A Cutting-Edge Combination

Crucible Industries

NIAGARA
SPECIALTY METALS

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Knife photo courtesy
of Chris Reeve Knives

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Niagara Specialty Metals was founded in 1982 by Barry Hemphill and Louis Valery. The mill was originally designed to roll tool steel billets into sheet and plate, and has evolved over the years so that today we now roll material for industries such as aerospace, electronics, medical and the specialty cutlery market.

For many years Niagara Specialty Metals rolled CPM®, tool steel, and stainless steel for Crucible. We were familiar with the popular knife alloys and knew they were of high quality. Crucible reorganized into Crucible Industries in late 2009, and we have been proud to sell CPM® in North America ever since. In fact, all of the steel we buy and sell is melted and made in the USA.

Crucible's roots can be traced back to 1776 when the Naylor and Sanderson Steel Mill was established in Sheffield England. A century later, the mill was exporting increasing quantities of steel to the United States and decided to open a facility in Syracuse NY. The mill, now known as Crucible Industries, has been in continuous operation ever since. The CPM process was developed by Crucible in the late 60's, and we have been introducing new grades for many critical industries and applications ever since.

Crucible Industries continues to be an innovator in the specialty metals industry. Together, we continue to listen to what the knife enthusiasts want from a blade steel and strive to meet those needs.

We rarely get to see where our product goes or how it gets used. This is not the case in the knife industry. Our employees love seeing pictures of your work and using knives made from the steel that they helped produce. It has been a privilege to work with so many established production knife makers, and with up and coming custom knife makers over the past few years. Your support for Crucible Industries and Niagara Specialty Metals has been humbling. We truly appreciate your business and we hope that you enjoy this booklet.

DATA SHEET

CPM S30V

Typical Composition

C	Cr	Mo	V
1.45	14.00	2.00	4.00

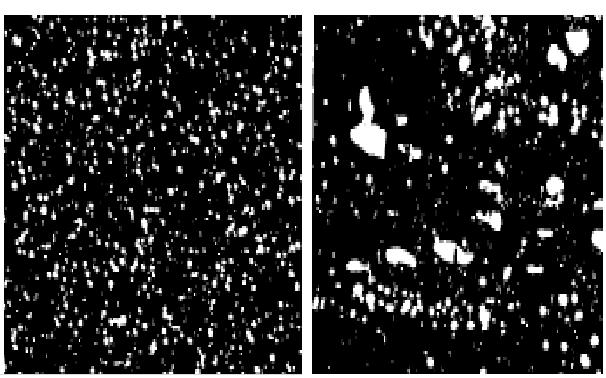
CPM S30V is a martensitic stainless steel designed to offer the best combination of toughness, wear resistance and corrosion resistance. Its chemistry has been specially balanced to promote the formation of vanadium carbides which are harder and more effective than chromium carbides in providing wear resistance. CPM S30V offers substantial improvement in toughness over other high hardness steels such as 440C and D2, and its corrosion resistance is equal to or better than 440C in various environments.

The CPM process produces very homogeneous, high quality steel characterized by superior dimensional stability, grindability, and toughness compared to steels produced by conventional processes.

The *typical applications* include long-wearing specialty cutlery, plastic injection and extrusion feed screws and dies, non-return valve components, pelletizing equipment, and wear components for food and chemical processing.

Machinability and Grindability

In the annealed condition, CPM S30V is much easier to machine than CPM S90V and is comparable to that of D2. Similar grinding equipment and practices used for high speed steels are recommended. “SG” type alumina wheels or CBN wheels have generally given the best performance with CPM steels.



CPM Steel Conventional Steel

Mechanical Properties

Toughness (Transverse Charpy C-notch Testing)

These higher transverse toughness results indicate that CPM S30V is much more resistant to chipping and breaking in applications which may encounter side loading. Its toughness makes it better for bigger blades in knife making.

Grade	Impact Energy
CPM S30V	10.0 ft.lbs
154 CM	2.5 ft. lbs
440C	2.5 ft. lbs

Edge Retention (CATRA Testing Relative to 440C)

Grade	%
CPM S30V	145
154 CM	120
440C	100

The CATRA test machine performs a standard cutting operation and measures the number of silica impregnated cards which are cut. It is considered a measure of relative wear resistance.

This data sheet is for informational purposes only. Alloy characteristics are subject to change due to chemical composition and/or processing. We do not certify the material’s suitability for specific applications.

DATA SHEET

Thermal Treatments

Forging: 2100°F (1150°C) do not forge below 1750°F (950°C).
Annealing: Heat to 1650°F (900°C), hold 2 hours, slow cool no faster than 25°F (15°C) per hour to 1100°F (595°C), then furnace cool or cool in still air to room temperature.
Annealed Hardness: About BHN 255

Stress Relieving
Annealed Parts: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.
Hardened Parts: Heat to 25-50°F (15-30°C) below original tempering temperature, hold 2 hours, then furnace cool or cool in still air.
Straightening: Best done warm 400-800°F (200-430°C).

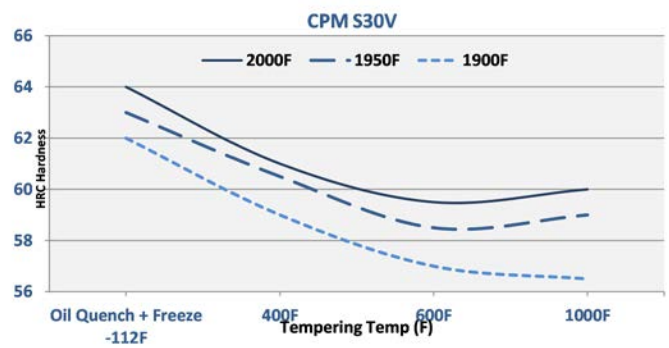
Hardening
Preheat: Heat to 1550-1600°F (845-870°C), Equalize.
Austenitize: 1900-2000°F (1035-1095°C), hold time at temperature 15-30 minutes.
Quench: Air or positive pressure quench (2 bar minimum) to below 125°F (50°C), or salt or interrupted oil quench to about 1000°F (540°C), then air cool to below 125°F (50°C).
Temper: Double temper at 400-750°F (200-400°C). Hold for 2 hours minimum each time. A freezing treatment may be used between the first and second tempers. Freezing treatments help to attain maximum hardenability and must always be followed by at least one temper.

NOTE: For optimum stress relieving, CPM S30V may be tempered at 1000-1025°F (540-550°C). Tempering in this range may result in a slight decrease in corrosion resistance.

Size Change: +0.05 to +0.10% when fully martensitic. The presence of retained austenite may reduce the net growth. When tempering at 400-750°F (200-400°C), freezing treatments may be necessary to minimize retained austenite.

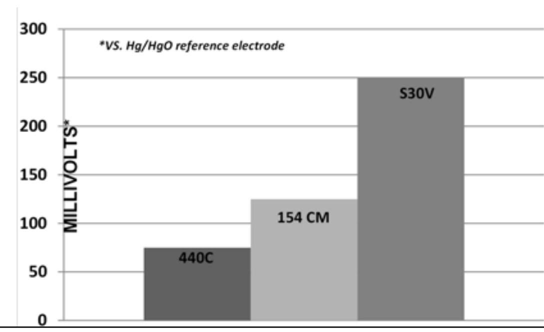
Recommended Heat Treatment:
Austenitize: 1950°F (1065°C). Quench to below 125°F (50°C). Double temper at 600°F (315°C) 2 hrs. minimum each temper. Cool to hand warm between tempers. A freezing treatment may be added between tempers.
Aim hardness: 58-61 HRC.

Heat Treat Response-Hardness (HRC) Austenitizing Temperature						
	1900°F (1040°C)		1950°F (1065°C)		2000°F (1095°C)	
Tempering Temp.	Oil	Oil & Freeze -112F	Oil	Oil & Freeze -112F	Oil	Oil & Freeze -112F
As Quenched	60.5	62	62	63	63.5	64
400°F(200°C)	57.5	59	57.5	60.5	59.5	61
600°F(315°C)	57.5	57	59	58.5	59	59.5
1000°F(540°C)	57	56.5	59.5	59	58.5	60
Results may vary with hardening method and section size. Salt or oil quenching will give maximum response. Vacuum or atmosphere cooling may result in up to 1-2 HRC points lower.						
Minimum Time at Aust. Temp.	30 min.		30 min.		20 min.	
Minimum Number of Tempers	2		2		2	



Corrosion Resistance

Average Pitting Potential measurements from Polarization Curves run in 5% NaCl (Sodium Chloride) Solution at Room Temp: (Higher voltage pitting potential indicates better corrosion resistance.)



DATA SHEET

CPM S35VN

Typical Composition				
C	Nb	Cr	Mo	V
1.40	0.50	14.00	2.00	3.00

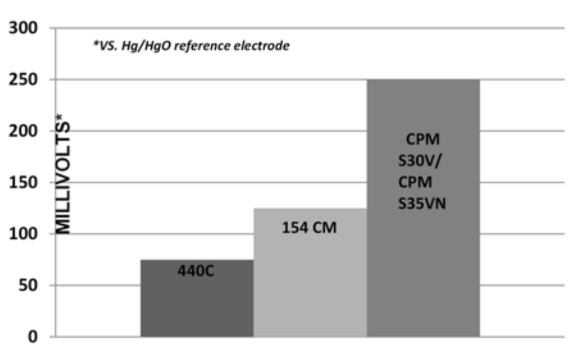
CPM S35VN is a martensitic stainless steel designed to offer improved toughness over CPM S30V. It is also easier to machine and polish than CPM S30V. Its chemistry has been rebalanced so that it forms some niobium carbides along with vanadium and chromium carbides. Substituting niobium carbides for some of the vanadium carbides makes CPM S35VN about 15-20% tougher than CPM S30V without any loss of wear resistance. CPM S35VN's improved toughness gives it better resistance to edge chipping. Because both vanadium and niobium carbides are harder and more effective than chromium carbides in providing wear resistance, the CPM stainless blade steels offer improved edge retention over conventional high chromium steels such as 440C and D2.

The CPM process produces very homogeneous, high quality steel characterized by superior dimensional stability, grindability, and toughness compared to steels produced by conventional melting practices.

The *typical applications* include: Long-wearing specialty cutlery, plastic injection and extrusion feed screws and dies, non-return valve components, pelletizing equipment, and wear components for food and chemical processing.

Corrosion Resistance

Average Pitting Potential measurements from Polarization Curves run in 5% NaCl (Sodium Chloride) Solution at Room Temperature: (Higher voltage pitting potential indicates better corrosion resistance.)



Toughness

Although the longitudinal toughness of all four grades is 25-28ft. lbs., the transverse toughness of the CPM grades is four times more than 440C and 154CM. CPM S35VN and CPM S30V are more resistant to chipping or breaking in applications with side loading and are better for bigger blades.

Grade	Impact Energy
CPM S35VN	12.0 ft. lbs.
CPM S30V	10.0 ft. lbs.
154 CM	2.5 ft. lbs.
440C	2.5 ft.lbs.

Edge Retention

The CATRA test is considered a measure of relative wear resistance compared to 440C, in the table.

Grade	%
S35VN	145*
S30V	145
154 CM	120
440C	100

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DATA SHEET

Thermal Treatments

Forging: 2100°F (1150°C) Do not forge below 1750°F (950°C).
Annealing: Heat to 1650°F (900°C), hold 2 hours, slow cool no faster than 25°F (15°C) per hour to 1100°F (595°C), then furnace cool or cool in still air to room temperature.
Annealed Hardness: About BHN 255

Stress Relieving
Annealed Parts: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.
Hardened Parts: Heat to 25-50°F (15-30°C) below original tempering temperature, hold 2 hours, then furnace cool or cool in still air.
Straightening: Best done warm 400-800°F (200-425°C).

Hardening
Preheat: Heat to 1550-1600°F (845-870°C), Equalize.
Austenitize: 1900-2000°F (1035-1095°C), hold time at temperature 15-30 minutes.
Quench: Air or positive pressure quench (2 bar minimum) to below 125°F (50°C), or salt or interrupted oil quench to about 1000°F (540°C), then air cool to below 125°F (50°C).
Temper: Double temper at 400-750°F (200-400°C). Hold for 2 hours minimum each time. A freezing treatment may be used between the first and second tempers. Freezing treatments help to attain maximum hardenability and must always be followed by at least one temper.
NOTE: For optimum stress relieving, CPM S35VN may be tempered at 1000-1025°F (540-550°C). Tempering in this range may result in a slight decrease in corrosion resistance.
Size Change: +0.05 to +0.10% when fully martensitic. The presence of retained austenite may reduce the net growth. When tempering at 400-750°F (200-400°C), freezing treatments may be necessary to minimize retained austenite.

Recommended Heat Treatment:
Austenitize 1950°F (1065°C). Quench to below 125°F(50°C). Double temper at 600°F (315°C) 2 hrs. minimum each temper. Cool to hand warm between tempers. A freezing treatment may be added between tempers.
Aim hardness: 58-61 HRC.

