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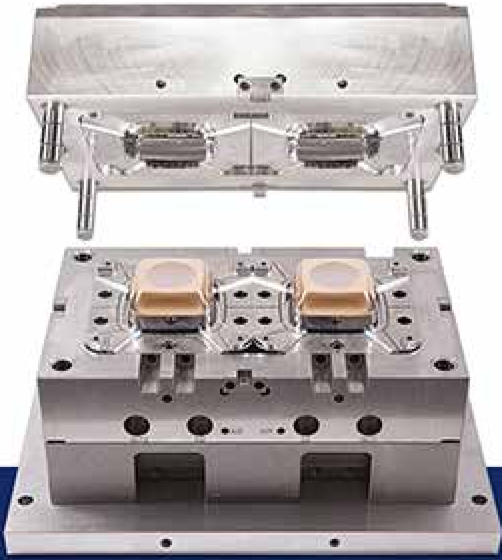
America's Premier Metals Service Center



TOOL AND DIE STEEL GUIDEBOOK

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Alro Steel

Metals & Plastics

MISSION STATEMENT

To ensure the long term success of Alro and its people by exceeding our customers' expectations.

SERVICE EXPECTATIONS

Tender Loving Care for all Customers
Everyone is your customer.

Next Day Delivery
Most customers rely on it.

Zero Errors
What good is great delivery if it's wrong?

Heroic Recoveries
Turn a problem into an opportunity. If something goes wrong, fix it now!
Figure out what happened later and learn from it.

FOUNDATIONS

PEOPLE • SAFETY • SYSTEMS • INVENTORY • FACILITIES • EQUIPMENT

Since 1948

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NOTE: Statistical information (pertaining to speeds, strength, specifications, proper working load of materials, tools, machines, etc.) contained in this catalog was derived from manufacturer's tables and reprinted by us for our customers' convenience. We assume no responsibility by this reprint.

What is Tool Steel?

Legend has it that tool steel was created in the medieval times when the knights were standing around the camp fire cooking the day's kill on their swords. It seems a messenger rode into the camp with bad news for one of the knights. After hearing the news, the knight stuck the messenger with the sword, killing him. A common tradition in those days. The knight later realized his sword held a better edge after it was heated and "quenched."

It did not take them long to realize they could use almost any liquid to quench their swords. This spared many messengers! We do not know if this is the true beginning of tool steel; however, it is an interesting story.

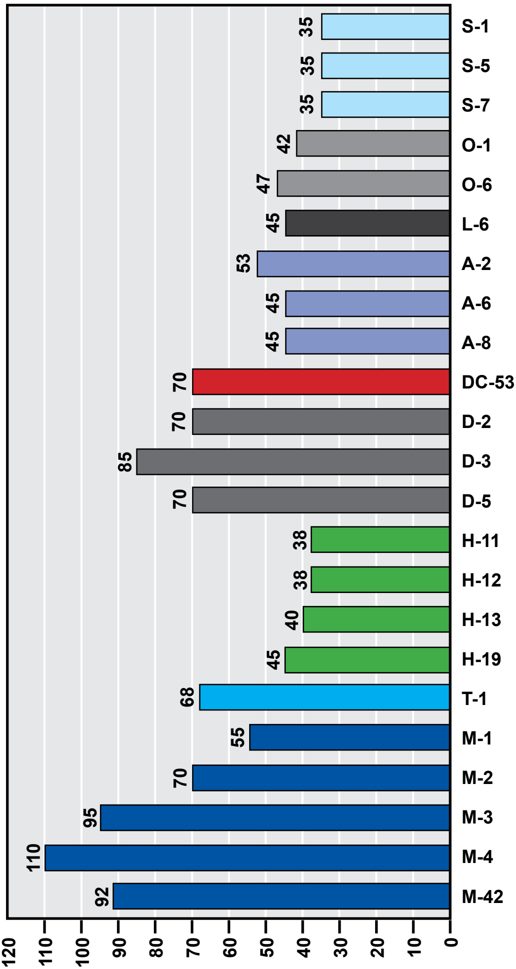
Tool steel refers to any alloy steel which is hardened and used in a tooling application. Today there are a wide variety of tool steels available. Most tool steels are now of the air hardening type; however, oil hardening and water hardening steels are still available. The advent of air hardening tool steels through increased element content has improved size stability, wear resistance, and toughness.

We hope this book will help in choosing the best steel for your application. It is provided for reference only. If you require additional information we have extensive data sheets, along with a very knowledgeable staff.

Tool Steel Comparison Guide

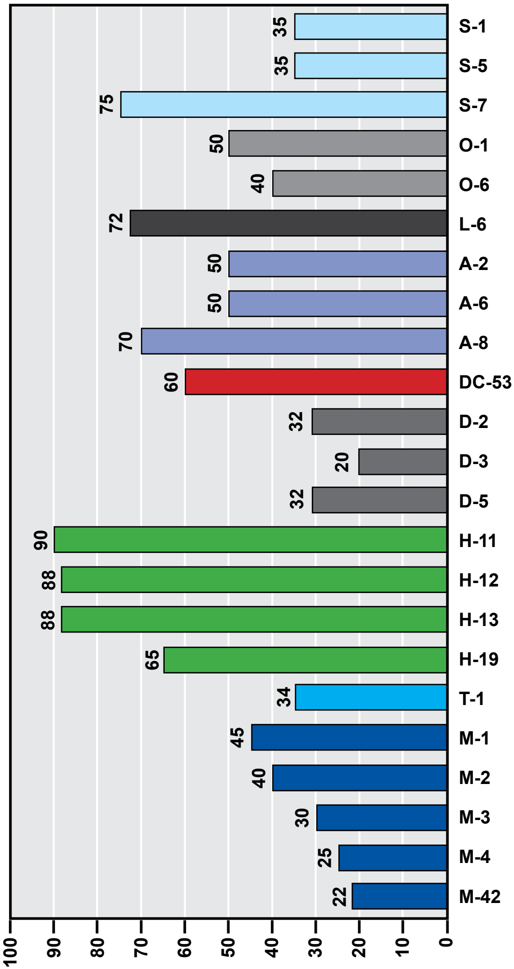
Comparison Chart

Relative Abrasion Resistance



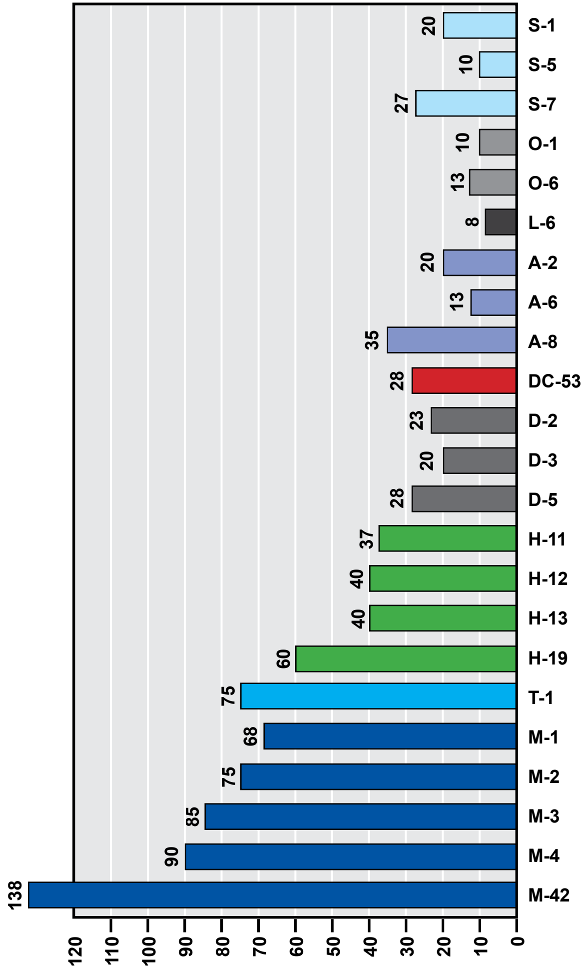
Comparison Chart

Relative Toughness



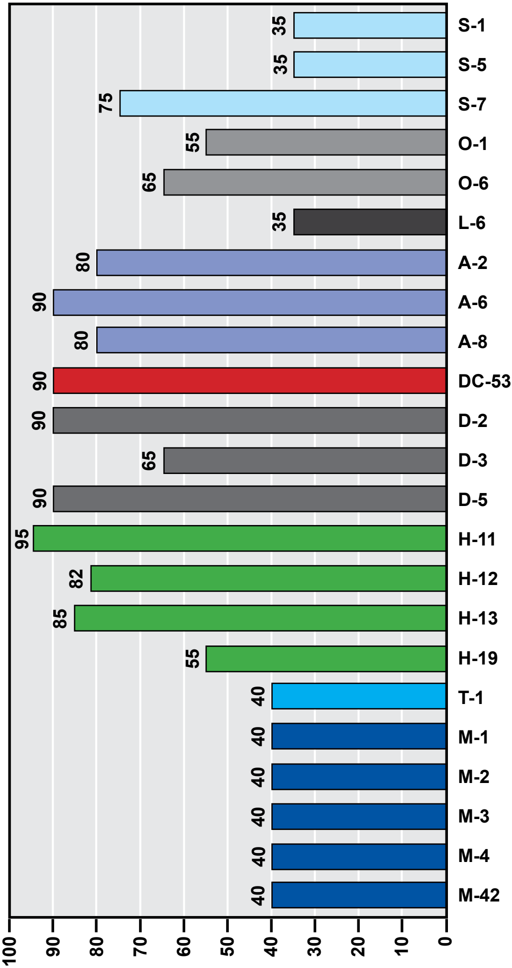
Comparison Chart

Relative Hot Hardness



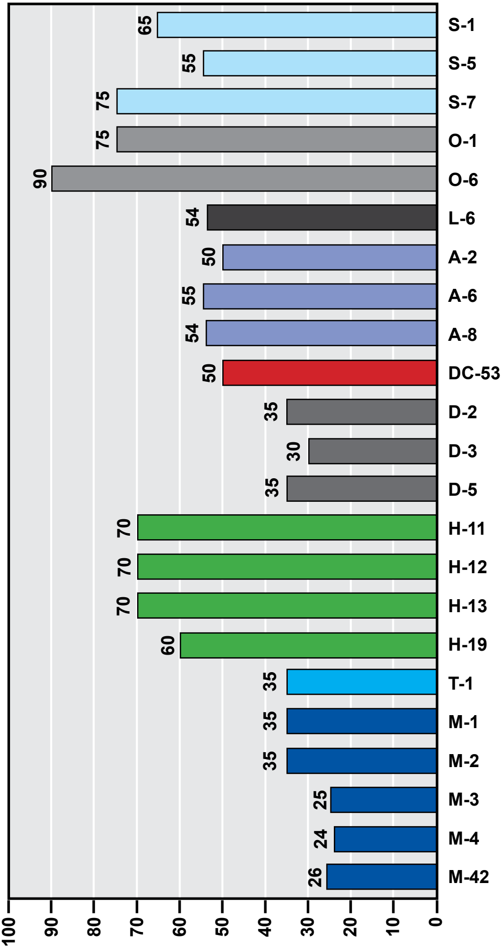
Comparison Chart

Relative Size Stability



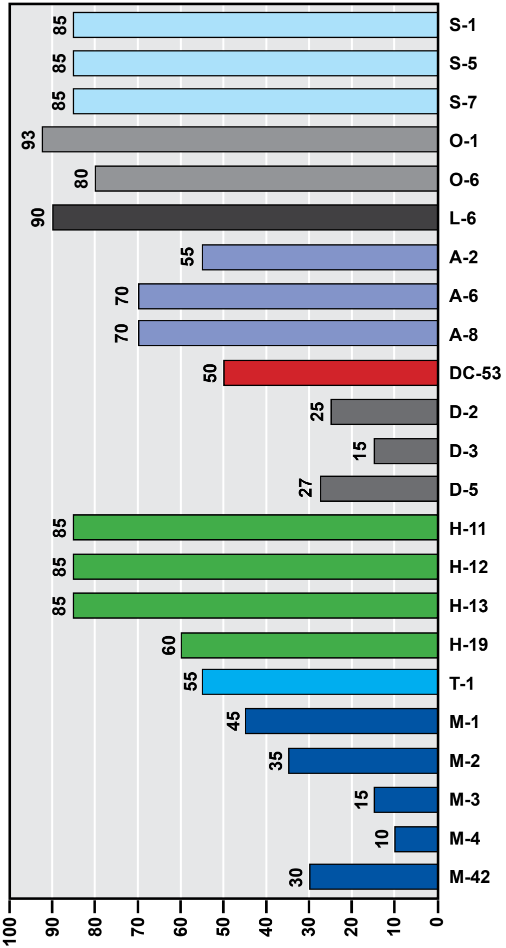
Comparison Chart

Relative Machinability



Comparison Chart

Relative Grindability



AISI A-2

Air Hardening Die Steel

Typical Analysis

C	Mn	Cr	Mo
0.95 - 1.05	1.00 max	4.75 - 5.50	0.90 - 1.40

V	Si	Ni	
0.15 - 0.50	0.50 max	0.30 max	

Advantages

- Good combination of wear resistance & toughness
- Very stable in heat treatment
- Not difficult to machine or grind
- Good hardenability

Availability

Readily available

Machinability

A-2 can be machined readily in fully annealed condition. Its machinability rating is about 65% of a 1% carbon tool steel. It also has a high grindability rating.

Annealing

Heat slowly to 1500° - 1600°F and furnace cool, allowing the temperature to drop about 75°F per hour to 1000°F. Then air cool. The annealed hardness is 202 to 248 Brinell.

AISI A-2

Air Hardening Die Steel

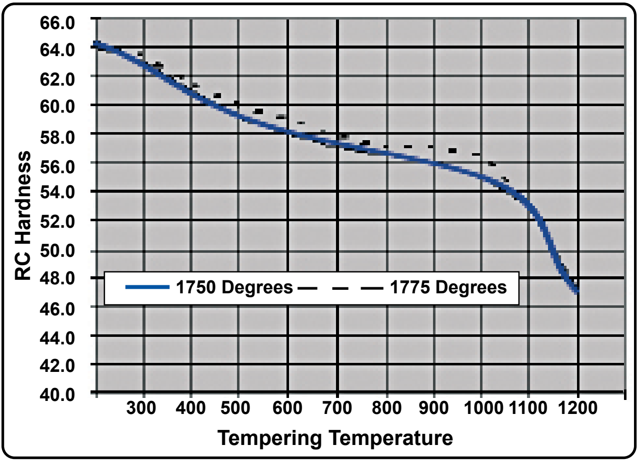
Hardening

A-2 should be preheated at 1200° to 1300°F then taken up to 1725° to 1750°F. When part is at temperature it should be soaked 30 minutes for the first inch of thickness and 15 minutes for each inch of thickness over one inch. If a controlled atmosphere or vacuum furnace is not available then part should be wrapped in stainless foil to prevent decarburization. When the piece is taken from the furnace the stainless foil must be removed (if applicable) and then cooled in still air. Large pieces may require forced air.

Tempering

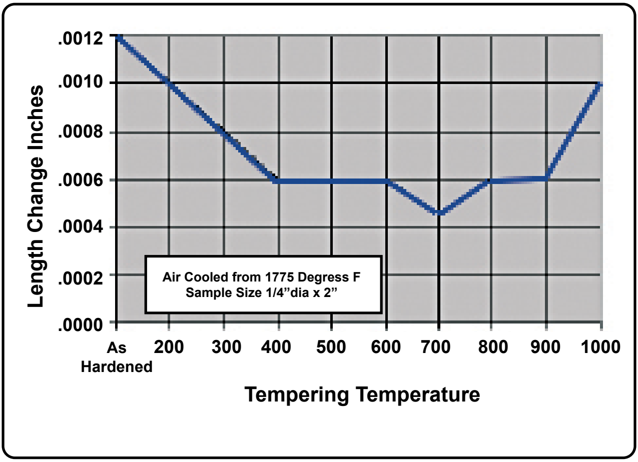
As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. Heat slowly to the tempering temperature selected to obtain the hardness desired. Double tempering is recommended.

Tempering Curve for A-2



Hardened	at 1750°F	at 1775°F
Single Tempered	Rc Hardness	Rc Hardness
As Quenched	64.0	64.5
300	63.0	63.5
400	61.0	61.5
500	59.0	60.0
600	58.0	59.0
700	57.0	58.0
800	56.5	57.0
900	56.0	57.0
1,000	55.0	56.5
1,100	53.0	53.0
1,200	47.0	47.0

A-2 Dimensional Size Change



AISI A-6

Air Hardening Die Steel

Typical Analysis

C	Si	Mn
0.65 - 0.75	0.50 max	1.80 - 2.50

Cr	Mo	Ni
0.90 - 1.20	0.90 - 1.40	0.30 max

Advantages

- Air hardening from low temperature
- Excellent size stability in heat treatment
- Deep hardening
- Easy to machine

Availability

Moderately available, not as available as A-2.

Applications

A-6 is a medium alloy steel used in die and mold applications. It has a very good balance of toughness, strength and wear resistance. Quite often it is chosen because of its good machinability and non-deforming characteristics in heat treatment.

Machinability

A-6 is readily machined in the annealed condition. Its machinability is about 65% of a 1% carbon tool steel. It also has a high grindability rating.

AISI A-6

Air Hardening Die Steel

Annealing

A-6 may be annealed in either a controlled atmosphere furnace or wrapped in stainless steel foil. Heat to 1350° to 1380°F and hold approximately one hour for each inch of thickness. Cool very slowly at a rate of 20° per hour to approximately 1000°F. Annealed hardness range is normally 212 to 235 Brinell.

