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Kouvel et al.

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[54] PROCESS FOR PRODUCING PLASTICALLY DEFORMED IRON-RHODIUM BASE ALLOY BODIES

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[52] **U.S. Cl.** **148/120**

[51] **Int. Cl.** **H01f 1/00**

[58] **Field of Search** 148/120, 121, 122; 75/122

[56] **References Cited**

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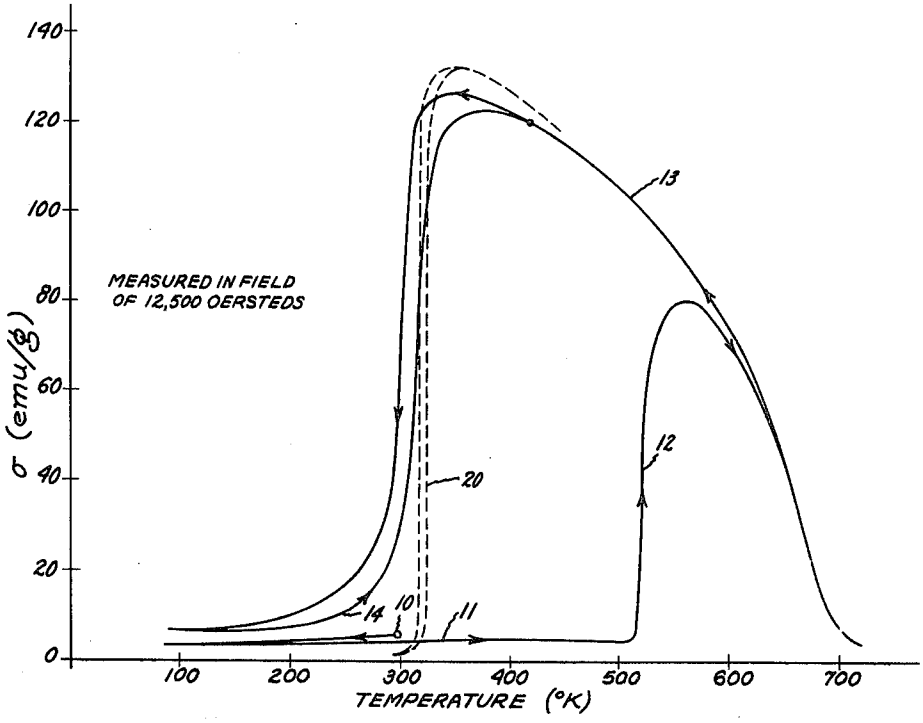
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[57] **ABSTRACT**

This invention concerns a new process for producing plastically deformed shapes of iron-rhodium base alloys which exhibit controlled magnetic transitions. The process comprises hot and cold reducing a starting body to some final dimension, the cold reduction causing an increase in the ductility of the starting body by partially rendering it crystallographically face-centered cubic, and then heat treating the final body at a temperature no lower than about 235° C. to produce a CsCl-type ordered crystal structure having an abrupt magnetic transition. Subsequent cold reducing of the heat-treated body by varying amounts alters the nature of the magnetic transition.

