than Type D-2B
Ni-Resist ductile iron Type D-4	-	Slightly more difficult than D-2B. Start at minimum speeds cited for D-2B.
Ni-Resist ductile iron Type D-5	-	Machinability parallel to Type D-2.

TURNING, FACING and BORING

Table VII

Speeds for Turning, Facing and Boring

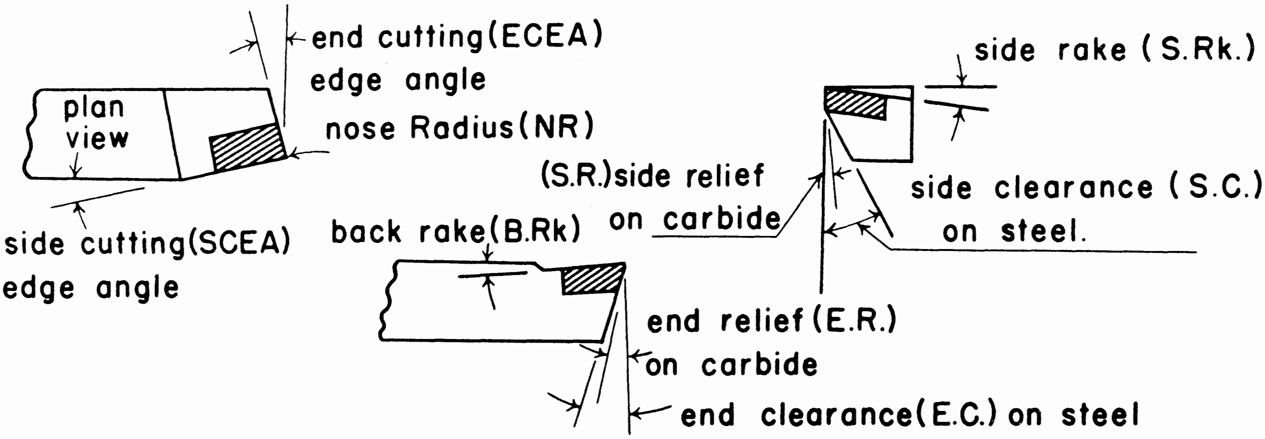
Ni-Resist Alloy	Surface Feet Per Min. (1) Tool Material H.S.S.	Cast Non-Ferrous	Cemented Carbide	Feed (ipr)
Type 1	75 - 100	100 - 150	250 - 350	to .018 inch
Types 2 & 3	65 - 85	80 - 130	200 - 300	to .018 inch
Type 2b	50 - 70	65 - 90	175 - 275	to .018 inch
Type D-2	35 - 60	45 - 75	130 - 225	to .018 inch
Type D-2B	20 - 40	35 - 60	100 - 150	to .018 inch

(1) The minimum speeds (fpm) cited are for rough cuts and for removing the as-cast surface.

The maximum speeds (fpm) cited are intended for finish machining operations.

Speeds for boring should approach the minimum of each speed range cited.

FIG. I – TURNING, FACING AND BORING*



* Increase in Side Rake, and Front Clearance Angles, to that noted here might be necessary on particular jobs, such as boring operations.

Tool Angles "Deg." (1)

	Cemented Carbide		H.S.S. & Cast Non-Ferrous
E.C.E.A.	8 to 12	E.C.E.A.	10
S.C.E.A.	15 to 20	S.C.E.A.	15 to 20
N.R.	1/32" to 1/16" (2)	N.R.	1/16" to 1/8" (2)
B.Rk.	-5 to +5	B.Rk.	2 to 6
S.Rk.	-5 to +5	S.Rk.	4 to 8
E.R.	4 to 6	E.C.	7
S.R.	4 to 6	S.C.	7
E.C.	8 to 10		
S.C.	8 to 10		

(1) Negative and minimum positive rake angles are intended for removing as-cast surfaces, for medium to heavy roughing cuts, for interrupted cuts and for machining castings of high mechanical properties.

(2) For 1/8" depth cut use 1/32" for C.C. tools and 1/16" for H.S.S. tools increasing radius slightly in proportion to depth of cut.

DRILLING

Table VIII

Drilling - H.S.S. - Spiral Drills

Drill Speeds

Ni-Resist Alloy	FPM
Type 1	70 - 90
Types 2 & 3	60 - 80
Type 2b	45 - 60
Type D-2	30 - 40
Type D-2B	20 - 35

Drill Feed

Dr. Diam. (inch)	(ipr)
1/8	.001 to .002
1/4	.005
1/2	.007
1	.012

(1) Adjust drill speed according to drill diameter and depth hole drilled; drills under 3/8 inch would approach the maximum of the cited speed range. The speed and feed of the drill should be decreased with increase depth of drilled hole. For instance, upon drilling a hole 5 times the drill diameter the drill speed would be decreased 30% and the feed 20%.

When drilling holes to a depth exceeding 2 to 3 times the drill diameter, retract the drill from the hole after it has penetrated 2 times its diameter to free the chips and afford intermittent cooling of drill and work.

Use heavy web drills.

Use drills that are surface treated for wear and abrasion.