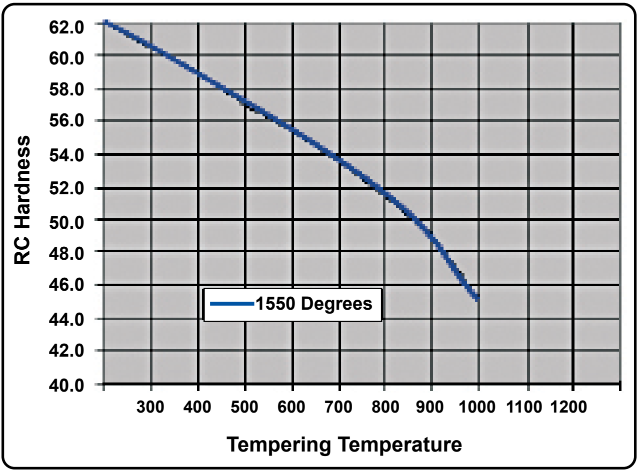
Hardening

A-6 should be heated to 1525° to 1600°F in a vacuum or atmospherically controlled furnace. The tool should be thoroughly heated and then cooled in air to 125° to 150°F. Preheating at 1200° to 1250°F is recommended for large or intricate tools.

Tempering

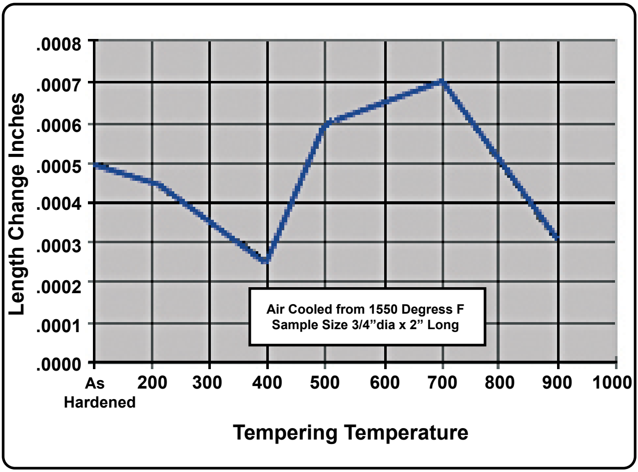
As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. To obtain high hardness with minimum distortion A-6 should be tempered at 350° to 400°F. Even the smallest tools should be tempered for one hour and a tempering time of one hour per inch of thickness is recommended.

Tempering Curve for A-6



Hardened	at 1550°F
Single Tempered	**Rc Hardness**
As Quenched	62.0
300	60.5
400	59.0
500	57.0
600	55.5
700	53.5
800	51.5
900	49.0
1,000	45.0

A-6 Dimensional Size Change



AISI A-8

Shock Resisting Die Steel

Typical Analysis

C	Si	Mn
0.55	1.00	0.30

Cr	Mo	W
5.00	1.25	1.25

Advantages

- The most versatile cold work die steel
- More toughness than A-2 or D-2
- More wear resistance than S-7
- Very stable in heat treatment

Availability

Limited.

Applications

A-8 combines good wearing qualities with excellent toughness characteristics. It is well suited for many metal working dies and punches which operate in the hardness range of 55 to 60 Rockwell C.

Machinability

A-8 has a machinability rating of 85% of a 1% carbon tool steel. It also has a high grindability rating.

AISI A-8

Shock Resisting Die Steel

Annealing

Heat in an atmosphere furnace to 1550°F and hold for one hour per inch of thickness. Furnace cool at 25°F per hour maximum to 1000°F then air cool. The annealed hardness of A-8 is approximately 197 to 229 Brinell.

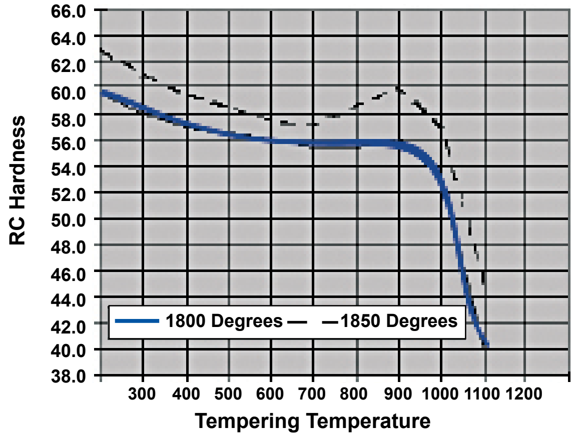
Hardening

A-8 should be heated slowly to 1800° to 1850°F, held at this temperature until uniformly and thoroughly heated, allowing a minimum soaking time of 30 minutes at temperature then air cooled. Sections over 1” in thickness should be soaked an additional 15 minutes per inch of thickness. This grade is normally air cooled but larger sections may be flash oil quenched to obtain desired hardness. An atmospherically controlled furnace or stainless foil wrap must be used to heat treat A-8 in order to prevent decarburization.

Tempering

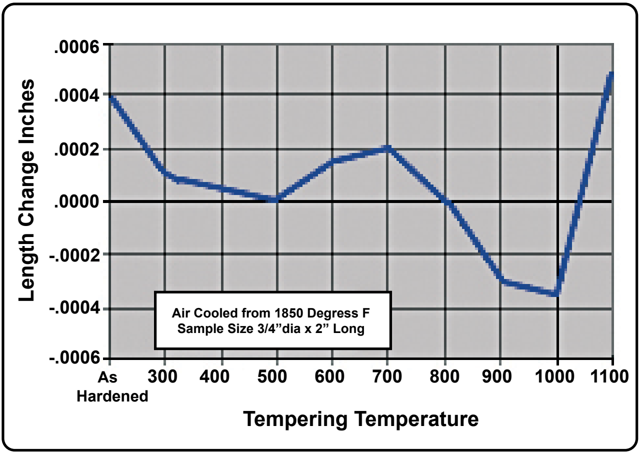
As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. Allow to heat slowly to the desired temperature and hold for a period of two hours. Remove from furnace and cool in still air. For most cold work applications tempering should be carried out in the range of 300° to 600°F. Double tempering is recommended for best results with tempering temperatures above 600°F.

Tempering Curve for A-8



Hardened	at 1800°F	at 1850°F
Single Tempered	Rc Hardness	Rc Hardness
As Quenched	59.5	63.0
300	58.0	61.0
400	57.0	59.5
500	56.5	58.5
600	56.0	57.5
700	55.5	57.0
800	55.5	58.5
900	56.0	60.0
1,000	53.0	57.0
1,100	40.0	45.0

A-8 Dimensional Size Change



AISI A-10

Graphitic Tool Steel

Typical Analysis

C	Si	Mn
1.35	1.20	1.80
Ni	**Mo**	
1.85	1.50	

Advantages

- Low hardening temperature
- Excellent size stability
- Self lubricating

Availability

Limited.

Applications

A-10 has excellent non-seizing properties for metal on metal applications.

Machinability

A-10 in the annealed condition has a machinability rating of 90% of a 1% carbon tool steel. It also offers excellent grindability.

AISI A-10

Graphitic Tool Steel

Annealing

Preferably A-10 should be atmosphere or vacuum annealed at 1450°F. Furnace cool to 1000°F at approximately 100° per hour, then cool in still air. This should result in a maximum hardness of 269 Brinell.

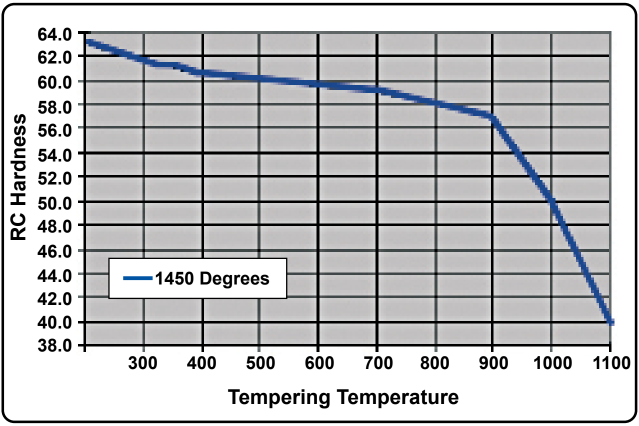
Hardening

Heat slowly to 1450° to 1500°F. and hold at temperature until well equalized. Remove from furnace and air cool to under 100°F. Large sections should be pre-heated to 1200°F.

Tempering

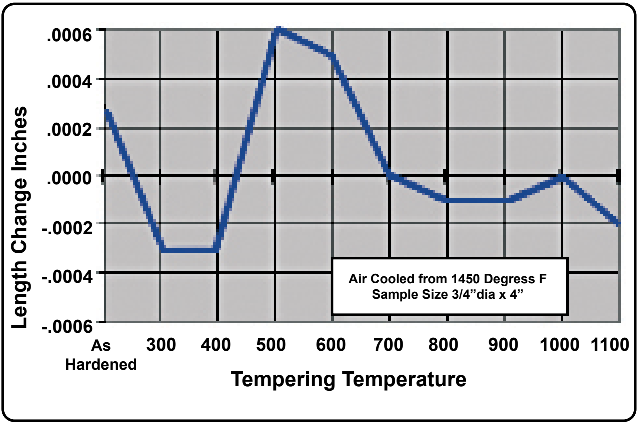
A-10 should be tempered immediately after quenching. Heat slowly to tempering temperature and hold for one hour per inch of thickness. For most applications 300° to 500°F is suggested. Double tempering is recommended.

Tempering Curve for A-10



Hardened	at 1450°F
Single Tempered	**Rc Hardness**
As Quenched	63.0
300	61.5
400	60.5
500	60.0
600	59.5
700	59.0
800	58.0
900	57.0
1,000	50.0
1,100	45.0

A-10 Dimensional Size Change



AISI O-6

Graphitic Tool Steel

Typical Analysis

C	Si	Mn
1.25 - 1.55	0.55 - 1.50	0.30 - 1.10

Mo	Cr	Ni
0.20 - 0.30	0.30 max	0.30 max

Advantages

- Excellent non-seizing properties.
- Good size stability for an oil hardening tool steel.

Availability

Limited.

Applications

O-6 has good size stability and excellent non seizing properties which make it a popular choice for metal on metal abrasive applications. Some typical choices are thread gages, draw dies, bushings, cam's and wear plates.

Machinability

O-6 in the annealed condition has a machinability rating of 90% of a 1% carbon tool steel. It also has a good grindability rating.

AISI O-6

Graphitic Tool Steel

Annealing

O-6 should be atmosphere or vacuum annealed at 1450°F. Furnace cool to 1000°F, at approximately 100° per hour, then finish cooling in still air. This should result in a maximum Brinell hardness of 229.

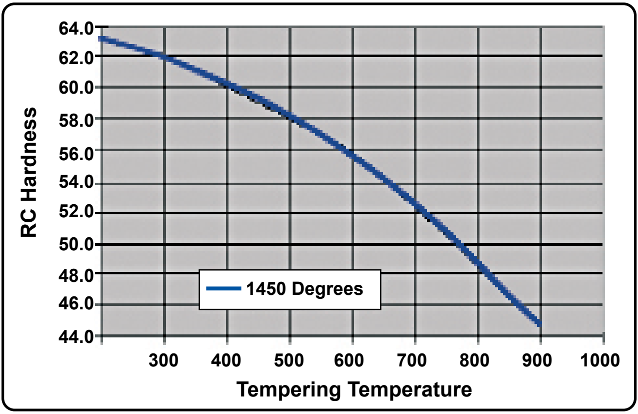
Hardening

O-6 should be heated slowly to 1450° to 1500°F. Hold until uniformly heated then quench in warm oil. Pre-heating is not normally necessary, except for large pieces. Pre-heat large pieces to 1200° to 1250°F.

Tempering

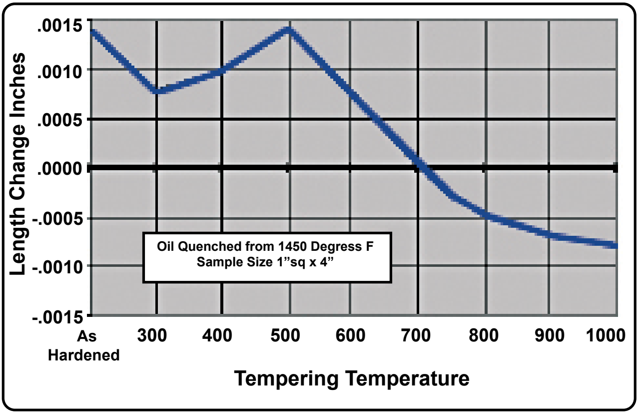
O-6 should be tempered immediately after quenching to room temperature, (125° to 150°F). To gain maximum hardness temper O-6 at 300° to 400°F.

Tempering Curve for O-6



Hardened	at 1450°F
Single Tempered	**Rc Hardness**
As Quenched	63.0
300	62.0
400	60.0
500	58.0
600	56.0
700	52.5
800	48.5
900	44.8

O-6 Dimensional Size Change



AISI O-1

Oil Hardening Die Steel

Typical Analysis

C	Si	Mn	Cr
0.85 - 1.00	0.50 max	1.00 - 1.40	0.40 - 0.60

W	V	Ni	
0.40 - 0.60	0.30 max	0.30 max	

Advantages

- Moderately wear resistant
- Hardens from low temperature
- Easy to machine

Availability

Readily available in flat ground stock and drill rod. Bar stock is rapidly being replaced by A-2.

Machinability

In the annealed condition O-1 carries a rating of 90% of a 1% carbon tool steel. It also has a high grindability rating.

Annealing

Preferably O-1 should be atmosphere or vacuum annealed at 1425° to 1450°F. About two or three hours at temperature is required. Then the charge should be furnace cooled 100° per hour and then cooled in still air from 1000°F. Annealed hardness is 187 to 217 Brinell.

AISI O-1

Oil Hardening Die Steel

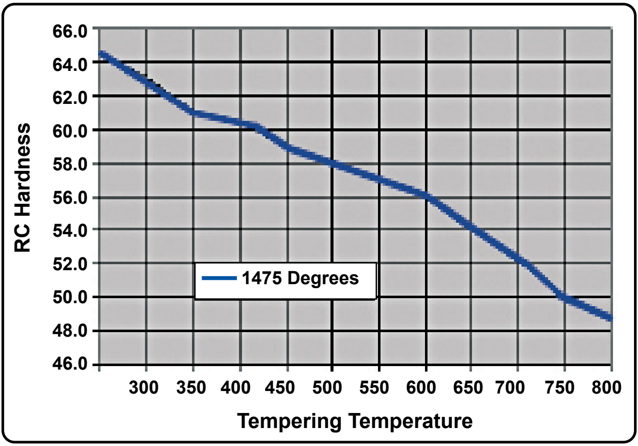
Hardening

O-1 should be heated slowly to 1475° to 1500°F, and held at this temperature until thoroughly and uniformly heated and then quenched in warm oil. When the part has cooled to approximately 150°F it should be removed from the oil and transferred to the tempering furnace.

Tempering

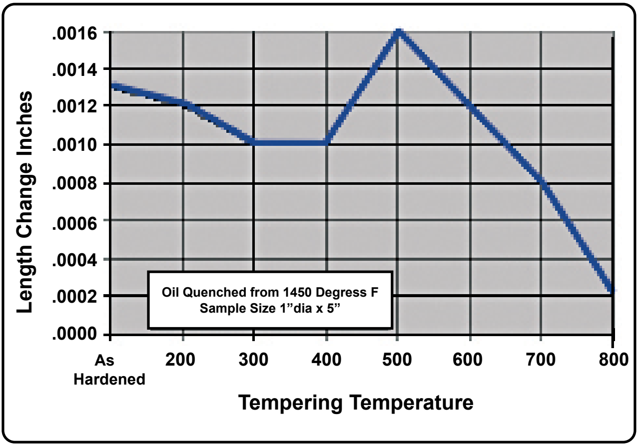
As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. Ordinary blanking and cold forming tools should be tempered about 375° to 400°F for one hour. Larger tools for heavy work will require a tempering temperature of 425° to 475°F.

Tempering Curve for O-1



Hardened	at 1475°F
Tempering Temp	**Rc Hardness**
As Quenched	64.5
300	62.5 - 63.0
350	61.0
400	60.5
450	59.0
500	58.0
550	57.0
600	56.0
650	54.0
700	52.5
750	50.0
800	48.0 - 49.0

O-1 Dimensional Size Change



AISI D-2

Air Hardening Die Steel

Typical Analysis

C	Si	Mn	Cr
1.40 - 1.60	0.60 max	0.60 max	11.0 - 13.0

Mo	V	Co	Ni
0.70 - 1.20	1.10 max	1.00 max	0.30 max

Advantages

- Extremely high wear resistance
- Excellent size stability in heat treatment
- Deep hardening in air

Availability

Readily available.

Applications

Used for cold work tools requiring very long runs and close tolerances. D-2 has high compressive strength and is used for blanking, stamping, and cold forming dies where emphasis is not on toughness. Some other applications are slitters, punches, thread rolling dies and trim dies.

Machinability

Although readily machinable in the annealed condition D-2 has a lower rating than most other tool steels. It is rated at 40% of a 1% carbon tool steel. It also has a low to medium grindability rating.

