

Niobium and Niobium Alloys—Machining and Forming Operations

INTRODUCTION

Niobium is a highly ductile, soft refractory metal. The machining characteristics of niobium and its common alloys are similar to those of 316 stainless steel, and in lathe turning they behave much like soft copper. The chemical compositions, along with the physical and mechanical properties of niobium and its two most common alloys are listed in Tables 1 and 2. Guidelines and recommendations for specific machining and forming operations are given below. The advice and data should be used as starting points for working with niobium and its alloys. Fine chips and grinding dust of niobium and niobium-based alloys may burn and sustain combustion. Please read the safety warning at the end of this data sheet.

Table 1: Chemical compositions of Niobium / Niobium alloys			
	Nb	Nb – 1 Zr	C-103
Niobium	99.7	98.5	86-89
Zirconium	---	0.8 – 1.2	0.7
Hafnium	---	0.01	9.0 – 11.0
Titanium	---	---	0.7 – 1.3
Tantalum	---	0.2	0.5
Tungsten	---	0.05	0.5
Other			
Impurities:	<0.3 total	< 0.03 oxygen	< 0.03 nitrogen
		< 0.03 nitrogen	< 0.03 nitrogen
		< 0.002 hydrogen	< 0.002 hydrogen

Table 2: Physical and mechanical properties of Niobium			
Physical Properties	Nb	Nb-1Zr	C-103
ATOMIC NUMBER	41	---	---
ATOMIC WEIGHT	92.91	---	---
DENSITY (g/cc at 20°C) (lbs/cubic inch)	8.66 0.310	8.59 0.310	8.87 0.320
MELTING POINT	2468°C (4474°F)	2407°C (4365°F)	2350°C (4260°F)
BOILING POINT	4927°C (8900°F)	---	---
COEFFICIENT OF THERMAL EXPANSION (per°C at 25°C/73F)	7.3 x 10-6	7.54 x 10-6	8.10 x 10-6
SPECIFIC HEAT (BTU / lb /°F)	---	0.065	0.082
ELECT. RESISTIVITY ohm-cm at 20°C (68F)	15.0	14.7	---
LATENT HEAT OF FUSION (kJ/mol)	26.8	---	---
LATENT HEAT OF VAPORIZATION(kJ/mol)	697	---	---
Mechanical Properties			
HARDNESS Brinell (MN/m ²) Vickers (MN/m ²)	736 1320	---	---
TENSILE STRENGTH	---	241	725
MPa (psi)	---	(35)	(105)
YIELD STRENGTH	---	138	670
MPa (psi)	---	(20)	(97)
POISSON'S RATIO	0.38	---	---

MACHINING OPERATIONS

Normal machining techniques may be used for niobium, however it does have a tendency to gall, tear and weld to the face of the cutting tool, which makes tool design and lubricant selection very important. Both carbide and high-speed steel tools may be used, although the tendency to gall is greater with the carbide tools. Water-soluble cutting oils that contain sulfur or chlorine are preferred for most machining operations on niobium, except in turning, where a soluble-oil emulsion is satisfactory. A dilute soluble-oil emulsion as a grinding fluid is also recommended, which is better for producing fine finishes. Information for specific operations are given below:

Turning

Niobium and niobium alloys can be turned using standard shop equipment, however there are a few special guidelines to follow. It is important to use high positive rake angles to reduce cratering and abrasive wear. Also, chip breakers have not proven to be practical because of niobium's tough, stringy nature. This makes tool design and selection critical to turning operations. Recommended operating parameters are given in Tables 3 and 4.

