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D E C I S I O N
of 2 September 2003

Case Number: T 0290/00 - 3.2.2

Application Number: 94120574.2

Publication Number: 0659894

IPC: C22C 33/02

Language of the proceedings: EN

Title of invention:
High-modulus iron-based alloy and a process for manufacturing the same

Applicant:
KABUSHIKI KAISHA TOYOTA CHUO KENKYUSHO

Opponent:
-

Headword:
-

Relevant legal provisions:
EPC Art. 52(1), 54, 56

Keyword:
"Novelty and inventive step - (yes - after amendments)"

Decisions cited:
-

Catchword:
-

Case Number: T 0290/00 - 3.2.2

D E C I S I O N
of the Technical Board of Appeal 3.2.2
of 2 September 2003

Appellant: KABUSHIKI KAISHA TOYOTA CHUO KENKYUSHO
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Decision under appeal: **Decision of the Examining Division of the European Patent Office posted 16 December 1999 refusing European application No. 94120574.2 pursuant to Article 97(1) EPC.**

Composition of the Board:

Chairman: W. D. Weiß
Members: S. S. Chowdhury
R. T. Menapace

Summary of Facts and Submissions

I. This appeal is against the decision of the examining division dated 16 December 1999 to refuse European patent application No. 94 120 574.2.

The grounds of refusal were that the subject-matters of claims 1 and 7 were not novel. The decision went on to note that there was no invention within the meaning of Article 56 EPC since the product of claim 1 did not provide a feature which causally effected the value of Young's modulus given in the claim.

The following documents were cited:

D1: Jüngling et al, New Hardmetals Based on TiB_2, 13th International Plansee Seminar, 24 to 28 May 1993, Plansee Procs., Volume 2, Wear Resistant Materials, pages 43 to 46.

D2: US-A-4 419 130

D3: EP-A-0 433 856

II. On 17 February 2000 the appellant (applicant) lodged an appeal against the decision and paid the prescribed fee on the same date. On 25 April 2000 a statement of grounds of appeal was filed.

III. The appellant requests that the decision under appeal be set aside and that a patent be granted with claims 1 to 10 as filed at the oral proceedings before the Board.

IV. The independent claims 1, 6, 7, 8, and 9 read as follows:

"1. A high-modulus iron-based alloy consisting of a matrix formed of ferritic, austenitic, or martensitic steel or iron and unavoidable impurities, and at least one boride selected from the group consisting of borides of Group IVa elements and complex borides of Group Va elements and iron, said at least one boride being uniformly dispersed in said matrix, the boride being thermodynamically stable in and in thermodynamic equilibrium with the matrix, said at least one boride being composed of fine particles having a diameter of not more than 100 μm, and the content of said at least one boride being from 10 to 50 % by volume, and said iron-based alloy having a Young's modulus of 23,120 kgf/mm^2 or more.

6. A process for manufacturing a high-modulus iron-based alloy, said process comprising the steps of mixing iron or steel powders and powders of at least one boride of Group IVa elements to prepare mixed powders, compacting said mixed powders into a shaped body, and sintering said shaped body, thereby uniformly dispersing particles of said at least one boride of said Group IVa elements in a matrix formed of ferritic, austenitic, or martensitic steel or iron and unavoidable impurities, whereby an iron-based alloy according to one of claims 1 to 5 is obtained.

7. A process for manufacturing a high-modulus iron-based alloy, said process comprising the steps of mixing iron or steel powders, ferroboron powders and ferroalloy powders containing at least one Group IVa

element to prepare mixed powders, compacting said mixed powders into a shaped body, and sintering said shaped body, thereby causing reaction of said ferroboron powders and said ferroalloy powders to form at least one boride of said Group IVa elements and to uniformly disperse particles thereof in a matrix formed of ferritic, austenitic, or martensitic steel or iron and unavoidable impurities, whereby an iron-based alloy according to one of claims 1 to 5 is obtained.

8. A process for manufacturing a high-modulus iron-based alloy, said process comprising the steps of mixing iron or steel powders and powders of at least one boride of Group Va elements to prepare mixed powders, compacting said mixed powders into a shaped body, and sintering said shaped body, thereby uniformly dispersing particles of at least one complex boride of at least one Group Va element and iron in a matrix formed of ferritic, austenitic, or martensitic steel or iron and unavoidable impurities, whereby an iron-based alloy according to one of claims 1 or 2 or 4 or 5 is obtained.

9. A process for manufacturing a high-modulus iron-based alloy, said process comprising the steps of mixing iron or steel powders, ferroboron powders and ferroalloy powders containing at least one boride of Group Va element to prepare mixed powders, compacting said mixed powders into a shaped body, and sintering said shaped body, thereby causing reaction of said ferroboron powders and said ferroalloy powders to form at least one complex boride of at least one Group Va element and iron and to uniformly disperse particles thereof in a matrix formed of ferritic, austenitic, or

martensitic steel or iron and unavoidable impurities, whereby an iron-based alloy according to one of claims 1 or 2 or 4 or 5 is obtained.".

Claims 2 to 5 are dependent on claim 1 and claim 10 is dependent on one of claims 6 to 9.

Reasons for the Decision

1. The appeal is admissible.

2. *Amendments*

New claim 1 defines an alloy consisting of a matrix formed of ferritic, austenitic, or martensitic steel or iron and unavoidable impurities. These features are supported by the application as originally filed, see page 5, lines 56 and 57 of EP-A2-0 659 894.

The claim defines the borides as being thermodynamically stable in and in thermodynamic equilibrium with the matrix, which feature is supported by page 4, lines 1 and 2 and 35 and 36 of the A2 publication, and this, moreover, is an essential feature of the invention, as explained in point 4.2 below.