Carbide Type and Volume

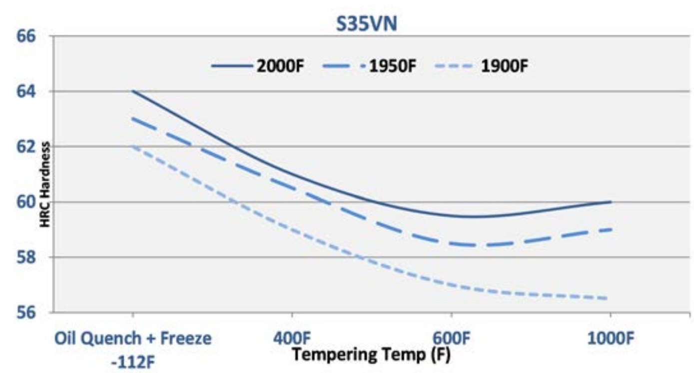
	Vanadium	Niobium	Chromium	Total
CPM S35VN	3.0%	0.5%	10.5%	14.0%
CPM S30V	4.0%		10.5%	14.5%
440C	0%		12.0%	12.0%
154 CM	0%		17.5%	17.5%
CPM S90V	9.0%		11.0%	20.0%

Heat Treat Response-Hardness (HRC)
Austenitizing Temperature

	1900°F (1040°C)		1950°F (1065°C)		2000°F (1095°C)	
Tempering Temp.	Oil	Oil +Freeze -112F	Oil	Oil + Freeze -112F	Oil	Oil + Freeze -112F
As Quenched	60.5	62	62	63	63.5	64
400°F(200°C)	57.5	59	57.5	60.5	59.5	61
600°F(315°C)	57.5	57	59	58.5	59	59.5
1000°F(540°C)	57	56.5	59.5	59	58.5	60

Results may vary with hardening method and section size. Salt or oil quenching will give maximum response. Vacuum or atmosphere cooling may result in up to 1-2 HRC points lower.

	1900°F	1950°F	2000°F
Minimum Time at Aust. Temp.	30 min.	30 min.	15 min.
Minimum Number of Tempers	2	2	2



Machinability and Grindability

In the annealed condition, CPMS35VN is much easier to machine than CPM S90V and easier to machine than CPM S30V. Similar grinding equipment and practices used for high speed steels are recommended. "SG" type alumina wheels or CBN wheels have generally given the best performance with CPM steels.

DATA SHEET

CPM 154

C	Cr	M
1.05	14.00	4.00

Typical Composition

CPM 154 is the CPM manufactured version of Crucible's standard 154 CM. The CPM manufacturing process produces a uniform distribution of the carbides in this grade, giving this CPM 154 easier grinding and polishing, plus better toughness, than conventional 154 CM, while retaining similar heat treat response and wear properties. CPM 154 offers better corrosion resistance, better wear resistance and better hot-hardness than 440C, plus higher toughness. For knifemakers, if offers better edge retention and chipping resistance than 440C.

The CPM process produces very homogenous, high quality steel characterized by superior dimensional stability, grindability, and toughness compared to steels produced by conventional processes.

The *typical applications* of CPM 154 include cutlery, bearings, and corrosion resistant tooling.

Machinability: Because of the CPM processing, CPM 154 is easier to machine and grind than standard 154 CM. General machining parameters are similar to 154 CM and 440C.

Conventional Steel CPM Steel

Mechanical Properties

Grade	Hardness (HRC)	Wear Resistance	Total Carbide Volume
154 CM	58.5	49 mg	17.5%
440C	57.5	66 mg, 55 mg	12%

*Wear resistance measured by the pin abrasion method. Lower number (mg.) is a lower weight loss (in mg) and therefore better wear resistance.

Hot Hardness

Heat Treatment	Initial HRC	HRC Test at:			Final HRC
		400°F	500°F	600°F	
A	62	59	58	55	60
B	62			55	62
C	64			57	64

DATA SHEET

Thermal Treatments

Annealing: Heat to 1650°F (900°C), hold 2 hrs., slow cool no faster than 25°F (15°C) per hour to 1200°F (650°C), then furnace cool or cool in still air to room temperature. Crucible 154 CM can be cycle annealed by heating to 1600°F (900°C), hold 2 hours, cool to 1300°F (704°C), hold 4 hours, then air cool.

Annealed Hardness: About BHN 235

Stress Relieving
Annealed Parts: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.

Hardened Parts: Heat to 25-50°F (15-30°C) below the original tempering temperature, hold 2 hours, then furnace cool or cool in still air.

Hardening
Preheat: Heat to 1400°F (760°C) Equalize.
Austenitize: 1900-2000°F (1037-1093°C), hold time at temperature 30-60 minutes.

Quench: Oil or positive pressure (4 bar minimum) to below
125°F (50°C) or salt quench to about 1000°F (540°C), then air cool to below 125°F (50°C). Salt bath treatment, if practical, will ensure the maximum attainable toughness for a given hardening treatment.

Temper: Twice at 400-1200°F (204-650°C), 2 hours minimum each time.

Note: As with all martensitic stainless steels, tempering at 800-1100°F (425-600°C) will result in sensitization which causes a minor reduction in both corrosion resistance and toughness. We recommend that this tempering range be avoided.

Aim hardness: HRC 55-62

Note: Properties shown throughout this data sheet are typical values. Normal variations in chemistry, size and heat treat conditions may cause deviations from these values.

Heat Treat Response HRC Hardness						
Austenitizing Temperature						
Tempering Temp.	1900°F (1040°C)		1950°F (1065°C)		2000°F (1095°C)	
Time at Temp	1 hr.		1 hr.		30 min.	
Quench (Optional Freeze)	Oil	Oil & Freeze	Oil	Oil & Freeze	Oil	Oil & Freeze
As Quenched	62	63	61	63	54	63
400°F(204°C)	59	60	59	62	52	62
600°F(315°C)	56	59	56	60	50	60
800°F(427°C)	56	56	57	60	50	61
900°F(482°C)	56	57	58	61	52	61
1000°F(540°C)	54	58	60	61	54	63
1050°F(565°C)	51	52	55	56	52	58
Results can vary with the use of the hardening method and section size. You will get the best result with Salt or Oil quenching. Vacuum or atmosphere cooling may result in up to 1-2 HRC points lower.						
Minimum Number of Tempers	2		2		2	

Recommended Heat Treat Practice

To completely transform any retained austenite, a freezing treatment with dry ice at -100°F(-74°C) is recommended either after the quench or in between the two tempers. The freezing treatment is most effective right out of the quench, however complex parts with sharp corners are more safely frozen between the two tempers. Thin sections can be successfully quenched in forced air and will obtain results to those in the table above.

Surface Treatments

If surface treatments such CVD, PVD, or nitriding are used, ensure that the coating process temperature is below the tempering temperature. Nitriding or tempering at 900°F or higher may reduce the corrosion resistance of CPM 154 or any other stainless steel.

NIAGARA SPECIALTY METALS

Crucible Industries®

DATA SHEET

CPM 3V

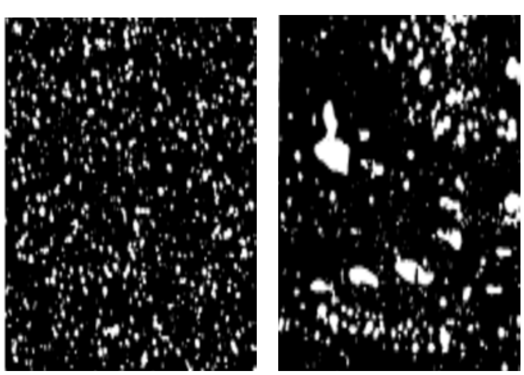
Typical Composition

C	Cr	Mo	V
0.80	7.50	1.30	2.75

CPM 3V, made by the Crucible Particle Metallurgy process, is designed to provide maximum resistance to breakage and chipping in a highly wear-resistant tool steel. CPM 3V offers impact toughness greater than A2, D2, Cru-Wear or CPM M4, approaching the levels of S7 and other shock resistant grades, yet it provides excellent wear resistance, high hardness and thermal stability for coatings. Intended to be used at HRC 58-60, CPM 3V can replace high alloy tool steels in wear applications where chronic tool breakage and chipping problems are encountered.

The CPM process produces very homogeneous, high quality steel characterized by superior dimensional stability, grindability, and toughness compared to steels produced by conventional processes.

The *typical applications* of CPM 3V are stamping or forming tools, punches and dies, powder compaction tooling, blanking dies, industrial knives and slitters, shear blades, fine blanking tools, scrap choppers, cold heading tooling, rolls, and plastic injection feeder screws and tips.



CPM Steel Conventional Steel

Mechanical Properties

Impact Toughness
The CPM microstructure gives 3V its high impact toughness which approaches that of the shock-resistant tool steels.

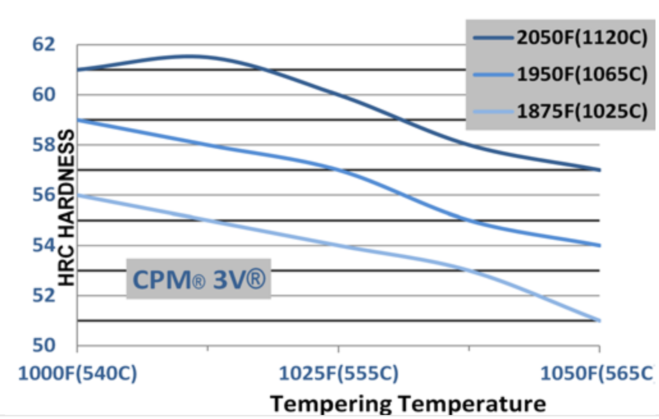
Wear Resistance
Due to the Vanadium carbides in it microstructure, CPM 3V has excellent wear resistance, like D2.

Relative Mechanical Properties
The combination of wear resistance and toughness of CPM 3V makes it an excellent alternative to S7, A2, D2, Cru-wear, M2 or CPM M4 due to its high impact toughness and high range of wear resistance.

DATA SHEET

	Heat Treatment Austenitizing Temp	HRC	Impact Toughness Ft.-lb. (J)	HRC
CPM 3V	1875°F	58	85	58
CPM 3V	1950°F	60	70	60
CPM 3V	2050°F	62	40	62
S7	1750°F	57	125	57
A2	1750°F	60	40	60
D2	1850°F	60	21	60
CRU-WEAR	1950°F	62	30	62
M2	2050°F	62	20	62
CPM M4	2050°F	62	32	62

Heat Treat Response HRC Hardness			
Austenitizing Temperature			
Tempering Temp	1875°F(1025C)	1950°F(1065C)	2050°F(1120C)
Minimum Time	45 Min	30 Min	20 Min
As Quenched	58	62	63
1000°F(540°C)	56	59	61
1025°F(555°C)	54	57	60
1050°F(565°C)	51	54	57
Minimum Tempers	2	3	3



Surface Treatments

Because of its high tempering temperatures (>1000°F) CPM 3V is suitable for nitriding, PVD coating or similar surface treatments. CVD coating processes generally exceed the critical temperature and may result in non-predictable dimensional changes.

Thermal Treatments

Annealing: Heat to 1650°F(900°C), hold 2 hours, slow cool no faster than 25°F (15°C) per hour to 1100°F (595°C), then furnace cool or cool in still air to room temperature.
Annealed Hardness: About BHN 241

Stress Relieving

Annealed Parts: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.
Hardened Parts: Heat to 25-50°F (15-30°C) below original tempering temperature, hold 2 hours, then furnace cool or cool in still air.

Hardening

Preheat: Heat to 1500-1550°F (815-845°C), Equalize.
Austenitize: 1875-2050°F (1025-1120°C), hold time at temperature 20-45 minutes.
Quench: Air or positive pressure quench (2 bar minimum) to below 125°F (50°C), or salt or interrupted oil quench to about 1000°F (540°C), then air cool to below 125°F (50°C). Salt bath treatment, if practical, will ensure the maximum attainable toughness for a given hardening treatment.
Temper: Three times at 1000-1050°F (540-565°C), 2 hours minimum each time. **Size Change: +0.03/0.05%**

Recommended Heat Treatment: For the best combination of toughness and wear resistance, austenitize at 1950°F(1065°C), hold 30-45 minutes, and quench. Temper 3 times at 1000°F (540°C).

Aim hardness: HRC 58-60 higher austenitizing temperatures can be used to obtain higher hardness, at a slight decrease in impact resistance. The lower austenitizing temperatures provide the best impact toughness.

Machinability and Grindability

Machinability in the annealed condition is similar to D2 and CRU-WEAR, but grindability will be slightly better. Similar grinding equipment and practices are acceptable. “SG” type alumina wheels or CBN wheels have generally given the best performance with CPM steels.

