

UNITED STATES PATENT OFFICE

2,257,535

METHOD OF WORKING THERMALLY
HARDENABLE BERYLLIUM-CONTAIN-
ING ALLOYS

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No Drawing. Application August 22, 1939,
Serial No. 291,360. In Germany May 17,
1938

3 Claims. (Cl. 29—148)

This invention relates to metallurgy and more particularly to an improved method of working and heat treating thermally hardenable beryllium-containing alloys of copper, nickel, iron or cobalt to improve the endurance limit and fatigue strengths of the said alloys.

One of the objects of the present invention is to improve the endurance limit and fatigue strength of thermally hardenable beryllium-containing alloys. Another object is to produce spring material comprised of a beryllium-containing alloy having a relatively high endurance limit and fatigue strength as compared with beryllium-containing alloys heretofore produced. Still another object is to provide an improved method of working and heat treating thermally hardenable beryllium-containing alloys. Other objects and advantages will be apparent as the invention is more fully hereinafter disclosed.

Thermally hardenable beryllium-containing alloys within the scope of the present invention are comprised of those alloys containing from small but effective amount up to about 3.5% of beryllium in a base consisting principally of one of the metals copper, iron, nickel or cobalt, with or without small amounts up to about 2% of at least one of the metals manganese, silicon, aluminum and manganese for purposes of deoxidizing the alloy prior to the beryllium additions thereto or for purposes of increasing the machinability of the alloy, which are hardenable by heat treatment at temperatures within the range from about 150° C. to about 600° C. by reason of a phase conversion of the beryllium content of the alloy and its precipitation out of solid solution in the base metal of the alloy.

Within the scope of the present invention also are those similarly thermally hardenable complex beryllium-containing alloys, basically known as Cu-Be; Ni-Be; Fe-Be; and Co-Be, wherein the beryllium content ranges from small but effective amounts up to about 3.5% and to which have been added one or more of the group of elements Cr, W, Mo; Fe, Ni, Mn, Co; Ca, Cer; Ti, Zr; Zn, Sn, Ag; Al, Mg, Si, Mg; Ta and Cb, in various proportions and combinations to produce alloys having special physical, chemical or working properties in addition to the thermal hardening properties imparted by the beryllium content thereof.

All of the alloys hereinabove identified are characterized by being softened and conditioned for cold deformation by heat treatment at a temperature above about 600° C. but below the fusion temperature, followed by rapid cooling to atmospheric temperatures. Thus treated, the beryllium-containing alloys may be mechanically deformed as by hammering, swaging, drawing and the like at atmospheric temperatures into wire, rod, bar, sheet or strip material.

In most instances it is desirable to form the desired spring article of the work hardened alloy rather than from the annealed alloy, as the tension imparted by reason of the work hardening in the alloy assists materially in preventing warping of the spring article during the thermal hardening heat treatment. The working process therefor is regulated with respect to intermediate annealing operations to remove work hardening in the wire, rod, sheet or strip, so that the final worked material has the desired amount of cold working to impart thereto the desired tension. Moreover, all other factors being constant, the fatigue strength and endurance limit of work hardened material is greater than that of unwork hardened material, after thermal hardening.

However, surface irregularities, indentations or inequalities are disruptive factors deleteriously affecting the endurance limit and fatigue strength of materials and we have discovered that the endurance limit and fatigue strength of all of the alloys hereinabove identified may be markedly increased over the limit and strengths heretofore obtained by effectively eliminating the surface irregularities, indentations or inequalities at a point during the cold reduction of the same which will enable us subsequently to cold work the material down to desired final thickness of sheet or strip or diameter of wire or rod, preferably in a manner adapted to introduce into the material the desired tension and to produce a final surface substantially free from the surface irregularities deleterious to the endurance limit and fatigue strength.