AISI D-2

Air Hardening Die Steel

Annealing

D-2 should be surface protected during annealing and slowly heated to 1600° to 1650°F. Hold at temperature for one hour per inch of thickness and then furnace cool 100° per hour to 1000°F or below. The part may then be cooled in still air. The annealed hardness of D-2 is 212 to 248 Brinell.

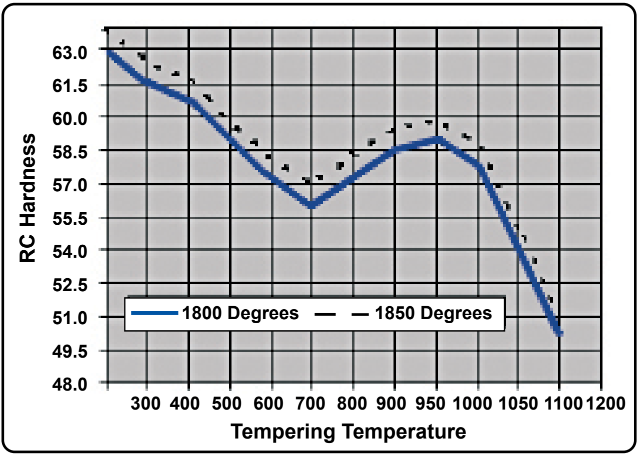
Hardening

It is very important to prevent decarburization of D-2 during heat treatment and it should be hardened in an atmospherically controlled or vacuum furnace or wrapped in stainless foil. After preheating at 1200° to 1300°F the tool should be brought to 1850° to 1875°F and allowed to soak thoroughly at that temperature. Holding time at temperature is 30 minutes for the first inch and 15 minutes each additional inch of cross section. The part should be cooled in still air. A circulating forced air quench for pieces over three inches thick is recommended.

Tempering

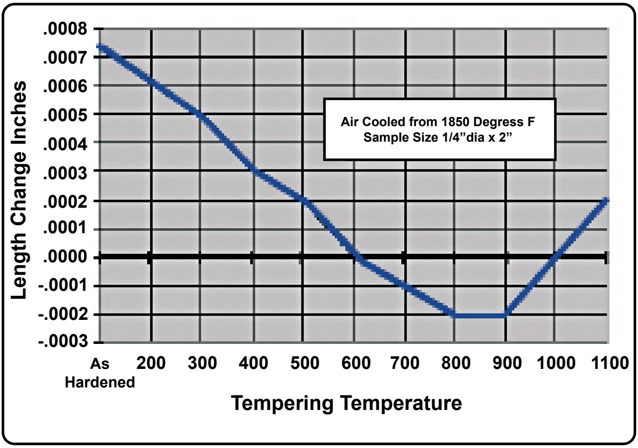
As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. Tools not subject to any appreciable shock where maximum abrasion resistance is desired may be tempered in the 300° to 500°F range. Where maximum toughness is needed or for semi-hot work applications a “high double draw” at 950° to 975° is recommended. Allow at least one hour at temperature for pieces up to 1” thick and up to two hours for sections over one inch.

Tempering Curve for D-2



Hardened	at 1800°F	at 1850°F
Single Tempered	Rc Hardness	Rc Hardness
As Quenched	63.0	64.0
300	61.5	62.5
400	60.7	61.7
500	58.9	59.9
600	57.3	58.3
700	56.0	57.0
800	57.3	58.3
900	58.5	59.5
950	58.9	59.9
1,000	57.9	58.9
1,050	54.0	55.0
1,100	50.0	51.0

D-2 Dimensional Size Change



AISI D-3

Oil Hardening Die Steel

Typical Analysis

C	Si	Mn	Cr
2.00 - 2.35	0.60 max	0.60 max	11.0 - 13.5

W	V	Ni	
1.00 max	1.00 max	0.30 max	

Advantages

- Extremely high wear resistance
- Very high compressive strength

Availability

Limited.

Applications

Used in specialized applications such as draw dies, forming rolls, powder metal tooling and lamination dies.

Machinability

Although readily machinable in the annealed condition D-3 has a lower rating than most other tool steels. It is rated at 45% of a 1% carbon tool steel. D-3 has a low grindability rating.

AISI D-3

Oil Hardening Die Steel

Annealing

D-3 should be surface protected during annealing and slowly heated to 1600° to 1650°F. Hold at temperature for one hour per inch of thickness. Furnace cool to 1000°F, and then cool in still air.

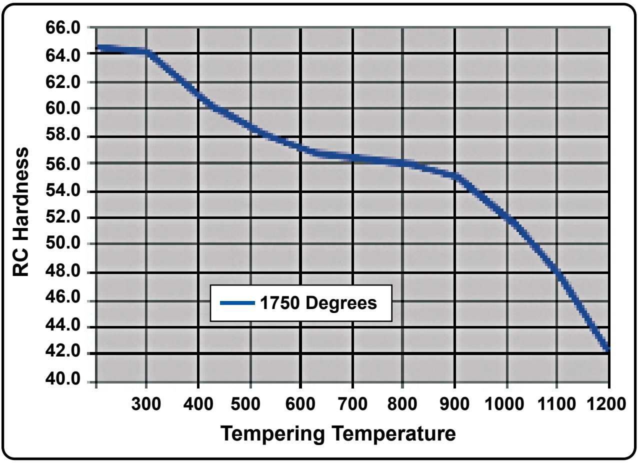
Hardening

D-3 should be protected against decarburization and scaling during heat treatment. Harden in a salt bath or vacuum furnace. After preheating at 1200° to 1250°F the tool should be brought to 1700° to 1750°F and allowed to soak thoroughly at temperature. Holding time at temperature is 30 minutes for the first inch and 15 minutes for each additional inch of cross section. Quench in warm oil until pieces have lost color, and then allow to cool in still air.

Tempering

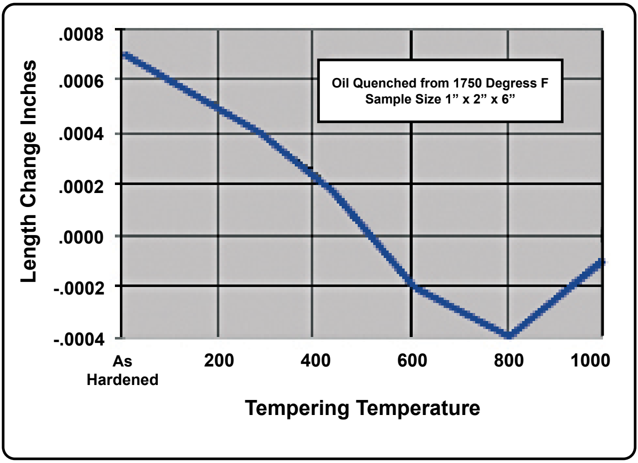
As soon as pieces have cooled to room temperature (100° to 125°F) tempering must begin. Place steel in furnace and raise to selected tempering temperature slowly. Allow at least one hour at temperature for pieces up to one inch thick and up to two hours for sections over one inch.

Tempering Curve for D-3



Hardened	at 1750°F
Tempering Temp	**Rc Hardness**
As Quenched	64.5
300	64.0
400	61.0
500	58.5
600	57.0
700	56.5
800	56.0
900	55.0
1,000	52.0
1,100	48.0
1,200	42.0

D-3 Dimensional Size Change



AISI D-5

Air Hardening Die Steel

Typical Analysis

C	Si	Cr	Mo
1.40 - 1.60	0.60 max	11.0 - 13.0	0.80

Ni	Co	Mn	V
0.30 max	2.50 - 3.50	0.60 max	1.00

Advantages

- Extremely high wear resistance
- Extra resistance to galling

Availability

Very limited.

Applications

Used for draw dies, forming rolls. The addition of cobalt, allows D-5 to be used in semi-hot work applications.

Machinability

D-5 has a machinability rating of 50 compared to a 1% carbon tool steel which is rated at 100.

AISI D-5

Air Hardening Die Steel

Annealing

D-5 should be protected from decarburization. Heat slowly to 1625° to 1650°F. Hold at temperature for one hour per inch of thickness, and then furnace cool 100° per hour to 1000°F or below. The part may then be cooled in still air.

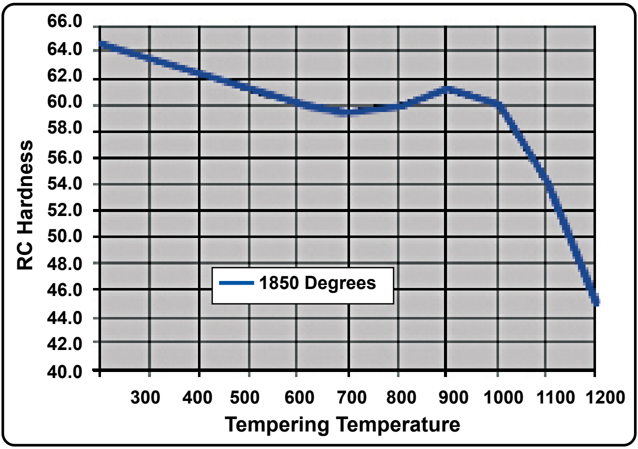
Hardening

It is very important to prevent decarburization of D-5 during heat treatment and it should be hardened in an atmospherically controlled furnace. After preheating at 1200° to 1250°F, raise temperature to 1825° to 1850°F and allow to soak thoroughly at that temperature. In large die sections pieces may be oil quenched to 800°F and allowed to cool in still air.

Tempering

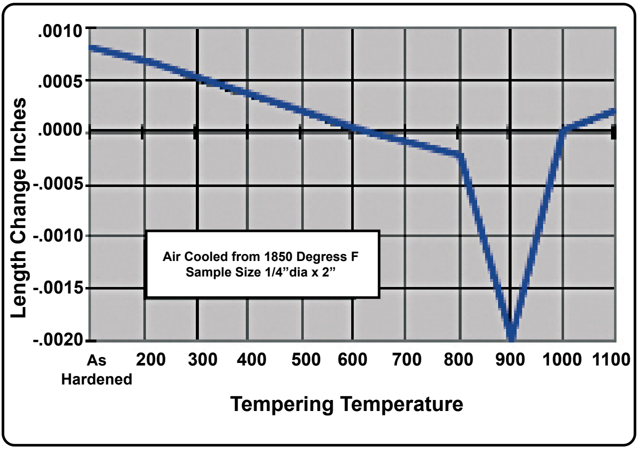
Temper as soon as pieces have reached room temperature. Tempering time should be long enough to allow thorough heat penetration. One hour per inch of thickness is recommended. Temper in the 350° to 600°F range for tools needing a balance between wear resistance and toughness. For semi-hot work tools, a range of 900° to 950°F is recommended. Double tempering of large sections is advisable.

Tempering Curve for D-5



Hardened	at 1850°F
Tempering Temp	**Rc Hardness**
As Quenched	64.5
300	63.5
400	62.5
500	61.0
600	60.0
700	59.5
800	60.0
900	61.0
1,000	60.0
1,100	54.0
1,200	45.0

D-5 Dimensional Size Change



DC-53

Air Hardening Die Steel

Typical Analysis

C	Si	Mn
1.00	1.00	0.40

Cr	Mo	V
8.00	2.00	0.30

Advantages

- Higher hardness (63-64 HRC) than D2 after heat treatment
- Twice the toughness of D2 with superior wear resistance
- Substantially higher fatigue strength compared to D2
- Secondary refining process (DLF) reduces impurities
- Smaller primary carbides than D2 protect the die from chipping and cracking
- Machines and grinds up to 40% faster than D2
- Less residual stress after wire EDMing

Availability

Readily available.

Applications

Used for stepped punch and press-punching dies, concrete sprayer parts rotor plates, swaging dies and backers, dies for cold forging, thread-rolling circular dies, piercing punch, thread-rolling dies for heat-treated bolts, forming dies, stripper plates for lead frame blanking, gauges, screws for injection molding machines and plastic molds.

Machinability

DC-53 machines and grinds better and faster than D2 for longer tool life and reduced tool manufacturing time.

DC-53

Air Hardening Die Steel

Hardening

DC53 can be hardened ideally to a hardness range of 58-64 HRC. After preheating at 1475°F to 1560°F, raise temperature to 1885°F to 1900°F and allow to soak thoroughly at temperature. Soak time for Vacuum Hardening, 20-30 minutes per inch of thickness for material 4" diameter/thickness and under. Material over 4" diameter/thickness, 10-20 minutes per inch of thickness. Please note, preheat and hardening soak times are the same. Vacuum hardening quench pressure recommended is 1½ to 2 bar, cooling in still air is also allowed.

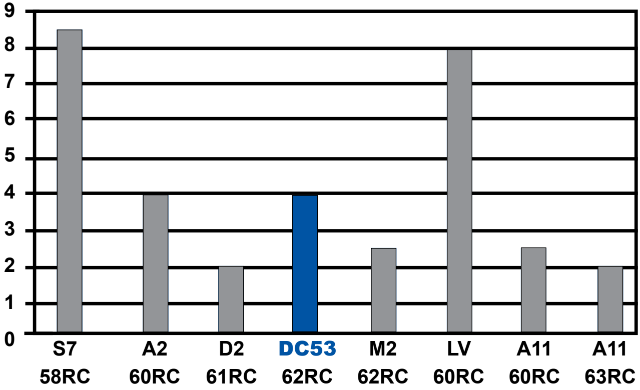
Tempering

As soon as material has cooled to temperature (150°F) tempering should begin. Place material in furnace and raise to selected tempering temperature slowly. Allow 60-90 minutes per inch of thickness at temperature for each temper. DC53 should be double tempered, a third temper is recommended (750°F) for components requiring EDM work or PVD coatings. Expect material growth .10%-.15% (.001" to .0015 per inch)

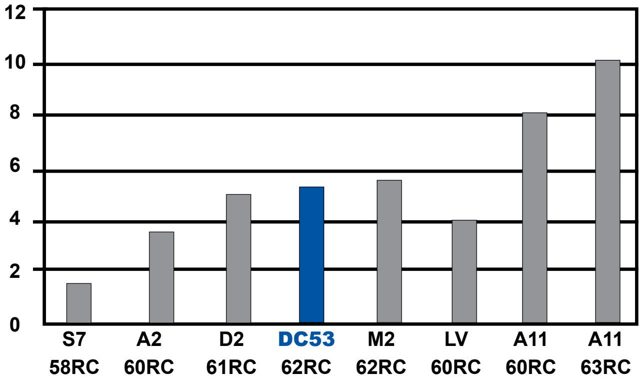
Austenitize	Double High Temperature Draw*	
1,030° C 1,885° F	520° C 968° F	HRC 62/64
	540° C 1,004° F	HRC 60/62
	550° C 1,022° F	HRC 58/60

* Material growth .10% to .15% (.001" to .0015" per inch). An optional third temper recommended for intricate high precision components requiring EDM work or PVD coatings

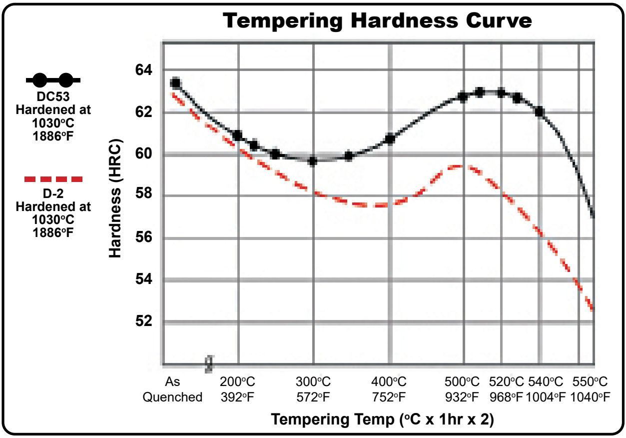
Toughness (Charpy)



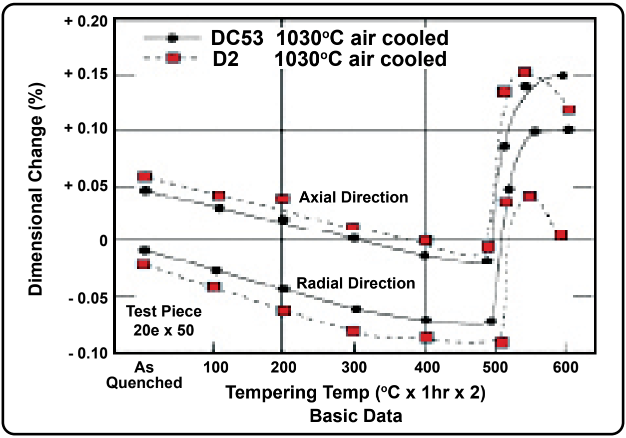
Wear Resistance



Tempering Hardness Curve for DC-53



DC-53 Dimensional Size Change



AISI L-6

Air Hardening Die Steel

Typical Analysis

C	Mn	Cr
0.65 - 0.75	0.25 - 0.80	0.60 - 1.20
Mo	**Ni**	
0.50 max	1.25 - 2.00	

Advantages

- Good toughness at lower hardness level
- Good wear at high hardness level

Availability

Mainly rounds.

Applications

L-6 was designed for general purpose tools where greater toughness is required, such as forming rolls, punches, blanking dies, shear blades, and spindles.

Machinability

L-6 has a machinability rating of 85% of a 1% carbon tool steel.

Annealing

L-6 should be annealed at 1400°F and held for one hour per inch of thickness. Cool at 20°F per hour to 900°F and then air-cool. A maximum hardness of 217 Brinell should be obtained.