DATA SHEET

CPM 4V

Typical Composition

C	Mn	Si	Cr	Mo	V
1.35	0.40	.80	5.0	2.95	3.85

CPM 4V, made by the Crucible Particle Metallurgy process, is a powder tool steel designed as an upgrade for **CPM 3V** for the blanking and advanced high strength steel applications. Crucible's primary goal was to design an alloy with high impact toughness and more wear resistance than currently available with **CPM 3V.** Knife makers have often regarded **CPM 3V** as a great heavy duty knife material and **CPM 4V** will be an improvement for those who need more wear resistance. Intended to be used at HRC 62-64. **CPM 4V** should be used in **CPM 3V** applications that require more wear resistance.

The *typical applications* of **CPM 4V** are powder compaction tooling, fine blanking tools, stamping or forming tools, and advanced high strength steel applications.

Mechanical Properties

Impact Toughness

The CPM microstructure gives 4V its high impact toughness which approaches that of the shock-resistant tool steels.

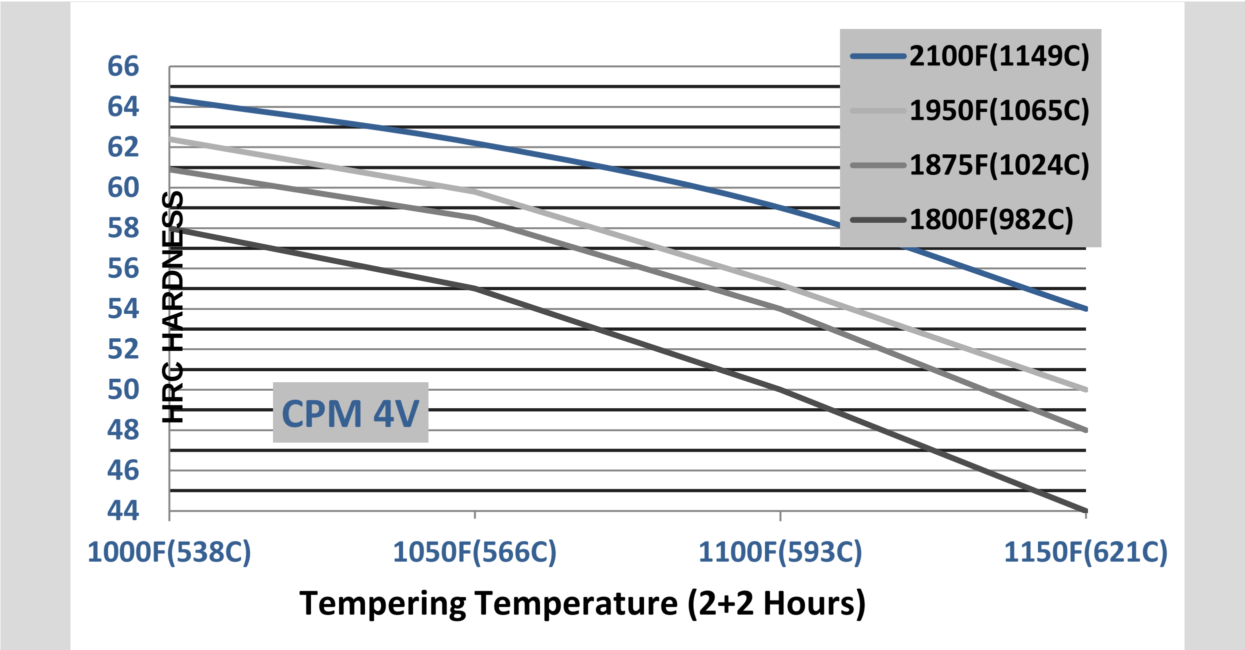
Relative Mechanical Properties

The combination of wear resistance and toughness of CPM 4V makes it an excellent alternative to some other tool steel due to its high impact toughness and high range of wear resistance.

Heat Treat Response

HRC Hardness				
	Austenitizing Temperature			
Tempering Temp Minimum Time	1800°F (982°C) 30 Min	1875°F (1024C) 30 Min	1950°F (1065C) 30 Min	2100°F (1149C) 15 Min
As Quenched	62.5	63.5	64.5	64.0
1000°F (540°C)	58.0	60.9	62.4	64.4
1050°F (565°C)	55.0	58.5	59.8	62.2
1100°F (593°C)	50.0	54.0	55.2	59.0
1150°F (621°C)	44.0	48.0	50.0	54.0
Minimum Tempers	2	3	3	3

DATA SHEET



Thermal Treatments

Hardening

Preheat: Heat to 1500-1550°F (816-845°C), equalize.

Austenitize: Following preheat heat material rapidly.

Quench: Air or positive pressure quench (4 bar minimum), or oil quench (black) to about 900°F (482°C), then air cool to 150°F - 125°F (66°C - 51°C). Salt bath treatment, if practical, will ensure the maximum attainable toughness for a given hardening treatment. Salt quench at 1000°F-1100°F (538°C-593°C), equalize, then air cool to 150°F-125°F (66°C-51°C).

Temper: Immediately after quenching, temper three times (two times minimum) at 1000-1100°F (538-593°C). Hold at temperature for 1 hour per inch of thickness, 2 hours minimum, then air cool. Do not temper below 1000°F (538°C).

Recommended Heat Treatment: For the best combination of toughness and wear resistance, austenitize (furnace or salt bath) at 1875-1950°F (1024-1065°C), soak 30 minutes, and quench. Temper 3 times at 1000°F (538°C). For maximum wear resistance austenitize (furnace or salt bath) at 2100°F (1149°C), soak 15 minutes, and quench. For maximum toughness austenitize (furnace or salt bath) at 1800°F (982°C), soak 30 minutes, and quench.

Aim hardness: HRC 62-64 higher austenitizing temperatures can be used to obtain higher hardness, at a slight decrease in impact resistance. The lower austenitizing temperatures provide the best impact toughness.

Annealing

Annealing must be performed after hot working and before rehardening. Heat at a rate no higher than 400°F (222°C) per hour to 1600-1650°F (871-899°C). Hold at temperature for 1 hour per inch of thickness, 2 hours minimum. Cool slowly with the furnace at a rate no higher than 50°F (28°C) to 1000°F (649°C), until cooled to ambient temperature, in the furnace or in air.

DATA SHEET

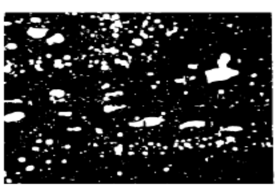
CPM S60V

Typical Composition			
C	**Cr**	**Mo**	**V**
2.15	**17.0**	**0.4**	**5.5**

CPM S60V is a corrosion-resistant, highly wear-resistant tool steel made by the Crucible Particle Metallurgy process. It is essentially 440C martensitic stainless steel enriched with a uniform dispersion of very fine vanadium carbides for exceptionally good wear resistance. CPM S60V offers corrosion resistance equivalent to 440C with substantial improvement in wear resistance over both 440C and D2, and other high chromium tool steels. With characteristics of both stainless steels and tool steels, S60V is ideally suited for corrosion-resistant applications requiring unusually high wear resistance, as well as for high wear applications, requiring corrosion resistance. To the custom knifemaker, CPM S60V offers a corrosion-resistant bladestock with exceptional edge-holding characteristics. Only CPM S90V surpasses S60V in both wear and corrosion properties, but, it should be noted that S60V is easier to grind due to its lower vanadium content.

The CPM process results in a finer, more uniform carbide distribution imparting improved toughness and grindability to high alloy steels. The CPM process also allows the design of more highly alloyed grades which cannot be produced by conventional steelmaking.

Typical Applications: Long-Wearing Specialty Cutlery, Industrial Knives, Slitters, Cutters, Pelletizing Equipment, and Wear Components for Food and Chemical Processing. (Note: these are some typical applications. Your specific application should not be undertaken without independent study and evaluation for suitability).



CONVENTIONAL STEEL CPM STEEL

Physical Properties

Elastic Modulus	$31X10^6$ psi	215 GPa
Density	0.27 lbs/in^3	7.4g/cm^3
Thermal Conductivity	@200°F (65°C)	
	10 BTU/hr-ft-°F	17.3 W/m-°K

Coefficient of Thermal Expansion

°F	°C	**in/in/°F**	**mm/mm/ °C**
70-400	20-200	6.1 X 10^{-6}	11.0 X 10^{-6}
70-600	20-315	6.4 X 10^{-6}	11.5 X 10^{-6}
70-1100	20-593	6.8 X 10^{-6}	12.2 X 10^{-6}

Mechanical Properties

	Hardness (1)		Impact Toughness (2)	
	HRC	Heat Treatment	Ft.lb	(Joules)
CPM S60V	56	(A)	16	(22)
CPM S60V	59	(B)	12	(16)
CPM S60V	60.5	(C)	11	(15)
440C	56	(D)	26	(35)
440C	58	(E)	16	(22)
D2	59	(F)	21	(29)

1.) A=Hardened 1850°F (1010°C), double tempered 400°F (205°C).
B=Hardened 1950°F (1065°C), double tempered 400°F (205°C).
C=Hardened 2050°F (1120°C), double tempered 400°F (205°C).
D=Hardened 1900°F (1040°C), double tempered 600°F (315°C).
E=Hardened 1900°F (1040°C), double tempered 400°F (205°C).
F=Hardened 1850°F (1010°C), double tempered 600°F (315°C).
2.) Charpy C-Notch impact test

DATA SHEET

Corrosion Resistance

The corrosion resistance of CPM S60V is generally comparable to that of 440C. High temperature oxidation resistance is somewhat lower than 440C.

Special Notes to Knifemakers:

Hardness: For bladestock, the recommended hardness is HRC 56/58, which is designed to provide and excellent combination of corrosion resistance, wear resistance, and edge toughness. Because of its high alloy content, CPM S60V will outperform higher hardness conventional grades of bladestock.

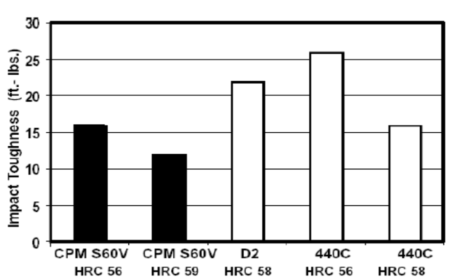
Heat Treatment: Proper heat treatment is critical to achieve optimum edge holding ability and good toughness. CPM S60V requires higher hardening temperatures than common knife grades and care must be taken to protect the blade's surface from oxidation during heat treatment. This requires the use of a furnace with atmosphere controls, or simply wrapping the blade with stainless foil wrap. CPM S60V is air hardening, like most high alloy tool steels, but a good fast air cool is recommended to achieve proper hardness. If the blade is wrapped in foil, the foil should be removed immediately following the high heat to avoid any insulating effect. Proper tempering is also highly important. Two draws are recommended at a high enough temperature and for sufficient time to relieve stress without degrading corrosion resistance or hardness.

Recommended Bladestock Heat Treatment:

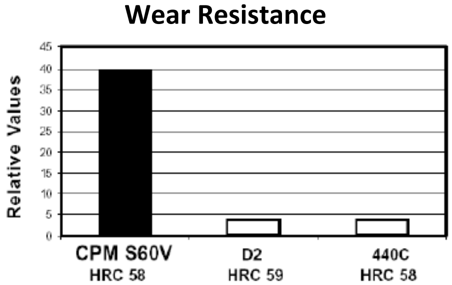
Austenitize: 2050° F (1120°C), fast air cool.

Temper: Double temper at 500°F (260°C) 2 hrs. each, air cooling to room temperature between tempers.

Impact Toughness



Wear Resistance



Thermal Treatments

Critical Temperature: 1580°F (860°C)

Annealing

Heat to 1650° F (900°C), hold 2 hours, slow cool at a maximum rate of 25° F (15°C) per hour to 1100° F (595°C), then furnace cool or cool in still air to room temperature.

Annealed Hardness: Approx. BHN 255/277

Stress Relieving

Annealed Parts: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.

Hardened Parts: Heat to 25-50° F (15-30°C) below original tempering temperature, hold 2 hours, then furnace cool or cool in still air.

Hardening

Austenitize: 1850-2050°F (1010-1120°C), hold time at temperature: 10-30 minutes depending on section size and austenitizing temperature. Lower temperatures require longer soak times. Lower austenitizing temperatures impart greater toughness, higher austenitizing temperatures impart higher wear resistance.

Quench: Salt quench, interrupted oil quench, positive pressure gas quench or air cool at a minimum cooling rate of 150°F/min (80°C/min) to below 1000°F (540°C). Cool to below 125°F (50° C) before tempering. For optimum vacuum heat treatment response, a minimum 4 bar gas quench is recommended.

Temper: Immediately after tools have cooled to below 125°F (50°C) double temper at 400-750° F (200-400°C). Hold for a minimum of 2 hrs. each temper. But tempering above 800°F (425°C) may result in some loss of corrosion resistance. A freezing treatment may be employed between the first and second tempers, if desired. Freezing treatments should always be followed by at least one temper.

PLEASE NOTE: Tempering between about 800 and 1000°F (425 and 540°C) is not recommended. All martensitic stainless steels suffer from embrittlement when tempered in this range.

