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AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

MATERIALS AND HARDWARE

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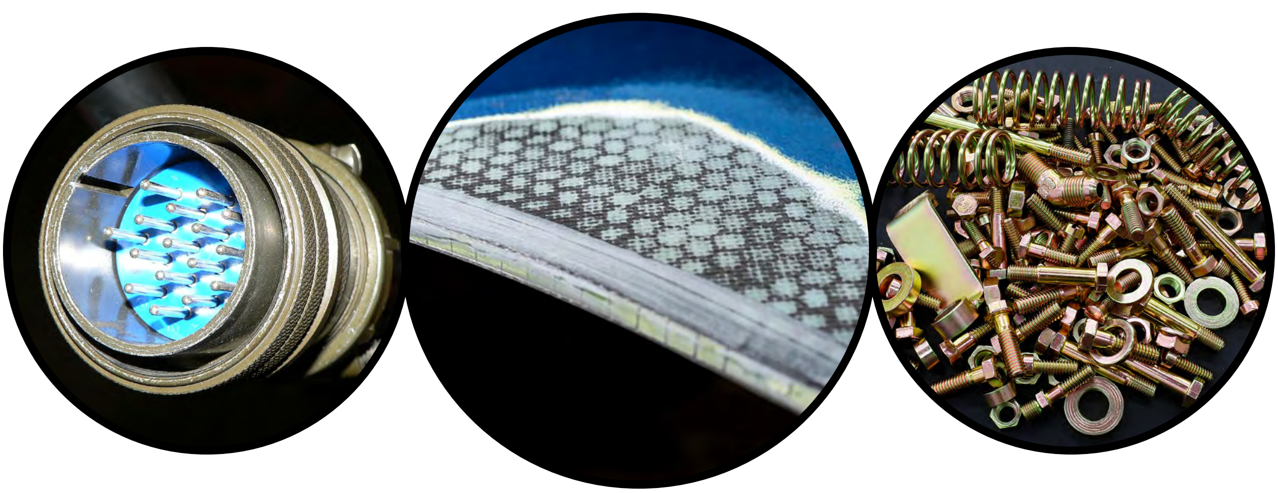

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TABLE OF CONTENTS

MATERIALS AND HARDWARE

TABLE OF CONTENTS

TABLE OF CONTENTS

a solid solution and a mechanical mixture. When an alloy is in the form of a solid solution, the elements and compounds which form the alloy are absorbed, one into the other, in much the same way that salt is dissolved in a glass of water, and the constituents cannot be identified even under a microscope.

When two or more elements or compounds are mixed but can be identified by microscopic examination, a mechanical mixture is formed. A mechanical mixture can be compared to the mixture of sand and gravel in concrete. The sand and gravel are both visible. Just as the sand and gravel are held together and kept in place by the matrix of cement, the other constituents of an alloy are embedded in the matrix formed by the base metal.

An alloy in the form of a mechanical mixture at ordinary temperatures may change to a solid solution when heated. When cooled back to normal temperature, the alloy may return to its original structure. On the other hand, it may remain a solid solution or form a combination of a solid solution and mechanical mixture. An alloy which consists of a combination of solid solution and mechanical mixture at normal temperatures may change to a solid solution when heated. When cooled, the alloy may remain a solid solution, return to its original structure, or form a complex solution.

HEAT TREATING EQUIPMENT

Successful heat treating requires close control over all factors affecting the heating and cooling of metals. Such control is possible only when the proper equipment is available and the equipment is selected to fit the particular job. Thus, the furnace must be of the proper size and type and must be so controlled that temperatures are kept within the limits prescribed for each operation. [**Figure 1-2**] Even the atmosphere within the furnace affects the condition of the part being heat treated. Further, the quenching equipment and the quenching medium must be selected to fit the metal and the heat treating operation. Finally, there must be equipment for handling parts and materials, for cleaning metals, and for straightening parts.

FURNACES AND SALT BATHS

There are many different types and sizes of furnaces used in heat treatment. As a general rule, furnaces are designed to operate in certain specific temperature ranges and attempted use in other ranges frequently results in work of inferior quality. In addition, using a furnace beyond its rated maximum temperature shortens its life and may necessitate costly and time consuming repairs.

Figure 1-2. A heat treating furnace used to manufacture aircraft landing gear.