Hardening

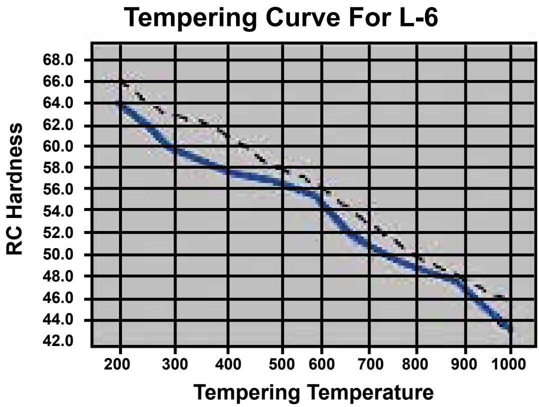
L-6 should be preheated to 1200°F then heated to 1500° to 1550°F and held for one hour per inch of thickness. Quench in oil to 150°F followed immediately by tempering. L-6 can also be air quenched in sections less than 1” thick.

AISI L-6

Air Hardening Die Steel

Tempering

L-6 should be tempered for a minimum of one hour per every inch of thickness and at 400°F. However, where increased toughness is desired, higher tempering temperatures are often used.



Hardened	at 1500°F	at 1550°F
Single Tempered	Rc Hardness	Rc Hardness
As Quenched	63.0	65.0
300	59.5	62.0
400	57.5	61.0
500	56.5	58.0
600	55.0	56.0
700	51.0	53.0
800	49.0	50.0
900	47.5	48.0
1,000	43.5	46.0

AISI H-11

Hot Work Die Steel

Typical Analysis

C	Si	Mn
0.40	1.00	0.30

Cr	Mo	V
5.00	1.30	0.50

Advantages

- Resists cracking when water cooled in service
- Superior properties at elevated temperatures
- Excellent impact strength

Availability

Very limited, usually available in block and plate.

Applications

H-11 is an excellent choice for a wide range of hot work and cold work applications. It has excellent non-deforming properties, and is used for hot shell punches, mandrels, and applications where resistance to splitting or cracking is desirable.

Machinability

H-11 has a machinability rating of 80 compared to a 1% carbon tool steel which is rated at 100.

AISI H-11

Hot Work Die Steel

Annealing

Heat slowly to 1550°F for one hour per inch of thickness. Cool 75° per hour to 1000°F and air cool. For surface protection an atmosphere furnace or stainless foil wrap must be used. The annealed hardness of H-11 should be 217 Brinell maximum.

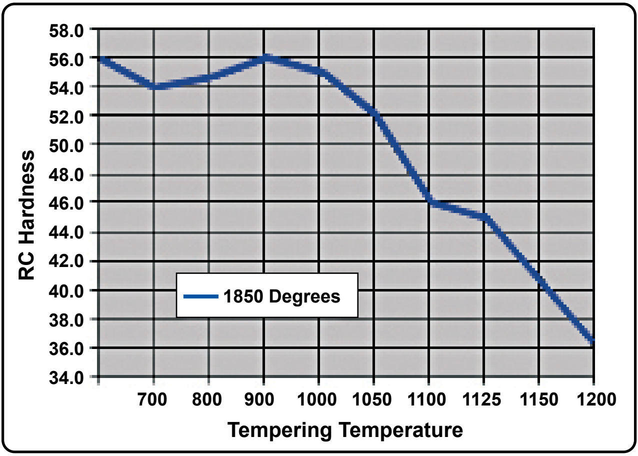
Hardening

The surface of H-11 must be protected during heat treating either by an atmospherically controlled or vacuum furnace or by the use of stainless foil wrap. The tool should be uniformly soaked at a preheating temperature of 1200° to 1400°F and then raised to 1850°F. It should be soaked at temperature for at least one hour for each inch of maximum block thickness, cool in still air.

Tempering

As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. Long tempering times and double tempering is recommended for hot work tools. The initial temper should be held at temperature for two to 10 hours depending on the size of the section and the application. 1050° to 1125°F is the typical range for tempering H-11.

Tempering Curve for H-11



Hardened	at 1850°F
Tempering Temp	**Rc Hardness**
As Quenched	56.0
700	54.0
800	54.5
900	56.0
1,000	55.0
1,050	52.0
1,100	46.0
1,125	45.0
1,150	41.0
1,200	36.0

H-11 Dimensional Size Change

Since H-11 is a strong air hardening steel it is capable of excellent size stability. When properly hardened (at 1850°F) and tempered, this material normally will show slight growth, not exceeding .001” per inch of cross section. Stress relieving H-11 after rough machining is recommended to avoid distortion during heat treatment.

AISI H-13

Hot Work Die Steel

Typical Analysis

C	Si	Mn
0.32 - 0.45	0.80 - 1.20	0.40
Cr	**Mo**	**V**
5.25	1.20	1.00

Advantages

- Good resistance to thermal fatigue
- Superior properties at elevated temperatures
- Excellent impact strength
- Deep hardening

Availability

H-13 is readily available.

Applications

H-13 is an excellent choice for a wide range of hot work and cold work applications. It is used extensively for aluminum, zinc and magnesium die casting dies where drastic water cooling is used and both high red hardness and resistance to heat checking are crucial. H-13 is often used as a cold work shock steel because of its excellent toughness due to the low carbon content and the 1% silicon. Other applications are, hot extrusion tooling, forging die inserts and header dies.

Machinability

The machinability of H-13 is rated at 70 as compared to 1% carbon tool steel which is rated at 100. It also has a high grindability rating.

AISI H-13

Hot Work Die Steel

Annealing

Heat slowly to 1550°F for one hour per inch of thickness. Cool 75° per hour to 1000°F and air cool. For surface protection an atmosphere furnace or stainless foil wrap must be used. The annealed hardness of H-13 should be 217 Brinell maximum.

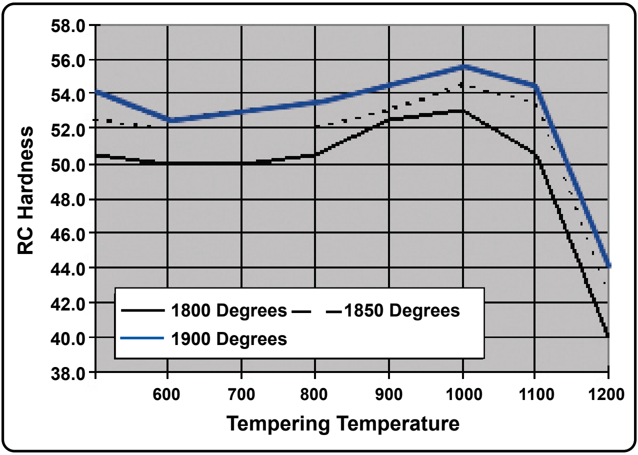
Hardening

The surface of H-13 must be protected during heat treating either by an atmospherically controlled or vacuum furnace or by the use of stainless foil wrap. The tool should be uniformly soaked at a preheating temperature of 1400° to 1500°F and then raised to 1825° to 1850°F. It should be soaked at temperature for a minimum of 30 minutes for the first inch plus 20 minutes for each additional inch of maximum block thickness. Cool in still air. Large sections of H-13 may need to be forced air cooled.

Tempering

As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. Long tempering times and multiple tempers are recommended for hot work tools. The initial temper should be held at temperature for one hour per inch of thickness. A second temper should be performed at about 25° lower than the first temper. Additional tempers would be beneficial and may be required to reach the desired hardness. All hot work steel should be tempered at a minimum of 50° above the maximum operating temperature of the tooling.

Tempering Curve for H-13



Hardened	at 1800°F	at 1850°F	at 1900°F
Single Tempered	Rc Hardness	Rc Hardness	Rc Hardness
As Quenched	50.5	52.5	54.0
600	50.0	52.0	52.5
700	50.0	52.0	53.0
800	50.5	52.0	53.5
900	52.5	53.0	54.5
1,000	53.0	54.5	55.5
1,100	50.5	53.5	54.5
1,200	40.0	42.5	44.0

H-13 Dimensional Size Change

Since H-13 is a strong air hardening steel it is capable of exceptionally good size stability. When properly hardened (at 1850°F) and tempered this material normally will show slight growth, not exceeding .001” per inch of cross section. Stress relieving of H-13 after rough machining is recommended to avoid distortion during heat treatment.

Toolox® 44

Pre-hardened Steel 45 HRC with ESR Properties

Typical Analysis

C	Si	Mn	P	S	Cr
0.32	0.6 - 1.1	0.80	Max 0.010	Max 0.002	1.35
Mo	**V**	**Ni**	**CEIIW**	**CET**	
0.80	0.14	Max 1.0	0.94 - 0.98	0.55 - 0.57	

Advantages

- Quench and tempered steel
- Ready to use, no additional heat treatment required
- Easy to machine with good dimensional stability
- High strength & toughness at elevated temperatures
- Double the toughness of comparable steels at the same hardness
- Excellent for etching, polishing and EDM
- Low residual stress, no stress relieving required
- Excellent substrate for surface treatments
- Supplied as (HR) plate, thickness 1” to 5-1/8”

Applications

Toolox® 44 is a great choice for machine and wear components, cold working tools, guide rails, die cast dies and forging dies. It is also ideal for making molds, both plastic molds and rubber molds.

Toolox® 44

Pre-hardened Steel 45 HRC with ESR Properties

Machinability

Despite a hardness of 45 HRC, Toolox® 44 is easily machined. Toolox is based on a low carbon concept, with low carbide content. Carbides are hard to machine, the low carbide content is the reason for the excellent machinability.

For more specific information on machining Toolox please refer to the Toolox® 44 brochure on our website under Metals Literature on alro.com.

Heat Treatment

Toolox® 44 is a highly engineered quench & tempered pre-hardened tool and machine steel with measured and guaranteed mechanical properties. Toolox® 44 is delivered ready to use, no heat treating required, saving you valuable production time, reducing risks and lowering overall costs.

Viscount 44®

Hot Work Tool Steel

Typical Analysis

C	Si	Mn
0.40	1.00	0.80
Cr	**Mo**	**V**
5.25	1.35	1.00

Advantages:

- Prehardened (42-46) Rc
- Free machining additives
- Elimination of size change in heat treatment
- Retains strength at high temperatures
- Machinable and weldable

Applications

Viscount 44® is a free machining “ready to use” type H-13 hot work tool steel. It is an excellent choice for all H-13 applications that would operate in the 42-46 Rockwell C range. Free machining additives make die work at this hardness level still practical

Besides the traditional H-13 applications such as die cast dies for Viscount 44® it also has outstanding performance as shear blades, upsetter dies, plastic mold cavities (where polish is not critical) and high strength shafting. It has a yield strength of 166,000 to 200,000 psi.

Viscount 44®

Hot Work Tool Steel

Machinability

The hardness range of Viscount 44®, 42-46 Rc, makes its machining considerably more difficult than machining of annealed tool steels. In most cases it will be necessary to decrease metal removal rates by 30% preferably by decreasing cutting speeds.

Heat Treatment

Since Viscount 44® is pre-hardened no further heat treating is necessary. However, for tools that might work at a slightly lower hardness level it may be desirable to temper the steel back to further enhance machinability.

Viscount 20®

Hot Work Tool Steel (Free Machining H-13)

Typical Analysis

C	Si	Mn
0.40	1.00	0.80

Cr	Mo	V
5.25	1.35	1.00

Plus Alloy Sulfides

Advantages

- Good resistance to thermal fatigue
- Superior properties at elevated temperatures
- Deep hardening
- Free machining additives allow Viscount 20® to be hardened and then machined

Availability

Viscount 20® is available in medium to large rounds.

Applications

Viscount 20® is an excellent choice for a wide range of hot work and cold work applications. It is used extensively for aluminum, zinc and magnesium die casting dies where drastic water cooling is used and both high hot hardness and resistance to heat checking are crucial, but a high polish is not required. Other typical applications are for hot extrusion tooling, forging die inserts and header dies.

Machinability

The machinability of Viscount 20® is rated at 80 as compared to 1% carbon tool steel which is rated at 100. It also has a high grindability rating.

Viscount 20®

Hot Work Tool Steel (Free Machining H-13)

Annealing

Heat slowly to 1550°F for one hour per inch of thickness. Cool 75° per hour to 1000°F and air cool. For surface protection an atmosphere furnace or stainless foil wrap must be used. The annealed hardness of Viscount 20® should be 217 Brinell maximum.

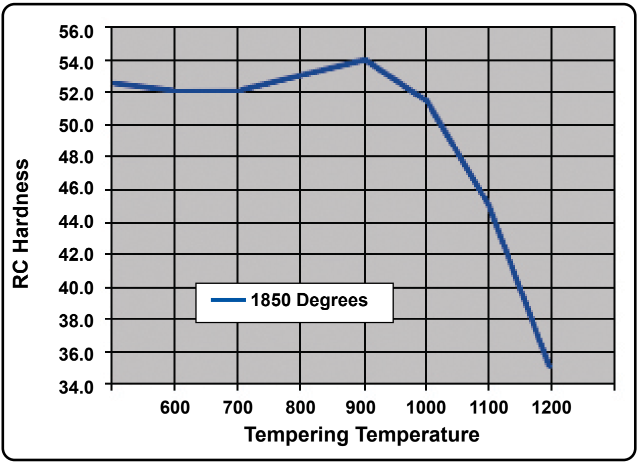
Hardening

The surface of Viscount 20 must be protected during heat treating either by an atmospherically controlled or vacuum furnace or by the use of stainless foil wrap. The tool should be uniformly soaked at a preheating temperature of 1400° to 1500°F and then raised to 1825° to 1850°F. It should be soaked at temperature for a minimum of 30 minutes for the first inch plus 20 minutes for each additional inch of maximum block thickness. Cool in still air. Large sections of Viscount 20 may need to be forced air cooled.

Tempering

As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. Long tempering times and multiple tempers are recommended for hot work tools. The initial temper should be held at temperature for one hour per inch of thickness. A second temper should be performed at about 25° lower than the first temper. Additional tempers would be beneficial and may be required to reach the desired hardness.

Tempering Curve for Viscount 20®



Hardened	at 1850°F
Single Tempered	**Rc Hardness**
As Quenched	52.5
600	52.0
700	52.0
800	53.0
900	54.0
1,000	51.5
1,100	45.0
1,200	35.0

Tool Room Tips:

Free Machining Steels

Free machining steels have risen in popularity in recent years. Free machining usually refers to additives put in the steel to help break up the chips to aid in machining. These additives include sulfur, calcium, lead, or other elements. The additives are put back into the steel, in a controlled manner, at the end of the steel making process. Free machining is common in pre-heat treated steels. While these elements do greatly benefit machinability, they also reduce the strength to a certain degree, and care should be taken not to use free machining steel where maximum strength is required.

AISI S-1

Shock Resisting Die Steel

Typical Analysis

C	Si	Mn	Cr
0.40 - 0.55	0.15 - 1.20	0.10 - 0.40	1.00 - 1.80

W	V	Mo	Ni
1.50 - 3.00	0.15 - 0.30	0.50 max	0.30 max

Advantages

- Good toughness
- Deep hardening

Availability

Very limited, usually available only as a mill make.

Applications

S-1 was designed for shock and impact applications such as chisels, shear knives and punches. A-8 and Staminal have replaced S-1 in many applications because of their minimum size change and lower cost.

Machinability

S-1 has a machinability rating of 80% of a 1% carbon tool steel making it readily machinable. It also has a high grindability rating.

AISI S-1

Shock Resisting Die Steel

Annealing

S-1 should be annealed at 1550°F. Heat to 1550°F and hold for one hour per inch of thickness at this temperature. Cool slowly with the furnace.

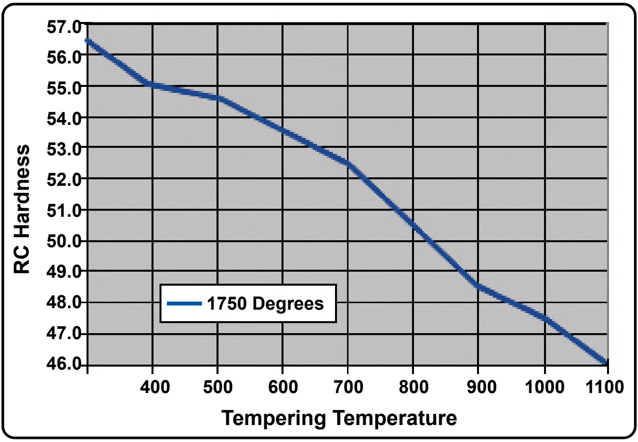
Hardening

S-1 should be preheated at 1200° to 1400°F and then heated to 1700° to 1750°F. Thoroughly soak at this temperature for on hour per inch of thickness. Quench in warm oil. Part should be wrapped in stainless foil if an atmosphere or vacuum furnace is not available.

Tempering

As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. S-1 should be tempered for two hours per inch of thickness at the temperature which will yield the hardness desired.

Tempering Curve for S-1



Hardened	at 1750°F
Tempering Temp	**Rc Hardness**
As Quenched	56.5
400	55.0
500	54.5
600	53.5
700	52.5
800	50.5
900	48.5
1,000	47.5
1,100	46.0

Tool Room Tips:

Impurities in Center

When molten steel is poured into ingot molds the center of the ingot is the last to cool. Therefore, any impurities, since they are lighter than steel, will tend to accumulate in the center and stay there throughout the process of rolling the ingots into bars. Consequently the centers of round and flat bars will have the least integrity.

AISI S-5

Shock Resisting Steel

Typical Analysis

C	Si	Mn
0.50 - 0.65	1.75 - 2.25	0.60 - 1.00

Cr	Mo	V
0.35 max	0.20 - 1.35	0.35 max

Advantages

- Very high shock resistance.
- Moderately good wear resistance.
- Good hardenability and fine grain in large section.
- Superior toughness at relatively high hardness.