Aim Hardness: HRC 56/58

Size Change: +0.02 to +0.05%

Size change shown is for a *fully martensitic microstructure*.

The presence of retained austenite may reduce the net growth. When tempering at 400-750°F (200-400°C), freezing treatments may be necessary to minimize retained austenite.

Machinability and Grindability

Due to its high vanadium carbide content, the machinability and grindability of S60V will be slightly more difficult than that of D2 or 440C. Similar grinding equipment and practices are acceptable. SG type alumina wheels or CBN wheels have generally given the best performance with the CPM steels.

Heat Treat Response - Hardness (HRC)

Tempering	1850 (1010)		1950 (1065)		2050 (1120)	
Temperature °F (°C)	Air	Oil	Air	Oil	Air	Oil
As Quenched	54	56	58	60	60	62
400 (205)	52	54	56	58	58	60
500 (260)	52	53	54	55	57	59
600 (315)	51	52	54	55	56	58
700 (370)	51	52	54	55	56	58

DATA SHEET

CPM S90V (CPM 420V)

Typical Composition

C	Cr	Mo	V
2.3	14.0	1.0	9.0

CPM S90V is a unique tool steel made by the Crucible Particle Metallurgy process. It is a martensitic stainless steel with a high volume of vanadium carbides for exceptionally good wear resistance. S90V offers substantial improvements in wear resistance over 440C and D2, and other high chromium tool steels, with corrosion resistance equal to or better than 440C. Its high vanadium content favors the formation of hard vanadium carbides instead of chromium carbides for wear resistance, leaving sufficient chromium in the matrix to provide good corrosion resistance.

The wear and corrosion resistance of S90V make it an excellent candidate to replace 440C, where increased wear is a primary concern. It can replace D2 or other tool steels in applications where improved corrosion resistance is also of benefit.

The CPM process results in a finer, more uniform carbide distribution imparting improved toughness and grind ability to high alloy steels. The CPM process also allows the design of more highly alloyed grades which cannot be produced by conventional steelmaking.

Typical Applications: Plastic injection and extrusion feed screws, non-return valve components, pelletizing equipment, gate and nozzle inserts, industrial knives, slitters, and cutters, long-wearing specialty cutlery, injection molds and inserts, wear components for food and chemical processing, bearings, bushings, valves, rolls and gear pumps.

CONVENTIONAL STEEL

CPM STEEL

Mechanical Properties

	Hardness (1)		Impact Toughness (2)		Wear (3)
	HRC	Heat Treatment	Ft.lb	(Joules)	
CPM S90V	58	(A)	19	(26)	35/40
CPM 9V	55	(B)	47	(63)	35/40
440C	58	(C)	16	(22)	3/4
D2	59	(D)	22	(30)	3/4

1.) A=Hardened 2050°F (1120°C), double tempered 500°F (260°C).
B=Hardened 2050°F (1120°C), double tempered 1025°F (550°C).
C=Hardened 1900°F (1040°C), double tempered 400°F (204°C).
D=Hardened 1850°F (1010°C), double tempered 600°F (315°C).
2.) Charpy C-Notch impact test
3.) Crossed-cylinder adhesive wear test (higher number=better wear resistance)

DATA SHEET

Corrosion Resistance

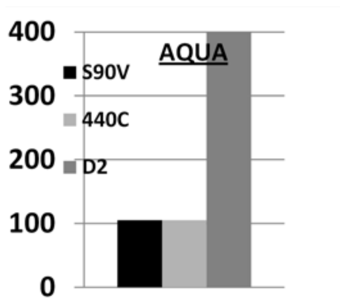
Corrosion tests measure the amount of material lost to corrosion. Therefore, lower numbers indicate better corrosion resistance.

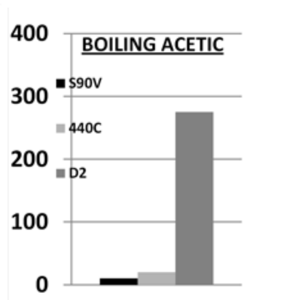
Corrosion Test Results (1) in mm/year		
	Boiling 10% Acetic(2)	Dilute Aqua-Regia(3)
CPM S90V	9/17	102/117
440C	29	109
D2	267	411

Notes:
(1)Lower numbers indicate better corrosion resistance. All grades heat treated to about HRC 56/58. Corrosion resistance depends strongly on heat treated condition and specific environment. Results should be used as a qualitative comparison only.
(2)24 Hrs.
(3)5% HNO_3-1% HCl (nitric + hydrochloric acids) at 24 °C.

Relative Corrosion Rates

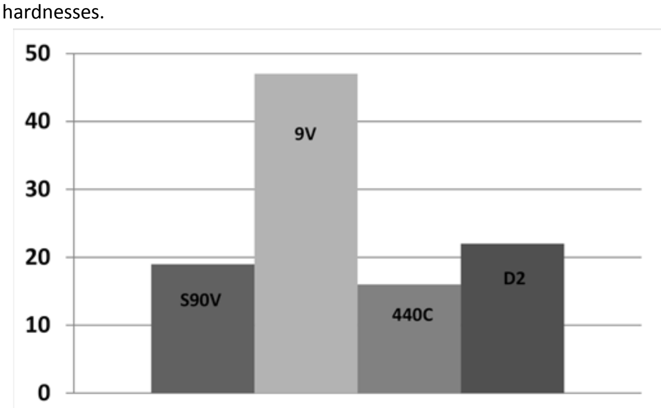
(Lower numbers indicate better corrosion resistance)





Impact Toughness

CPM S90V offers higher impact toughness than 440C at comparable hardnesses.



Thermal Treatments

Annealing

Heat to 1650° F (900°C), hold 2 hours, slow cool at a maximum rate of 25° F (15°C) per hour to 1100° F (595°C), then furnace cool or cool in still air to room temperature

Annealed Hardness: Approx. BHN 277

Stress Relieving

Annealed Parts: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.

Hardened Parts: Heat to 25-50° F (15-30°C) below original tempering temperature, hold 2 hours, then furnace cool or cool in still air.

Hardening

Austenitize: 2100-2150°F (1150-1175°C), hold time at temperature: 20 minutes.

Quench: Salt quench, interrupted oil quench, positive pressure gas quench or air cool at a minimum cooling rate of 150°F/min (80°C/min) to below 1000°F (540°C). Cool to below 125°F (50° C) before tempering. For optimum vacuum heat treatment response, a minimum 4 bar gas quench is recommended.

Temper: Double temper at 400-750° F (200-400°C). Hold for a minimum of 2 hrs. each temper. For optimum stress relieving and dimensional stability, S90V may be double tempered at 1000-1025° F (540-550°C), but tempering above 800°F (425°C) may result in some loss of corrosion resistance. A freezing treatment may be employed between the first and second tempers, if desired. Freezing treatments should always be followed by at least one temper.

PLEASE NOTE: Tempering between about 800 and 1000°F (425 and 540°C) is not recommended. All martensitic stainless steels suffer from embrittlement when tempered in this range.

Tempering Temperature	
400°F-800°F	Best corrosion resistance & wear resistance
800°F-1000°F	**AVOID THIS RANGE** (Embrittlement)
1000°F-1025°F	Stress Relieving and Dimensional Stability

Aim Hardness: HRC 56/59

Size Change: +0.03 to +0.05%

Size change shown is for a *fully martensitic microstructure*.

The presence of retained austenite may reduce the net growth. When tempering at 400-750°F (200-400°C), freezing treatments may be necessary to minimize retained austenite.

Machinability and Grindability

Due to its high vanadium carbide content, the machinability and grindability of S90V will be slightly more difficult than that of D2 or 440C. Similar grinding equipment and practices are acceptable. SG type alumina wheels or CBN wheels have generally given the best performance with the CPM steels.

DATA SHEET

CPM® 20CV

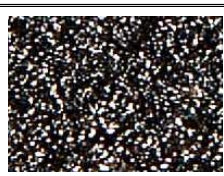
Typical Composition

C	Cr	Mo	V	W
1.9%	20.0%	1.0%	4.0%	0.6%

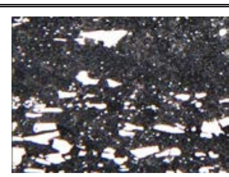
CPM 20CV is a unique tool steel made by the Crucible Particle Metallurgy Process. It is a martensitic stainless steel with a high volume of vanadium carbides for exceptionally good wear resistance. CPM 20CV contains the highest amount of chromium of any high-vanadium stainless steel currently available. The chromium rich matrix provides outstanding corrosion resistance. CPM 20CV an excellent steel for plastic injection feed screws, barrel liners, screw tips and mold cavities, especially for plastic resins which contain abrasive fillers.

The CPM process results in a finer, more uniform carbide distribution imparting improved toughness and grindability to highly alloyed steels. The CPM process also alloys for the design of more highly alloyed grades which cannot be produced by conventional steelmaking.

Typical Applications: High performance, long-wearing specialty cutlery, plastic injection and extrusion feed screws and dies, granulator knives, pelletizing equipment, wear components for Food and Chemical Processing.



CPM Steel



Conventional Steel

Edge Retention

(CATRA Test Relative to 440C)

GRADE	%
CPM 20CV	180
14-2-4 CrMoV	145
14-4 CrMo	120
440C	100

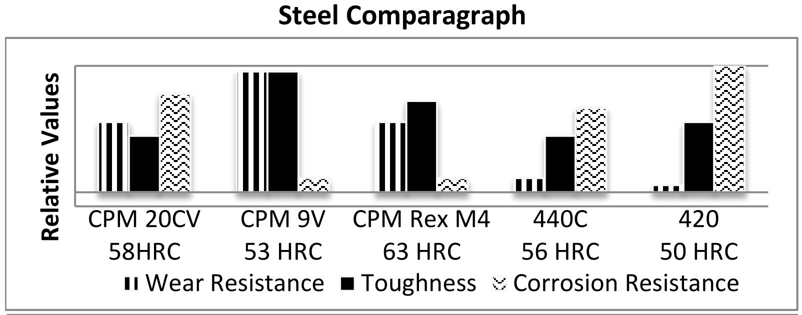
The CATRA (Cutlery & Allied Research Association) test machine measures the total number of silica impregnated cards cut in a sequence of passes along the blade. It is considered a relative measure of edge retention and wear resistance.

Physical Properties

Density: 0.275 lb/in3 (7616 kg/m3)
Modulus of Elasticity: 31x106 psi (214 GPa)
Machinability: 35-40% of a 1% carbon steel
Coefficient of Thermal Expansion:

Temperature °F	in/in/°F x 10^{-6}	Temperature °C	mm/mm/°C x 10^{-6}
68 - 212	6.06	20 - 100	10.9
68 - 392	6.23	20 - 200	11.2
68 - 572	6.56	20 - 300	11.8
68 - 752	6.73	20 - 400	12.1
68 - 932	6.84	20 - 500	12.3

Steel Comparagraph



This data sheet is for informational purposes only. Alloy characteristics are subject to change due to chemical composition and/or processing. We do not certify the material's suitability for specific applications.

DATA SHEET

Thermal Treatments

Annealing

Annealing must be performed after hot working and before rehardening. Heat at a rate not exceeding 400°F per hour (222°C per hour) to 1860-1900°F (1016-1038°C), and hold at temperature for 1 hour per inch (25.4 mm) of maximum thickness; 2 hours minimum. Then cool slowly with the furnace at a rate not exceeding 30°F per hour (15°C per hour) to 1000°F (538°C). Continue cooling to ambient temperature in the furnace or in air. The resultant hardness should be approximately 30 HRC or lower.

Hardening

Preheat: Heat to 1400-1450°F (760-788°C) and equalize.

Austenitize: Heat rapidly from the preheat to a temperature to within 1960-2150°F (1071-1177°C). A lower austenitizing temperature will maximize impact toughness. A higher austenitizing temperature will maximize wear resistance and corrosion resistance. Soak at the austenitizing temperature for 30 minutes.

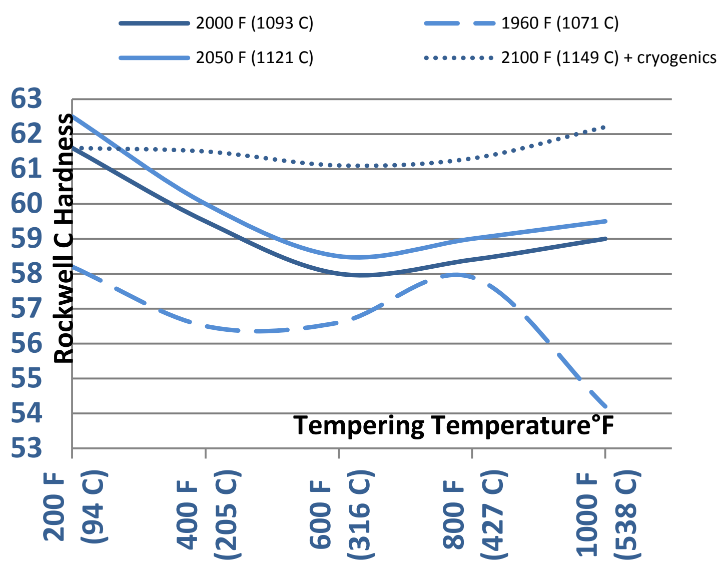
Quench: Pressurized gas or warm oil. For pressurized gas, the furnace should have a minimum quench pressure of 4 bars. A quench rate of approximately 400°F (222°C) per minute to below 1000°F (538°C) is critical to obtain the desired properties. For oil, quench until black, about 900°F (482°C), then cool in still air to 150-125°F (66-51°C).