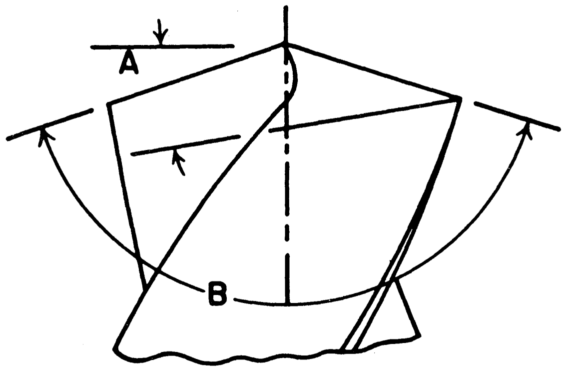
Use drills as short as possible.

A drill bushing assists in maintaining drill rigidity.

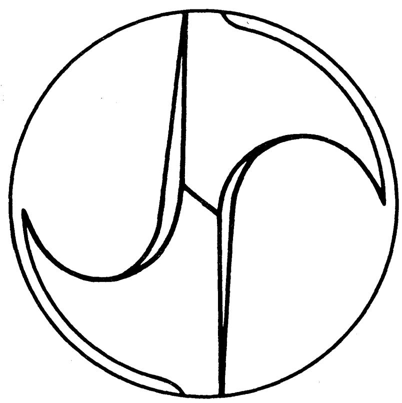
Use oil hole drills for drilling deep holes.

Do not let the drill dwell in the hole as this will result in work-hardening the material.

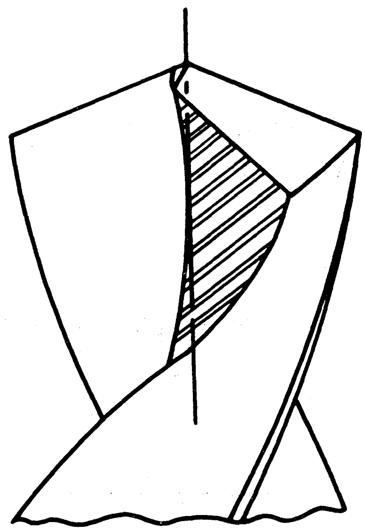
FIG. 2 – SPIRAL DRILL



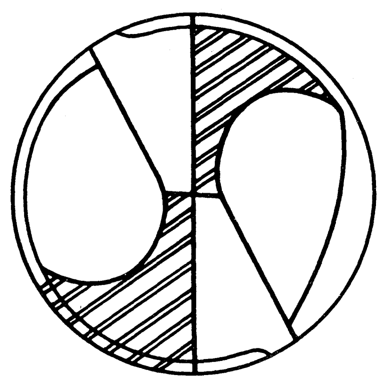
Drill Point Angle



Conventional Web Thinning



DRILL GRIND	Angle Deg.	
Ni-Resist Alloy	A	B
Types 1, 2 & 3	14	118 to 120
Type 2b	14	118 to 120
Type D-2	14	120 to 130
Type D-2B	14	120 to 130