Fuel fired furnaces (gas or oil) require air for proper combustion and an air compressor or blower is therefore necessary. These furnaces are usually of the muffler type; that is, the combustion of the fuel takes place outside of and around the chamber in which the work is placed. If an open muffler is used, the furnace should be designed to prevent the direct impingement of flame on the work.

In furnaces heated by electricity, the heating elements are generally in the form of wire or ribbon. Good design requires incorporation of additional heating elements at locations where maximum heat loss may be expected. Such furnaces commonly operate at up to a maximum temperature of about 1 100°C. Furnaces operating at temperatures up to about 1 400°C usually employ resistor bars of sintered carbides.

TEMPERATURE MEASUREMENT AND CONTROL

Temperature in the heat-treating furnace is measured by a thermoelectric instrument known as a pyrometer. This instrument measures the electrical effect of a thermocouple and, hence, the temperature of the metal being treated. A complete pyrometer consists of three parts—a thermocouple, extension leads, and meter.

Pyrometers may have meters either of the indicating type or recording type. Indicating pyrometers give direct reading of the furnace temperature. The recording type produces a permanent record of the temperature range throughout the heating operation by means of an inked stylus attached to an arm which traces a line on a sheet of calibrated paper or temperature chart. Pyrometer installations on all modern furnaces provide automatic regulation of the temperature at any desired setting. Instruments of this type are called controlling potentiometer pyrometers. They include a current regulator and an operating mechanism, such as a relay.

HEATING

The object in heating is to transform pearlite (a mixture of alternate strips of ferrite and iron carbide in a single grain) to austenite as the steel is heated through the critical range. Since this transition takes time, a relatively slow rate of heating must be used. Ordinarily, the cold steel is inserted when the temperature in the furnace is from 150°C to 260°C below the hardening temperature. In this way, too rapid heating through the critical range is prevented.

If temperature measuring equipment is not available, it becomes necessary to estimate temperatures by some other means. An inexpensive, yet fairly accurate method involves the use of commercial crayons, pellets, or paints that melt at various temperatures within the range of 50°C to 870°C. The least accurate method of temperature estimation is by observation of the color of the hot hearth of the furnace or of the work. The heat colors observed are affected by many factors, such as the conditions of artificial or natural light, the character of the scale on the work, and so forth. Steel begins to appear dull red at about 550°C, and as the temperature increases, the color changes gradually through various shades of red to orange, to yellow, and finally to white. A rough approximation of the correspondence between color and temperature is indicated in **Figure 1-3**.

It is often necessary or desirable to protect steel or cast iron from surface oxidation (scaling) and loss of carbon from the surface layers (decarburization). Commercial furnaces, therefore, are generally equipped with some means of atmosphere control. This usually is in the form of a burner for burning controlled amounts of gas and air and directing the products of combustion into the furnace muffle. Water vapor, a product of this combustion, is detrimental and many furnaces are equipped with a means for eliminating it. For furnaces not equipped with atmosphere control, a variety of external atmosphere generators are available. The gas so generated is piped into the furnace and one generator may supply several furnaces. If no method of atmosphere control is available, some degree of protection may be secured by covering the work with cast iron borings or chips.

Since the work is done in salt or lead baths is surrounded by the liquid heating medium, the problem of preventing scaling or decarburization is simplified. Vacuum furnaces also are used for annealing steels, especially when a bright non-oxidized surface is a prime consideration.