4 Claims, 2 Drawing Figures



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SHEET 1 OF 2

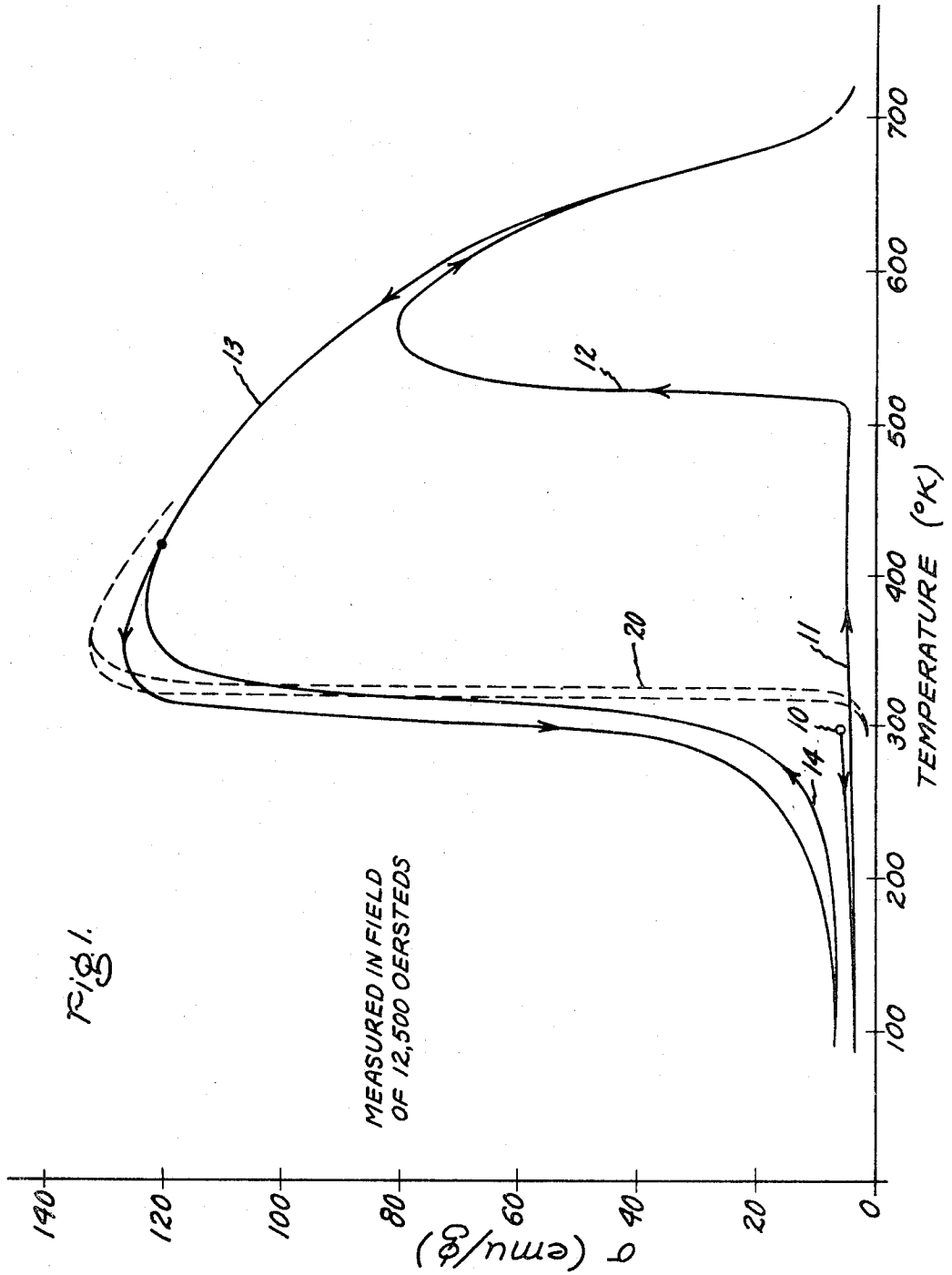


Fig. 1.

