programmable hoists are in operation for steels requiring austenitizing temperatures of 802–1302°C (1475–2375°F).

13.5.6 Through-Hardening, High-Carbon–Chromium Bearing Steels

13.5.6.1 General Treatment

The high hardness and high strength required for through-hardening bearing steels are achieved by first austenitizing at a temperature sufficiently high to provide carbon solution and then cooling sufficiently fast into the bainite or martensite temperature ranges to avoid the formation of undesirable soft constituents. Heat treatment of these steels generally involves temperatures of approximately 802–871°C (1475–1600°F), uniform soaking and quenching into a medium of salt, water, or synthetic oil, controlled between approximately 27°C and 230°C (80°F and 445°F). The resulting "as-quenched" hardness range for martensite-hardened components is normally Rockwell C (R_C) 63–67; for bainite-hardened components, R_C 57–62. Although bainite-hardened components do not require subsequent thermal treatment, martensite-hardened components are tempered.

13.5.6.2 Martensite

The MS temperature is lowered as the austenitizing temperature and the time at temperature are increased, permitting more carbon to go into solid solution. Correspondingly, the tendency exists for more austenite to be retained during the martensite transformation. The morphology of the resultant martensite also depends on the dissolved carbon content: high amounts of dissolved carbon are associated with plate martensite formation, and low amounts promote a tendency to form lath martensite.

High austenitizing temperatures also have the tendency to coarsen the material grain size. This condition is evident both visually and under low-power magnification of fracture surfaces. Properly heat-treated, high-carbon–chromium grades of steel show a fine, silk-like appearance on fracture faces.

After quenching, components are washed and tempered to relieve stresses and improve toughness. Tempering at temperatures at or slightly above the MS point will also transform the retained austenite to bainite. The penalty for tempering at higher temperatures is the loss of hardness, which can adversely affect the load-carrying capacity and endurance of the bearing component. Components of lower hardness are also more prone to handling and functional surface damage than their harder counterparts.

13.5.6.3 Marquenching

Quenching into a low-temperature medium (49–82°C [120–180°F]) can produce thermal shock and nonuniform phase transformation stresses. Components with nonuniform cross-sections or sharp corners can warp or fracture. Transformation stresses may be reduced by quenching the part into a hot-oil or hot-salt medium controlled at a temperature between 177°C and 218°C (350°F and 425°F), the uppermost portion of the martensite transformation range. Temperature equalization throughout the cross-section of the component permits uniform phase transformation to progress during subsequent air cooling to room temperature. Although the as-quenched hardness is normally R_C 63–65, tempering cycles for martempered parts are similar to those used in straight martensite hardening.

13.5.6.4 Bainite

Bainite hardening is an austempering-type heat treatment in which the component is quenched from the austenitizing temperature to a temperature slightly above the MS temperature, which is the lower bainite transformation zone. Molten salt baths between 220 and 230°C (425 and 450°F) are normally used for this type of heat treatment. Water can be added to the quench bath to achieve the critical quench rate, thus avoiding the formation of undesirable soft constituents. Bainite-hardening grades of steel are again selected on the basis of component cross-sectional area. The higher the hardenability, the greater is the permissible cross-sectional area or thickness of a given component. As the alloy content increases, the nose and knee of the transformation curve are pushed further to the right, which lengthens the time for bainite transformation to begin.

These alloys normally require 4 hours or more for complete transformation to bainite. Hardness values of R_C 57–63 are achieved in components processed in this manner; subsequent tempering is not required. Quenching into molten salts and holding at these temperatures significantly reduce stresses induced due to thermal shock and phase transformation.

Bainite hardening produces components with small compressive surface stresses, in contrast to martensite hardening, which produces small tensile stresses in the as-quenched surface layers. A bainite microstructure is coarser, with a more feathery needle than that produced in straight martensite hardening.

13.5.7 Surface Hardening

13.5.7.1 Methods

Surface hardening is done by altering the chemical composition of the base material—for example, by carburizing or carbonitriding—or by selectively heat treating the surface layer of a given high-carbon bearing steel component. Induction-hardening and flame-hardening are used to fabricate production bearings. Laser beam and electron beam processes are also possible, depending on the hardness depth required.

Surface hardening of bearing steels produces well-defined depths of high surface hardness and wear characteristics as well as residual compressive stresses in the surface layer. These compressive stresses generally tend to enhance rolling contact fatigue resistance. The surface layer is supported by a softer and tougher core, which tends to retard crack propagation.