Notch Grind

Table IX

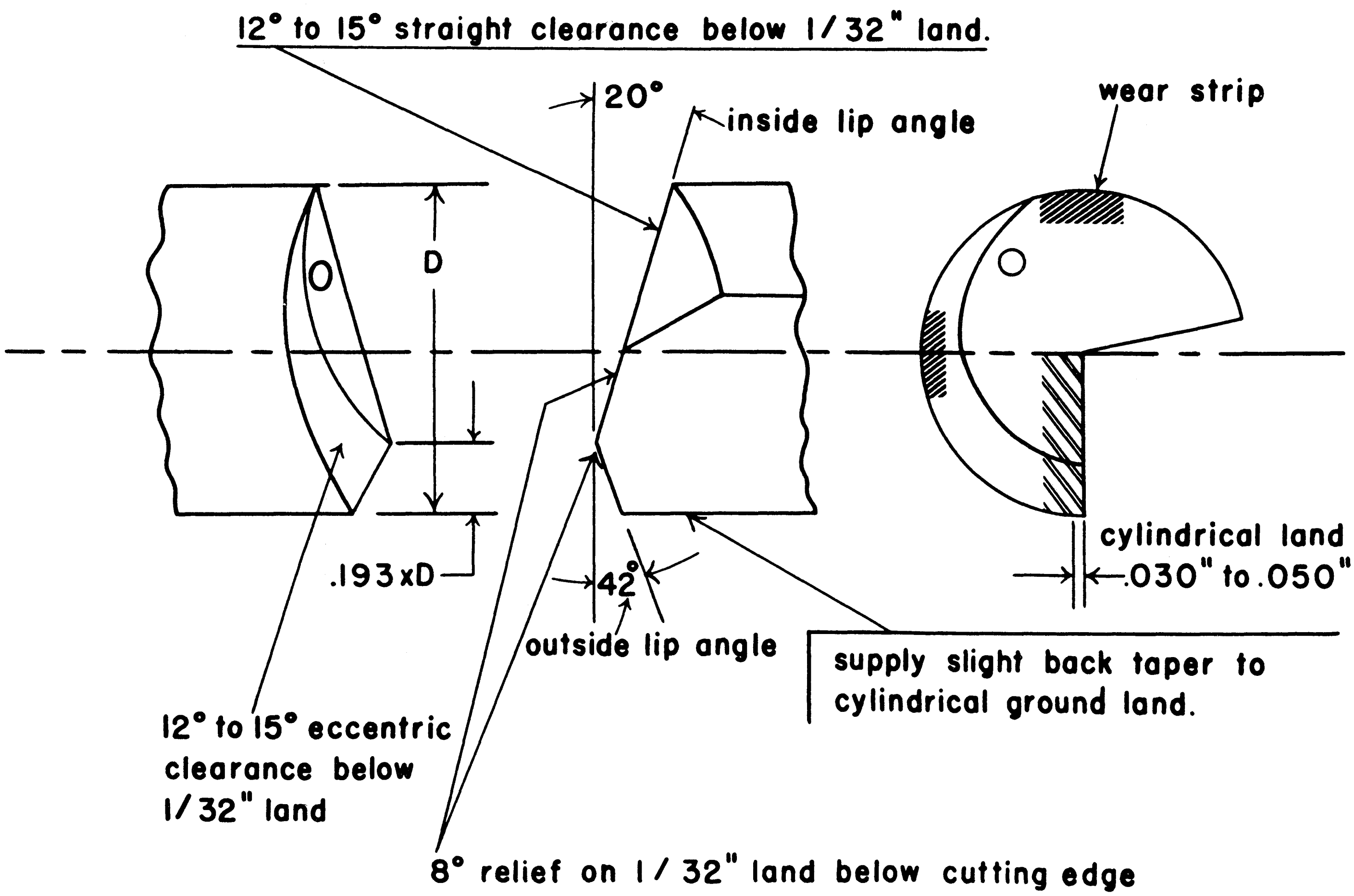
Cemented Carbide Gun Drilling Speeds

Ni-Resist Alloy	Drill Speed FPM	Feed (ipr)
Type 1	125 - 208	.0007 to .002
Types 2 & 3	100 - 175	.0007 to .002
Type 2b	90 - 140	.0007 to .002
Type D-2	60 - 90	.0007 to .002
Type D-2B	50 - 70	.0007 to .002

Rigidity of setup is very important on gun drilling operations. Support the gun drill with a drill bushing. Force feed cutting lubricant into hole at 300 to 400 psi. Retract drill from hole periodically to free chips and permit intermittent cooling of work and drill. The cutting edge of the drill should not be above the center of the work. It should be set on center or certainly not more than 0.001 to 0.002 inch below center.

FIG. 3 - GUN DRILL

Suitable for H.S.S.; Cemented Carbide or Cast-Non Ferrous Tool Materials.



REAMING

Table X

Reaming Speeds (FPM)

Ni-Resist Alloy	H.S.S.	Cemented Carbide
Type 1	75	120
Types 2 & 3	65	100
Type 2b	40	70
Type D-2	30	60
Type D-2B	20	50

Reamer Feeds

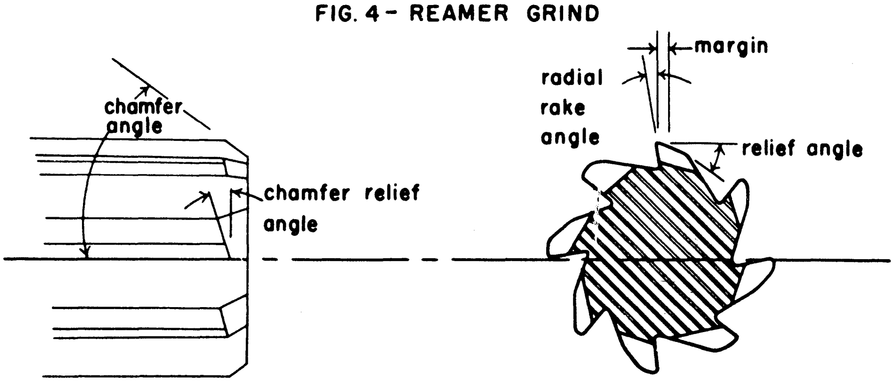
Reamer Diameter	Feed (ipr)
Under 1/8"	.002 - .004
1/8" to 1/4"	.004 to .008
1/4" to 1/2"	.008 to .012
1/2" to 1"	.012 to .024
Above 1"	.024 to .050

Stock allowed on diameter for machine reaming should not be excessive. It is good practice to set the maximum allowance at 1/64 inch. With heavy feed use less allowance than with light feed. Hand reaming requires less allowance than machine reaming.

Wherever possible, use short fluted reamers.

Reamer guide bushings aid in reaming holes straight.

FIG. 4 - REAMER GRIND



ANGLE	H.S.S.	Cemented Carbide
Chamfer	45°	45°
Chamfer relief	10° to 12°	9° to 10°
Rake	0° to 7°	0° to 5°
Margin (1)	.004" to .020"	.004" to .020"
Margin relief (1)	.5° to 18°	5° to 18°

(1) Margin width and relief decrease as reamer diameter increases; for example:

Reamer Diam.	Margin Width		Relief
1/8"	.004"	to	18°
1/2"	.010"		9°
3/4"	.012"		7°
1"	.014"		5°

TAPPING

Table XI

Tapping Speeds
H.S.S. Taps

Ni-Resist Alloy	Speed FPM
Types 1, 2 & 3	40 to 55
Type 2b	30 to 40
Type D-2	25 to 30
Type D-2B	15 to 25

Use taps as short as possible. Either eccentric or con-eccentric relieved taps are suitable. The latter type relief is suggested for horizontal tapping.

Grind the tap point diameter equal to or slightly below the size of hole to be tapped so that each chamfer tooth does its share of the work.

Chamfer should contain 4 to 5 threads.

Roughing and finishing taps are suggested for acme threads.

Decrease width of land as shown at "A" in sketch of tap to relieve tap binding and metal pickup. Never tap without a lubricant.