Temper: Temper immediately after quenching, or after quenching and cryogenic treatment. Typical temperature range is 400-800°F (204-427°C). Hold at temperature for 1 hour per inch (25.4mm) of thickness, 2 hours minimum, then air cool to ambient temperature. The typical service hardness is 56-59 HRC, although higher hardness may be used for increased wear resistance. *Tempering between 800 and 1100°F (427-583°C) will decrease corrosion resistance and toughness.*

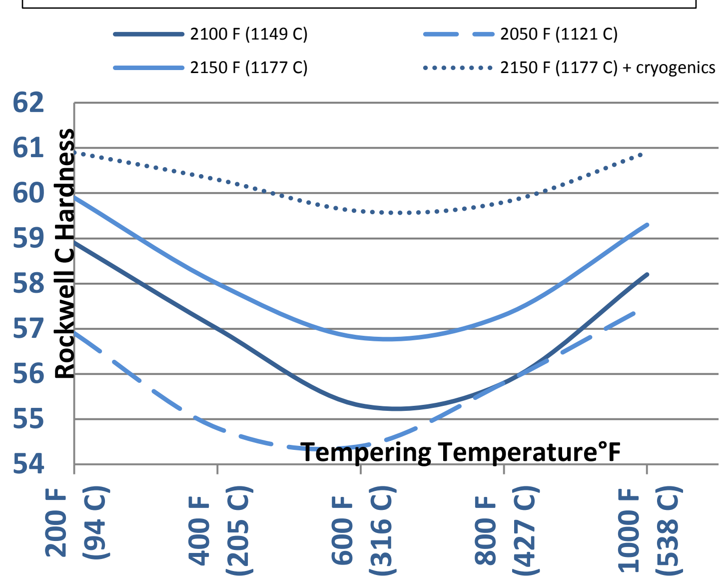
Cryogenic Treating: For austenitizing at 2100°F (1149°C) or higher, a cryogenic treatment is recommended after quenching to 150 to 125°F (66-51°C) to reduce retained austenite. Cool to -100°F (-73°C), remove from the cooling medium, and allow part to warm to ambient temperature in still air.

HEAT TREATMENT RESPONSE

For Furnace or Salt Bath Hardening:
Oil Quenched from



For Vacuum Furnace Hardening:
Vacuum Hardened and 4 bar Nitrogen Gas quenched from



DATA SHEET

CPM® CRU-WEAR®

Typical Composition

C	Cr	W	Mo	V
1.15	**7.5**	**1.0**	**1.6**	**2.4**

CPM® CRU-WEAR® is an air-hardening powder metallurgy tool steel, heat treatable to HRC 60-65. The original conventionally melted CRU-WEAR® was designed as an upgrade to A2 and D2, for better wear resistance, greater toughness and higher attainable hardness. CPM® CRU-WEAR® was introduced as a way to make the conventionally melted version easier to machine and more resistant to chipping. Compared to the chemistry of D2, (D2 = 1.55% carbon, 11.5% chromium, 0.8% vanadium, and 0.9% molybdenum), CPM® CRU-WEAR® has less carbon and less chromium, but more vanadium and tungsten. The overall carbide content of CPM® CRU-WEAR® is less than D2 which helps make it tougher than D2. CPM® CRUWEAR®'s higher attainable hardness results from the fact that it contains sufficient tungsten and molybdenum to cause a secondary hardening response. Finally, CPM® CRU-WEAR® tempers at a higher range (900-1050°F) than D2 (400-600°F), so it is more compatible with a wide variety of surface treatments.

	Heat Treatment Austent. Temp.	**HRC**	**Impact Toughness Ft.-lb**	**(J)**	**Wear Resistance Adhesive**
CPM® Cru-Wear®	1950F (1065C)	62	35	(46)	6-7
S7	1750F (955C)	57	125	(165)	1
A2	1750F (955C)	60	40	(53)	2-3
D2	1850F (1010C)	60	21	(28)	3-4
M2	2050F (1025C)	62	20	(27)	8-10

Mechanical Properties

Wear Resistance-CPM® CRU-WEAR® will offer better wear resistance then that of the AISI D2, approaching AISI M2.

Impact Toughness-CPM® CRU-WEAR® has greater toughness than the AISI D2 approaching the AISI A2.
NOTE: Lowering the hardening temp. reduces the grain size and increases toughness.

This data sheet is for informational purposes only. Alloy characteristics are subject to change due to chemical composition and/or processing. We do not certify the material's suitability for specific applications.

NIAGARA SPECIALTY METALS

Crucible Industries®

DATA SHEET

Thermal Treatments

Annealing: Heat to 1550-1650°F (840-900°C), hold 2 hours, slow cool 50°F (25°C) per hour to 1200°F (650°C).
Annealed Hardness: About BHN 225/255

Stress Relieving

Annealed Parts: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.

Hardened Parts: Heat to 25°F (15°C) below the original tempering temperature, hold 2 hours, then furnace cool or cool in still air.

Hardening

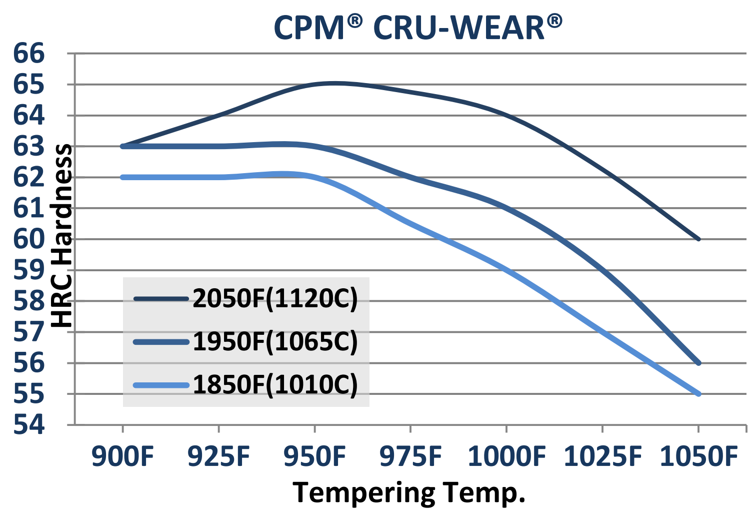
It is customary to use two furnaces: one furnace to preheat and the second furnace to austenitize. This ensures that the transition from the pre-heat temperature to the austenitizing temperature occurs fairly rapidly.
Preheat: Heat to 1550-1600°F (840-870°C), Equalize.
Austenitize: 1850-2050°F (1010-1120°C), Hold time at temperature 20-45 minutes.
Quench: Air or positive pressure quench (2 bars minimum) to below 125°F (50°C). Salt bath treatment, if practical will ensure the maximum attainable toughness for a given hardening treatment.
Temper: 900-1050°F (480-565°C). Double tempering is mandatory, and triple tempering is recommended. Cool to room temperature in between tempers. Temper 2 hours minimum each time or at least 1 hour per inch (25mm) of thickness for sections over 2" (50mm) thick.
Size Change: Approx. +0.15%

Recommended Heat Treatment: For the best combination of toughness and wear resistance, austenitize at 1950°F (1065°C). Temper 3 times at 1000°F (540°C).

Aim hardness: HRC 62 Higher austenitizing temperatures can be used to obtain higher hardness, at a slight decrease in impact resistance. The lower austenitizing temperatures provide the best impact toughness.

Note: Properties shown throughout this data sheet are typical values. Normal variations in chemistry, size and heat treat conditions may cause deviations from these values.

Tempering Temp.	1850°F (1010°C)	1950°F (1065°C)	2050°F (1120°C)
As Quenched	63-65	63-65	62-64
900°F(480°C)	61-63	62-64	61-63
950°F(510°C)	61-63	62-64	64-66
1000°F(540°C)	57-59	60-62	63-65
1025°F(550°C)	56-58	58-60	61-63
1050°F(620°C)	54-56	58-60	61-63
Minimum Time at Aust. Temp.	45 min.	30 min.	20 min.



Surface Treatments

Because of its high tempering temperatures (900-1050°F) CPM® CRU-WEAR® is suitable for nitriding, PVD coating or similar surface treatments. It will retain its hardness after such processes, making it a more suitable substrate than D2.
NOTE: CVD coating processes are generally performed at temperatures which exceed the critical temperature and may result in non-predictable dimensional distortion.

Machinability

Machinability of CPM® CRU-WEAR® in the annealed condition is similar to D2 but grindability will be slightly better. Similar grinding equipment and practices are acceptable. "SG" type alumina wheels or CBN wheels have generally given the best performance.

DATA SHEET

CPM S110V

Typical Composition

C	Nb (Cb)	Co	Cr	Mo	V
2.8	3.0	2.50	15.25	2.25	9.0

CPM S110V is a high alloy martensitic stainless tool steel produced by the Crucible Particle Metallurgy (CPM) process. CPM S110V contains a high volume fraction of both vanadium-rich and niobium-rich primary alloy carbides for exceptionally good wear resistance compared to other commercially available PM tool steels. It also offers better corrosion resistance than 440C or CPM S90V.

CPM S110V is currently available on special request in the as-HIP condition or as a clad layer on components. It is also available in hot rolled decarb free sheet.

The CPM process results in a fine and uniform carbide distribution in CPM S110V compared to conventionally produced high alloy tool steels which results in relatively good machining, grinding, and toughness characteristics despite the high alloy content.

Typical Applications: As-HIP solid or clad components requiring a combination of high wear resistance and good corrosion resistance such as: Screw elements, barrel liners for compounding machines, industrial knives, high end cutlery, slitters and circular cutters, rolls and wear components for food and chemical processing applications.

CPM S110V

AISI 440C

Machining and Grinding

Due to its carbide content and high annealed hardness, machining and grinding CPM S110V will be more difficult than 440C (or D2), and comparable to or slightly more difficult than CPM S90V. Grinding equipment and practices similar to those used for CPM S90V are acceptable. SG type alumina wheels or CBN wheels are recommended for best performance with CPM steels.

DATA SHEET

Thermal Treatments

Annealing

Heat to 1650°F (900°C), hold 2 hours, slow cool at a maximum rate of 25°F (15°C) per hour to 1100°F(595°C), then furnace cool or cool in still air to room temperature

Annealed Hardness: Approximately 350-400 BHN

Stress Relieving

Annealed Material: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.

Hardened Material: Heat to 25-50°F (15-30°C) below original tempering temperature, hold 2 hours, then furnace cool or cool in still air.

Hardening

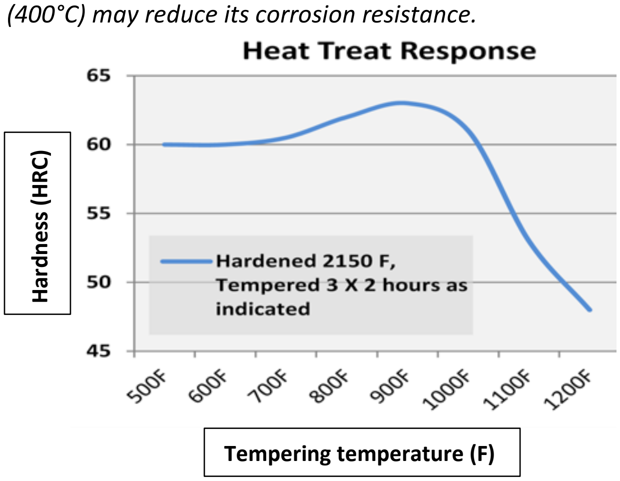
Austenitize: 2150°F (1175°C) Hold 20 minutes.

Quench: Salt quench, interrupted oil quench, positive pressure gas quench or air cool at a minimum cooling rate of 250°F/min (140°C/min) to below 1000°F (540°C). Cool to below 125°F (50° C) before tempering. For optimum vacuum heat treatment response, a minimum 4 bar gas quench is recommended.

Temper: Temper three times, minimum hold time 2 hours at temperature each temper. Cool completely to room temperature between tempers.

Tempering temperatures: 400-750°F (200-400°C): Best corrosion resistance 975-1000°F (525-540°C): Maximum hardness and compressive yield strength, reduced corrosion resistance 1025-1050° F (550-565°C): Optimum for best stress relieving and dimensional stability.

Note: Tempering any martensitic stainless steel above 750°F (400°C) may reduce its corrosion resistance.