13.5.7.2 Carburizing

The carburizing source or medium (gas, liquid, or solid) supplies carbon for absorption and diffusion into the steel. The same precautions followed for through-hardening furnace operations are followed in carburizing to minimize handling damage, to reduce part distortion, and to provide process economy. The normal carburizing temperature range is 899–982°C (1650–1800°F), with the carbon diffusion rate increasing with temperature. Therefore, it is easier to control narrow case depth ranges at the lower carburizing temperatures.

Based on the alloy steel that is processed, time, temperature, and atmospheric composition determine the resulting carbon gradient. The resulting carbon content affects the hardness, the amount of retained austenite, and the microstructure of the carburized case. The hardness profile and compressive residual stress field depend on the carbon profile.

Although the practice of quenching directly from the carburizing furnace is used to heat-treat bearing components, it is a general practice to reharden carburized components to develop both case and core properties and, at the same time, to employ fixture-quenching devices to reduce part distortion.

Based on the grade of steel that is carburized, the carbon potential or the furnace atmosphere must be adjusted so that large carbides or a carbide network are not formed. Alloying elements such as chromium, which lower the eutectoid carbon content, are most likely to form globular carbides. Carbon can be further precipitated to the grain boundaries if

3.4.5 Pre-Hardening Stress Relieving

Shall be accomplished prior to hardening by heating in the range 1000 to 1250 °F (538 to 677 °C), soaking for not less than the time specified in Table 4, and cooling to ambient temperature.

3.4.6 Normalizing

Shall be accomplished by heating to the temperature specified in Table 2, soaking for the time specified in Table 4, and cooling in air or atmosphere to ambient temperature. Circulating air or atmosphere is recommended for thicknesses greater than 3 inches (76.2 mm). Normalizing may be followed by tempering or subcritical annealing.

3.4.7 Hardening (Austenitizing and Quenching)

All parts, except those made from H-11, 52100, or M-50 steels, shall be in one of the following conditions prior to austenitizing: normalized, normalized and tempered, normalized and overaged, or hardened. If such parts have been normalized only, without tempering or overaging, they shall be preheated within the range of 850 to 1250 °F (454 to 677 °C) before exposure to the austenitizing temperature (See Table 2 Note 2). Welded parts and brazed parts with a brazing temperature above the normalizing temperature shall be normalized before hardening. Welded parts should be preheated in accordance with 3.4.1. Hardening shall be accomplished by heating to the austenitizing temperature specified in Table 2, soaking for the time specified in Table 4, and quenching as specified in Table 2. The parts shall be cooled to or below the quenchant temperature before tempering.

3.4.8 Tempering or Aging

Shall be accomplished by heating quenched parts to the temperature required to produce the specified properties. Parts should be tempered within 2 hours of quenching (See 3.4.8.1). Tempering for specific tensile strengths for each alloy is shown in Table 3. Soaking time shall be not less than 2 hours plus 1 hour additional for each inch (25 mm) of thickness or fraction thereof greater than 1 inch (25 mm). Thickness is defined in AMS2759. When load thermocouples are used, the soaking time shall be not less than 2 hours. Multiple tempering is permitted. When multiple tempering is used, parts shall be cooled to ambient temperature between tempering treatments.

3.4.8.1 Prior to final tempering parts may be snap tempered for 2 hours at a temperature, usually 400 °F (204 °C), that is lower than the final tempering temperature (See 8.5.1).

3.4.9 Straightening

When approved by the cognizant engineering organization, straightening shall be accomplished at either ambient temperature, during tempering, or by heating to not higher than 50 °F (28 °C) below the tempering temperature. Ambient temperature straightening or hot or warm straightening after tempering shall be followed by stress relieving. It is permissible to retemper at a temperature not higher than the last tempering temperature after straightening during tempering.

3.4.10 Post-Tempering Stress Relieving

When required by the cognizant engineering organization, parts shall, after operations which follow hardening and tempering, be stress relieved by heating the parts to 50 °F (28 °C) below the tempering temperature and soaking for not less than 1 hour plus 1 hour additional for each inch (25 mm) of thickness or fraction thereof greater than 1 inch (25 mm). When load thermocouples are used, the soaking time shall be not less than 1 hour. Stress relief is prohibited on parts that have been peened or thread- or fillet-rolled after hardening and tempering.

3.5 Properties

Parts shall conform to the hardness specified by the cognizant engineering organization or to the hardness converted from the required tensile strength in accordance with AMS2759.