As one skilled in the art will recognize, the invention is adapted to wide modification, depending upon the ultimate results desired without essential departure from the same. As one specific embodiment of the practice of the present inven-

tion, we will disclose the same as applied to the manufacture of rods approximating $\frac{1}{8}$ inch in diameter for use in the forming of helical springs, the said rods being comprised of a beryllium-nickel alloy containing:

	Per cent
Be.....	1.9-2.0
Ni.....	96.1-96
Ti.....	1.0
Mn.....	1.0
Total.....	100

This alloy is formed in the usual manner and cast into ingots which are heated prior to cold working to temperatures approximating 1050° C. and cooled rapidly as by quenching in water to condition the same for cold mechanical deformation. The heated and quenched alloy is first rough rolled to a rod form approximating $\frac{1}{8}$ inch diameter, with frequent annealings at the same high temperature of treatment, followed by quenching to eliminate work hardening effects, and then is given a final heat treatment to condition the same for the final cold working operation. The softened rod then is swaged and drawn through appropriate sized dies until the diameter of the rod is approximately 110% of the desired final size and is then subjected to a grinding and polishing operation adapted to remove all surface indentations, irregularities and inequalities, following which the rod is cold worked down to the desired final size under such conditions as will prevent the development of surface irregularities, indentations and inequalities.

The particular stage in the cold working process at which the final annealing operation is applied, and the extent of cold working effects introduced thereafter in the rod prior to the practice of the surface smoothing step of the present invention, and the extent of cold working effects introduced in the rod subsequently to the surface smoothing step may be widely varied without essential departure from the present invention.

We have found it preferable in most instances to allow for at least a 10% reduction in area subsequently to the surface smoothing step for the reason that the surface irregularities are exceedingly variable along the length of the rod and this per cent reduction in area insures the obtainance of a uniform diameter along the length of the rod at the desired final size.

In the cold working of the rod to desired final size subsequently to the surface smoothing step, we preferably employ a rolling method and apparatus known in the art as the Friemel method and apparatus wherein the rod is rotated about its axis parallel to the rotation axis of equally rotating barrel-shaped or hyperbolically formed breaking down rolls contacting the surface of the rod, as this type of cold reduction appears to most satisfactorily retain the smooth surface characteristic desired in the rod at the final size. Alternatively, carefully conditioned drawing dies or carefully controlled swaging conditions may be made equally as effective in producing the desired final surface condition on the rod.

As an illustration of the benefits derived from the practice of the present invention, the rod material above identified, when cold reduced in accordance with prior art practice to desired final size (10 to 30% reduction in area from last previous annealing heat treatment to soften) has,

in its work hardened condition, an endurance limit of approximately 30 kg./mm². When thermally hardened by heat treatment within the range 300-500° C. the maximum endurance limit obtainable in the alloy approximates 32 kg./mm². In accordance with the present invention, we have been able to increase the endurance limit of the rod of the same diameter and having substantially equivalent amounts of cold working effects therein to values above 67 kg./mm², the maximum obtainable heretofore, the precise value depending in part upon the degree of cold working imparted subsequently to the surface smoothing and in part upon the heat treating temperatures and times employed.

The binary and complex beryllium-containing alloys hereinabove identified are each similarly benefited by subjecting the alloy to a surface smoothing step at a point during the final cold reduction operation wherein subsequent reduction in area is required to bring the alloy to desired thickness or diameter, the best results being obtained when the cold reduction subsequently to the surface smoothing step is controlled and regulated so as to preserve and maintain surface smoothness and uniform thickness or diameter in the material at its final size or thickness.

It is believed obvious to one skilled in the art that inasmuch as the working properties of the alloys are known to vary widely depending upon composition, the precise point at which the surface smoothing operation is introduced into the final cold reduction step may be varied as widely without essential departure from the present invention and will depend to a great extent upon the workability of the particular alloy to which it is applied. In all alloys of the type herein described beneficial results upon the endurance limit and fatigue strength of the alloy is obtained by the practice of the present invention.

By the use of the term "beryllium-containing alloys" as hereinafter appearing in the following claims, the type of alloy hereinabove described is enumerated and all such alloys as are hereinabove disclosed are included within this generic term.

What we claim is:

1. The method of improving the endurance limit and fatigue strength of thermally hardenable beryllium-containing alloys consisting of one of the base metals Cu, Fe, Ni and Co, and from small but effective amounts up to 3.5% Be, which comprises subjecting the alloy during the final cold working step to final size and before reaching said final size to a surface smoothing operation to eliminate therefrom substantially all surface irregularities, indentations and inequalities and thereafter cold reducing the surface smoothed material for at least a 10% reduction in area to desired final size.

2. The method of claim 1, wherein said beryllium-containing alloy comprises a beryllium-nickel alloy containing beryllium 1 to 3.5% and the said surface smoothing operation is applied at a diameter at least 10% greater than the desired final diameter.

3. The method of claim 1, wherein the cold reduction subsequently to the surface smoothing operation is accomplished in accordance with the Friemel cold rolling method.

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