ALLOY CLASSIFICATION. In the manufacture of noble metal alloys, the constituents of the alloy, i.e., the element it contains, are accurately weighed, placed in a crucible, melted and cast into ingot form. The ingot is then processed by rolling, wire drawing, etc. to the final dimensions required.

Materials are often classified by reference to some part of their processing history.

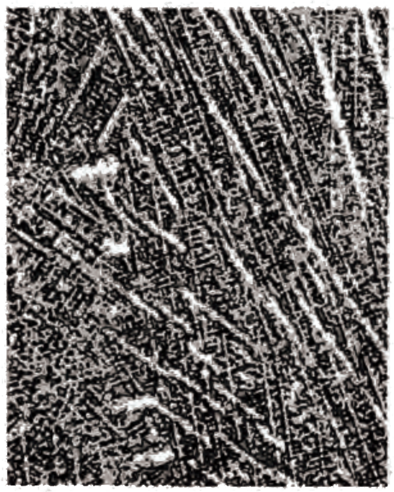


Fig. 2-20. Metallographic structure of Paliney® 7 cast ingot. Note the dendritic (branch-like) structure. Magnification 67X.

Work Hardening. When the rolling or wire drawing is done below the temperature range at which annealing (softening) would occur, it is called cold working. Whereas the ingot immediately after casting is fully annealed, the plastic deformation during cold working causes strain hardening or work hardening. he work hardening tends to raise the strength and hardness properties and decrease the ductility, often to the e tent that rolling or drawing must be interrupted periodically for an in process anneal. material that is work hardened is one which has gained some significant portion of its strength or hardness properties by virtue of the deformation received during processing. he increased properties are the result of internal stresses in the material. ll of the ey alloys are work hardenable to some e tent, although not all of them are regularly used in this condition.

Fig. 2-21. Metallographic structure of Paliney® 7 in the work hardened condition. The direction of working is parallel to the elongated fibers. Magnification 532X.

The amount of cold working given a material following its last in-process anneal is expressed in one of three ways: by the *temper designation* as used by the copper alloy industry; or by Brown & Sharpe (*B & S*) gage numbers of *reduction*; or by percent reduction in cross sectional area. The interrela-tion of these designations is given in Table II-l.

Note that the percent reduction for wire is different from that for strip, where both have the same gage number reduction. This is because percent reduction is based on cross sectional area. If, for example, a wire is reduced from .020" dia. to .010" the percent reduction is

$$100 - \frac{(.010)^2}{(.020)^2} \times 100 = 75\%$$

Temper Designation	Reduction B & S Gage Numbers	Approx. % Reduction	
		Wire	Strip
Quarter Hard	1	20.7	10.9
Half Hard	2	37.1	20.7
Three-Quarter Hard	3	50.0	29.4
Hard	4	60.5	37.1
Extra Hard	6	75.0	50.0
Spring	8	84.4	60.5
Extra Spring	10	90.2	68.7

Table II-1. Relation of cold working nomenclature

whereas if a strip is reduced from .020” to .010” thickness, the width does not change appreciably and the percent reduction is

$$100 - \frac{.010}{.020} \times 100 = 50\%$$

As expected, wire and strip with the same Temper Designation (Table II-1) will not ordinarily have the same tensile and hardness properties. The strip will be softer and lower in tensile properties than the wire, due to the lesser percent reduction in cross-sectional area. For this reason, and because terms like quarter hard, half hard, etc. have different meanings in, for instance, the aluminum industry, these terms should be avoided in ordering or specifying noble metal alloys. The use of limits on tensile and hardness properties is much preferred.

Annealing. After a material has been work hardened, the internal stresses causing the increased properties can be removed by subjecting it to a thermal treatment (a controlled heating and cooling) which is known as annealing. As with most thermal treatments, there is a time-temperature effect. Some part of this thermal treatment must be at temperatures high enough to cause recrystallization, in which the distorted elongated grains produced by the previous cold working are replaced by small more symmetrical grains which continue to grow at the expense of the strained grains until the latter are replaced by the newly formed unstressed grains. If the annealing time and/or temperature is excessive, undesirable grain growth results, as shown in Figs. 2-22 and 2-23. This weakens the material but in this case its ductility is lower than a properly-annealed material.

The recrystallization temperature is different for each alloy and is de creased for a given alloy with an increased amount of cold working. Thus a severely worked material recrystallizes at a lower temperature than one with less working. Solution annealing will be described in 2.3.4.

With materials that can be hardened only by the work hardening mechanism, the application of heat can have only one effect, which is the tendency to soften them.

Fig. 2-22. Metallographic structure of Paliney® 7 in the annealed condition. Note the formation of small grains. Some of the effect of work hardening is still visible. Magnification 532X.

Fig. 2-23. (a) Metallographic structure of an alloy annealed at the proper temperature. 500X magnification.

(b) Metallographic structure of same alloy shown in (a) but annealed at a temperature 100°F too high. 500X magnification.

Stress Relieving. In the broadest sense, stress relieving is a partial annealing accomplished without producing significant recrystallization. As used in the noble metal industry, *stress relieved* material is that in which the time-temperature treatment applied to work hardened material has been geared to reducing enough internal stresses for improved ductility, but at the minimum sacrifice in tensile strength and hardness. The process of heat straightening inherently produces stress relieving in a material that hardens only by cold working. At times the need for straightness is the sole reason for the stress relieving operation.

Fig. 2-24. Metallographic structure of Paliney® 7 in the stress relieved condition. Note the similarity to work hardened structure, as shown in Fig. 2-21. Magnification 532X.