Availability

S-5 is readily available in rounds, limited availability in flat bar.

Applications

S-5 can withstand heavy shock before bending or breaking. This unique combination of abrasion resistance and toughness at higher hardness levels make it a popular choice for hand and pneumatic chisels, heavy duty forming tools and punches, shear blades, stamps, etc. This grade is a popular choice for shanks of carbide tipped cutting tools. Its resistance to tempering back at higher temperatures keeps it strong in the area affected by 1200°F brazing temperatures.

AISI S-5

Shock Resisting Steel

Machinability

S-5 has a machinability rating of 75% of a 1% carbon tool steel making it readily machinable. It also has a high grindability rating.

Annealing

To anneal S-5, heat slowly to 1450° to 1500°F and cool in the furnace. It must be protected by stainless foil wrap or an atmosphere furnace. The annealed hardness is 202 to 235 Brinell.

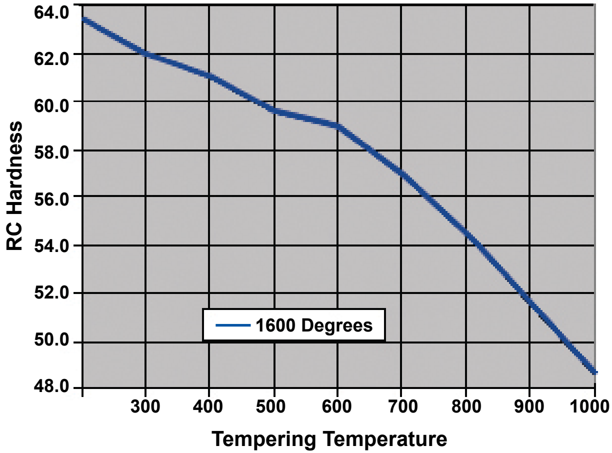
Hardening

This grade has a high tendency for decarburization and adequate surface protection throughout the heat treating process is essential. Hardening of S-5 consists of heating to 1600° to 1700°F and soaking for complete equalization. This should be followed by a quench in warm oil to about 150°F.

Tempering

As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. When maximum hardness is desired, temper at 350° to 400°F, holding at temperature for 1 hour per inch of thickness. For a higher degree of toughness temper at 800° to 900°F.

Tempering Curve for S-5



Hardened	at 1600°F
Single	Oil Quench
Tempered	**Rc Hardness**
As Quenched	63.5
300	62.0
400	61.0
500	59.5
600	59.0
700	57.0
800	54.5
900	51.5
1,000	48.5

Tool Room Tips:

Why Pre-Heat Steel?

It is important to preheat tool steel before hardening to reduce the possibility of thermal shock. Thermal shock can occur when you place cold steel into a hot furnace. Preheating will minimize distortion, cracking and will aid in the austenitizing conversion.

Thermal shock is defined as the development of steep temperature gradients and accompanying high stresses within a tool.

AISI S-7

Shock Resisting & Plastic Mold Steel

Typical Analysis

C	Si	Mn
0.45 - 0.55	0.20 - 1.00	0.20 - 0.80

Cr	Mo	V
3.00 - 3.50	1.30 - 1.80	0.30 max

Advantages

- Excellent combination of high strength & toughness
- Useful in moderate hot work as well as cold work tooling
- Good size stability when air hardened

Availability

Readily available.

Applications

S-7 is a general purpose air hardened tool steel well suited for many tools requiring exceptional toughness, good wear resistance and dimensional stability in heat treatment. It is an excellent choice for high hardness cavity inserts in plastic molds.

Machinability

S-7 is readily machinable in the annealed condition. Its machinability rating is about 85% of a 1% carbon tool steel. It also has a high grindability rating.

AISI S-7

Shock Resisting & Plastic Mold Steel

Annealing

S-7 should be annealed at 1550°F. Heat slowly to this temperature and then furnace cool 25°F per hour maximum to 1000°F then air cool. The annealed hardness is 187 to 223 Brinell.

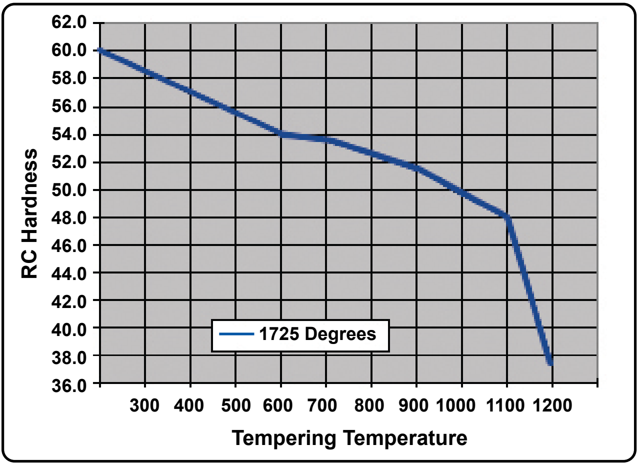
Hardening

S-7 should be preheated to 1200° to 1300°F and then heated to 1725° to 1750°F. When part is at temperature it should be soaked 30 minutes for the first inch of thickness and 15 minutes for each inch of thickness over one inch. Part should be wrapped in stainless foil if an atmosphere or vacuum furnace is not available. When part is taken from the furnace remove wrap and quench in still air. Sections over 2-1/2" might require flash oil quenching to attain full hardness. (Part is quenched in warm oil until it loses its cherry red color and then cooled in air.)

Tempering

As soon as pieces have been cooled to room temperature (100° to 150°F) tempering must begin. It should immediately be heated slowly to the tempering temperature and held at heat for one hour per inch of thickness followed by air cooling. Most cold work tools are tempered in the 400° to 500°F range. For hot work applications double tempering at 900° to 1000°F is recommended.

Tempering Curve for S-7



Hardened	at 1725°F
Single Tempered	**Rc Hardness**
As Quenched	60.0
300	58.5
400	57.0
500	55.5
600	54.0
700	53.5
800	52.5
900	51.5
1,000	49.5
1,100	48.0
1,200	37.5

S-7 Dimensional Size Change

When hardening at 1725°F, still air cool to 150°F and then tempered at 400°F, S-7 normally will show growth at a rate not exceeding .001” per inch.

Tool Room Tips:

Pre-Heat Treated Steels

Pre-heat treated steels have many advantages in today’s tool room. Tools can be made from these “pre-hard” steels and immediately put into use without heat treating and subsequent grinding. Several steels are available in this pre-hard condition, and include, “Brake Die” and “Viscount 44®” both of which are covered in this book. Pre-hard steels are good for emergency tools where a quick replacement is required, short run dies, applications where heat treat is critical with no “size change factor,” and many other applications.

AISI A-11

Powder Metal Tool Steel

Typical Analysis

C	Mn	Si
2.45	0.50	0.90
Cr	**Mo**	**V**
5.25	1.35	9.80

Advantages

- Extremely high wear resistance.
- Impact toughness comparable to D2.

Machinability

35-40% of a 1% carbon steel.

Annealing

Heat at rate not exceeding 400°F per hour to 1600-1650°F and hold at temperature for one hour per inch of maximum thickness; two hours minimum. Cool slowly with the furnace at a rate not exceeding 50° per hour to 1000°F. Continue cooling to ambient temperature in the furnace or in air. The resultant hardness should be a maximum of 277 HB.

Hardening

Preheat: 1500 - 1550°F, equalize Austenitizing (High heat): Heat rapidly from the preheat, typically by transferring to a second furnace. For optimum wear resistance: soak for 5 to 15 minutes. Furnace or salt bath: 2150°F. For balance of wear resistance and toughness: Soak for 15 to 30 minutes. Furnace or Salt Bath: 2050°F. For maximum toughness and minimum distortion in cooling: Soak for 30 to 60 minutes. Furnace at 1975°F, Salt Bath at 1950°F, without further soaking it should be quenched in pressurized gas, warm oil, or salt, then cool in still air to 150 - 125°F.

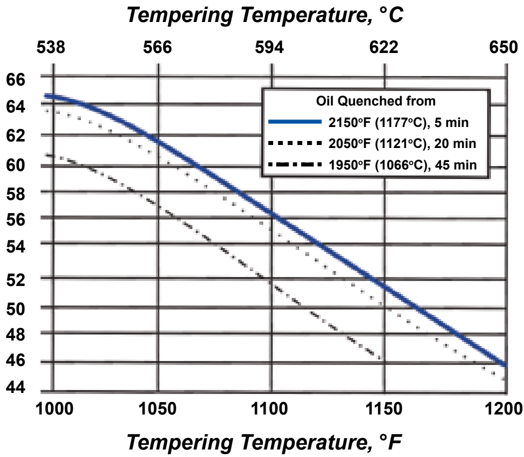
Tempering

Temper immediately after quenching. Typical temperature range is 1000 - 1100°F. Do not temper below 1000°F. Hold at temperature for two hours then air cool to ambient temperature. Double tempering is required. Triple tempering is required when austenitized at 2100°F or higher.

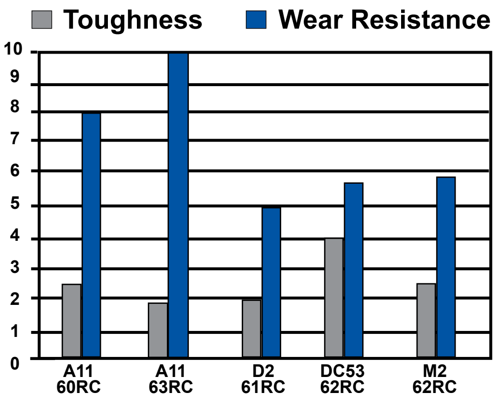
Heat Treatment Response

As Oil Quenched from	HRC
1,950°F (1,066°C), 45 minutes	65
2,050°F (1,121°C), 20 minutes	65
2,100°F (1,149°C), 15 minutes	64
2,150°F (1,177°C), 5 minutes	63

Tempering Curve for A-11



Relative Properties (Charpy)



Coefficient of Thermal Expansion

Temp. °F	in./in./°F x 10^{-6}	Temp. °C	mm/mm/°C x 10^{-6}
70° - 212°	5.96	21° - 100°	10.71
70° - 212°	6.10	21° - 149°	10.97
70° - 212°	6.20	21° - 204°	11.15
70° - 212°	6.39	21° - 260°	11.49
70° - 212°	6.55	21° - 427°	11.77
70° - 212°	6.85	21° - 538°	12.31

Physical Properties for A-11

Density: 0.267 lb/in3 (7418 kg/m3)
Specific Gravity: 7.41
Modulus of Elasticity: 32 x 106 psi (221 GPa)

Machinability: 35-40% of a 1% carbon steel

AISI M-2

High Speed Steel

Typical Analysis

C	Cr	Mo	V
0.78 - 0.88	3.75 - 4.50	4.50 - 5.50	1.75 - 2.20
W	**Mn**	**Si**	**Ni**
5.50 - 6.75	0.15 - 0.88	0.20 - 0.45	0.30 max

Advantages

- Very high red hardness
- Outstanding wear resistance
- High hardening response

Availability

Rounds and flats are readily available, rounds are usually De-carb free, flats are mostly hot rolled.

Applications

M-2 is the most widely used high speed steel for general purpose cutting applications. At a high working hardness M-2 has an optimum combination of wear resistance and toughness making it desirable for non-machining applications such as punches, die buttons, cold heading inserts and cold forming rolls.

Machinability

The machinability of fully annealed M-2 is rated at 55% of a 1% carbon tool steel. It also has a low to medium grindability rating.

AISI M-2

High Speed Steel

Annealing

M-2 must be adequately surface protected against decarburization and should be annealed at 1500° to 1600°F. It should be furnace cooled 30° per hour to 1000°F and then cooled to room temperature. The annealed hardness of M-2 is approximately 202 to 248 Brinell.

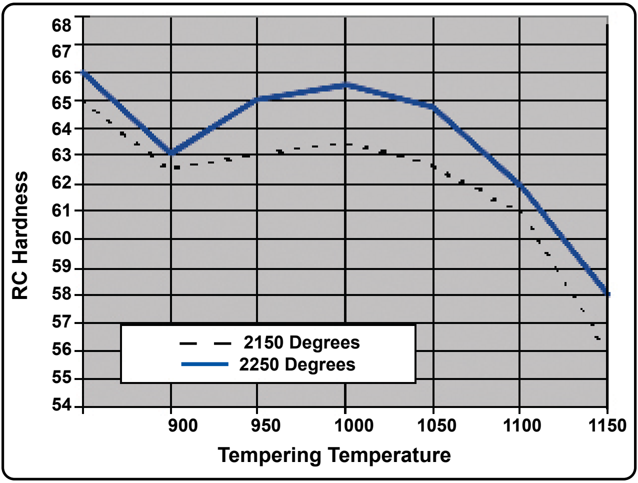
Hardening

All high speed steels including M-2 should be preheated slowly to 1500° to 1600°F in a protective atmosphere furnace. The temperature should then be raised rapidly to 2150° to 2275°F and soaked until uniformly heated. Without further soaking it should then be quenched in warm oil until losing its cherry red color and then cooled in air. Sections under 1" may be air quenched from the furnace.

Tempering

As soon as pieces have been cooled to room temperature (100° to 125°F) tempering must begin. The most common tempering range for M-2 is 1000° to 1100°F with 1025° - 1075°F being considered best for cutting tools. Heat slowly to the tempering temperature and hold for two hours per inch of thickness. Cool to room temperature. Best practice requires double tempering for improved tool life.

Tempering Curve for M-2



Hardened	at 2150°F	at 2250°F
Single Tempered	Rc Hardness	Rc Hardness
As Quenched	65.0	66.0
900	62.5	63.0
950	63.0	65.0
1,000	63.5	65.5
1,050	62.7	64.8
1,100	61.0	62.0
1,150	56.0	58.0

Tool Room Tips:

Heat Treat Foil Wrap

321 stainless steel is the most common grade of heat treat foil wrap. The standard size is .002 X 24 inches wide and is available in 50' and 100' Rolls. This grade can endure temperatures up to 2000°F. 309 stainless steel wrap is used for heat treating above 2000°F. It is important to wrap your part tightly to eliminate air from getting inside your package.

Packing with small amounts of paper, cast iron chips, or charcoal chips is helpful in burning off any air that maybe trapped inside. Wrapping your part twice is recommended. Avoid wrinkles in the foil, these are weak spots, these can cause small holes to develop and possibly damage to your part. It is important to remove the foil wrap immediately after hardening, this will allow your steel to retain its maximum hardness during quenching.

AISI PM4

Powder Metal High Speed Steel

Typical Analysis

C	Mn	S	Si
1.45	0.25	0.008	0.25

Cr	W	Mo	V
4.50	5.50	4.50	3.85

Advantages

- Excellent wear resistance
- High impact toughness
- High transverse bend strength
- High red hardness

Applications

Typical tools include branches, end mills, for tools, milling cutters and die inserts. The lower cost of M-4,compared to M-42 is due, in part, to PM4 replacing cobalt with vanadium.

Machinability

40-45% of a 1% carbon steel.

Annealing

Annealing must be performed after hot working and before rehardening. Heat at a rate not exceeding 400°F per hour to 1575 - 1600°F and hold at temperature for one hour per inch of maximum thickness: two hours minimum. Cool slowly with the furnace at a rate not exceeding 50°F per hour to 1000°F. Continue cooling to ambient temperature in the furnace or in air. The resultant hardness should be a maximum of 255 HB.

Hardening

PM4 should be preheated slowly to 1500 - 1550°F. A second preheat at 1850 - 1099°F is recommended for vacuum hardening. Heat rapidly from the preheat. For cutting tools, soak for five to 15 minutes in furnace at 2150 - 220°F, in salt bath at 2125 - 2175°F. For cold work tools, soak for 20 to 45 minutes in furnace at 1875°F, in salt bath at 1850 - 2100°F.

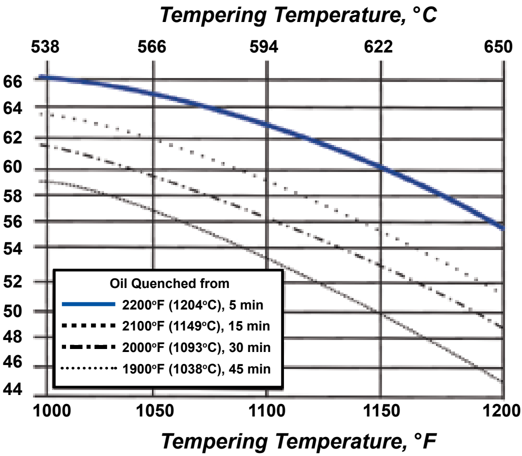
Quenching

Pressurized gas, warm oil, or salt. For pressurized gas quenching, the quench rate to below 1000°F is critical to obtain the desired properties. For oil, quench until black, about 900°F, then cooling in still air to 150 - 125°F. For salt maintained at 1000 - 1100°F, equalize in the salt, then cool in still air to 150 - 125°F.

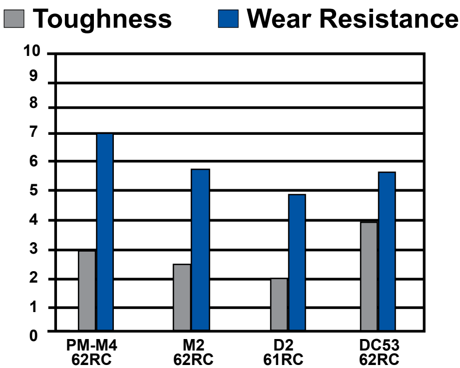
Tempering

Temper immediately after quenching. Do no temper below 1000°F. Hold at temperature for two hours then air cool to ambient temperature. Double tempering is required. Triple tempering is required when austenitized at 2100°F or higher.