Table 3: Single point turning of Niobium						
Carbide Tool				High Speed Steel Tool		
Depth of cut in (mm)	Tool material AISI (ISO)	Speed fpm (m/min)	Feed ipr (mm/r)	Tool material AISI (ISO)	Speed fpm (m/min)	Feed ipr (mm/r)
0.040	C-2	250	0.005	T15, M42	80	0.005
0.150	C-2	240	0.005	T15, M42	70	0.005
(1.0)	(K20, M20)	(80)	(0.13)	(S9, S11)	(24)	(0.13)
(4.0)	(K20, M20)	(75)	(0.13)	(S9, S11)	(21)	(0.13)

Table 4. Feed ipr (mm/r)									
Tool	Speed	Cutoff Tool Width			Form Tool Width				
AISI(ISO)	fpm (m/m)	.062 in (1.5mm)	.125in (3mm)	.250in (6mm)	.500 in (12mm)	.750 in (18mm)	1.00 in (25mm)	1.50 in (35mm)	2.00 in (50mm)
T15, M42	55	.001	.001	.0015	.0015	.0015	.001	.0007	.0007
C-2	185	.001	.001	.0015	.0015	.0015	.001	.0007	.0007
(S9, S11)	(20)	(.025)	(.025)	(.038)	(.038)	(.038)	(.025)	(0.018)	(0.018)
(K40, M40)	(58)	(.025)	(.025)	(.038)	(.038)	(.038)	(.025)	(0.018)	(0.018)

Milling

There are two important factors to consider when milling niobium and its alloys: first, selecting a good cutting fluid, and also using the proper tool design. It is best to use a 0 axial rake angle and a positive 40 radial rake angle. Data for specific milling operations is listed in Tables 5 – 10.

Table 5: Face milling of Niobium						
Carbide Tool				High Speed		
				Steel Tool		
Depth of cut in (mm)	Tool material AISI (ISO)	Speed fpm (m/min)	Feed per tooth in (mm)	Tool material AISI (ISO)	Speed fpm (m/min)	Feed per tooth in (mm)
0.040	C-2	150-165	0.002	T15, M42	100	0.003
0.150	C-2	140-155	0.004	T15, M42	80	0.003
(1.0)	(K10, M20)	(46-50)	(0.10)	(S9, S11)	(30)	(0.10)
(4.0)	(K10, M20)	(43-47)	(0.15)	(S9, S11)	(24)	(0.15)

Table 6: Slab milling of Niobium

Depth of cut in (mm)	Tool material AISI (ISO)	Speed fpm (m/min)	Feed per tooth in (mm)
0.040	M2, M7	70	0.004
0.150	M2, M7	60	0.004
(1.0)	(S4, S2)	(21)	(0.102)
(4.0)	(S4, S2)	(18)	(0.102)

* 27° or more angle

Table 7: Hollow milling of Niobium

Tool material AISI or C (ISO)	Speed fpm (m/min)	Feed ipr (mm/r)
M2, M7	40	0.004
C-2	110	0.008
(S4, S2)	(12)	(0.102)
(K20)	(34)	(0.20)

Table 8: Side and slot milling of Niobium

Carbide Tool				High Speed		
				Steel Tool		
Depth of cut in (mm)	Tool material AISI (ISO)	Speed fpm (m/min)	Feed per tooth in (mm)	Tool material AISI (ISO)	Speed fpm (m/min)	Feed per tooth in (mm)
0.040	C-2	165 to 200	0.003	T15, M42	135 to 150	0.003
0.150	C-2	150 to 190	0.004	T15, M42	125 to 140	0.004
0.300	C-2	140 to 175	0.005	T15, M42	115 to 125	0.005
(1.0)	(K10, M20)	(46-55)	(0.15)	(S9, S11)	(41)	(0.13)
(4.0)	(K10, M20)	(43-52)	(0.18)	(S9, S11)	(38)	(0.15)
(8.0)	(K10, M20)	(40-49)	(0.20)	(S9, S11)	(35)	(0.18)