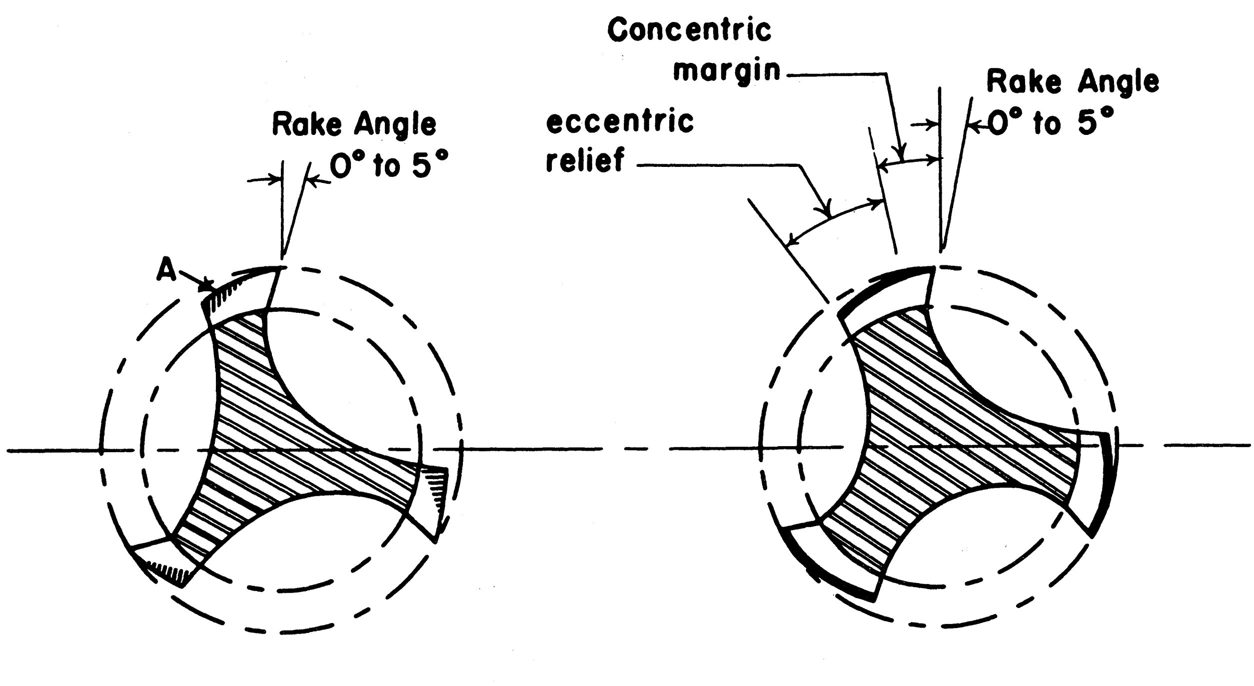
The hole to be tapped must be in good condition for satisfactory tapping; its finish should be smooth. It also should be straight and not egg-shaped.

Selection of tap drill size is important.

The use of a tap drill that produces a 65% thread depth eases the tapping operation.

Serial taps are recommended for tapping deep holes.

FIG.5 - TAP GRIND



Eccentric Tap

Con-eccentric Tap

THREADING

Milled and hobbed chaser inserts are ground to 20° throat angle and 0° to 3° radial rake angle. Milled chasers to 5/16 inch thread size are relieved 10°. Chasers above 5/16 inch thread size are relieved on the order of 5°. Tangent type thread chasers are ground to a rake angle of 12 to 18°.

A chaser throat angle of 12° is suggested for single acme threads and 9° to 10° for double acme threads.

For chasing taper threads, die heads with receding chasers are recommended.

Ni-Resist irons Types 1, 2 and 3 are threaded with self-opening dies at 30 to 50 feet per minute. Use speeds on the order of 30 fpm for Type 2b.

Speeds of 20 to 40 fpm are suitable for this type threading on Ni-Resist ductile irons. Use speeds approaching 20 fpm for Types D-2B, D-3 and D-4.

Where these alloys are to be lathe threaded with single point cutting tools, an operating speed of 20 to 50 (fpm) is suggested, using the minimum speed noted for the Ni-Resist ductile iron.

MILLING

Table XII - Milling Speeds (FPM)

Ni-Resist Alloy	Tool Material: H.S.S.	Cast-Non Ferrous	Cemented Carbide
Type 1	75 - 90	90 - 125	200 - 300
Types 2 & 3	60 - 80	75 - 100	200 - 275
Type 2b	40 - 75	50 - 100	175 - 250
Type D-2	25 - 40	40 - 60	100 - 175
Type D-2B	20 - 30	30 - 50	80 - 120

