

UNITED STATES PATENT OFFICE

2,679,455

METHODS FOR HEAT-TREATING MOLYBDENUM-BASE ALLOYS

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No Drawing. Application October 6, 1951,
Serial No. 250,201

6 Claims. (Cl. 75-176)

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This invention relates to refractory metal alloys and more particularly to cast, heat-treatable alloys containing molybdenum and beryllium and to a method of heat treating the same; and the present application is a continuation-in-part of applicants' copending application, Serial No. 218,527, filed March 30, 1951, now abandoned.

The alloys of the present invention are especially useful in applications of the type which require a material to retain its high hardness, strength or resistance to creep at elevated temperatures. Applications of this type include points for piercing seamless steel tubing, electrodes for heating molten glass, die-casting dies for brass and other metals, etc.

An American Society for Metals publication, preprint No. 33 of 1949, by Kessler, and Hansen, reports on experiments with molybdenum-chromium alloys, a few of which contained between .1% and .2% beryllium and no carbon. The report does not mention any forging tests on beryllium-containing alloys and it indicates that while some increase in hardness resulted from beryllium additions, no precipitation or age hardness was obtained.

The principal objects of this invention are to provide cast molybdenum-base alloys which are capable of being worked at elevated temperatures; to provide cast molybdenum-base beryllium-containing alloys which are capable of being worked or machined into the desired shape and form and thereafter hardened materially by heat-treatment; to provide a method for heat-treating such alloys that will markedly increase their hardness; and, in general, to provide improved molybdenum-base alloys which are characterized by high temperature properties superior to those of heretofore known materials.

The terms "cast" and "casting" as used in this specification are intended to designate the product resulting from the melting of metal and solidifying the same in a mold whether or not the metal has been subjected to subsequent working or machining. The term "casting" is also used to designate any process or method which involves melting metal and solidifying the same in a mold.

It has now been found that certain molybdenum-base alloys containing beryllium are age or precipitation hardened when subjected to the hereinafter described heat-treatment, and that improved high temperature properties are induced by such heat-treatment and are retained at elevated temperatures even after prolonged periods of time. Such heat-treatable alloys may

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be cast, annealed, then fabricated into the desired shape and thereafter hardened by the heat-treatment. This invention is also concerned with molybdenum-base alloys containing beryllium which are subject to heat-treatment in accordance with this invention but which are not capable of being worked by forging, rolling, pressing, swaging, drawing, etc. Such unworked alloys are useful in the as-cast form after heat-treatment, and in some applications may be used without heat-treatment.

If the alloy is to be worked at elevated temperatures, it may contain up to a maximum of .25% beryllium. It has not been possible to hot-work alloys containing more than .25% beryllium. However, larger quantities of beryllium may be present if no working is required.

Cast molybdenum-base alloys containing small quantities of oxygen cannot be worked at elevated temperatures if molybdenum oxide is segregated at the grain boundaries of the cast alloy since that oxide materially reduces intergranular cohesion. Small quantities of carbon or aluminum appear to overcome this defect when the amount of oxygen is limited. Similarly, it is found that in the presence of beryllium within the limits contemplated by the present invention, alloys capable of being worked at elevated temperatures are obtained even though no carbon or aluminum is present. While the reasons for this phenomenon are not fully understood, it is believed that oxides of beryllium replace those of molybdenum, and that the beryllium oxides are less detrimental. In any event, alloys containing from .001 to .25% beryllium and not more than .05% oxygen can be worked at elevated temperatures to a beneficial degree if the beryllium is present in an amount at least sufficient to react with all the oxygen to form beryllium oxide.

Although not essential, it is preferred that the molybdenum-beryllium alloys of the present invention also contain small quantities of carbon and/or aluminum. These elements, aside from the beneficial effect upon the forging characteristics, have the effect of increasing the strength of a sintered rod formed of the powder materials employed in the alloy and thus facilitate the practice of forming a casting by using such a sintered rod as a consumable electrode in an arc furnace. Moreover, carbon in amounts of about .02% or more makes it possible to employ lower temperatures in the heat-treatment hereinafter described. Thus, cast alloys of the present invention which are capable of being worked at