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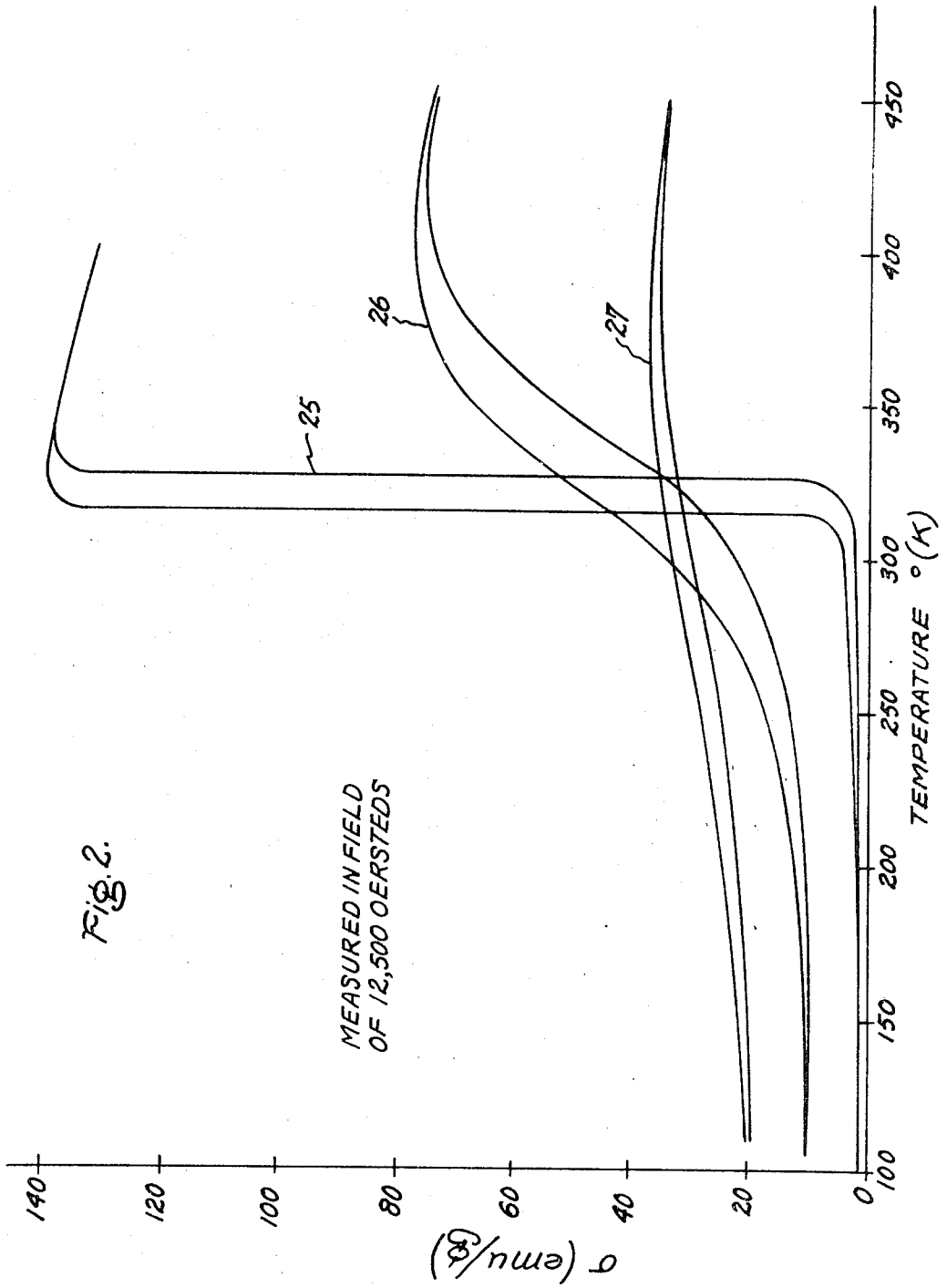


Fig. 2.

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PROCESS FOR PRODUCING PLASTICALLY DEFORMED IRON-RHODIUM BASE ALLOY BODIES

The alloys with which this invention deals are iron-rhodium base alloys having in the heat-treated condition a CsCl-type ordered crystal structure, which alloys may or may not contain additional alloying elements. These alloys undergo an antiferromagnetic-ferromagnetic transition which occurs abruptly at different temperatures depending upon the precise composition of the alloy. In addition to iron-rhodium binary alloys, for example as disclosed in General Electric Research Report No. 61 RL 2870M, Nov. 1961, Kouvel et al., iron-rhodium alloys such as those disclosed in U.S. Pat. No. 3,144,324, Bither, Jr., Aug. 11, 1964 and U.S. Pat. No. 3,144,325, Walter, Aug. 11, 1964, constitute examples of iron-rhodium materials amenable to the process of the present invention.