TABLE 2A - ANNEALING, NORMALIZING, AND AUSTENITIZING TEMPERATURES AND QUENCHANTS, INCH/POUND UNITS

Material Designation	Annealing (1) Temperature, °F	Normalizing Temperature, °F	Austenitizing (2) Temperature, °F	Hardening Quenchant
4330V, 4330M (2)	1575	1650	1600	oil, polymer
4335, 4335M (2)	1550	1650	1600	oil, polymer
4340 (2)	1550	1650	1500 (16)	oil, polymer
Hy-Tuf (2)	1400	1725	1600	oil, polymer
300M (2)	1550	1700	1600	oil, polymer
4340 Mod (2)	1550	1700	1600	oil, polymer
H-11 (3)	1600	--	1850	air, oil, polymer
98BV40 (2)	1550	1600	1550	oil, polymer
D6AC (2)	1550	1725	1625 (4)	oil, polymer
52100	(6)	1650	1550 (7)	oil, polymer (5) (15)
9Ni-4Co-0.30C (2) (5)	(8)	1700	1550	oil, polymer (5)
M-50	--	(9)	2025 (10)	salt (11)
AF1410 (2) (5)	1650 (12)	1650 (12)	1525	oil, polymer (5)
AerMet ® 100 (2)	--	1650 (13)	1625	air, oil, polymer (14)

NOTES:

1. Cool at a rate not to exceed 200 °F per hour to below 1000 °F, except cool 4330V, 4335V, and 4340 to below 800 °F, and 300M to below 600 °F.
2. All parts, except those made from H-11, 52100, or M-50 steels, shall be in one of the following conditions prior to austenitizing: normalized, normalized and tempered, normalized and overaged, or hardened. If such parts have been normalized only, without tempering or overaging, they shall be preheated within the range of 850 to 1250 °F before exposure to the austenitizing temperature.
3. H-11 parts shall be in the annealed condition prior to the initial austenitizing treatment.
4. 1700 °F permitted for D6AC parts, when approved by the cognizant engineering organization.
5. Immediately after quenching refrigerate parts made from 52100, 9Ni-4Co-0.30C, and AF1410 at -90 °F or lower, hold 1 hour minimum, and air warm to room temperature. For parts made from 52100 with high propensity to crack during refrigeration, a snap temper before refrigeration is recommended (See 8.5.1).
6. Anneal parts made from 52100 at 1430 °F for 20 minutes, cool to 1370 °F at a rate not faster than 20 °F per hour, cool to 1320 °F at a rate not to exceed 10 °F per hour, cool to 1250 °F at a rate not faster than 20 °F per hour, and air cool to ambient temperature.
7. 1500 °F permissible for parts made from 52100 requiring distortion control. Parts shall be hardened from the spherodize annealed condition or the normalized condition.
8. 9Ni-4Co-0.30C parts shall be duplex subcritical annealed by heating at 1250 °F for 4 hours ± 1/4, air cooling to ambient temperature, reheating at 1150 °F for 4 hours ± 1/4, and air cooling to ambient temperature or shall be annealed by heating at 1150 °F for not less than 23 hours minimum and air cooling to ambient temperature.
9. Normalizing of M-50 parts should be avoided due to grain growth.
10. M-50 parts shall be preheated to 1550 °F prior to austenitizing.
11. For M-50 use 1125 °F followed by air cool to ambient temperature or air cool directly to ambient temperature.
12. For AF1410, to facilitate machining, normalize and then heat to 1250 °F for not less than 6 hours and air cool.
13. For Aermet ® 100, to facilitate machining, normalize and then heat to 1250 °F for not less than 16 hours and air cool.
14. For AerMet ® 100, quench in oil (160 °F or lower), polymer, gas quench, or air cool below 400 °F within 2 hours. Within 8 hours of quenching, cool parts to -100 °F or lower, hold 1 hour per inch of thickness or fraction thereof, and warm in any convenient manner to room temperature.
15. For 52100 a salt marquench may be used if specified by the cognizant engineering organization (See 8.5.2).
16. Parts made from 4340 may be austenitized at a set temperature of 1525 °F.

Aermet® 100 is a registered trade name of Carpenter Technology.