Tempering Curve for PM4



Relative Properties (Charpy)



Coefficient of Thermal Expansion

Temp. °F	in./in./°F x 10^{-6}	Temp. °C	mm/mm/°C x 10^{-6}
100° - 500°	5.30	38° - 260°	9.53
100° - 800°	6.31	38° - 427°	11.34
100° - 1000°	6.65	38° - 538°	11.95
100° - 1200°	6.81	38° - 649°	12.24
100° - 1500°	7.00	38° - 816°	12.58

Physical Properties for PM4

Density: 0.286 lb/in3 (7916 kg/m3)
Specific Gravity: 7.92
Modulus of Elasticity: 31 x 106 psi (214 GPa)

Machinability: 40-45% of a 1% carbon steel

AISI M-4

High Speed Steel

Typical Analysis

C	Si	Mn	Cr
1.32	0.25	0.25	4.50

Mo	V	W	
4.50	4.00	5.50	

Advantages

- Excellent wear resistance
- Excellent red hardness
- High hardening response

Applications

M-4 is a high speed steel used to machine abrasive alloys, castings and heat treated materials. Typical tools include broaches, endmills, form tools, milling cutters, and die inserts. The lower cost of M-4, compared to M-42, makes it a popular choice of punch manufactures for making super high wear punches. This lower cost is due in part to M-4 replacing cobalt with vanadium.

Machinability

The machinability of fully annealed M-4 is 49% of a 1% carbon tool steel. It has a low grindability rating.

AISI M-4

High Speed Steel

Annealing

M-4 must be adequately surface protected against decarbuurization and should be annealed at 1550° to 1600°F. Hold at temperature for one hour per inch of thickness then cool slowly with furnace. This should result in a hardness of 255 Brinell maximum.

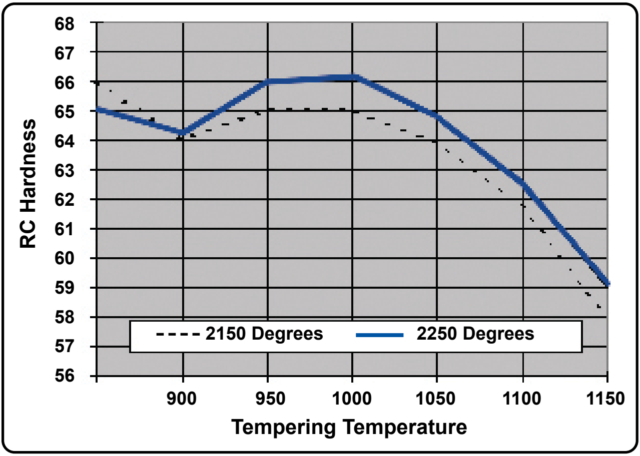
Hardening

M-4 should be preheated slowly to 1500° to 1600°F in a protective atmosphere furnace. Rapidly raise the temperature to 2100° to 2200°F and soak until uniformly heated. Without further soaking it should be quenched in a salt bath or warm oil, until black heat then complete quench in still air.

Tempering

M-4 should be tempered as soon as pieces have reached room temperature. 1000° to 1100°F is common for most applications. Hold at temperature for two to four hours. M-4 must be double or triple tempered.

Tempering Curve for M-4



Hardened	at 2150°F	at 2250°F
Single Tempered	**Rc Hardness**	**Rc Hardness**
As Quenched	66.0	65.0
900	64.0	64.2
950	65.0	65.9
1,000	65.0	66.1
1,050	63.9	64.8
1,100	61.7	62.5
1,150	58.0	59.0

Tool Room Tips:

Flash Oil Quenching

Flash oil quenching is used when large sections of “air hardened” tool steel are hardened. Oil quenching will help the tool to obtain optimum hardness. Immerse the tool in warm oil until the cherry red color is gone (also known as “black heat”), then quench in air to room temperature.

AISI M-42

High Speed Steel

Typical Analysis

C	Si	Co	Cr
1.05 - 1.15	0.15 - 0.65	7.75 - 8.75	3.50 - 4.25

Mo	V	W	Mn	Ni
9.00 - 10.00	0.95 - 1.35	1.15 - 1.85	0.15 - 0.40	0.30 max

Advantages

- Very high hardening response.
- Outstanding wear resistance.
- High red hardness.
- Good grindability compared to T-15.

Applications

M-42 is a super high speed steel used where long production runs or heavy duty machining is involved. It is especially useful for cutting difficult materials such as ultra-high strength steels, stainless steels, or high strength heat resistant alloys.

Annealing

M-42 should be atmosphere or vacuum annealed at 1550°F. Hold one hour for every one inch of thickness at temperature. Cool slowly not to exceed 50°F. per hour to 1000°F. Then allow to cool in still air. This should result in a maximum hardness of 269 Brinell.

AISI M-42

High Speed Steel

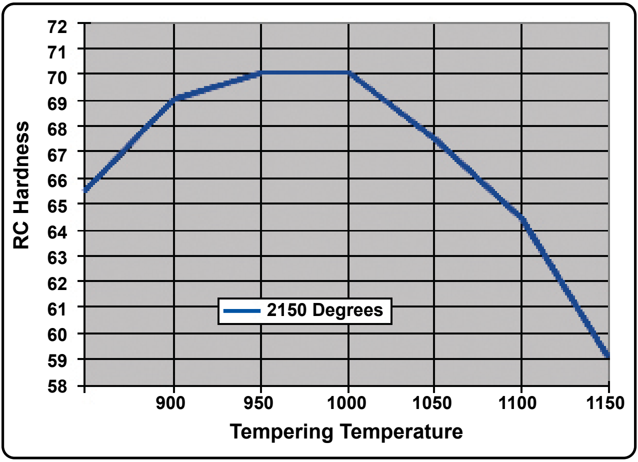
Hardening

Because of its higher carbon and cobalt content M-42 is capable of attaining hardnesses of 68-70 Rc. It should be preheated thoroughly at 1500° to 1600°F. A controlled atmosphere furnace must be used and most tools should be hardened from the range of 2125° to 2150°F. After a short hold at hardening temperature quench without further soaking in warm oil.

Tempering

M-42 is generally tempered between 1000° and 1100°F. Double or triple tempering should be employed with a minimum of two hours at temperature per cycle.

Tempering Curve for M-42



Hardened	at 2150°F
Single Tempered	**Rc Hardness**
As Quenched	65.5
900	69.0
950	70.0
1,000	70.0
1,050	67.5
1,100	64.5
1,150	59.0

Tool Room Tips:

Tool Steel Surface Finishes

Modern tool steel is normally furnished with the outer scale removed. It is also oversize to allow steel to finish to nominal size. Steel with this type of finish is commonly called De-Carb Free. It is also called Redi-Finish, Deluxe Finish, Thrift Finish, Premium Finish, or Economiser. All of these terms refer to the same "oversize to finish" product.

Most of the tool steel flat bar today is produced from plate. The process begins by milling the surface on both sides, then grinding to give a smooth finish. Thicker plate is commonly compete after milling. The plate is then cut into bars on a plate saw. The bars are cut "oversize" to allow width to finish to nominal size.

Round bar usually involves "rough turning," grinding, or "pealing," to remove the scale, while leaving stock to finish. For tolerances and surface finish standards see the section at the end of this book.

AISI T-1

High Speed Steel

Typical Analysis

C	Si	Mn	Cr
0.75	0.25	0.25	4.10

Mo	V	W	
0.70	1.10	18.00	

Advantages

- Excellent red hardness.
- Excellent grindability, compared to other high speed steels.
- Retains a fine cutting edge.

Applications

T-1 is a popular choice where red hardness is a concern, in making cutting tools and hot furnace tips. The popularity of T-1 has declined due to the greater availability of Molybdenum based tool steels such as M-2. Molybdenum based tool steels offer a lower price, better toughness, and better wear resistance.

AISI T-1

High Speed Steel

Annealing

T-1 should be atmosphere or vacuum annealed at 1650°F. Hold at temperature for one hour per inch of thickness, then slow cool with the furnace. This should result in a maximum Brinell of 248.

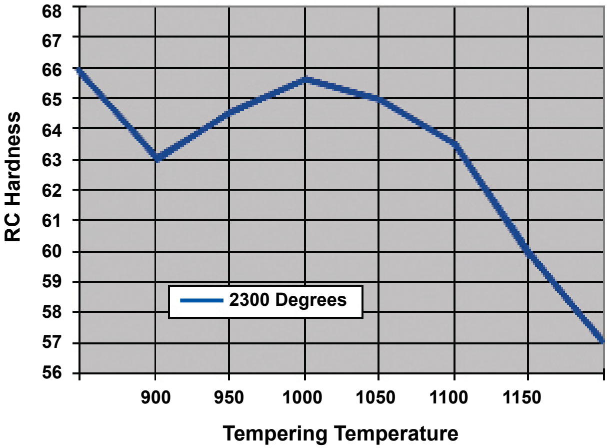
Hardening

T-1 should be preheated to 1550°F, then increased rapidly to 2300° to 2325°F, hold until uniformly heated then quench in warm oil. Remove from oil and quench in still air.

Tempering

T-1 should be tempered immediately after quenching to room temperature (125° to 150°F). Most common temper is 1025° to 1050°F. Hold for one hour per every inch of thickness at temperature then remove and air cool. Double tempering is recommended.

Tempering Curve for T-1



Hardened	at 2300°F
Single Tempered	**Rc Hardness**
As Quenched	66.0
900	63.0
950	64.5
1,000	65.6
1,050	65.0
1,100	63.5
1,150	60.0
1,200	57.0

Tool Room Tips:

Decarburization

Tool steel is rolled into shapes at a temperature over 2000°F. Loss of carbon from the surface layer will occur due to a chemical reaction with oxygen in the air. This “decarburized” layer must be removed prior to any heat treatment of the tool steel.

Decarburization can also occur during heat treatment. The use of stainless foil, a vacuum furnace or an atmospherically controlled furnace will prevent decarburization of a tool.

AISI T-15 PM

Typical Analysis

C	Si	Mn	S
1.55	0.30	0.30	0.07

W	Cr	V	Co
12.25	4.00	5.00	5.00

Advantages

- Improved machinability over conventional T-15.
- Improved grindability.

Applications

T-15 PM is suggested for premium cutting tools, particularly used in machining abrasive alloys, castings, and heat treated metals where high speeds and feeds or heavy cuts are required. Typical uses include broaches, end mills, circular and dovetail form tools, threading tools, and cutting tool inserts.

Annealing

Pack anneal in sealed container to prevent excessive decarburization or scaling. Heat slowly to 1650 - 1670°F and hold for one hour per inch of thickness. Cool slowly with oven. This should yield 269 Brinell or less.

AISI T-15 PM

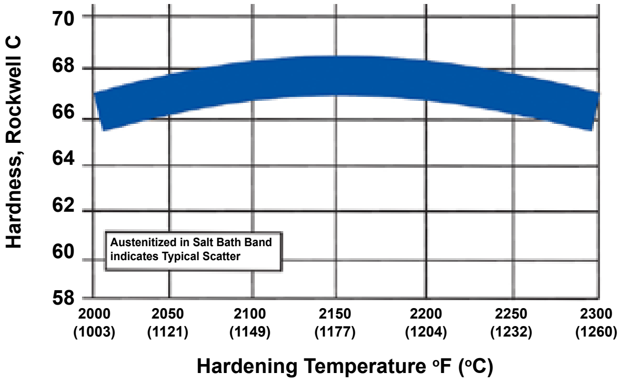
Hardening

Thoroughly preheat at 1450 - 1550°F in a properly rectified salt bath or controlled atmosphere furnace. Transfer to salt bath or furnace immediately with the general range of 2220 - 2250°F in a salt bath and 2240 - 2270°F if a furnace is used. Allow to uniformly soak. Quench into salt-maintained at 1000 - 1100°F or warm oil. Allow it to equalize at bath temperature, then complete the quench in still air to at least 150°F.

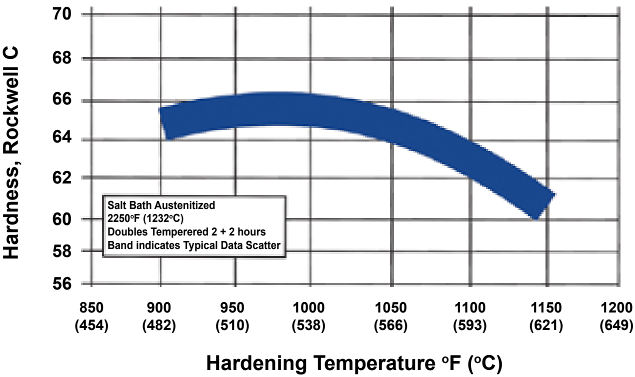
Tempering

T-15 PM should be tempered as soon as pieces have cooled to room temperature (125 - 150°F). Lesco T-15 PM should be tempered in the range of 1000 - 1050°F. Heat slowly to tempering temperature and hold for two hours per inch of thickness. Cool in still air to room temperature. For optimum tool life, double or triple tempering is recommended.

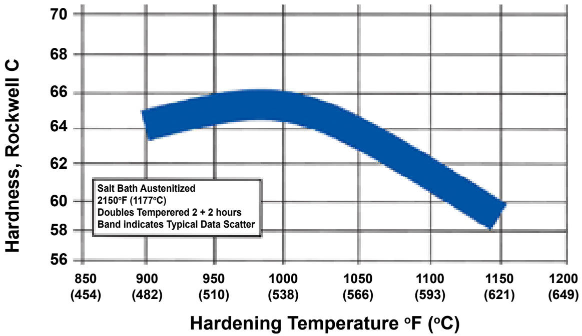
Tempering Curve



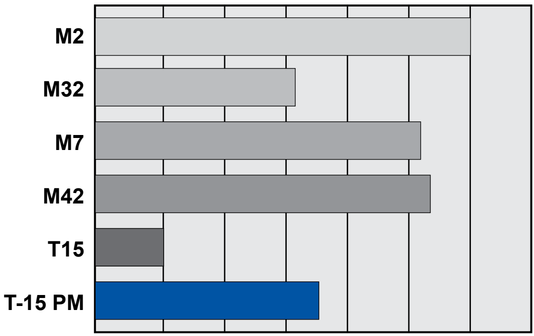
Hardening Curve



Tempering Curve



Relative Grindability



AISI T-15

High Speed Steel

Typical Analysis

C	Si	Mn	Cr
1.57	0.07	0.30	4.00

Co	V	W	
5.00	4.90	12.25	

Advantages

- Excellent wear resistance
- High red hardness

Applications

T-15 should be used for making premium cutting tools. Typical tools are broaches, endmills, form tools, and milling cutters. The availability of high tungsten tool steel is limited so a comparable and less expensive substitute for T-15 would be M-42.

Annealing

T-15 should be atmosphere or vacuum annealed at 1650°F, and held for one hour per every inch of thickness then slow cooled with the furnace. This should result in a maximum hardness of 269 Brinell.

AISI T-15

High Speed Steel

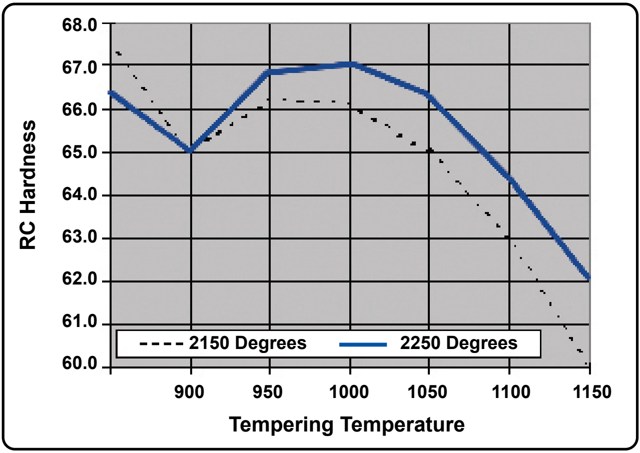
Hardening

Preheat to 1500° to 1600°F. in a protective atmosphere furnace, then raise temperature rapidly to 2150° to 2250°F until uniformly soaked. Without further soaking it should be quenched in a salt bath or warm oil then continue to quench in still air.

Tempering

T-15 should be tempered as soon as pieces have cooled to room temperature (100° to 125°F). The most common tempering range is 1000° to 1050°F. Heat slowly to tempering temperature and hold for two hours per inch of thickness, then cool to room temperature. A double or triple temper is recommended.

Tempering Curve for T-15



Hardened	at 2150°F	at 2250°F
Single Tempered	**Rc Hardness**	**Rc Hardness**
As Quenched	67.5	66.4
900	65.0	65.0
950	66.2	66.8
1,000	66.1	67.0
1,050	65.0	66.3
1,100	63.0	64.4
1,150	60.0	62.0

Tool Room Tips:

Tempered Martensite

When steel is at its high temperature in the hardening process its molecular structure is called austenite. During the quenching period most of the austenite will convert to martensite. Multiple tempers, usually two or three will convert the untempered martensite to tempered martensite, which is the ideal metallurgical structure for tool steel. Using the highest tempering temperature will maximize the tempered martensite conversion.