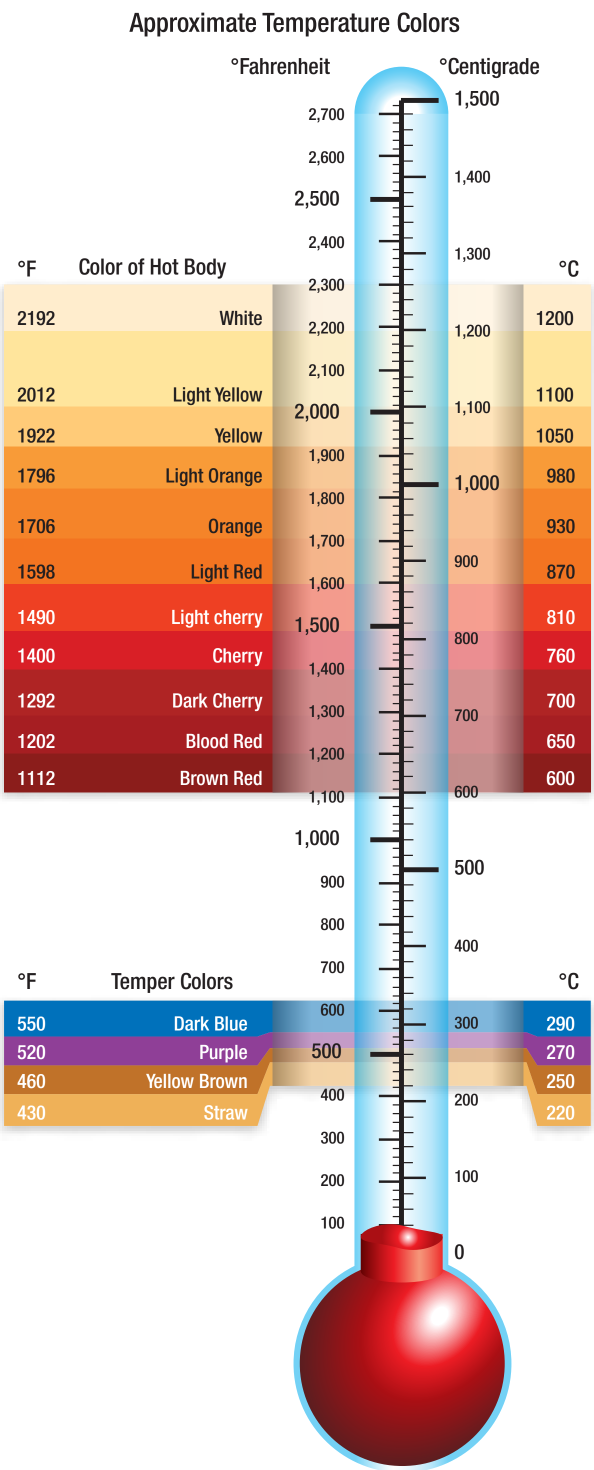

Figure 1-3. Temperature chart indicating conversion of Centigrade to Fahrenheit or vice versa, color temperature scale for hardening temperature range, and tempering temperature range.

SOAKING

The temperature of the furnace must be held constant during the soaking period, since it is during this period that rearrangement of the internal structure of the steel takes place. Soaking temperatures for various types of steel are specified in ranges varying as much as 40°C. [**Figure 1-4**]

Small parts are soaked in the lower part of the specified range and heavy parts in the upper part of the specified range. The length of the soaking period depends upon the type of steel and the size of the part. Naturally, heavier parts require longer soaking to ensure equal heating throughout. As a general rule, a soaking period of 30 minutes to 1 hour is sufficient for the average heat treating operation.

COOLING

The rate of cooling through the critical range determines the form that the steel will retain. Various rates of cooling are used to produce the desired results. Still air is a slow cooling medium, but is much faster than furnace cooling. Liquids are the fastest cooling media and are therefore used in hardening steels. There are three commonly used quenching liquids—brine, water, and oil. Brine is the strongest quenching medium, water is next, and oil is the least. Generally, an oil quench is used for alloy steels, and brine or water for carbon steels.

Quenching solutions act only through their ability to cool the steel. They have no beneficial chemical action on the quenched steel and in themselves impart no unusual properties. Most requirements for quenching media are met satisfactorily by water or aqueous solutions of inorganic salts, such as table salt or caustic soda, or by some type of oil. The rate of cooling is relatively rapid during quenching in brine, somewhat less rapid in water, and slow in oil.

Brine usually is made of a 5 to 10 percent solution of salt (sodium chloride) in water. In addition to its greater cooling speed, brine has the ability to "throw" the scale from steel during quenching. The cooling ability of both water and brine, particularly water, is considerably affected by their temperature. Both should be kept cold—well below 15°C. If the volume of steel being quenched tends to raise the temperature of the bath appreciably, add ice or use some means of refrigeration to cool the quenching bath.