Age Hardening. When a material undergoes a thermal treatment that increases its tensile strength and hardness, we say that it has been *age hardened*. (Unfortunately, this condition is also called "heat treated" in many cases, but "heat treated" should apply to any treatment at an elevated temperature.) The two metallurgical mechanisms used for the age hardenable Ney alloys are precipitation hardening and *order hardening.*

Before controlled precipitation hardening can be accomplished, the alloy must be given a *solution anneal* during which it is heated to a suitable temperature and held at that temperature long enough to allow one or more of the alloying constituents to enter into solid solution. Rapid cooling then holds these constituents in solution. The metal is now in a supersaturated unstable state and ready to be age hardened.

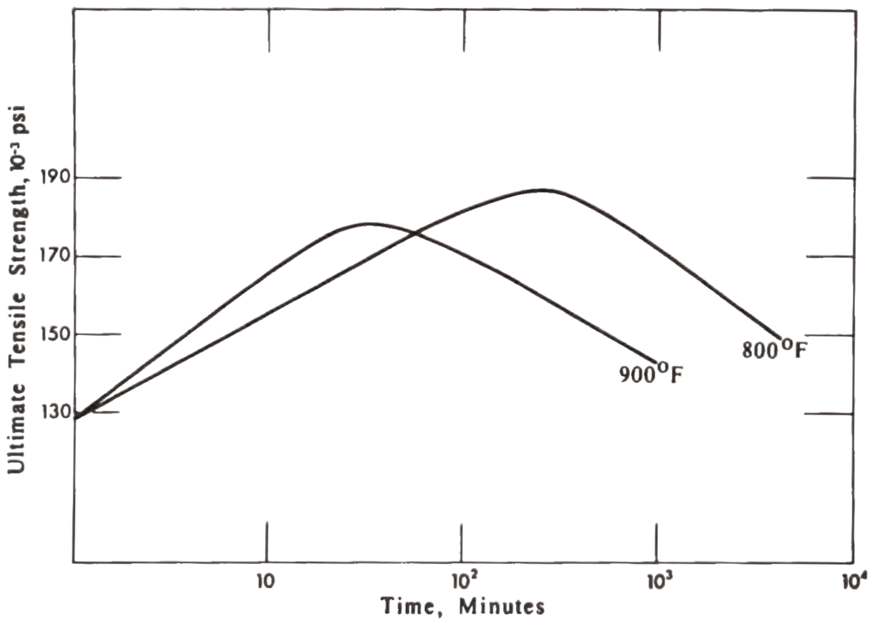


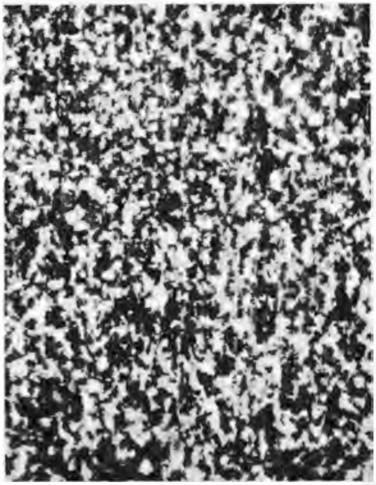
Fig. 2-25. Time of age hardening vs. ultimate tensile strength for a palladium alloy aged at 800°F and at 900°F.

epending on the alloy, this solution annealing may be done before the final work hardening, as, for instance, with copper-beryllium alloy, which can be purchased work hardened, yet is heat treatable.

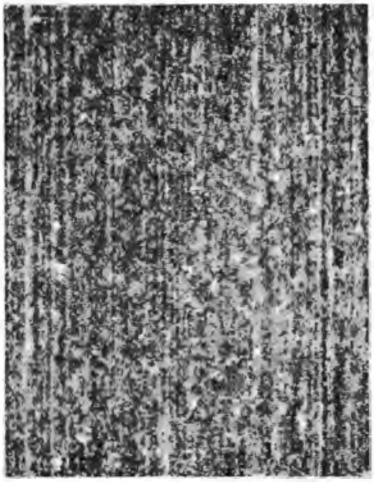
Precipitation hardening is the type of age hardening in which a constituent precipitates from the supersaturated solution into preferred sites such as the grain boundaries or slip planes, reducing the ease of deformation within the material, which effectively increases the strength and hardness. Paliney® 6, Paliney 7 and Paliney 8 are among the alloys that can be precipitation hardened. Whereas solution annealing temperatures for these alloys are about 1550 to 1600°F, the precipitation hardening is done at a lower temperature ranging from 700°F to 1000°F, depending on the alloy and the desired physical properties. Time-at-temperature ranges from 10 minutes to 2 hours.

In the case of age hardening by the order hardening mechanism, the atoms of the unaged alloy are in rather random or *disordered* positions as a result of annealing or cold working. Then by treating the alloy at a suitable time-temperature combination, preferential position (ordering) of the atoms within the structure is obtained. This ordering reaction produces lattice strains which result in an increase in strength and hardness.

(a) Metallographic structure of Paliney® 7 in the Ductile HT (partially age hardened) condition. Magnification 532X.



(b) Metallographic structure of Paliney® 7 in the fully age hardened condition. Magnification 532X.



(c) Metallographic structure of Paliney® 7 in the over-aged condition. Magnification 532X.

Fig. 2-26.

This type of hardening mechanism is typical of gold-copper alloys, and is the principal reason for Neyoro® G being age hardenable. The hardening can be obtained in Neyoro G in either the annealed state or in the work hardened state and is performed at temperatures ranging from 700 to 900 F with times ranging from 10 to 30 minutes, both time and temperature being selected to produce specific desired physical properties.