4140/4142 Modified Alloy

Medium Carbon Alloy, Pre-Hardened (Cut from Plate)

Typical Analysis

C	Si	Mn	Cr
0.36 - 0.46	0.15 - 0.45	0.70 - 1.70	0.75 - 1.20

Mo	P	S	Ni
0.15 - 0.35	0.035 max	0.040 max	0.50 max

Advantages

- Can be machined and immediately put into use without heat treatment
- Has higher toughness and higher wear than annealed low carbon mild steel

Characteristics

4140 alloys are steels in the family of SAE steel grades, as specified by the Society of Automotive Engineers (SAE). 4140 alloys have excellent strength-to-weight ratio and are considerably stronger and harder than standard 1020 steel; however, 4140 is not easily welded and needs pre and post weld thermal treatment to avoid cold cracking.

Applications

4140 is typically used for die strippers, die plates, die shoes, steel molds, wear plates and base plates, fixtures, jigs, couplings, gears, sprockets, rams and other wear components and tooling.

4140/4142 Modified Alloy

Medium Carbon Alloy, Pre-Hardened (Cut from Plate)

Alro carries alloy bars in 4140 Annealed DCF, 4140 HR Alloy, 4140 HR Annealed, 4140 HR Heat Treated, and 4140 HT DCF. Additional thermal processing of 4140 HT such as heat treatment or welding is not recommended.

Machinability

4140/4142 is machinable in its hardened state 260/321 Brinell.

Annealing

Heat 1475°F and furnace cool.

Hardening

Harden at 1500° to 1575°F and quench in oil. Temper to desired hardness. Pre-hardened steels should be annealed before hardening.

Normalizing

Heat to 1575° to 1600°F and cool in air.

Nitriding

4140/4142 can be nitride easily by standard nitriding procedures

Availability

Readily available

4140/4142 Modified Alloy

Medium Carbon Alloy, Pre-Hardened (Cut from Plate)

Welding

Welding prehardened materials is not recommended because the heat used in the welding process may cause the metal surrounding the weld joint to become brittle and crack if proper heating & cooling methods are not used to prepare the metal.

However by utilizing appropriate pre & post welding heat treatments, choosing weld joints that evenly distribute stress on the metal, welding may be successful.

4140/4142 Modified Alloy

Medium Carbon Alloy, Pre-Hardened (Cut from Plate)

AISI Number	Condition	*Tensile Strength	*Yield Point	Elongation %, 2”	Reduction Area, %
4140	HR Annealed	89	62	26	57
4140	CD Annealed	102	90	18	50
4140	Heat Treated	153	131	16	45
4140	Heat Treated	140	135	20	62
4140	Heat Treated	133	123	21	65

***** Tensile Strength and Yield Point based on 1,000 lbs. PSI***

				Heat Treatment		
AISI Number	Hardness, Brinell	Hardness, Rockwell	Mach. %	Quenched From	Tempered At	Medium
4140	187	B91	57	---	---	---
4140	223	C19	66	---	---	---
4140	311	C33	---	1550°	1000°	Oil
4140	285	C30	---	1550°	1100°	Oil
4140	269	C28	---	1550°	1200°	Oil

The information shown above represents the average results of a number of tests made at steel mill laboratories. Tensile strength, yield point, elongation, reduction of area and hardness are all affected by the size of the section being heat treated and permissable variations in analysis. This information, therefore, is only a guide and cannot be used as a basis for the acceptance or rejection of material. Physical properties can be guaranteed only on steels ordered heat treated to acceptable commercial limits. All tests were made on 1” diameter round bars.

Brake Die

Alloy Steel (4140/50 Heat Treated)

Typical Analysis

C	Mn	Cr	Mo
0.50	0.85	1.00	0.20

Advantages

- Can be machined and immediately put into use without heat treatment.
- Has higher toughness and higher wear than annealed low carbon mild steel.
- Can be flame hardened to the mid 50 Rc Range.

Characteristics

Brake Die (4150 Modified) is a strong, tough alloy steel of good hardenability. Its excellent combination of strength, wear resistance, and toughness in the heat treated condition makes it suitable for a variety of heavy duty applications. An outstanding characteristic of this steel is its excellent machinability. Machining rates 15 to 25% faster than other alloy steels at comparable strength levels are typical. 4150 Modified is available in the annealed condition or preheat-treated to 269 to 321 Brinell (28 to 32 Rc) hardness range.

Availability

Readily available.

Brake Die

Alloy Steel (4140/50 Heat Treated)

Applications

4150 Modified has been widely used for spindles, lead and feed screws, splined shafts, gears, crankshafts, and connecting rods in punch and brake presses, planer and router shafts, axles, gears, chuck screws, boring bars, bolts, tie rods and die holders. It is also an excellent choice for short run dies.

Machinability

4150 Modified Heat Treated is easily machined, due to the sulphur content.

Annealing

Heat 1475°F and furnace cool.

Hardening

Harden at 1500° to 1575°F and quench in oil. Temper to desired hardness. Pre-hardened steels should be annealed before hardening.

Normalizing

Heat to 1575° to 1600°F and cool in air.

Brake Die

Alloy Steel (4140/50 Heat Treated)

Nitriding

4150 Modified heat treated bar stock can be nitrided by the usual nitriding procedures at 950° to 980°F. The dissociation of the nitriding gas should be 30%. A holding time of 40 hours at the nitriding heat will produce a .010” to .015” deep case. The core will remain at the original heat treated hardness.

Welding

Use only low-hydrogen welding materials and practices. The usual care in welding alloy steel should be exercised. This involves pre-heating to 500° to 700°F before welding and maintaining temperature during welding. After welding the part should be slow cooled or given post weld heat treatment depending upon the circumstances. Recommended for shielded metal-arc welding are AWS A5.1 E70XX through A5.5 E120XX low hydrogen electrodes.

Brake Die

4150 - Oil Quenched Test Piece

Tempering Temp., (°F)	Tensile Strength, (ksi)	Yield Point, (ksi)	Elong. in 2”, (%)	Reduction of Area, (%)	Brinell Hardness	Rockwell Hardness, C
300	346	334	5	8	601	57
400	317	260	9	29	578	56
500	295	255	10	32	555	55
600	270	236	10	37	514	52
700	242	220	9	33	477	50
800	232	213	10	34	461	46
900	207	194	12	46	415	44
1,000	185	176	15	51	375	40
1,100	163	148	16	53	331	35
1,200	138	125	20	61	285	30
1,300	120	112	23	64	241	23

C-1018 Mild Steel

The most widely used general purpose shafting steel. Used for parts where strength does not require higher carbon or alloy steels. Easily carburized, responds well to cold bending and forming.

Cold finishing gives bars a smooth finished surface suitable for many applications without further machining. The cold finishing process also substantially improves size tolerances and concentricity. This dimensional accuracy minimizes or eliminates the need for extra machining operations. Cold finishing can include any of the following:

Typical Analysis

C	Si	Mn	P	S
0.15 - 0.20	0.10 - 0.30	0.60 - 0.90	0.04 max	0.05 max

Cold Drawing

Cold drawing is the most common of the cold finishing methods. It starts with a hot rolled bar that has been descaled and coated with a lubricant. The bar is then pulled through a precision die that is dimensionally smaller than the hot rolled bar. Cold drawn bars are available in rounds, squares, flats or hexagons.

Cold drawing gives the hot rolled bar a clean, uniform surface. It increases tensile and yield strength but decreases ductility. The increase in yield strength is about 2-1/2 times greater than the increase in tensile. Cold drawing also increases torsional strength, surface hardness and wear resistance. Cold drawing significantly improves machinability. Due to the cold drawn process, the bars are slightly undersize and will not finish to nominal size.

C-1018 Mild Steel

Turning & Polishing

Instead of cold drawing, hot rolled round bars may be cold finished by machining to the desired size on a lathe or turning machine, then polished by rotating them through hardened steel rolls. Turning completely removes the hot rolled bar surface and with it, decarburization, seams, slivers, and other surface imperfections. Polishing produces a finer, brighter, smoother finish than is obtained by cold drawing. Since there is no compression or elongation of the bar in these operations, no cold working strains are set up. The mechanical properties remain comparable to those of the original hot rolled bar.

Grinding & Polishing

Grinding and polishing is a cold finishing operation applied to round bars subsequent to turning or cold drawing. The bars are first ground to close tolerances in centerless grinders, which also maintain their straightness. Following centerless grinding, the bars are sawed on both ends for a square, true cut. They are then polished (burnished) to a brilliant bright finish. The results are bars with extremely close size tolerances, a high degree of straightness and a superior finish. Mechanical properties are virtually unchanged by this operation and remain comparable to those established following cold drawing or turning.

Size Tolerances of Cold Finished Carbon Steel Bars

Cold Drawn

Cold Drawn		
Size in inches	28% maximum carbon or less	28% to 55% max. carbon
Rounds:	**Tolerances**	**Tolerances**
Up to & Including 1-1/2"	-0.002"	0.003"
Over 1-1/2" to 2-1/2"	-0.003"	0.004"
Over 2-1/2" to 4"	-0.004"	0.005"
Hexagons:	**Tolerances**	**Tolerances**
Up to & Including 3/4"	-0.002"	-0.003"
Over 3/4" to 1-1/2"	-0.003"	-0.004"
Over 1-1/2" to 2-1/2"	-0.004"	-0.005"
Over 2-1/2" to 4"	-0.005"	-0.006"
Squares:	**Tolerances**	**Tolerances**
Up to & Including 3/4"	-0.002"	-0.004"
Over 3/4" to 1-1/2"	-0.003"	-0.005"
Over 1-1/2" to 2-1/2"	-0.004"	-0.006"
Over 2-1/2" to 4"	-0.006"	-0.008"
Flats:	**Tolerances**	**Tolerances**
Up to & Including 3/4"	-0.003"	-0.004"
Over 3/4" to 1-1/2"	-0.004"	-0.005"
Over 1-1/2" to 3"	-0.005"	-0.006"
Over 3" to 4"	-0.006"	-0.008"
Over 4" to 6"	-0.008"	-0.010"
Over 6"	-0.013"	-0.015"

Width governs the tolerances for both width and thickness of flats. For example, when the maximum of carbon range is 0.28 percent or less, the width tolerance for a flat 2" wide and 1" thick is 0.005" and the thickness tolerance is the same, namely 0.005".

Size Tolerances of Cold Finished Carbon Steel Bars

Turned & Polished

Turned & Polished		
	28% maximum carbon or less	28% to 55% max. carbon
Diameters:	**Tolerances**	**Tolerances**
Up to & Including 1-1/2”	-0.002”	-0.003”
Over 1-1/2” to 2-1/2”	-0.003”	-0.004”
Over 2-1/2” to 4”	-0.004”	-0.005”
Over 4” to 6”	-0.005”	-0.006”
Over 6” to 8”	-0.006”	-0.007”
Over 8” to 9”	-0.007”	-0.008”
Over 9” Dia.	-0.008”	-0.009”

Turned, Ground & Polished

Diameters:	Tolerances
Up to & Including 1-1/2”	-0.0010”
Over 1-1/2” to 2-1/2”	-0.0015”
Over 2-1/2” to 3”	-0.0020”
Over 3” to 4”	-0.0030”
Over 4” to 6”	-0.004” *
Over 6” Dia.	-0.005” *

**For nonsulphurized steels (steels specified to maximum sulphur limits under 0.08%) or for steels thermally treated, the tolerance is increased by 0.001”.*

Typical Mechanical Properties

(Average for normal cold finishing practices, not to be used for specification)

C-1018

Finish	Tensile, PSI	Yield, PSI	Elongation in 2" %	Reduction of Area	Machinability % of B1112	Hardness SFM	BHN
CD	82,000	70,000	15%	57	78%	130	163

C-1018 is readily welded by all commercial welding procedures including gas, air, and submerged arc. Preheat and post, heat treatments not necessary.

C-1045

Finish	Tensile, PSI	Yield, PSI	Elongation in 2" %	Reduction of Area	Machinability % of B1112	Hardness SFM	BHN
CD	102,000	89,000	18%	45	60%	101	217

C-1045 can be heat treated by heating to 1475° to 1550°F, and quenching in oil or water, temper to desired hardness. The weldability of C-1045 is fair.

Design Tools to Avoid Failure

Tools and machine parts made from tool steels are often subjected to high stress in operation. These parts also have a certain amount of internal stress as a result of their fabrication and heat treatment. When these stresses, either singly or in combination, exceed the strength limits of the steel, cracking, breaking or warping of the part results. Many fully hardened tool steels, particularly highly alloyed types, can withstand relatively high compressive loading, but only limited tensile loading.

Tool engineers should seek to minimize tensile stresses through proper design and use of support tooling so as to permit use of the highest performance die steels on crucial components. When required tooling designs must involve significant tensile stresses, then selection of a tougher tool steel with reduced wear resistance (most likely one of the shock resisting grades) is advised.

Design Tips

Common Errors in Tool Design

1. Use of sharp corners; failure to use fillets or adequate radii.
2. Presence of nonuniform sections of tooling, causing variation in stress distribution in service as well as variable quenching rates during hardening.
3. Use of improper clearance between punch and die edges.
4. Tool designs involving excessive unit stresses or overloading during operation. Tools should be redesigned to operate at a lower unit stress.

Sensitive Tooling Designs

If sharp corners and variable sections cannot be avoided in the design of a part, the use of an air hardening die steel is essential for greatest safety in hardening. Cracking and/or distortion are more apt to occur on such sensitive sections when liquid quenching is employed during hardening.

Design Tips

Proper Tool Clearance

Tool clearance is the distance between adjacent punch and die edges. In general the press load required for a given operation decreases as clearance increases, so tools are more highly stressed with a small degree of punch and die clearance. Enlarging clearance from 5 to 10% of stock thickness usually will improve tool life. Although the finish of the sheared edges of parts may improve with small clearances, tool life will be shortened. Breakage due to misalignment may also result.

While acceptable clearance is often 10% of the stock thickness, this subject is debatable, since many variables besides stock thickness influence clearance, including stock material, hardness and surface (scale condition and finish) and the required finish on the shear cut.

Design Tips

Preventing Distortion During Heat Treatment

Two different kinds of distortion or size change can occur during heat treatment: size distortion and shape distortion. Size distortion involves changes in volume by expansion and contraction during heating and cooling, respectively, accompanied by the phase changes of metallurgical transformation to austenite and then to martensite during hardening. Other structural transformations also occur during tempering. Size distortion is inherent in the heat treating process; it can be controlled or allowed for but not eliminated.

Shape distortion consists of changes in the geometric form of the work. It is influenced mainly by thermal stresses during heat treatment and mechanical stresses developed before or during heat treatment. Typical factors that influence shape distortion include:

1. Lack of uniformity in the tooling material
2. Abnormal mechanical stresses in material, such as from an extensive amount of machining in material prior to hardening.
3. Thermal stresses from excessive heating rates.
4. Sagging of work in furnace.
5. Excessive mechanical stresses from improper straightening procedure following hardening.
6. Inadequate tempering of work prior to finish grinding.

Design Tips

Although exactly pinpointing dimensional change during heat treatment of complex die sections, even in air hardening grades, is difficult, these basic procedures are suggested for minimizing both size and shape distortion:

1. Select the proper die steel, preferably an air hardening type.
2. Stress relieve tools at 1200° to 1300°F after rough machining.
3. Support tools effectively in hardening furnace to prevent sagging. Vertical support of long slender sections is usually best.
4. Preheat tools during the hardening cycle to lessen thermal shock. “Step” preheating at several temperatures prior to high heat helps minimize distortion during hardening of large and/or intricate sections.
5. Thoroughly equalize the work at high heat to insure that all parts of the section have been brought to temperature.
6. Quench work as uniformly as possible, preferably in still air for least distortion. If oil quenching must be used be sure that the oil is warm (100° to 130°F) and well agitated.
7. Use an interrupted quench but not at temperatures above 1000°F for complex, large section to minimize distortion as they enter the martensite transformation range.
8. Temper the work promptly when it has reached hand warmth (100° to 130°F). When tempering sensitive tool designs that reduce a temper above 500°F. Place work in furnace at 500°F or lower allow to equalize at temperature, then bring work up with furnace. This conservative heating cycle is not essential on the second tempering cycle.

Finish Grinding Guidelines

Avoiding a Common Cause of Short Tool Life

In a grinding operation, the many very small cuts made at high speed by the abrasive particles can easily develop high temperatures in the surface layers of the steel being ground. When these temperatures exceed the tempering temperature of a hardened and tempered steel, phase changes will result. These phase changes cause size changes in the surface of the steel. The size changes set up residual stresses which can cause cracking of the part. In extreme cases, high enough temperatures can develop in the surface layers to reharden the steel. This type of heat damage from grinding is one of the most common causes of short tool life.

The goal in grinding a tool steel should be to achieve the maximum metal removal rate possible without damaging the surface layers. Annealed steels are more easily cut and are less susceptible to grinding damage than are hardened and tempered steels. Steels with low tempering temperatures are more susceptible to thermal damage than steels with high tempering temperatures. Grinding fluids may cool the work and reduce thermal damage. However, if very severe heating develops, the quenching effect of a grinding fluid may accentuate damage from phase changes.

Water soluble fluids are suggested for most normal grinning. Frequent dressing of the grinding wheel helps assure the sharp abrasive particles will cut efficiently. Normal stock removal should be .001”/.002” per pass for roughing cuts and .0005” per pass for finishing cuts.