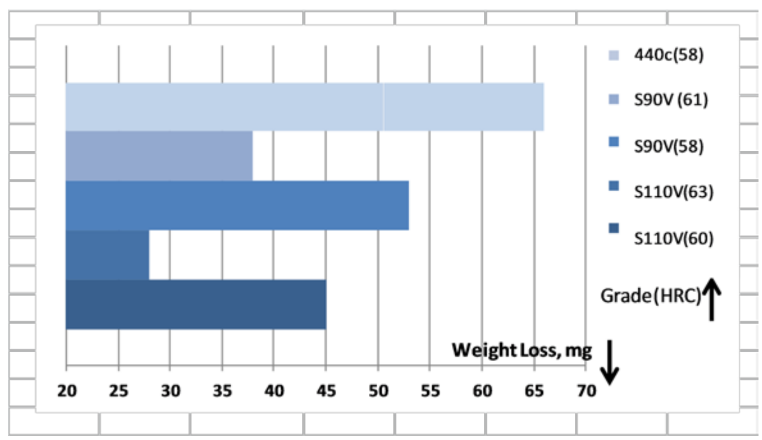
Deep freezing (optional): When tempering at or below 750°F (400°C), a freezing treatment may be used between the first and second tempers to reduce retained austenite and maximize hardness. Freezing treatments should always be followed by at least one temper.

Size Change: +0.03 to +0.05% for a fully martensitic microstructure. The presence of retained austenite may reduce the net growth.

Typical Application Hardness: 58/61 HRC

Wear Resistance

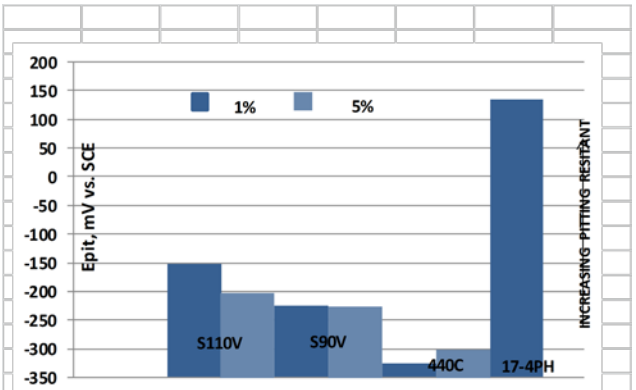
CPM S110V features the same high vanadium content as CPM S90V, plus the added contribution of 3.5% niobium, resulting in 25% greater volume of wear-resistant carbides, including 50% more of the wear-resistant MC type. The abrasive wear resistance of CPM S110V at various hardnesses is compared to other wear-and corrosion-resistant grades below.



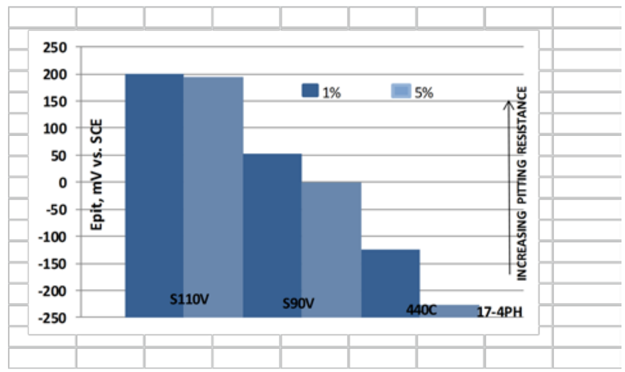
Corrosion Resistance

CPM S110V displays enhanced corrosion resistance compared to other high hardness martensitic stainless tool steels such as 440C and CPM S90V. Corrosion tests results in representative media are illustrated by the following laboratory test data.

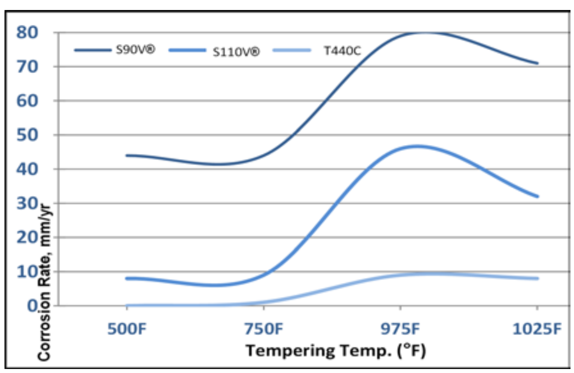
DATA SHEET



Pitting resistance in 1% and 5% NaCl solutions (Tempering at 1025F)



Pitting resistance in 1% and 5% NaCl solutions (Tempering at 500F)



Corrosion Rate in Dilute Aqua Regia (2.5% HN03+0.5% HCI+H20)

DATA SHEET

CPM REX M4 HC (HS)

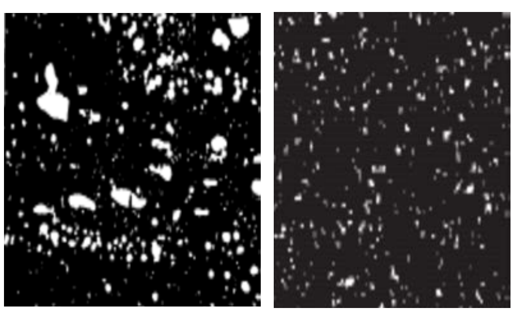
Typical Composition						
C	Mn	S	Cr	W	Mo	V
1.42	0.30	0.06	4.00	5.50	5.25	4.00

CPM REX M4 HC (HS) is a high vanadium special purpose high speed steel exhibiting better wear resistance and toughness than M2 or M3 in cold work punches, die inserts, and cutting applications involving high speed and light cuts.

The high carbon (HC) modification to standard M4 is designed to provide optimum hardening response in larger cross-section tools or in vacuum or atmosphere heat treating. The high sulfur (HS) modification is standard for larger diameter bars, providing enhanced machinability and grindability.

The CPM process produces very homogeneous, high quality steel characterized by superior dimensional stability, grindability, and toughness compared to steels produced by conventional processes.

Typical Applications: broaches, milling cutters, gear hobs, rolls, shaper cutters, punches, shaving cutters, and dies.



Conventional Steel CPM Steel

Machinability: In the annealed condition, the machinability of CPM Rex M4 HC is approximately 45% of W1 tool steel (1% C) with additional improvement of about 30% for the high sulfur (HS) modification.

Grindability: Because of its uniform distribution of fine carbides, the grindability of CPM Rex M4 HC compares favorably with that of conventional high speed steels. Grinding wheels designed for conventional high speed steels can be used. In special cases, the advice of a grinding wheel manufacturer should be sought.

DATA SHEET

Thermal Treatments

Critical Temperature: 1545°F (840°C)
Forging: 2000-2100°F (1095-1150°C) Do not forge below 1700°F (930°C). Slow Cool.
Annealing: Heat to 1600°F (870°C), hold 2 hours, slow cool no faster than 30°F (15°C) per hour to 1000°F (540°C), then furnace cool or cool in still air to room temperature.
Annealed Hardness: About BHN 225/255

Stress Relieving

Annealed Parts: Heat to 1100-1300°F (595°-700°C), hold 2 hours, then furnace cool or cool in still air.
Hardened Parts: Heat to 25-30°F (15°C) below original tempering temperature, hold 2 hours, then furnace cool or cool in still air.
Straightening: Best done warm 400-800°F (200-430°C)

Hardening

Preheat: Heat to 1500-1550°F (820-845°C), Equalize. Second pre-heat stage at 1850-1900°F (1010-1040°C) suggested for vacuum or atmosphere hardening.
Austenitize: 1875-2200°F (1025-1205°C) Hold time at temperature: 5-45 minutes. For cutting tools use 2150-2200°F (1175-1205°C). For cold work applications use 1875-2125°F (1025-1160°C).
Quench: Air or positive pressure quench (2 bar minimum) to below 125°F (50°C), or salt or interrupted oil quench to about 1000°F (540°C), then air cool to below 125°F (50°C). Salt bath treatment, if practical, will ensure maximum attainable toughness for a given hardening treatment. A fast quench rate from hardening temperature to below 1100°F (595°C) is critical to achieve optimum heat treat response. A slower cooling rate below 1000°F (540°C) may be used to minimize distortion.
Temper: Double temper at 1000°F (540°C) minimum. Triple temper recommended when hardening from 2100°F (1150°C) or higher. 2 hours minimum each temper. Air cool to room temperature between tempers.
Size Change: +0.15%

Surface Treatments

Because of its high tempering temperatures (>1000°F) CPM M4 HC (HS) is suitable for nitriding, PVD coating or similar surface treatments. CVD coating processes generally exceed the hardening temperature and may result in non-predictable dimensional changes.

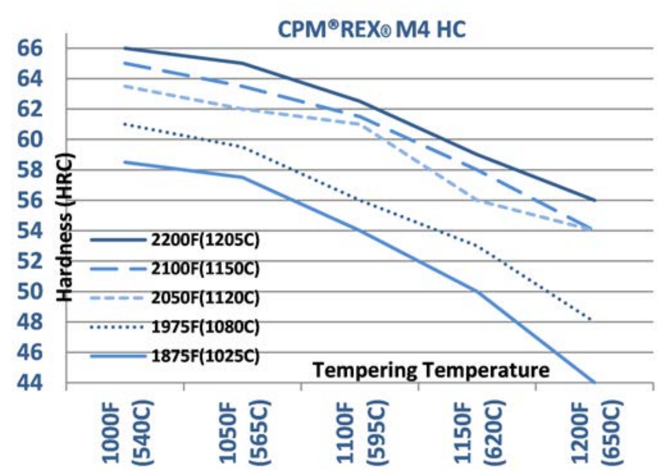
Toughness:

Depending on the hardness requirement, lowering the hardening temp. (underhardening) increases toughness.

Hardening Temp.	Tempering Temp.	HRC	Charpy C-Notch Ft-lb	(J)	Bend fracture strength Ksi	(Mpa)
2200°F	1025°F	65.5	20	27	738	5088
2125°F	1050°F	63.5	28	38	744	5129

Heat Treat Response
HRC Hardness

Tempering Temp.	Austenitizing Temperature 1875°F (1025°C)	1975°F (1080°C)	2050°F (1120°C)	2100°F (1150°C)	2150°F (1175°C)	2200°F (1205°C)
As Quenched	59.5	62.5	64.5	65	65	63.5
1000°F(540°C)	58.5	61	62.5	63.5	65	66
Optimum for Maximum Toughness and Effective Stress Relieving						
1025°F(550°C)	58	60.5	62	63	64.5	65.5
1050°F(565°C)	57.5	59.5	61	62	63.5	64.5
1100°F(595°C)	54	56	58.5	60	61.5	62.5
1150°F(620°C)	50	53	55	56	58	59
1200°F(650°C)	44	48	51	52	54	55
Results can vary with the use of the hardening method and its section size. You will get the best result with Salt or Oil quenching. Vacuum or atmosphere cooling may result in up to 1-2 HRC points lower.						
Minimum Time at Aust. Temp.	45 min.	30 min.	20 min.	15 min.	10 min.	5 min.
Minimum Number of Tempers	2	2	2	3	3	3



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DATA SHEET

154 CM

Typical Composition		
C	Cr	Mo
1.05	14.00	4.00

154 CM is a modification of 440C martensitic stainless steel to which molybdenum has been added. 154 CM has better corrosion resistance, better wear resistance and better hot-hardness than 440C. For knife makers, it offers better edge retention than 440C. It also has higher attainable hardness and better through hardening characteristics than 440C.

The *typical applications* include cutlery, bearings, valve ports, and bushings.

Surface Treatments

If surface treatments such as CVD, PVD, or nitriding are used, ensure that the coating process temperature is below the tempering temperature. *NOTE: Nitriding will reduce the corrosion resistance of Crucible 154 CM or any other stainless steel.*

Due to its higher carbide volume, Crucible 154 CM is a little more difficult to machine than 440C. With high speed or carbide tooling, the following machining parameters are suggested:

Machining Operation	Speed (fpm)	Feed(in/rev)
High Speed Tools		
Turning	50/60	0.003
Forming	50/60	0.001
Drilling	40	0.002
Cutoff	50/60	0.001
Carbide Tools		
Turning	150	0.010
Forming	100	0.0015
Cutoff	100	0.0015

Mechanical Properties

Grade	HRC	Wear Resistance	Total Carbide Volume
154 CM	58.5	49 mg.	17.5%
440C	57.5	66 mg.,55 mg.	12%

*Wear resistance measured by the pin abrasion method. Lower number (mg.) is a lower weight loss 9 in mg. and therefore better wear resistance.

Hot Hardness					
Heat Treatment	Initial HRC	HRC tested at 400F	500F	600F	Final HRC
A	62	59	58	55	60
B	62			55	62
C	64			57	64

(A)Austenitized at 1950°F 1hr., Oil Quench, cryo treated, tempered at 600°F 1hr.
(B) Austenitized at 1950°F 1hr. Oil Quench, cryo treated, tempered at 1000°F 1hr.
(C) Austenitized at 2000°F 20 min. Oil Quench, cryo treated, tempered 1000°F 1hr.