Steel Number	Temperatures			Quenching Medium (n)	Tempering (drawing) Temperature for Tensile Strength (psi)				
	Normalizing Air Cool (°C)	Annealing (°C)	Hardening (°C)		100 000 (°C)	125 000 (°C)	150 000 (°C)	180 000 (°C)	200 000 (°C)
1020	900–955	870–925	855–910	Water	—	—	—	—	—
1022 (x1020)	900–955	870–925	855–910	Water	—	—	—	—	—
1025	870–925	870–900	855–910	Water	(a)	—	—	—	—
1035	855–900	855–885	830–870	Water	470	—	—	—	—
1045	845–870	845–870	800–845	Oil or Water	620	—	—	(n)	—
1095	800–845	790–815	775–815	Oil	(b)	—	595	455	400
2330	800–830	775–800	790–815	Oil or Water	595	510	423	—	—
3135	870–900	815–845	800–830	Oil	675	565	480	400	345
3140	870–900	815–845	800–830	Oil	720	580	495	413	370
4037	870	830–855	830–855	Oil or Water	665	595	525	—	—
4130 (x4130)	870–925	830–855	830–885	Oil (c)	(d)	565	480	370	300
4140	870–900	830–855	830–855	Oil	730	595	550	440	355
4150	845–870	800–830	845	Oil	—	690	635	565	510
4340 (x4340)	845–885	830–855	800–845	Oil	—	650	565	510	455
4640	910–925	830–855	815–845	Oil	—	650	565	400	330
6135	870–925	845–870	855–885	Oil	705	580	495	425	400
6150	870–900	830–855	845–885	Oil	(d)(e)	650	540	480	425
6195	870–900	830–855	815–845	Oil	(f)	—	—	—	—
NE8620	—	—	830–855	Oil	—	540	—	—	—
NE8630	900	830–855	830–855	Oil	—	605	525	415	355
NE8735	900	830–855	830–855	Oil	—	635	550	470	415
NE8740	885	815–845	815–845	Oil	—	650	580	495	455
30905	—	(g)(h)	(i)	—	—	—	—	—	—
51210	830–855	830–855	970–995(j)	Oil	650	595	(k)	400	—
51335	—	830–855	970–1 010	Oil	—	—	—	—	—
52100	885–925	760–790	830–845	Oil	(f)	—	—	—	—
Corrosion resisting (16–2)(1)	—	—	—	—	(m)	—	—	—	—
Silicon chromium (for springs)	—	—	925–940	Oil	—	—	—	—	—

NOTES:

(a) Draw at 620°C for tensile strength of 70 000 psi.
(b) For spring temper draw at 425-480°C. Rockwell hardness C-40-45.
(c) Bars or forgings may be quenched in water from 815–870°C.
(d) Air cooling from the normalizing temperature produces a tensile strength of approximately 90 000 psi.
(e) For spring temper draw at 455–510°C. Rockwell hardness C-40-45.
(f) Draw at 175–230°C to remove quenching strains. Rockwell hardness C-60-65.
(g) Anneal at 870–925°C to remove residual stresses due to welding or cold work. May be applied only to steel containing titanium or columbium.
(h) Anneal at 1 040–1 150°C to produce maximum softness and corrosion resistance. Cool in air or quench in water.
(i) Harden by cold work only.
(j) Lower side of range for sheet 0.06 inch and under. Middle of range for sheet and wire 0.125 inch. Upper side of range for forgings.
(k) Not recommended for intermediate tensile strengths because of low impact.
(l) AN-QQ-S-770—It is recommended that prior to tempering corrosion–resisting (16 Cr–2 Ni) steel be quenched in oil from a temperature of 1 025–1 040°C after a soaking period of 30 minutes at this temperature. To obtain a tensile strength at 115 000 psi the tempering temperature should be approximately 275°C. A holding time at these temperatures of about 2 hours is recommended. Tempering temperatures between 370°C and 595°C is not approved.
(m) Draw at approximately 425°C and cool in air for Rockwell hardness of C-50.
(n) Water used for quenching shall be within the temperature range of 25–60°C.

Figure 1-4. Heat treatment procedures for steels.

When steel is quenched, the liquid in immediate contact with the hot surface vaporizes; this vapor reduces the rate of heat abstraction markedly. Vigorous agitation of the steel or the use of a pressure spray quench is necessary to dislodge these vapor films and permit the desired rate of cooling. The tendency of steel to warp and crack during the quenching process is difficult to overcome because certain parts of the article cool more rapidly than others. The following recommendations will greatly reduce the warping tendency:

- Never throw a part into the quenching bath. Allowing it to lie on the bottom of the bath, it will cool faster on the top side than on the bottom side, causing it to warp or crack.
- Agitate the part slightly to destroy the coating of vapor that could prevent it from cooling evenly and rapidly. This allows the bath to dissipate its heat to the atmosphere.
- Immerse irregular shaped parts so that the heavy end enters the bath first.