While these alloys are valuable because of the unique, abrupt transition form, a nonmagnetic to a magnetic condition on heating, limitations arise in fabrication of the alloys due to their extreme physical hardness. While the intermetallic compound FeRh, for example, is of interest as a sensor material because of its first-order phase change at approximately 330° K.(57° C.), where there is an abrupt change in magnetization, its use is limited by the fact that small samples must be prepared either by thin film techniques, which produce samples that do not have any sharp phase changes, cf. Lommel (J. Appl. Phys. 37, 1483 (1966), or by machining or grinding a cast ingot.

It is a principal object of this invention to provide a process for producing plastically deformed shapes of iron-rhodium base alloys.

It is an additional object of this invention to provide a process for producing plastically deformed shapes of iron-rhodim base alloys which exhibit controlled magnetic transitions ranging from abrupt to essentially linear.

Other objects and advantages of this invention will be in part obvious and in part explained by reference to the accompanying specification and drawings.

In the drawings:

FIG. 1 is a graph of magnetization (per gram) as a function of temperature showing the manner in which a severely cold-worked sample (i.e., filings) recovers its rapid magnetic transition after it is heated to about 510° k.(235° C.).

FIG. 2 is a graph similar to FIG. 1 showing the manner in which the nature of the magnetic transition can be varied by the present process.

Generally, the present invention is concerned with a process for producing plastically deformed shapes of iron-rhodium base alloys by first hot reducing a starting body to some preselected intermediate thickness and then cold working the body from the intermediate thickness down to a final desired thickness or shape. During cold reduction, it is necessary to effect intermediate anneals between cold reduction stages to maintain the integrity of the material. Upon being finally cold reduced, the material does not exhibit an abrupt magnetic transition. However, it has now been found that an abrupt transition can be obtained in the worked material by subjecting it to a final heat treatment no lower than about 235° C. and preferably not less than about 425° C. Further, by cold working the annealed material, the abruptness of the transition can be changed varying amounts, depending upon the degree of work, until an essentially linear magnetic transition is obtained.

It was indicated earlier that iron-rhodium and iron-rhodium containing minor amounts of various alloying agents, are very hard materials and therefore have not, prior to this invention, been produced in small sizes by mechanical shaping procedures. That is, they have not been produced in a plastically deformed condition. We have found, unexpectedly, that iron-rhodium base alloys, upon being subjected to some cold reduction, transform from an ordered body-centered cubic crystallographic arrangement to a disordered face-centered cubic crystallographic arrangement. In the face-centered cubic condition, the material is presumably more susceptible to cold work.

According to the present process, a starting body of an iron-rhodium material, for example a cast ingot, is initially heated to an elevated temperature not lower than about 850° C. and hot reduced to some lesser thickness. The hit reduction can be effected by various means such as hot rolling, hot forging or hot extrusion. Following hot reduction to some intermediate size, the material is then cold reduced to some preselected final thickness. During cold reduction, the material undergoes at least a partial phase transformation from the ordered body-centered cubic to the disordered face-centered cubic crystallographic arrangement. In this cold-worked condition, the material will not possess the abrupt antiferromagnetic-ferromagnetic transition that is characteristic of annealed iron-rhodium base alloys. However, the abrupt magnetic transition can be obtained in the plastically deformed material if it is heated to a temperature no lower than about 235° C. (510° K.). Preferably, a substantially higher temperature should be used both to speedup the transformation from the face-centered cubic to the body-centered cubic structure and to improve the abruptness of the magnetic transition.

Considering a specific example, an ingot of FeRh 0.3 inch × 0.3 inch × 3 inches in size was cast and then annealed in vacuum at 975° C. for 26 hours to homogenize the composition. Homogenization can be effected at temperatures ranging from about 850° to 1,000° C., for example. The ingot was then cut into three pieces, each of the pieces being 0.3 inch × 0.3 inch × 1 inch in dimension. Two of the samples were hot forged and rolled at temperatures between 850° to 1,000° C. to 50 mils and one piece was hot forged and rolled directly to 25 mils. Following hot rolling, the specimens were put between stainless steel sheets and cold-pack rolled in reduction stages of about 5 percent per pass to a final thickness of about 10 mils. Pack-rolling is not required but due to the comparatively small size of the samples it was expeditious in this instance. Between cold rolling stages, the samples were annealed at about 950° C. for stress relieving purposes.