Table 9: End milling of Niobium

Axial depth of cut	Tool material	Speed	Feed in/tooth (mm/tooth) Width of Slot			
			3/8 in (10mm)	1/4 in (12mm)	3/4 in (18mm)	1-2 in (25-50mm)
In (mm)	AISI (ISO)	fpm (m/min)				
0.030	T15, M42	60	.0007	.001	.0015	.002
0.060	T15, M42	55	.0005	.0015	.002	.003
dia/4	T15, M42	50	---	.001	.0015	.002
(0.75)	(S9, S11)	(18)	(.018)	(.025)	(.038)	(.050)
(1.5)	(S9, S11)	(17)	(.013)	(.038)	(.050)	(.075)
(dia/4)	(S9, S11)	(15)	---	(.025)	(.038)	(.050)

Table 10: Thread milling of Niobium

Tool material AISI or C (ISO)	Speed fpm (m/min)	Feed in/tooth/rev (mm/tooth/rev)
M2, M7	60	0.0015
(S4, S2)	(18)	(0.038)

*Requires high rake angle

Drilling

Drilling niobium and its alloys is accomplished using standard high-speed drills. It is necessary to check the peripheral lands of the drill often for excessive wear; this will prevent drilling undersized holes. A rigid setup and good drill design will give the best results. Drill may oversize up to 10%; double drilling may be appropriate. Operating recommendations for drilling niobium and its alloys are listed in Tables 11 – 14.

Table 11: Drilling of Niobium									
		Feed ipr (mm/r) Nominal Hole Diameter							
Tool	Speed								
AISI or C (ISO)	fpm (mm/min)	1/16 in (1.5mm)	1/8 in (3mm)	1/4 in (6mm)	1/2 in (12mm)	3/4 in (18mm)	1 in (25mm)	1-1/2 in (35mm)	2 in (50mm)
T15, M42	50	0.001	---	---	---	---	---	---	---
T15, M42	80	---	0.003	0.005	0.007	---	---	---	---
(S9, S11)	(15)	(.025)	---	---	---	---	---	---	---
(S9, S11)	(24)	---	(.075)	(0.13)	(0.18)	---	---	---	---

Table 12: Tapping of Niobium				
Tool material	Speed			
	fpm (m/min) Threads per inch			
	7 or less	8-15	16-24	over 24
	(Pitch – mm)			
AISI (ISO)	(over 3)	(1.5-3)	(1-1.5)	(1 or less)
M10, M7, M1	3	7	9	10
(S2, S3)	(0.9)	(2.1)	(2.7)	(3.0)
As tapping is the most difficult operation listed here, broken taps are to be expected.				

Table 13: Boring of Niobium						
Carbide Tool				High Speed		
				Steel Tool		
Depth of cut in (mm)	Tool material AISI (ISO)	Speed fpm (m/min)	Feed per tooth in (mm)	Tool material AISI (ISO)	Speed fpm (m/min)	Feed per tooth in (mm)
0.010	C-2	280 to 250	0.002	M2, M3	80	0.002
0.050	C-2	225 to 200	0.004	M2, M3	65	0.004
0.100	C-2	175 to 158	0.005	M2, M3	55	0.005
(0.25)	(K20, M20)	(78)	(0.050)	(S4, S5)	(24)	(0.050)
(1.25)	(K20, M20)	(62)	(0.102)	(S4, S5)	(20)	(0.102)
(2.5)	(K20, M20)	(48)	(0.13)	(S4, S5)	(17)	(0.13)

Table 14: Reaming of Niobium							
		Feed ipr (mm/r) Nominal Hole Diameter					
Tool	Speed						
AISI or C (ISO)	fpm (mm/min)	1/8 in (3mm)	1/4 in (6mm)	1/2 in (12mm)	1 in (25mm)	1-1/2 in (35mm)	2 in (50mm)
M1, M2, M7	90 (rough) 40 (finish)	.003	.004	.006	.008	.009	.010
C-2	120 (rough) 60 (finish)	.004	.005	.007	.009	.011	.012
(S2, S3, S4)	27 (rough) 12 (finish)	(.075)	(.102)	(.15)	(.20)	(.23)	(.25)
(K20)	37 (rough) 18 (finish)	(.102)	(.13)	(.18)	(.23)	(.28)	(.30)