Milling Feeds

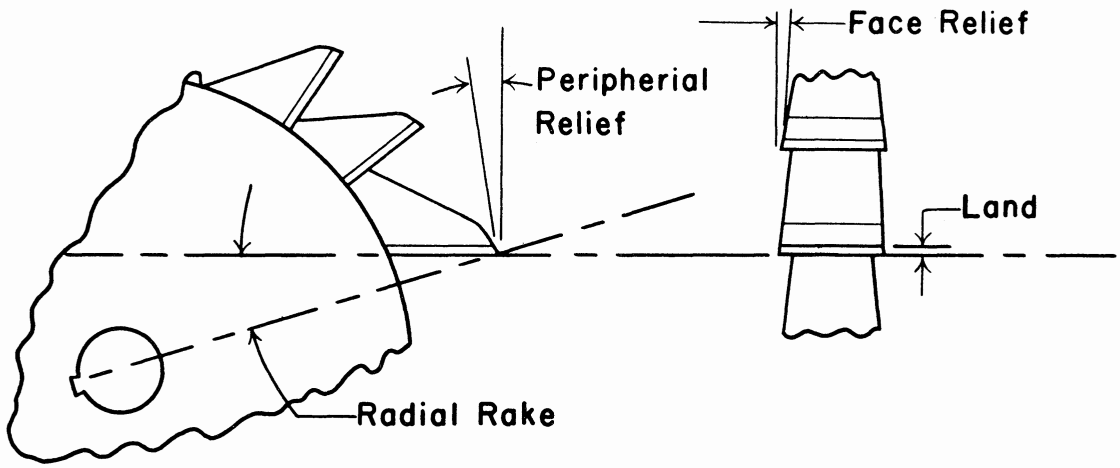
Type Cut	Feed per Cutter Tooth (1): H.S.S. & Cast Non-Ferrous Tools	Cemented Carbide Tools
Plain or Slab	.005 - .007	.007 - .010
Straddle Milling	.005 - .008	.007 - .010
Slot Milling	.004 - .007	.005 - .007
Face Milling	.008 - .010	.008 - .012
End Milling	.004 - .006	.005 - .006

(1) Rigid setups, light cuts and soft material permit heavy feed while frail setups, high finish requirements and milling slots call for low feeds.

The surface speed (FPM) should be in inverse proportion to the mechanical properties of the material.

Finish improves with speed increase, low feed and shallow depth cuts.

FIG. 6 – PLAIN MILLING CUTTERS
SLAB, STRADDLE AND SLOTTING



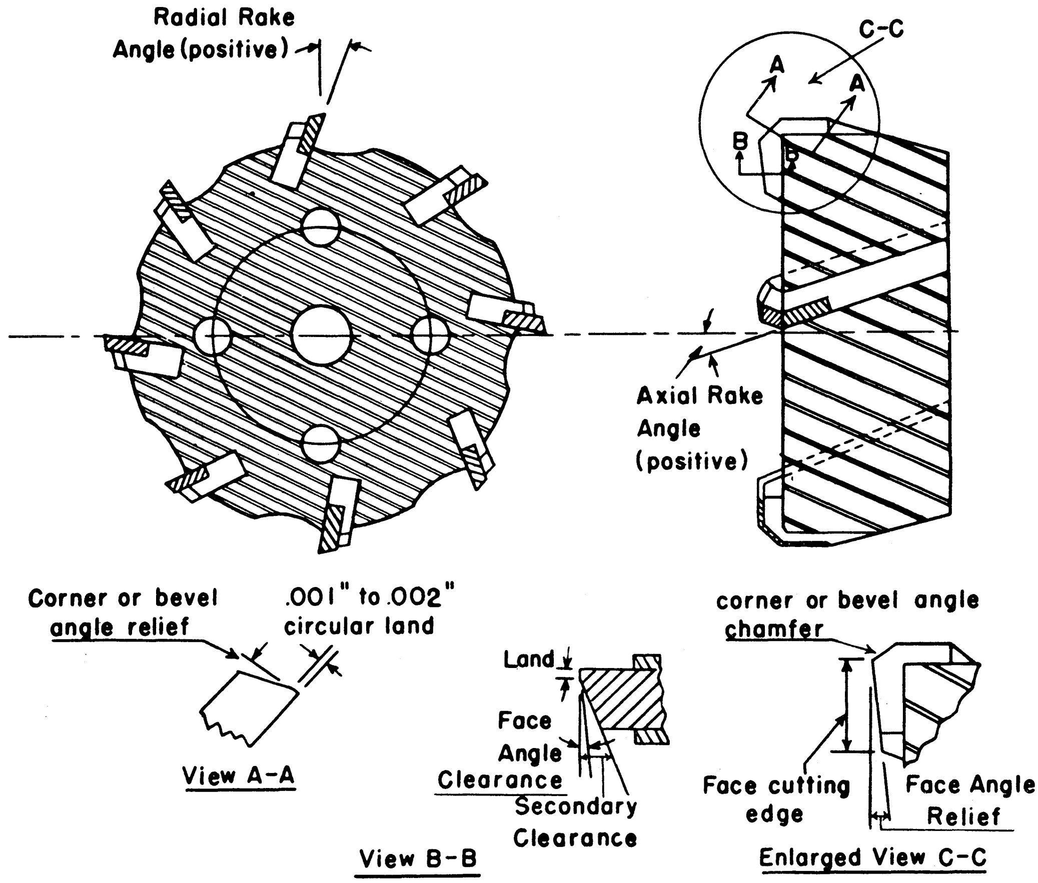
For slotting staggered tooth cutters with alternate teeth of opposite helix are preferred.

For slab milling helical tooth cutters are preferred.

	Angle - "Deg" H.S.S.	Cast Non-Ferrous	Cemented Carbide
Radial Rake (Face Rake)	7 to 10	4 to 8	0 to 5
Land (1)	1/64 to 1/16	1/64 to 1/16	1/64 to 1/16
Peripherial Relief (Land Relief) (2)	4 to 6	3 to 5	3 to 5
Face Relief (Side Relief)	3 to 4	3 to 4	3 to 4

(1) Land increases with cutter diameter.
(2) Small cutters below 3 inch diameter will require large clearance angles.

FIG. 7 – FACE MILLING CUTTER



CUTTER GRIND "DEG."