A sample was examined at the end of cold rolling and found to be principally face-centered cubic but with some body-centered cubic structure remaining. Further, magnetic testing upon raising the material to that temperature where magnetic transition normally occurs in FeRh, viz 300° K., showed a broad, rather than sharp magnetic transition. The samples were then heat treated at about 1,000° C. and subsequent testing showed that the sharp magnetic transition characteristic of FeRh had been redeveloped.

The manner in which the magnetic properties of the material are affected can be seen by referring to the curves of the drawings. The temperature at which FeRh base alloys normally change from the antiferromagnetic to ferromagnetic state upon heating is approximately 330° K. (57° C.). However, a severely cold-worked sample consisting of filings of FeRh, starting at the location **10** and following the curve in the directions of the indicating arrows, upon being cooled to slightly less than 100° k. and then heated along the line **11** exhibited no magnetic transition at the temperature where it normally would occur. Upon being heated to about 510° K., a crystallographic phase change occurred in which the material reverted from the face-centered to the body-centered cubic structure and an abrupt change in magnetization occurred along the line **12**. Further elevation of temperature to slightly in excess of 700° K. caused a decrease in the magnetization to virtually zero, in the normal manner for a ferromagnetic material near its Curie temperature. Cooling of the material caused the magnetization to follow the line **13** which indicates a rise in the magnetization, reaching a peak at a temperature of about 330° to 340° K. and then decreasing rapidly to where the magnetization is again substantially nonexistent at a temperature of about 200° to 250° K. When the sample exhibiting this type of behavior was again heated, as along the line **14**, it underwent a magnetic transition at about the same temperature characteristic of well-annealed iron-rhodium material. The dotted loop **20** indicates the abrupt magnetic change exhibited by other iron-rhodium bodies given a heat treatment at 1,000° C., followed by a fast cooling to room temperature.

While the abrupt magnetization change is extremely important in many applications, there are significant situations where a different and more gradual transition is greatly preferred. We have found that FeRh material processed as outlined above to exhibit an abrupt magnetic transition, can be further processed to alter the basic character of the transition. Specifically, by further plastically deforming the annealed material in amounts ranging up to about 50 percent reduction, the magnetization change with temperature becomes increasingly linear.

This characteristic can best be seen by referring to FIG. 2 of the drawings in which curve 25 illustrates the abrupt magnetic transition in a well-annealed FeRh alloy. Curve 26 shows how the transition becomes more gradual when the alloy is cold reduced about 30 percent following the anneal. Curve 27 shows the increased effect of a 50 percent cold reduction. With about 50 percent reduction, the magnetic transition has become virtually linear.

The present process provides, for the first time, a method by which a characteristically hard material having unique magnetic properties can be fabricated into plastically deformed shapes and then treated so that it possesses the magnetic properties for which it is valued.

Although the present invention has been described in connection with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and the appended claims.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A process for producing plastically deformed shapes of iron-rhodium base alloys having the CsCl-type ordered body-centered cubic structure exhibiting a temperature-dependent abrupt magnetic transition between the antiferromagnetic and the ferromagnetic states comprising hot and cold reducing a starting body of the base alloy to a preselected final dimension using intermediate anneals between cold-reducing stages as required, the cold reduction causing the base alloy to undergo crystallographic transition from the ordered body-centered cubic structure to the disordered face-centered cubic structure, and heat treating the cold reduced alloy shape of final dimension at a temperature no lower than about 235° C. for a time sufficient to produce the ordered body-centered cubic structure having an abrupt magnetic transition.

2. A process as defined in claim 1 wherein the hot and cold reduction is accomplished by forging and rolling.

3. A process as defined in claim 1 wherein the hot reduction is effected at temperatures ranging from about 850° to 1,000° C.

4. A process as defined in claim 1 wherein the heat treatment of the cold-reduced alloy is effected at temperatures no lower than about 235° C.

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