HEAT TREATMENT AND APPLICATION OF ALLOY STEELS

The first important consideration in the heat treatment of a steel part is to know its chemical composition. This, in turn, determines its upper critical point. When the upper critical point is known, the next consideration is the rate of heating and cooling to be used. Carrying out these operations involves the use of uniform heating furnaces, proper temperature controls, and suitable quenching mediums.

BEHAVIOR OF STEEL DURING HEATING AND COOLING

Changing the internal structure of a ferrous metal is accomplished by heating to a temperature above its upper critical point, holding it at that temperature for a time sufficient to permit certain internal changes to occur, and then cooling to atmospheric temperature under predetermined, controlled conditions.

At ordinary temperatures, the carbon in steel exists in the form of particles of iron carbide scattered throughout an iron matrix known as "ferrite." The number, size, and distribution of these particles determine the hardness of the steel. At elevated temperatures, the carbon is dissolved in the iron matrix in the form of a solid solution called "austenite," and the carbide particles appear only after the steel has been cooled. If the cooling is slow, the carbide particles are relatively coarse and few. In this condition, the steel is soft. If the cooling is rapid, as by quenching in oil or water, the carbon precipitates as a cloud of very fine carbide particles, and the steel is hard. The fact that the carbide particles can be dissolved in austenite is the basis of the heat treatment of steel. The temperatures at which this transformation takes place are called the critical points and vary with the composition of the steel. The percentage of carbon in the steel has the greatest influence on the critical points of heat treatment.

HARDENING

Pure iron, wrought iron, and extremely low carbon steels cannot be appreciably hardened by heat treatment, since they contain no hardening element. Cast iron can be hardened, but its heat treatment is limited. When cast iron is cooled rapidly, it forms white iron, which is hard and brittle. When cooled slowly, it forms gray iron, which is soft but brittle under impact.

In plain carbon steel, the maximum hardness depends almost entirely on the carbon content of the steel. As the carbon content increases, the ability of the steel to be hardened increases. However, this increase in the ability to harden with an increase in carbon content continues only to a certain point. In practice, that point is 0.85 percent carbon content. When the carbon content is increased beyond 0.85 percent, there is no increase in wear resistance.

For most steels, the hardening treatment consists of heating the steel to a temperature just above the upper critical point, soaking or holding for the required length of time, and then cooling it rapidly by plunging the hot steel into oil, water, or brine. Although most steels must be cooled rapidly for hardening, a few may be cooled in still air. Hardening increases the hardness and strength of the steel but makes it less ductile.

HARDENING PRECAUTIONS

A variety of different shapes and sizes of tongs for handling hot steels is necessary. It should be remembered that cooling of the area contacted by the tongs is retarded and that such areas may not harden, particularly if the steel being treated is very shallow hardening. Small parts may be wired together or quenched in baskets made of wire mesh. Special quenching jigs and fixtures are frequently used to hold steels during quenching in a manner to restrain distortion.

TEMPERING

Tempering reduces the brittleness imparted by hardening and produces definite physical properties within the steel. Tempering always follows, never precedes, the hardening operation. In addition to reducing brittleness, tempering softens the steel. Tempering is always conducted at temperatures below the low critical point of the steel. In this respect, tempering differs from annealing, normalizing, or hardening, all of which require temperatures above the upper critical point. When hardened steel is reheated, tempering begins at 100°C and continues as the temperature increases toward the low critical point. By selecting a definite tempering temperature, the resulting hardness and strength can be predetermined. Approximate temperatures for various tensile strengths are listed in **Figure 1-4**. The minimum time at the tempering temperature should be 1 hour. If the part is over 1 inch in thickness, increase the time by 1 hour for each additional inch of thickness. Tempered steels used in aircraft work have from 125 000 to 200 000 psi ultimate tensile strength.

Generally, the rate of cooling from the tempering temperature has no effect on the resulting structure; therefore, the steel is usually cooled in still air after being removed from the furnace.

ANNEALING

Annealing of steel produces a fine grained, soft, ductile metal without internal stresses or strains. In the annealed state, steel has its lowest strength. In general, annealing is the opposite of hardening.

Annealing of steel is accomplished by heating the metal to just above the upper critical point, soaking at that temperature, and cooling very slowly in the furnace. (See **Figure 1-4** for recommended temperatures.) Soaking time is approximately 1