Grinding Wheel Selection

Avoiding a Common Cause of Short Tool Life

Although vitrified aluminum oxide wheels satisfy most grinding requirements on hardened tool steels, some conditions merit consideration of other types such as silicon carbide or CBN (cubic boron nitride) abrasives. Here are some general rules to aid in the selection of grinding wheels:

(1) In any operation, use the widest and largest diameter wheel possible.

(2) For soft steels, use a harder grade and a coarser grit size wheel.

(3) For harder steels, use a softer grade and a finer grit size wheel.

(4) For heavier feeds, use a coarser grit wheel.

(5) For fine surface finish, use creep feeds and a finer grit size wheel.

(6) To grind large areas, use a softer grade wheel.

(7) To grind small areas, use a harder grade wheel.

(8) For form grinding, use a finer grit size and high density wheel.

Grinding performance with a given wheel may be improved by these operating techniques depending upon whether the wheel is tending to wear down or burn on a given job.

Finish Grinding Guidelines

Avoiding a Common Cause of Short Tool Life

If wearing down is the problem:

- Increase peripheral speed of wheel
- Reduce work speed
- Reduce feed
- Dress wheel at slower rate

These measures will reduce grinding pressure and improve wheel life and form retention.

If grinding burn is the problem:

- Reduce peripheral speed of wheel
- Increase work speed
- Increase feed
- Dress wheel at faster rate

These measure will reduce grinding wheel loading or glazing through increased grinding pressure, thus preventing burn.

Repairing Tools by Welding

When welding tool steels the area around the weld will tend to harden in annealed steels, and re-harden in heat treated steels. The risks of cracking tool steels during welding, particularly in the heat treated condition are great, so the practice should be avoided if at all possible. In addition the steel's structure is never quite the same even after careful welding.

Nevertheless, unexpected design changes and machining errors do occur in tool making, and these situations often can be corrected by welding, or the much greater expense of making new tooling. Also, welding is sometimes performed to restore worn cutting edges on tools and to repair parts that have cracked either during heat treatment or in service.

If welding must be done it is best performed in the annealed condition to reduce the thermal stress hazards.

Repairing Tools by Welding

General Procedures for Proper Welding

(1) Fully anneal tooling under protective atmosphere if tooling is not already in the annealed condition.
(2) Prepare area to be welded by U-grooving or V-grooving (U-grooving preferred) to remove any cracks. Examination of weld area, such as magnetic particle inspection, is suggested to insure removal of all cracks.
(3) Select a welding rod material which will match the composition of the original tooling or at least match the hardness of the original tooling after heat treatment. Use the smallest diameter weld rod that will do the job to reduce heat buildup.
(4) Make certain that both the weld rods and tooling surfaces to be welded are clean and dry.
(5) If possible, position the work so that beads are laid slightly upward.
(6) Preheat area to be welded at 400°- 800°F.
(7) Conduct welding so as to allow minimum heat buildup, using minimum arc voltages and amperages. Try to maintain the preheat temperature during welding. Clean slag from each bead and peen carefully, while still hot, before proceeding with the next bead. Do not peen weld when cool! A finishing allowance of at least 1/16" in weld metal should be deposited to be later removed by grinding.
(8) Immediately after welding, but not before the tool has reached hand warmth, transfer the tool to a warm furnace (400°F min.) and fully anneal.

Repairing Tools by Welding

General Procedures for Proper Welding

(9) Machine or grind the welds to the desired tool dimensions, using care to avoid scorching or cracking.

(10) Heat treat the tool by using standard hardening and tempering procedures for the grade involved.

If welding must be performed on tooling in the hardened condition (without prior annealing) the risk of cracking is greater. General welding procedure applies to hardened tooling with these modifications:

(1) Added precautions should be taken in weld area preparation to avoid grinding strain or cracking in view of greater sensitivity of hardened material.

(2) Weld area should be preheated to 400°- 800°F.

(3) Postheat cycle should consist of a tempering treatment about 25°F lower than the original tempering cycle on the tooling, conducted after the newly welded tooling has reached hand warmth. After the steel has cooled to room temperature following the first tempering cycle, it should by retempered immediately.

The toolmaker should also consult literature from tool steel weld rod manufactures (or contact then directly) for further recommendations on producing successful welds.

Typical Machining Allowances

Rounds:

Decarb Free, 125 RMS max.	Allowances
1/2” to under 1-1/2”	+.010” to .015”
1-1/2” to under 3-1/16”	+ .020” to .035”
3-1/16” to under 4-1/16”	+ .040” to .060”
4-1/16” to under 6-1/16”	+ .065” to .115”
6-1/16” and over	+ .090” to .140”

Flats:

- Decarb free, 125 RMS max.
- Allowance to finish (in inches).
- Add .015 to width and thickness.
- Tolerance: +.020-.000

Bar Tolerances

Hot Rolled Alloy Bars

Variation from Size

Specified Sizes (Rounds or Squares)	Over	Under	Out-of-Round or Square
To 5/16” including	.005”	.005”	.008”
Over 5/16” to 7/16” incl.	.006”	.006”	.009”
Over 7/16” to 5/8” incl.	.007”	.007”	.010”
Over 5/8” to 7/8” incl.	.008”	.008”	.012”
Over 7/8” to 1” incl.	.009”	.009”	.013”
Over 1” to 1-1/8” incl.	.010”	.010”	.015”
Over 1-1/8” to 1-1/4” incl.	.011”	.011”	.016”
Over 1-1/4” to 1-3/8” incl.	.012”	.012”	.018”
Over 1-3/8” to 1-1/2” incl.	.014”	.014”	.021”
Over 1-1/2” to 2” incl.	1/64”	1/64”	.023”
Over 2” to 2-1/2” incl.	1/32”	0	.023”
Over 2-1/2” to 3-1/2” incl.	3/64”	0	.035”
Over 3-1/2” to 4-1/2” incl.	1/16”	0	.046”
Over 4-1/2” to 5-1/2” incl.	5/64”	0	.058”
Over 5-1/2” to 6-1/2” incl.	1/8”	0	.070”
Over 6-1/2” to 8-1/4” incl.	5/32”	0	.085”
Over 8-1/4” to 9-1/2” incl.	3/16”	0	.100”
Over 9-1/2” to 10” incl.	1/4”	0	.120”

Straightness Tolerance

Hot Rolled Steel Bars

Rounds, Squares, Hexagons, Octagons,
Flats, and Spring Flats

Measurement is taken on the concave side of the bar with a straight edge.

Normal Straightness

1/4" in any 5 foot
or
1/4" x (Length in Feet / 5)

Special Straightness

1/8" in any 5 foot
or
1/8" x (Length in Feet / 5)

Note: Because of warpage, straightness tolerances do not apply to bars if any subsequent heating operation or controlled cooling has been performed.

Note: Tolerances shown are based upon ASTM A29

Machining Allowance

Hot Rolled Steel Bars

Minimum Stock Removal (Diameter)

Standard Grades	2% per side
Resulphurized Grades	3% per side

Note: Based on bars within special straightness tolerance. Since straightness is a function of length, additional machining allowance may be required for turning on centers.

Hardness Conversion Table

Brinell Number	Rockwell		Tensile Strength 1,000 PSI
	"B"	"C"	
745	-	65.3	-
712	-	-	-
682	-	61.7	-
653	-	60.0	-
627	-	58.7	-
601	-	57.3	-
578	-	56.0	-
555	-	54.7	298
534	-	53.5	288
514	-	52.1	274
495	-	51.6	269
477	-	50.3	258
461	-	48.8	244
444	-	47.2	231
429	-	45.7	219
415	-	44.5	212
401	-	43.1	202
388	-	41.8	193
375	-	40.4	184
363	-	39.1	177
352	(110.0)	37.9	171
341	(109.0)	36.6	164
331	(108.5)	35.5	159
321	(108.0)	34.3	154
311	(107.5)	33.1	149
302	(107.0)	32.1	146
293	(106.0)	30.9	141
285	(105.5)	29.9	138
277	(104.5)	28.8	134
269	(104.0)	27.6	130

Values in (   ) are beyond normal range, and are presented for information only devalues above 500 are for Tungsten Carbide Ball, below 500 for Standard Ball.

Hardness Conversion Table

Brinell Number	Rockwell		Tensile Strength 1,000 PSI
	"B"	"C"	
262	(103.0)	26.6	127
255	(102.0)	25.4	123
248	(101.0)	24.2	120
241	100.0	22.8	116
235	99.0	21.7	114
229	98.2	20.5	111
223	97.3	(18.8)	-
217	96.4	(17.5)	105
212	95.5	(16.0)	102
207	94.6	(15.2)	100
201	93.8	(13.8)	98
197	92.8	(12.7)	95
192	91.9	(11.5)	93
187	90.7	(10.0)	90
183	90.0	(9.0)	89
179	89.0	(8.0)	87
174	87.8	(6.4)	85
170	86.8	(5.4)	83
167	86.0	(4.4)	81
163	85.0	(3.3)	79
156	82.9	(0.9)	76
149	80.8	-	73
143	78.7	-	71
137	76.4	-	67
131	74.0	-	65
126	72.0	-	63
121	69.8	-	60
116	67.6	-	58
111	65.7	-	56

Values in ( ) are beyond normal range, and are presented for information only devalues above 500 are for Tungsten Carbide Ball, below 500 for Standard Ball.

Through Hardening

Tool Steel Strengths and Formulas

1. Brinell hardness times 500 equals ultimate tensile strength.
2. 130% times ultimate tensile equals compressive strength.
3. 60% times ultimate tensile strength equals shear strength. 85% times ultimate tensile strength equals yield strength.

Weight & Area Tables

	Weight (lbs/sqft or ft)		Area (square inches)	
Size	Square	Round	Square	Round
1/4	0.306	0.182	0.0625	0.0491
9/32	0.373	0.229	0.0791	0.0621
5/16	0.447	0.280	0.0977	0.0767
11/32	0.528	0.337	0.1182	0.0928
3/8	0.615	0.399	0.1406	0.1104
13/32	0.709	0.466	0.1650	0.1296
7/16	0.810	0.539	0.1914	0.1503
15/32	0.917	0.616	0.2197	0.1726
1/2	1.031	0.699	0.2500	0.1963
17/32	1.151	0.787	0.2822	0.2217
9/16	1.279	0.881	0.3164	0.2485
19/32	1.412	0.979	0.3525	0.2769
5/8	1.553	1.083	0.3906	0.3068
21/32	1.700	1.192	0.4307	0.3382
11/16	1.854	1.306	0.4727	0.3712
23/32	2.014	1.426	0.5166	0.4057
3/4	2.181	1.550	0.5625	0.4418
25/32	2.355	1.730	0.6103	0.4794
13/16	2.535	1.867	0.6602	0.5158

Weight & Area Tables

Size	Weight (lbs/sqft or foot)		Area (square inches)	
	Square	Round	Square	Round
27/32	2.722	2.009	.7119	.5591
7/8	2.916	2.157	.7656	.6013
29/32	3.116	2.309	.8213	.6450
15/16	3.323	2.467	.8789	.6903
31/32	3.537	2.631	.9385	.7371
1	3.757	2.799	1.000	.7854
1-1/16	4.217	3.152	1.129	.8866
1-1/8	4.704	3.525	1.266	.9940
1-3/16	5.218	3.920	1.410	1.108
1-1/4	5.758	4.335	1.563	1.227
1-5/16	6.325	4.771	1.723	1.353
1-3/8	6.918	5.229	1.891	1.485
1-7/16	7.538	5.707	2.066	1.623
1-1/2	8.184	6.206	2.250	1.767
1-9/16	8.858	6.862	2.441	1.918
1-5/8	9.557	7.408	2.641	2.074
1-11/16	10.283	7.976	2.848	2.237
1-3/4	11.036	8.564	3.063	2.405
1-13/16	11.816	9.173	3.285	2.580
1-7/8	12.622	9.803	3.516	2.761
1-15/16	13.454	10.453	3.754	2.948
2	14.314	11.125	4.000	3.142
2-1/16	15.199	11.818	4.254	3.341
2-1/8	16.112	12.531	4.516	3.547
2-3/16	17.051	13.266	4.785	3.758
2-1/4	18.016	14.021	5.063	3.976
2-5/16	19.008	14.797	5.348	4.200
2-3/8	20.027	15.595	5.641	4.430
2-7/16	21.072	16.413	5.941	4.666
2-1/2	22.144	17.252	6.250	4.909
2-9/16	23.243	18.112	6.566	5.157
2-5/8	24.368	18.993	6.891	5.412

Weight & Area Tables

Size	Weight (lbs/sqft or foot)		Area (square inches)	
	Square	Round	Square	Round
2-11/16	25.520	19.894	7.223	5.673
2-3/4	26.698	20.817	7.563	5.940
2-13/16	27.903	21.761	7.910	6.213
2-7/8	29.134	22.725	8.266	6.492
2-15/16	30.392	23.711	8.629	6.777
3	31.677	25.778	9.000	7.069
3-1/8	34.326	27.896	9.766	7.670
3-1/4	37.081	30.099	10.56	8.296
3-3/8	39.943	32.385	11.39	8.346
3-1/2	42.911	34.754	12.25	9.621
3-5/8	45.985	37.208	13.14	10.32
3-3/4	49.166	39.745	14.06	11.05
3-7/8	52.453	42.365	15.02	11.79
4	55.846	45.070	16.00	12.57
4-1/8	60.776	48.198	17.02	13.36
4-1/4	64.425	51.079	18.06	14.19
4-3/8	68.180	54.045	19.14	15.03
4-1/2	72.041	57.094	20.25	15.90
4-5/8	76.009	60.226	21.39	16.80
4-3/4	80.083	63.443	22.56	17.72
4-7/8	84.263	66.743	23.77	18.67
5	88.550	70.126	25.00	19.64
5-1/8	92.943	73.594	26.27	20.63
5-1/4	97.443	77.145	27.56	21.65
5-3/8	102.049	80.779	28.89	22.69
5-1/2	106.761	84.498	30.25	23.76
5-5/8	111.579	88.300	31.64	24.85
5-3/4	116.504	92.185	33.06	25.97
5-7/8	121.535	96.154	34.52	27.11
6	126.673	100.207	36.00	28.27
6-1/8	131.917	105.584	37.52	29.47
6-1/4	137.267	109.830	39.06	30.68

Weight & Area Tables

Size	Weight (lbs/sqft or foot)		Area (square inches)	
	Square	Round	Square	Round
6-3/8	142.724	114.158	40.64	31.92
6-1/2	148.287	118.571	42.25	33.18
6-5/8	153.956	123.067	43.89	34.47
6-3/4	159.731	127.646	45.56	35.79
6-7/8	165.613	132.310	47.27	37.12
7	171.602	137.057	49.00	38.49
7-1/8	177.697	144.924	50.77	39.87
7-1/4	183.898	149.891	52.56	41.28
7-3/8	190.205	154.940	54.39	42.72
7-1/2	196.619	160.074	56.25	44.18
7-5/8	203.139	165.291	58.14	45.66
7-3/4	209.765	170.592	60.06	47.17
7-7/8	216.498	175.977	62.02	48.71
8	223.337	181.445	64.00	50.27
8-1/8	230.283	186.997	66.02	51.85
8-1/4	237.335	192.632	68.06	53.46
8-3/8	244.493	198.351	70.14	55.09
8-1/2	251.757	204.154	72.25	56.75
8-5/8	259.128	210.041	74.39	58.43
8-3/4	266.606	216.011	76.56	60.13
8-7/8	274.189	222.065	78.77	61.86
9	281.879	228.202	81.00	63.62
9-1/8	289.675	234.423	83.27	65.40
9-1/4	297.578	240.728	85.56	67.20
9-3/8	305.587	247.116	87.89	69.03
9-1/2	313.702	253.589	90.25	70.88
9-5/8	321.924	260.144	92.64	72.76
9-3/4	330.252	266.784	95.06	74.66
9-7/8	338.687	273.507	97.52	76.59
10	347.227	280.423	100.0	78.54
10-1/8	355.874	287.315	102.5	80.52
10-1/4	364.628	294.291	105.1	82.52

Weight & Area Tables

Size	Weight (lbs/sqft or foot)		Area (square inches)	
	Square	Round	Square	Round
10-3/8	373.488	301.350	107.6	84.54
10-1/2	382.454	308.492	110.3	86.59
10-5/8	391.526	315.719	112.9	88.66
10-3/4	400.705	323.029	115.6	90.76
10-7/8	409.990	330.423	118.3	92.89
11	419.382	337.900	121.0	95.03
11-1/8	428.880	345.461	123.8	97.21
11-1/4	438.484	353.106	126.0	99.40
11-3/8	448.195	360.834	129.4	101.6
11-1/2	458.012	368.646	132.3	103.9
11-5/8	467.935	376.733	135.1	106.1
11-3/4	477.965	384.714	138.1	108.4
11-7/8	488.101	392.779	141.0	110.8
12	498.343	400.928	144.0	113.0

Weight Formulas:

Square and rectangular bar, (inches) —
Thickness x width x length x .2836 = Pounds

Glossary

Annealing

The heating to and holding at a suitable temperature followed by cooling at a suitable rate, used primarily to soften metallic materials.

Stress Relieving

Heating to a suitable temperature, holding long enough to reduce residual stresses and then cooling slowly enough to minimize the development of new residual stress.

Hardening

Increasing hardness by suitable treatment, usually involving heating and cooling.

Temper

Reheating hardened steel to some temperature below the eutectoid temperature for the purpose of decreasing hardness and increasing toughness.

Fatigue

The phenomenon leading to fracture under repeated or fluctuating stresses having a maximum value less than the tensile strength of the material.

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