	H.S.S.	Cast Non Ferrous	Cemented Carbide
Axial Rake	10	0 to 6	-5 to +6
Radial Rake	10	0 to 10	-10 to 6
Corner Bevel Angle	15	15 to 45	15 to 45
Face Angle Relief	3 to 5	3 to 5	3 to 5
Corner or Bevel Angle Relief	5 to 7	4 to 6	4 to 6
Face Angle Clearance	2 to 4	2 to 4	2 to 3

SAWING

Power Hacksawing

Molybdenum high speed steel or tungsten high speed steel saw blades are recommended. Rigidity of work, machine and saw blade are necessary for satisfactory sawing. The width and thickness of the blade determines its strength and its rigidity under proper conditions of setup. Blades at least .062 inch X 1 1/4 inch are suggested. Do not use a blade longer than is necessary for the cut as short blades afford the highest rigidity. The saw blade should be carefully aligned in the machine and tightened to proper tension. Where the tension in the blade setup is judged by feel, the blade should be tensioned until it produces a dull ring when struck lightly.

Use saw blades having raker set teeth.

Two or three teeth should be imbedded in the work continually. Blades of 6 to 10 tpi serve for most work; where sections under 1/2 inch are sawed a blade having 14 tpi is suggested.

Saw speeds range between 70 and 90 sfpm for the Ni-Resist Irons.

Saw speeds for Ni-Resist Ductile Irons range between 40 and 65 sfpm.

The maximum speeds cited are used for sawing the irons of low hardness and low chromium content. Remarks on page 11 as to the relative machinability of Ni-Resist and Ni-Resist Ductile Irons might be used as a guide for selecting sawing speeds for particular type irons.

Maintain a constant feed pressure on the saw. Use light to medium pressure for thin sections and medium pressure for heavy sections.

Supply a smooth continuous stream of cutting lubricant to the sawing operation. A rich solution of soluble oil and water (10 parts water to 1 part soluble oil) is satisfactory as is chlorinated sulfurized fatty mineral and/or sperm oil.

<u>Bandsawing</u>

Saw bands of high speed steel (hard edge, flexible back) or of alloy steel, specified hard edge flexible back in "A" temper, are recommended. Under proper operating conditions, the former afford the longest cutting life.

The strength of a particular saw band is largely governed by its gauge and width. Ni-Resist and Ni-Resist Ductile Irons have a high degree of toughness and therefore require medium to high feed pressures. Consequently, a stout saw band is indicated. Where possible use a saw band at least .035 inch thick X 3/4 to 1 inch wide.

Saw bands having raker set teeth generally serve best.

Suggested band sawing speeds are cited in Table XIII for several types of Ni-Resist and Ni-Resist Ductile Irons.

Ample cutting lubricant should be supplied to the sawing operation. Suitable lubricants are chlorinated sulfurized fatty mineral and/or sperm oil and soluble oil and water mixed 5 parts water to 1 part soluble oil.

<u>Friction Sawing</u>

Friction sawing Ni-Resist and Ni-Resist Ductile Irons is accomplished at 8000

Table XIII

Band Sawing Speeds-Ni-Resist and Ni-Resist Ductile Irons

MATERIAL (1)	Band Sawing Speeds (Hard edge flexible back) (High Speed Steel Saw bands)							
	Saw Pitch (teeth per in.)				Saw Velocity, fpm.			
	Work thickness, inch.							
	1/16	1/4	1	3	1/16	1/4	1	3
Ni-Resist, Type 1	18	14	8	6	150	120	90	70
Ni-Resist, Type 2b	18	10	8	6	130	90	75	60
Ni-Resist Ductile Iron, Type D-2	18	12	10	6	90	75	60	35
Ni-Resist Ductile Iron, Type D-2B	18	12	10	6	80	65	40	30

(1) The relative machinability tabulation on page 11 may be used as a guide for selecting band sawing speeds for the alternate type irons.

to 13,000 sfpm. Saw bands specifically produced for friction sawing are recommended. The bands should have raker set teeth. A saw band 1 inch wide X .035 inch thick having 10 tpi is quite suitable for straight cuts. Contour sawing is feasible; however, saws less than 1/2 inch wide should be used cautiously.

The limiting work thickness for friction sawing these alloys is generally considered to be 1/2 inch. Somewhat thicker material can be sawed by rocking the work to present a narrow surface of material to the saw.

GRINDING

Cylindrical External Grinding

Generally, for cylindrical (external) grinding, aluminum oxide vitrified or resinoid bonded grinding wheels of open structure and of medium to soft grade are preferred for grinding the Ni-Resist irons and the Ni-Resist ductile irons. In the case, however, of grinding extremely low strength Ni-Resist irons the silicon carbide wheels may be employed successfully.

Cylindrical Internal Grinding

Grinding wheels of aluminum oxide are generally preferred for internal grinding Ni-Resist irons and Ni-Resist ductile irons.

Surface Grinding

Aluminum oxide abrasive grinding wheels are used for surface grinding these alloys. The softer grade wheels of friable aluminum oxide are used where large wheel-work contact area is encountered. However, for grinding interrupted surfaces, harder grade wheels of regular aluminum oxide or medium to soft grade wheels of silicon carbide are used.

Grinding Coolants

Supply a generous continuous stream of coolant to every grinding operation. Keep the coolant at a constant low temperature; it should be filtered. Suggested coolants are:

Emulsifying oil mixed 60 parts water to 1 part of oil.