* Anticipate 20 micro-inch surface finish at best

Grinding

Niobium and its alloys can be difficult to grind. Most grinding wheels will quickly load, making selection and application of grinding fluid crucial to obtaining a good finish. Care must also be taken to prevent the metal surface from heating up during grinding to prevent a surface hydrogen pickup. Specific guidelines for the different grinding types are shown in Tables 15 – 18.

Table 15: Surface grinding of Niobium

Wheel speed fpm (m/s)	Table speed fpm (m/min)	Downfeed in/pass (mm/pass)	Crossfeed in/pass (mm/pass)	Wheel Identification ANSI (ISO)
2000-4000	40-60	Rough: 0.001 Finish: 0.0005 max	0.020 – 0.200 max=1/12 of wheel width	C46JV
(15)	(12)	(Rough: 0.025) (Finish: 0.013 max)	(0.5 – 5.0) (max=1/12 of wheel width)	C46JV

Table 16: Cylindrical grinding of Niobium

Wheel speed rpm	Work speed fpm (mm/min)	Infeed On Diameter in/pass (mm/pass)	Traverse wheel width per revolution of work	Wheel Identification ANSI (ISO)
3600 to 6000	50 – 100	Rough: 0.001 Finish: 0.0003 max	1/5 – 1/10	C46jV
	(15-30)	(Rough: 0.025) (Finish: 0.008 max)	(1/5 – 1/10)	(C46jV)

Table 17: Internal grinding of Niobium				
Wheel Speed rpm	Work speed fpm (m/min)	Infeed On Diameter in/pass (mm/pass)	Traverse wheel width per revolution of work	Wheel Identification ANSI (ISO)
6000	50 – 150	Rough: 0.001 Finish: 0.0005 max	1/3 – 1/6	C46jV
	(15-46)	(Rough: 0.025) (Finish: 0.013max)	(1/3 – 1/6)	(C46jV)

Table 18: Centerless grinding of Niobium			
Wheel speed fpm (m/s)	Thrufeed of work on diameter in/min (m/min)	Infeed in/pass (mm/pass)	Wheel Identification ANSI (ISO)
4000	50 – 150	Rough: 0.001 Finish: 0.0005 max	A60LV
(20)	(1.3 – 3.8)	(Rough: 0.025) (Finish: 0.013 max)	(A60LV)

Sawing

No special considerations are necessary when sawing niobium and its alloys. High-speed steel blades can be used with power hacksaws, band saws, and circular saws. Sawing data is given in Tables 19 – 21.

Table 19: Power hack sawing of Niobium

Material thickness in (mm)	Teeth per inch pitch in (mm)	Speed strokes/min (strokes/min)	Feed in/stroke (mm/stroke)	Pressure
< .25	10	60	0.003	Light
.25 - .75	10	60	0.003	Light
.75 - 3	6	55	0.006	Medium
> 2	4	55	0.006	Medium
(< 6)	(2.5)	(60)	(0.075)	(Light)
(6 - 18)	(2.5)	(60)	(0.075)	(Light)
(18 - 50)	(4)	(55)	(0.15)	(Medium)
(> 50)	(6.3)	(55)	(0.15)	(Medium)

Table 20: Band sawing of Niobium

Material thickness in (mm)	Tooth form	Teeth per inch pitch in (mm)	Band speed fpm (m/min)
< .50	precision	14	100
.50 - 1	precision	10	90
1 - 3	precision	8	75
> 3	precision	6	65
(<12)	(precision)	(1.8)	(30)
(12 - 25)	(precision)	(2.5)	(27)
(25 - 75)	(precision)	(3)	(23)
(>75)	(precision)	(4)	(20)