DATA SHEET

Thermal Treatments

Annealing: Heat to 1650°F (900°C),hold 2 hrs., slow cool no faster than 25°F (15°C) per hour to 1200°F (650°C), then furnace cool or cool in still air to room temperature. Crucible 154 CM can be cycle annealed by heating to 1600°F (900°C), hold 2 hours, cool to 1300°F (704°C), hold 4 hrs., then air cool.

Annealed Hardness: About BHN 235

Stress Relieving

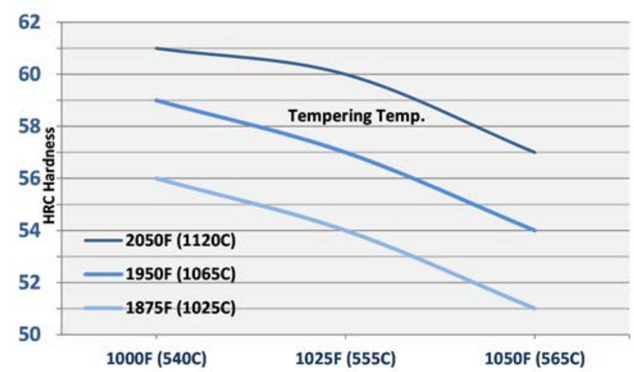
Annealed Parts: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.
Hardened Parts: Heat to 25-50°F (15-30°C) below the original tempering temperature, hold 2 hours, then furnace cool or cool in still air.

Hardening

Preheat: Heat to 1400°F (760°C), Equalize.
Austenitize: 1900-2000°F (1037-1093°C), hold time at temperature 30-60 minutes.
Quench: Oil or positive pressure (4 bar minimum) to below 125°F (50°C), or salt quench to about 1000°F (540°C), then air cool to below 125°F (50°C). Salt bath treatment, if practical, will ensure the maximum attainable toughness for a given hardening treatment.
Temper: Twice at 400-1200°F (204-650°C), 2 hours minimum each time.

Note: As with all martensitic stainless steels, tempering at 800-1100°F (425-600°C), will result in sensitization which causes a minor reduction in both corrosion resistance and toughness. We recommend that this tempering range be avoided.

Aim hardness: HRC 55-62



Heat Treat Response
Hardness HRC
Austenitizing Temperature

Tempering Temp.	1900°F (1038C)		1950°F (1065C)		2000°F (1093C)	
Time at Temp.	1 hr.		1 hr.		30 min.	
Quench (optional freeze)	Oil	Oil & Freeze	Oil	Oil & Freeze	Oil	Oil & Freeze
As Quenched	62	63	61	63	54	63
400°F(204C)	59	60	59	62	52	62
600°F(315C)	56	59	56	60	50	60
800°F(427C)	56	56	57	60	50	61
900°F(482C)	56	57	58	61	52	61
1000°F(540C)	54	58	60	61	54	63
1050°F(565C)	51	52	55	56	52	58
1100°F(593C)	47	48	47	48	49	51
1200°F(649C)	43	44	45	46	45	47
Time at Temp.	2 hrs.		2hrs.		2 hrs.	
No. of Tempers	2		2		2	

*Results may vary with hardening and section size. Salt or oil quenching will give maximum response. Vacuum or atmosphere cooling may result in up to 1-2 HRC points lower.

Recommended Heat Treat Practice

To completely transform any retained austenite, a freezing treatment with dry ice at -100°F (-74°C) is recommended either after the quench or in between the two tempers. The freezing treatment is most effective right out of the quench; however complex parts with sharp corners are more safely frozen between the two tempers. Thin sections can be successfully quenched in forced air and will obtain results to those in the table above.

DATA SHEET

440C

Typical Composition

C	Mn	Si	Cr	Mo
0.95/1.20	1.00 Max	1.00 Max	16.00/18.00	0.75

440C is a hardenable chromium steel. It has one of the highest attainable hardnesses of the corrosion and heat resisting grades. This grade is magnetic at all times. For those applications where superior machinability is desired and where slightly lower corrosion resistance is satisfactory 440C can be supplied.

The *typical applications* of 440C include ball bearings, bushings, valve parts and cutlery.

Cutlery Applications

440C is particulary designed for cutlery appications requiring a high hardness and an excellent retention of the cutting edge. When this grade is ordered specifically for mirror-finish cutlery applications, material will be supplied which has been processed in such a manner as to insure the obtaining of a polished surface of "mirror-finish" quality. Care should be taken in grinding and polishing this grade so that excessive heat is not produced by this operation as the resistance to staining will be lowered. In general, 440C resembles tool steels in that it required great care in fabrication and hardening.

Forging

440C should be forged at 1950 to 2050° F and finished not lower than 1750° F. Reheating should be used if necessary. This grade should be allowed to cool slowly after forging.

Annealing

440C should be annealed for maximum softness by thorough soaking at 1650°F for six hours followed by a furnace cool. This grade can be *cycle annealed by heating to 1600°F, holding two hours, cooling to 1300°F, and holding four hours. The steel may be cooled in air if desired.

**Cycle (isothermal) annealing is most practical for applications in which full advantage may be taken of the rapid cooling to the transformation temperature and from this temperature down to room temperature. Thus, for small parts which can be conveniently handled in salt or lead baths, this isothermal annealing makes possible large time savings as compared with the conventional slow furnace cooling. The method offers no particular advantage for applications such as batch annealing of large furnace loads in which the rate of cooling to the center of load may be so slow as to preclude any rapid cooling to the transformation temperatures. For such applications, the conventional full annealing method usually offers better assurance of obtaining the desired microstructure and properties.*

DATA SHEET

Hardening and Tempering

440C can be hardened for maximum hardness by oil quenching or air cooling from 1850 to 1900°F. Large sections or complex parts should be preheated to 1425°F, equalize, and then raised to the austenitizing temperature. If the finished part is not to be ground and polished, the surface may be improved by packing in a neutral material during heating. Tempering should be at the proper temperature to give the desired approximate hardness as indicated below.

Tempering Temperature (F)	HRC
As quenched	59
212°	59
400°	56
600°	54
800°	55
1000°	51

It is desirable to avoid tempering between 800 and 1100°F, as there is a drop in impact strength within this range, coincidental with which there is also a reduction in resistance to corrosion.

Welding

440C should be welded with Type 440C filler weld metal if the mechanical properties of the weld metal must be similar to those of the parent metal. In welding annealed material, the steel should be preheated to 600°F and annealed following welding by heating uniformly and thoroughly at 1300°F followed by the air cooling. When welding hardened and tempered material, preheat to the tempering temperature, weld and post-heat at the appropriate tempering temperature for 2 hours.

Resistance to Scaling

440C scales at approximately 1400°F. This temperature will vary with the type of atmosphere, type of construction, and cycle of operation.

General Corrosion Resistance

440C is resistant to corrosion in atmosphere environments, fresh water, mild acids, alkalies, and fruit and vegetable juices. The better the finish of the hardened and tempered part, the better will be its corrosion resistance.

Machining Data

440C STAINLESS STEEL

Operation	Tooling Width or Depth of cut (in)	High Speed Tooling*		Carbide Tooling	
		Speed (fpm)	Feed (in/rev)	Speed (fpm)	Feed (in/rev)
Turning Single point	0.050	65	0.0045	200	0.010
	0.250	65	0.0040	200	0.020
	0.500	60	0.0035	175	0.025
Forming	1/2 wide	65	0.0012	120	0.002
	1 wide	65	0.0010	120	0.002
	1 1/2 wide	60	0.0008	120	0.002
	2 wide	60	0.0008	120	0.001
Cutoff	1/16 wide	60	0.0010	120	0.002
	1/8 wide	60	0.0010	120	0.002
	3/16 wide	65	0.0012	120	0.002
	1/4 wide	65	0.0015	120	0.003
Drilling	1/16 dia.	40	0.0010		
	1/8 dia.	40	0.0020		
	1/4 dia.	45	0.0025		
	1/2 dia.	45	0.0030		
	3/4 dia.	45	0.0035		
	1 dia.	45	0.0040		

**Use the higher speeds for the finer threads.*

Specifications

440C has found wide industry acceptance and meets the following specifications

QQ-S-763d	AMS 5630C	ASTM A-276-67	ASTM A-580-67

DATA SHEET

D2 (AIRDI 150)

Typical Composition

C	Cr	Mo	V
1.55	**11.5**	**0.9**	**0.8**

D2 is an air-hardening, high carbon, high chromium tool steel, heat treatable to HRC 60-62. It offers excellent abrasion resistance, due to a large volume of carbides in the microstructure. D2 has been widely used for many years in cold work applications requiring very high wear resistance. It is machinable in the annealed condition and like other air-hardening tool steels, exhibits minimal distortion on hardening.

Typical Applications: stamping or forming dies, punches and dies, forming rolls, blanking dies, thread rolling dies, coining dies, lamination dies, trim dies, industrial knives and slitters, shear blades, fineblanking tools, scrap choppers, wear parts, tire shredders, and plastic injection feed screws and tips.

MECHANICAL PROPERTIES

	Heat Treatment Austenitizing Temp.	HRC	Impact Toughness Ft.-lb.	(J)	Wear Resistance Adhesive
D2 (AIRDI 150)	1850°F(1010C)	60	21	(28)	3-4
S7	1750°F(955C)	57	12 5	(165)	1
A2	1750°F(955C)	60	40	(53)	2-3
Cru-Wear	1950°F(1065C)	62	30	(40)	5-6
3V	1950°F(1065C)	60	70	(95)	7
M2	2050°F(1120C)	62	20	(27)	8-10
M4	2050°F(1120C)	62	32	(43)	20-25
10V	2150°F(1175C)	63	14	(19)	90

Machinability

The machinability of D2 as annealed is about 35% of W1 tool steel.

Surface Treatments

D2 can be given standard surface treatments such as nitriding, TiN (titanium nitride) coating or hard chrome playing if desired. When using surface treatments, harden from the high side of the austenitizing range and temper at or above the process temperature of the treatment.

DATA SHEET

Thermal Treatments

Annealing: Heat to 1600°F (870°C), hold 2 hours, slow cool 25°F (15°C) per hour to 1000°F (540°C) then air cool. Or heat to 1600°F (870°C), hold 2 hrs., cool to 1425°F (775°C) hold 6 hrs., then air cool.

Annealed Hardness: About BHN 221/225

Stress Relieving

Annealed Parts: Heat to 1200-1250°F (650-675°C), hold 2 hours, then cool in still air.

Hardened Parts: Heat to 25-50°F (15-25°C) below the original tempering temperature, hold 2 hours, then cool in still air.

Hardening

Preheat: Heat to 1100-1200°F (595-650°C), equalize, then to 1400-1450°F (760-790°C), equalize.

Austenitize: 1825-1875°F (995-1025°C). Hold time at temperature 30-45 minutes.

Quench: Air or positive pressure quench (2 bar minimum) to below 150°F (65°C).

Temper: 400-1000°F (205-540°C). Temper 2 hours minimum each time or at least 1 hour per inch (25mm) of thickness. Double Temper. Cool to room temperature in between tempers.

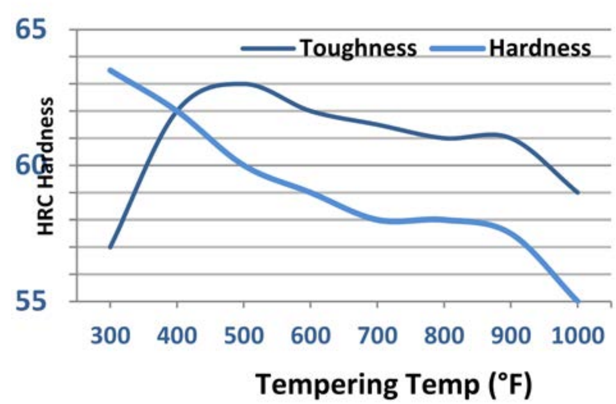
Cryogenic Treating: Refrigeration after the first temper may improve long term dimensions stability by transforming retained austenite. Any refrigeration treatment must be followed by a temper.

Size Change: (The amount of retained austenite has a significant effect.)

Hardening Temp.	Tempering Temp.	HRC	Longitudinal Size Change
1850°F(1010C)	400°F(205C)	61	+0.025%
1850°F(1010C)	600°F(315C)	59	-0.010%
1850°F(1010C)	800°F(425C)	58	-0.017%
1850°F(1010C)	1000°F(425C)	55	-0.006%

Heat Treat Response
Hardness and Impact Toughness Data
Austenitize 1850°F (1010°C) Air Cool

Tempering Temp.	HRC	Charpy C-Notch Ft. lbs.	Charpy C-Notch Joules
As Quenched	63		
300°F (150°C)	62	17	23
400°F (205°C)	61	21	29
500°F(260°C)	60	23	31
600°F(315°C)	59	22	30
700°F(370°C)	58	22	30
800°F(420°C)	58	21	29
900°F(480°C)	58	21	29
1000°F(540°C)	55	19	26



Welding

Use air hardening tool steel filler material.