Chemical active water soluble oils mixed 40 to 60 parts of water to 1 part of oil.

A mixture of 25 gallons of water to 1 pound of sal soda.

Tests

The Norton Company [1] of Worcester, Massachusetts, has conducted grinding tests on two types of Ni-Resist irons and on two types of Ni-Resist ductile irons as shown in Table XIV. These tests include external, internal (both cylindrical), surface grinding and cut-off. No distinguishable difference was noted in the grinding action of any of the alloys tested. Aluminum oxide wheels were preferred.

Since the alloys tested cover a fairly wide range of mechanical properties and hardness without displaying different grinding characteristics, it may be assumed that the Ni-Resist irons and Ni-Resist ductile irons will be ground similarly. The data presented for the following operations was taken from the above mentioned tests.

TABLE XIV

Ni-Resist Alloy	Condition	Tensile Strength (psi)	Hardness BHN
Type 2*	As cast	27,000	138
Type 3	As cast	37,000	138
Type D-2	As cast	58,800	170
Type D-3	As cast	61,800	170

*Only this type material was subjected to surface grinding; it was also used for flat lapping tests.

(1) The cooperation of Norton Company is gratefully appreciated.

a. Cylindrical External Grinding

Recommended Wheel - 23A60-L5VBE

Machine - NORTON 10 x 36" CTU

Wheel Size - 24" diam. x 2" face x 12" hole

Wheel Speed - 6,500 surface feet per minute

Work Speed - 80 to 120 r.p.m., on 2" diameter piece

Table Traverse - Rough cut 60" per minute - 23 microinch, root mean square

Finish cut 23" per minute - 4 microinch, root mean square

Feeds per pass - Roughing .002" per table reversal

Finishing .0005" per table reversal

Truing-Roughing .002" index per table reversal at table speed of 40" per minute

Truing-Finishing .0005" index per table reversal at table speed of 11" per minute

All truing is done wet with a single point diamond

Coolant - Water soluble oil 1 to 60

b. Cylindrical Internal Grinding

Recommended Wheels - Roughing - 23A36-H8VBE

Finishing - 32A60-H8VBE

Wheel Speed - 6,000 s.f.p.m.

Wheel Size - 2-1/2" diameter x 1" face x 7/8" hole, recess one side 1-1/2" x 3/8"

Work Speed - 225 r.p.m.

Traverse - 50" per minute

Rate of Feed - .0003 to .0006" per minute

Coolant - Water Soluble Oil 1 to 40

c. Surface Grinding - Straight Wheel

Recommended Wheels - Roughing - 32A46-H8VBE

Finishing - 38A80-G8VBE

Machine - NORTON - S3 6 x 18"

Wheel Size - 8" diameter, 1/2" face, 1-1/4" hole

Wheel Speed - 5,800 s.f.p.m.

Table Speed - Roughing 60 feet per minute

Finishing 60 feet per minute

Downfeed Roughing - .005" per cross-feed

Finishing - .001" per cross-feed

Cross-Feed Roughing - .050" per table reversal

Finishing - .050" per table reversal

Truing - Single point diamond, wet

Coolant - Water soluble oil 1 to 60

Finish Obtained - Roughing - 15-20 microinch, R.M.S.

Finishing - 10-12 microinch, R.M.S.

(nonreflective)

SNAGGING

The grinding wheels listed below are suitable for the indicated type of snagging operations on the Ni-Resist irons and Ni-Resist ductile irons.

Type of Grinding	Type of Wheel	Wheel Marking
Snagging		
General	Straight	A16Q
Notching	Raised Hub	A24-RBD
Blending	Raised Hub	A24-KBFR

CUTTING-OFF

a. General

Recommended Wheels - Dry - A30-P6B9FS

Wet - A46-M6R50

Coolant - Rust inhibitor and water 1 to 60 ratio

Rate of cut - 6 seconds per 2-1/8" piece

Wheel Wear - .02 on diameter per cut

Results - No burn, no burr

b. Gates and Risers

Aluminum oxide reinforced cut-off wheels of BNA resnoid bond are suitable for cutting-off gates and risers. This type wheel is also used for cleaning slots in castings and removing light burrs. A general purpose wheel designated A24-RBNA is suggested. If a more rigid wheel is needed use A24-R14BN.

HONING

Silicon carbide honing stones of vitrified bond and of J to S grade are usually satisfactory. Material of high hardness is honed with a softer grade stone than material of lower hardness.

The rotation of the hone is 125 to 225 feet per minute with a reciprocating speed of 40 to 80 feet per minute. Endeavor to maintain a cross-hatch pattern on the order of 60^{o} to 80^{o}.

Suitable honing coolants are:

Sulfur base oil and kerosene mixed 1 part oil and 10 parts kerosene.

A mixture of 50 percent oletic acid, 35 percent kerosene and 15 percent turpentine, kerosene and mineral seal oil are also suitable.

Honing coolants should be filtered and maintained at low constant temperature.

Specimens 3 inch I.D. X 5 inch O.D. X 8 inches long of Ni-Resist irons and Ni-Resist ductile irons noted below were honed by Micromatic Hone Corporation, (1) Detroit, Michigan to obtain general honing information on this family of alloys. The specimens for honing were in the as-cast condition. These materials are shown in Table XV.

TABLE XV

Material	Tensile Strength PSI	Hardness BHN
Type 2	31,600	153
Type 3	29,200	149
Type D-2	74,200	179
Type D-3	70,700	192

(1) The cooperation of Micromatic Hone Corporation is gratefully appreciated.