Table 21: Circular sawing of Niobium

Stock diameter or thickness in (mm)	Tool Material AISI (ISO)	Pitch in/tooth (mm/tooth)	Speed fpm (m/min)	Feed in/tooth (mm/tooth)
.25 - 3	M2, M7	0.20 - 0.75	70	0.005
3 - 6	M2, M7	0.50 - 1.10	55	0.005
6 - 9	M2, M7	0.75 - 1.30	45	0.007
9 - 15	M2, M7	0.90 - 1.75	35	0.007
(6 - 80)	(S2, S4)	(5 - 20)	(21)	(0.13)
(80 - 160)	(S2, S4)	(12 - 30)	(17)	(0.13)
(160 - 250)	(S2, S4)	(20 - 35)	(14)	(0.18)
(250-400)	(S2, S4)	(25 - 45)	(11)	(0.18)

FORMING OPERATIONS

The forming characteristics of niobium and niobium alloys should be similar to copper and some mild steels. A copper blank is sometimes attempted before utilizing niobium. Niobium sheet metal can be formed easily without special working techniques. These operations are facilitated by niobium's low rate of work hardening. There are two unusual features that must be considered when working with niobium and its alloys. First, no appreciable softening occurs below 400°C (752°F), because of its high melting point. Also, sheathing protection is not practical, since the sheathing material is likely to be softer than the niobium. Niobium's cold working properties are excellent. Annealing is necessary after the surface has been worked 90%, with heat treatment at 1200°C (2192°F) for one hour causing complete recrystallization of material cold worked over 50%. The annealing must be performed in an inert gas, or preferably, in a high vacuum. Guidelines for a few select forming operations are given below:

Spinning

Normal techniques of metal spinning may be applied successfully to niobium, with minor modifications. It is generally better to work the metal in stages; for example, when spinning a right-handed cup from flat sheet, several formers should be used to give steps of approximately 10°. Wooden formers may be used for rough spinning, but a brass or bronze former is essential for finishing, because the metal is soft and takes up the contour of the former. For small work, aluminum bronze or Narite tools should be used with a radius of approximately 3/8 inch. If sharp angles are required, the tool must be shaped accordingly. Yellow soap, or tallow, is suitable for lubricating the material, which must be cold worked continually. The peripheral speed of the work piece should be about 500 feet per minute. When spinning, niobium is prone to thinning and care must be taken to avoid this. The tool should be worked in many long sweeping strokes using a light pressure rather than a few heavy strokes.

Deep Drawing

Deep drawing of annealed niobium can be accomplished without much difficulty. Tool materials such as steel, aluminum bronzes, and beryllium copper can all be used for drawing operations. Single draws can be made if the depth of the draw does not exceed the diameter of the blank, and if multiple draws are made, the depth of the first draw should not exceed 40% of the blank diameter. For multiple draws, it may necessary to perform an intermediate vacuum anneal. Sulfonated tallow can be used as a lubricant.

Punching and Blanking

Normal dies and punches made of steel can be used satisfactorily for niobium and niobium alloys. The recommended clearance between the punch and die is 6% and light oils can be used to prevent scoring the dies. There are no special techniques required for stamping niobium. Tools made of steel, aluminum bronzes, and beryllium copper may be used, but they should be polished to prevent galling. A light oil lubricant can also be used to limit the amount of galling. Frequent cleaning of tooling may be necessary as galling and pickup of niobium on tooling can be expected.

SAFETY

Niobium is non-toxic and there are no specific safety requirements for working with it. Although coarse metal niobium and niobium alloy powders are difficult to ignite, even at 300°C (572°F), small surface area powder, chips, or filings of less than 5 microns may auto-ignite at room temperature. If a fire does start, it is best to let it burn itself out. Small fires can be controlled with Type D dry powder extinguishers or with dry salt. Under no circumstances should water be used, as a violent explosion may result.