TABLE 3A - TEMPERING OR AGING TEMPERATURES, °F, INCH/POUND UNITS

Material Designation	Tensile Strength Range, ksi (1) 220 to 240	Tensile Strength Range, ksi (1) 260 to 280	Tensile Strength Range, ksi (1) 270 to 290	Tensile Strength Range, ksi (1) 280 to 305
4330V, 4330M (2)	500 (3)	-	-	-
4335V, 4335M (2)	500 (3)	-	-	-
4340 (2)	-	425 to 490	-	-
Hy-Tuf (2)	550 (4)	-	-	-
300M (2)	-	-	550 to 600	575 (5)
4340 Mod (2)	-	-	550 to 600	575
H-11 (6)	1025 (3)	(7)	(7)	(7)
98BV40	-	-	-	500 (3)
D6AC (2)	(8)	(9)	-	-
52100 (2) (10)	-	-	-	-
9Ni-4Co-0.30C (2)	1000 to 1050 (3)	-	-	-
M-50 (11) (12)	-	-	-	-
AF1410 (2)	925	-	-	-
Aermet 100 (13)	-	900 (14)	-	900 (15)

NOTES:
1. Absence of values indicates the respective steel is not recommended for the specified tensile strength range.
2. At least two tempering operations required.
3. Suggested temperature only.
4. 220 to 250 ksi for Hy-Tuf.
5. Use this tempering temperature for 275 to 305 ksi range for 300M, when specified.
6. At least three tempering operations required for H-11.
7. Final tempering for H-11 shall be at or above 1000 °F. The tempering temperature shall be not lower than that of previous temper nor should it be more than 25 °F higher than the previous temper.
8. For D6AC, 1st temper: 1000 °F minimum; 2nd temper: 1015 to 1060 °F.
9. For D6AC, 1st temper: 550 °F minimum; 2nd temper: 550 to 700 °F.
10. For 52100, 58 to 65 HRC, temper at 340 to 450 °F.
11. Triple tempering required for M-50; double tempering permitted when approved by the cognizant engineering organization.
12. For M-50, 60 to 64 HRC, temper at 1000 to 1025 °F.
13. Aging temperature for Aermet 100.
14. For Aermet 100, hold 6 to 10 hours. Required hardness is 50 to 53 HRC; if parts exceed 53 HRC, parts may be reaged.
15. 280 to 300 ksi for Aermet 100. Hold 4 to 8 hours. Required hardness is 52 to 55 HRC.

TABLE 4 - SOAK TIME FOR ANNEALING, NORMALIZING, AND AUSTENITIZING

Thickness [1] Inches	Thickness [1] Millimeters	Minimum Soak Time [2], [3], [4], [5], [6], [7] Air or Atmosphere	Minimum Soak Time [2], [3], [4], [5], [6], [7] Salt
Up to 0.250	Up to 6.35	25 minutes	18 minutes
Over 0.250 to 0.500	Over 6.35 to 12.70	45 minutes	35 minutes
Over 0.500 to 1.000	Over 12.70 to 25.40	1 hour	40 minutes
Over 1.000 to 1.500	Over 25.40 to 38.10	1 hour 15 minutes	45 minutes
Over 1.500 to 2.000	Over 38.10 to 50.80	1 hour 30 minutes	50 minutes
Over 2.000 to 2.500	Over 50.80 to 63.50	1 hour 45 minutes	55 minutes
Over 2.500 to 3.000	Over 63.50 to 76.20	2 hours	1 hour
Over 3.000 to 3.500	Over 76.20 to 88.90	2 hours 15 minutes	1 hour 5 minutes
Over 3.500 to 4.000	Over 88.90 to 101.60	2 hours 30 minutes	1 hour 10 minutes
Over 4.000 to 4.500	Over 101.60 to 114.30	2 hours 45 minutes	1 hour 15 minutes
Over 4.500 to 5.000	Over 114.30 to 127.00	3 hours	1 hour 20 minutes
Over 5.000 to 8.000	Over 127.00 to 203.20	3 hours 30 minutes	1 hour 40 minutes
Over 8.000	Over 203.20	[8]	[9]

NOTES:

1. Thickness is the minimum dimension of the heaviest section of the part.
2. Soak time commences as specified in 3.4.2 as modified by 3.4.2.1.
3. In all cases, the parts shall be held for sufficient time to ensure that the center of the most massive area has reached temperature and the necessary transformation and diffusion have taken place.
4. Maximum soak time shall be twice the minimum specified, except for subcritical annealing.
5. Austenitizing of M-50 for more than 10 minutes should be avoided due to grain growth.
6. Longer times may be necessary for parts with complex shapes or parts that do not heat uniformly.
7. Minimum soaking time for Aermet 100 is 1 hour.
8. 4 hours plus 30 minutes for every 3 inches (76 mm) or increment of 3 inches (76 mm) greater than 8 inches (203 mm).
9. 2 hours plus 20 minutes for every 3 inches (76 mm) or increment of 3 inches (76 mm) greater than 8 inches (203 mm).