Annealed Material: Preheat 700-900°F (370-485°C), maintain the temperature of the workpiece at 700°F (370°C) minimum during welding. Reanneal after welding or temper at 1425°F (775°C) for 6 hours.

Hardened Material: Preheat 25-50°F (15-30°C) below original tempering temperature or 350°F (175°C) minimum. Maintain the temperature of the workpiece at 350°F (175°C) minimum during welding. Cool to below 150°F (65°C) after welding. Temper 25°F (15°C) below original tempering temperature or 350°F (175°C) minimum.

DATA SHEET

CRU-WEAR

Typical Composition

C	Cr	W	Mo	V
1.1	7.5	1.15	1.6	2.4

CRU-WEAR is an air-hardening tool steel, heat treatable to HRC 60-65. Designed as an upgrade to D2, it offers better wear resistance, greater toughness and higher attainable hardness. Compared to the chemistry of D2, (D2 = 1.55% carbon, 11.5% chromium, 0.8% vanadium, and 0.9% molybdenum), CRU-WEAR has less carbon and less chromium, but more vanadium and tungsten. Both D2 and CRU-WEAR contain carbides for wear resistance, but CRU-WEAR has more vanadium carbides than D2. Vanadium carbides are harder than chromium carbides and are much more effective in providing wear resistance. Because CRU-WEAR contains less carbon than D2, its overall carbide volume is lower, making it tougher than D2. *(Note: Although CRU-WEAR contains fewer total carbides, it has more of the type of carbides that are most effective for wear resistance.)* CRUWEAR's higher attainable hardness results from the fact that it contains sufficient tungsten and molybdenum to cause a secondary hardening response, (up to HRC 65), which does not occur in D2. Finally, CRU-WEAR tempers at a higher range (900-1050°F) than D2 (400-600°F), so it is more compatible with a wide variety of surface treatments.

The *typical applications* include stamping or forming tools, punches and dies, rolls, blanking dies, thread rolling dies, coining dies, lamination dies, trim dies, industrial knives and slitters, shear blades, fineblanking tools, scrap choppers, wear parts, tire shredders, and plastic injection feeder screws and tips.

	Heat Treatment Austenitizing Temp.	HRC	Impact Toughness Ft.-lb	(J)	Wear Resistance Adhesive
Cru-Wear	1950F (1065C)	62	30	(40)	5-6
S7	1750F (955C)	57	125	(165)	1
A2	1750F (955C)	60	40	(53)	2-3
D2	1850F (1010C)	60	21	(28)	3-4
M2	2050F (1025C)	62	20	(27)	8-10

Mechanical Properties

Wear Resistance-CRU-WEAR will offer better wear resistance then that of the AISI D2, approaching the AISI M2.

Impact Toughness-CRU-WEAR has greater toughness than the AISI D2 approaching the AISI A2. *NOTE: Lowering the hardening temp. reduces the grain size and increases toughness.*

This data sheet is for informational purposes only. Alloy characteristics are subject to change due to chemical composition and/or processing. We do not certify the material's suitability for specific applications.

DATA SHEET

Thermal Treatments

Annealing: Heat to 1550-1650°F (840-900°C), hold 2 hours, slow cool 50°F (25°C) per hour to 1200°F (650°C).
Annealed Hardness: About BHN 225/255

Stress Relieving

Annealed Parts: Heat to 1100-1300°F (595-705°C), hold 2 hours, then furnace cool or cool in still air.

Hardened Parts: Heat to 25°F (15°C) below the original tempering temperature, hold 2 hours, then furnace cool or cool in still air.

Hardening

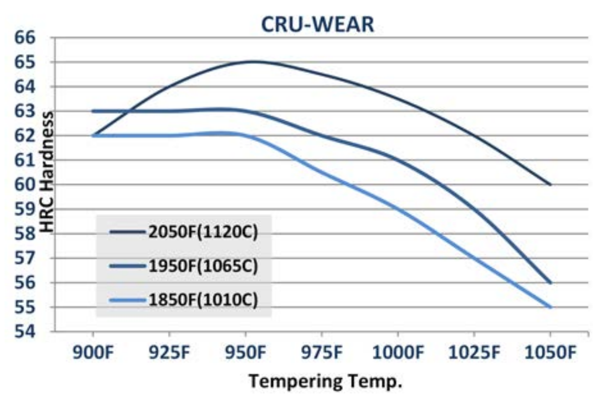
It is customary to use two furnaces: one furnace to preheat and the second furnace to austenitize. This ensures that the transition from the pre-heat temperature to the austenitizing temperature occurs fairly rapidly.
Preheat: Heat to 1550-1600°F (840-870°C), Equalize.
Austenitize: 1850-2050°F (1010-1120°C), Hold time at temperature 20-45 minutes.
Quench: Air or positive pressure quench (2 bar minimum) to below 125°F (50°C). Salt bath treatment, if practical will ensure the maximum attainable toughness for a given hardening treatment.
Temper: 900-1050°F (480-565°C). Double tempering is mandatory, and triple tempering is recommended. Cool to room temperature in between tempers. Temper 2 hours minimum each time or at least 1 hour per inch (25mm) of thickness for sections over 2" (50mm) thick.
Size Change: Approx. +0.15%

Recommended Heat Treatment: For the best combination of toughness and wear resistance, austenitize at 1950°F (1065°C). Temper 3 times at 1000°F (540°C).

Aim hardness: HRC 62 Higher austenitizing temperatures can be used to obtain higher hardness, at a slight decrease in impact resistance. The lower austenitizing temperatures provide the best impact toughness.

Note: Properties shown throughout this data sheet are typical values. Normal variations in chemistry, size and heat treat conditions may cause deviations from these values.

	Heat Treat Response Hardness (HRC)		
	Austenitizing Temperature		
Tempering Temp.	1850°F (1010°C)	1950°F (1065°C)	2050°F (1120°C)
As Quenched	63-65	63-65	62-64
900°F(480°C)	61-63	62-64	61-63
950°F(510°C)	61-63	62-64	64-66
1000°F(540°C)	57-59	60-62	63-65
1025°F(550°C)	56-58	58-60	61-63
1050°F(620°C)	54-56	55-57	59-61
Minimum Time at Aust. Temp.	45 min.	30 min.	20 min.



Surface Treatments

Because of its high tempering temperatures (900-1050°F) CRU-WEAR is suitable for nitriding, PVD coating or similar surface treatments. It will retain its hardness after such processes, making it a more suitable substrate than D2.
NOTE: CVD coating processes are generally performed at temperatures which exceed the critical temperature and may result in non-predictable dimensional distortion.

Machinability

Machinability of CRU-WEAR in the annealed condition is similar to D2 but grindability will be slightly better. Similar grinding equipment and practices are acceptable. "SG" type alumina wheels or CBN wheels have generally given the best performance.

DATA SHEET

416 Plus

Typical Composition

C	MN	P	S	SI	CR	MO
.15 Max	1.25 Max	.06 Max	.15 Max	1.00 Max	12.00/14.00	.6

Crucible 416 PLUS is a hardenable chromium steel with improved machinability and non-galling characteristics. Better machinability than that of standard 416 Stainless is obtained by the use of balanced chemistry and special manufacturing techniques. This grade is magnetic in all conditions. Typical applications are screw-machine products and all machines parts requiring good corrosion resistance.

The *typical applications* of 416 PLUS include bolts, nuts, and screws, carburetor parts, gate valve parts, instrument parts, shafts, parts made in screw machines, and valve trim.

Forging

416 PLUS should be forged at 2050°F to 2150°F and finished above 1400°F. 416 PLUS is not adaptable to severe upset forging operations.

Annealing

416 PLUS should be annealed for maximum softness at 1550°F followed by a furnace cool. For better machinability, a semi-anneal at 1300°F is recommended.

Hardening and Tempering

416 PLUS can be hardened by air cooling or oil quenching from 1750 to 1850°F. When air hardening small or thin sections, a temperature in the upper part of this range should be used. Tempering should be at the proper temperature to give the desired properties. It is desirable to avoid tempering between 800 and 1100°F as there is a drop in impact strength within this range with a coincidental drop in resistance to corrosion. This condition disappears when the tempering temperature is 1100°F or higher.

Note: Temperatures throughout data sheet are metal temperatures.

Attainable Hardness

Attainable hardness is defined as the hardness obtained on cooling a sample approximately ½” in thickness in air from 1825°F. This hardness gives some idea of the mechanical properties of the material which might be expected after hardening and tempering. The attainable hardness of 416 PLUS is guaranteed to RC35 minimum.

Forming

416 PLUS will withstand only gradual cold working. It is not adaptable to severe cold-forming operations.

Welding

416 PLUS is not generally recommended for welding as porosity results where sulfur (or selenium) is introduced.

Resistance to Scaling

416 PLUS scales at approximately 1250°F. This temperature can vary with the type of atmosphere and application.

DATA SHEET

General Corrosion Resistance

The corrosion resistance of 416 PLUS was evaluated in a variety of corrosion tests normally used for this type of stainless. Comparisons were made to 416 stainless. The corrosive resistance of 416 PLUS is comparable to that of standard 416 stainless. Comparative data are given below.

Surface area showing corrosion (in percent)

Grade	Water Vapor Column (24 Hours) CGA		Water Vapor Column (24 Hours) Hardened & Tempered		100% Relative Humidity (200 Hours)		5% Salt Spray (2 Hours) CGA	
	U	P	U	P	U	P	U	P
Type 416	20	1	13	10	6	4	19	13
Type 416 Plus	20	1	18	4	5	0	23	13

CGA - Center less Ground Annealed | U - Unpassivated | P - Passivated

Passivation

It is recommended that finished parts machined from stainless steel be passivated for optimum corrosion resistance. Free-machining types are prone to dulling and discoloration in passive treatments. It is important that correct procedures be followed when passivation is specified. The recommended treatment for 416 PLUS is shown below.

Acid concentration by volume of concentrated nitric acid	Sodium dichromate by weight	Bath temperature (F)	Immersion time (min.)
40-60%	2.00%	110 – 140 (120 Typ.)	15 - 30

Machining

The machining of all high-chromium steels is characterized by the tendency of the chip to gall or build up on the cutting edges and radii of the tool. 416 PLUS gives freer cutting properties and minimizes the tendency of the steel to form a built-up edge on the tool. The chips are short and brittle which results in relatively easy chip control. For the majority of applications material which has been heat treated to about 200 Brinell or annealed and cold drawn is preferred to materials in the annealed condition. The additional hardness obtained by either heat treating or cold drawing reduced the tendency of the chip to build up on the cutting edge, thus allowing a better machine finish. 416 PLUS provides increased productivity through the use of higher cutting speeds or feed rates in comparison to 416 stainless. Initial speed or feed rates may be 10% higher than for standard 416, but substantially greater improvements than this may be expected depending on the particular job. In addition, a significant improvement in tool life can be realized over standard 416 even at the increased speeds and feeds. Figures 1 and 2 demonstrate the improvement to be expected. Recommended feeds and speeds are given below.

Facts and Formulas

Key elements for high performance blade steels:

Chromium (Cr) serves several functions in blade steels. In 400 series stainless steels, in concentrations of 11% or more, Cr is essential in forming a passive film that protects the steel's surface from corrosion. It also allows the steels to through harden, and forms carbides. In tool steels Cr is responsible for through hardening and forms carbides. The average hardness of chrome carbides is 67 Rc.

Molybdenum (Mo) helps increase the resistance to the initiation of surface pitting in 400 series stainless steels. Mo also forms carbides with an average hardness of 75 Rc. In some tool steels, Tungsten (W) is substituted for Mo to form similar type carbides.

Vanadium (V) promotes the formation of very hard (83 Rc) and very small carbides which increase the wear resistance of any blade steels that contains V as low as 1%.

Niobium (Nb) is added, primarily as a substitute for V, to select high performance alloys as a way to increase the toughness without sacrificing wear resistance. When added, it will improve grindability in the heat treated condition.

Carbon (C) is the most important element to consider when designing an alloy. The working hardness of an alloy will increase as the carbon content is increased. Carbon also forms both simple and complex carbides with the elements mentioned above. There can be too much of a good thing as too much carbon will increase the brittleness and decrease the corrosion resistance of an alloy.

Weight Calculations: Weight = Volume x density. The density of most knife alloys is .285 lbs/cubic inch.
Volume= width × length × thickness.   Length= Pounds ÷ (width × thickness ×.285)

Ex: .285(density) × 1.5"W × .250"T × 36"L = weight. The weight equals 3.85 pounds
Ex: 10lbs ÷ (1.5"W × .187"T × .285) = length. The length equals 125.09 inches

Historical notes:

A common belief is that if a knife is given as a gift, the relationship of the giver and recipient will be severed. Something such as a small coin should be exchanged for the gift, rendering "payment."

A knife placed under the bed while giving birth is said to ease the pain.