RESULTS C ͞ HONING TE: TS ON MATERIALS LISTED IN TABLE XV

	Type 2 Ni-Resist iron Type D-2 & Type D-3 Ni-Resist ductile iron	Type 3 Ni-Resist iron
Hole diameter honed	3"	3"
Designation of Honing Stone	C80-R-VE	C60-N4-VE
Spindle Speed	160 rpm 125 fpm	135 rpm 105 fpm
Reciprocating Speed, strokes-Up and Down	50 per min. 75 fpm; 9" stroke	45 67 fpm; 9" stroke
Honing lubricant	30% Union Base oil plus 70% Kerosene	30% Union Base oil plus 70% Kerosene
Surface Roughness in Micro Inches	40 - 80	40 - 80

Five 3/8 inch square X 4 inch long honing stones were mounted in each hone head.

These data are intended to establish basic honing factors for the materials rather than to exemplify the smoothest attainable finish. Smoother finishes than those recorded are attainable with finer abrasive stones and by decreasing the honing pressure as the finished honed size is reached. For instance, with 280 grit abrasive, a 15 to 20 microinch finish would be projected.

LAPPING

Lapping is accomplished with a bonded abrasive wheel lap, or with cast iron laps using loose abrasives carried in a vehicle.

Upon using the latter lapping method it is preferred that the lap material be lower in hardness than the material being lapped. Aluminum oxide grain has served satisfactorily for lapping. Sperm oil or mineral seal oil is a suitable lapping abrasive vehicle. Use low lapping pressures.

Following grinding of the specimens noted in Table XIV Norton Company, Worcester, Massachusetts subjected them to lapping. There was no distinguishable difference between the lapping characteristics of the materials. The data tabulated below from this work will serve as basic information for lapping each of the various Types of Ni-Resist irons and Ni-Resist ductile irons produced.

Cylindrical rolls must first be cylindrically ground to insure roundness.

Cylindrical Lapping - Vertical Machine

Machine - NORTON #28 Lapper with gray cast iron laps of 28 to 32 Scleroscope hardness; not serrated.

Lapping Medium - U. S. Products - 38-1200 Hard Alumina of 2-3 microns grit size.

Speeds - Upper Lap - 0 r.p.m.
Lower Lap - 30 r.p.m.

Eccentricity - 1/8"

Lubricant - Esso Lapping Oil; 10 parts Mentor #28 to 1 part Fanox #32

Finish Obtained - 3 to 4 Microinch R.M.S.

Flat Lapping - Vertical Machine Using Bonded Abrasive Wheels

Recommended Lapping Wheel - Roughing - 39C180-J9V with 3/8" perforations.

Finishing - A500-L8B

Machine - NORTON #26 HYPROLAP

Speeds - Upper Lap - 92 r.p.m.
Lower Lap - 100 r.p.m.

Eccentricity - 1/4"

Lubricant - Mineral seal oil, filtered

Finish Obtained - Roughing - 8-16 Microinch R.M.S.
Finishing - 2-6 Microinch R.M.S.

Material Removed - Roughing - .0165" per minute
Finishing - .001" per minute

SUPERFINISHING

Ni-Resist iron and Ni-Resist ductile iron specimens 2 inches O.D. X 4-1/2 inches long were superfinished by Gisholt Machine Company, (1) Madison, Wisconsin to obtain basic information on their response to superfinishing. The materials evaluated appear in Table XVI.

TABLE XVI

Ni-Resist Alloy	Condition	Tensile Strength (psi)	Hardness (BHN)
Type 2	As Cast	27,000	138
Type 3	As Cast	37,000	138
Type D-2	As Cast	59,000	170
Type D-3	As Cast	61,800	170

(1) The cooperation of the Gisholt Machine Company is gratefully appreciated.

RESULTS OF SUPERFINISHING TESTS ON MATERIALS LISTED IN TABLE XVI

Ni-Resist Alloy	Diam. of Specimen		RMS of Specimen		RPM of Machine Spindle		Designation of Superfinishing Stone
	Before	After	Before	After	Roughing	Finishing	
Type 2	1.9985	1.995	125-220	3-5	300	600	C-600-P5 Sulfur Treated
Type 2	1.999	1.9965	120-210	3-6	300	600	C-600-M7 "
Type 3	2.000	1.9975	100-150	4-8	300	500	C-600-P5 "
Type 3	1.999	1.998	100-210	4-7	300	500	C-600-P5 "
Type D-2	1.9975	1.994	90-140	3-6.5	400	800	C-600-J9 "
Type D-2	1.997	1.993	70-135	3-6.5	400	800	C-600-J9 "
Type D-3	1.998	1.9935	135-200	3-4	400	500	C-600-P5 "
Type D-3	1.980	1.975	75-210	3-6	400	600	C-600-M7 "

All specimens were superfinished from a machined surface.

The superfinish stone was oscillated at approximately 300 oscillations per minute.

The transverse rate of the superfinishing unit was 3-1/2 inches in 7 seconds.

The pressure on the stone for roughing was 80 psi and for finishing 40 psi.

The lubricant used in this instance for superfinishing was Vacmul 3D, a product of Socony Vacuum. Other proprietary lubricants would, of course, be suitable. For instance, a mixture of 10 per cent of International Chemical Company's No. 155 compound with 90 per cent kerosene or mineral seal oil.

The lubricant was filtered through 10 ply filter paper.