The claim also defines the borides as being uniformly dispersed in the matrix, and composed of fine particles having a diameter of not more than 100 μm and the content of the boride being from 10 to 50% by volume. These amendments are supported by original claims 5 and 6.

The feature that the alloy has a Young's modulus of 23,120 kgf/mm^2 or more is supported by the results reported in Tables 1 to 3. Although taken from the Examples only, these amendments are considered to fairly support the claimed invention since the Examples disclose a variety of compositions for alloys having the desired high Young's modulus of at least 23,120 kgf/mm^2.

The amendments to claim 1 meet the requirement of Article 123(2) EPC, accordingly. The independent process claims 6 to 9 have been similarly amended and are equally allowable.

3. *Novelty*

The objection of lack of novelty of the alloy of claim 1 over D2, set out in the impugned decision, is no longer valid, at least since the claim now defines a range of boron content of 10 to 50% by volume, that is clearly outside the ranges described in D2. Although D2 mentions an amount of TiB_2 of up to 10 weight % (column 2, lines 36 and 37) the Examples disclose the use of much lower amounts of titanium and boron, the maximum being 2.94 weight % in Example 3.

The process of Example 4 of D3 does not anticipate the process of claim 6 (corresponding to claim 7 of the claims rejected in the impugned decision) since the claimed process must produce the alloy according to claim 1, which excludes the presence of nitrides, and Example 4 of D3 includes a significant amount (5 volume %) of titanium nitride. Also, this prior art process does not initially mix iron or steel powder with a boride powder as required by claim 6. Instead, in D3 titanium nitride and titanium boride are initially mixed and compacted, after which the compact is placed in a crucible and surrounded by a powder mixture of carbonyl iron and melted, which is a quite different method to that of claim 6. Moreover, this method of introducing iron will not produce a uniform dispersion of boron particles in an iron or steel matrix, and is, furthermore, not likely to result in a boride particle size below 100 microns.

The same arguments apply to independent claims 7 to 9. For these reasons the subject-matter of the independent claims is novel.

4. *Inventive step*

4.1 Prior art methods of manufacturing high modulus iron-based alloys are reviewed on page 2 of the application (EP-A2-0 659 894). A significant prior art method involves dispersing borides of chromium or molybdenum in an iron-alloy matrix, which yields alloys having a Young's modulus of about 25, 000 kgf/mm^2, but complex borides having a high specific gravity are formed so that the specific Young's modulus is low. Other methods involve embedding particles of reinforcing material having a high modulus, for example carbides and nitrides of transition elements, in an iron-based matrix by mechanical alloying, but the transition elements are partly substituted by iron atoms in the matrix, leading to low values of Young's modulus.

4.2 The present inventors have discovered that, in order to provide an alloy with the required Young's modulus, the reinforcing material must not only itself have a high Young's modulus, but it must also be in thermodynamic equilibrium with the matrix material, so that the particles can keep their ordered crystal structure rather than result in the transformation to a complex iron compound which leads to a lowering of the value of Young's modulus.

Furthermore, they have found that borides of a Group IVa element or complex borides of a Group Va element have an orderly crystal structure and are thermodynamically stable in and in thermodynamic equilibrium with a matrix formed of ferritic, austenitic, or martensitic steel or iron and unavoidable impurities, so that a high-modulus iron-based alloy containing boride particles uniformly dispersed therein is attainable.

The high-modulus iron-based alloy can be manufactured by a process which comprises the steps of mixing an iron or iron-alloy powder and a powder of at least one boride of a Group IVa element or a complex boride of a Group Va element to prepare a mixed powder, compacting the mixed powder into a shaped body, and sintering. The borides of the Group IVa element or a complex boride of a Group Va element are uniformly dispersed in the iron with a particle size of up to several microns. In other aspects of the invention ferroboron powders, and ferroalloy powders may be used to cause reaction of the ferroboron powders and the ferroalloy powders to form at least one complex boride of at least one Group Va element. The alloy can be manufactured at a low cost since routine PM technology is used.

4.3 These teachings were not available in the prior art, so that the claims also meet the inventive step requirement of Article 52(1) EPC. In particular, the documents D1, D2, and D3 do not provide such teachings.

D1 describes hardmetals based on TiB_2 and comprising a major portion of a hard phase and a minor amount of iron as a metallic binder. D3 also relates to hardmetals comprising borides, nitrides, and oxides of titanium and zirconium. Here too a major portion of hard phase and a minor portion of the binder metal are employed. The only Example having a boride content of less than 50 volume % is Example 4, but this also includes titanium nitride.

The hardmetals described in D1 and D3 are, therefore, not iron or steel based alloys, but relate to a different class of metals than the ones claimed in the application. The person skilled in the art wishing to develop iron and conventional steels to improve their Young's modulus (see page 3, lines 24 to 27 of the application) would not consult these documents.

D2 describes methods of dispersion-strengthening iron material by developing a uniform distribution of inert particles which strengthen the alloy by impeding dislocation motion (D2, column 1, lines 26 to 31 and column 2, lines 46 to 48). It is desired to precipitate ultrafine particles of TiB_2 in order to obtain a reinforced ferrous alloy having a high strength. Very fine particles, typically less than 0.1 in diameter (column 2, lines 35 to 39), of TiB_2 are produced by rapidly cooling and solidifying a molten ferrous alloy containing titanium and boron. The fineness of the dispersion is critical to obtaining good properties of the alloy (column 3, lines 64 to 67) in order to avoid dislocation movement during plastic deformation. This document is silent as regards Young's modulus.

This is to be contrasted with the present application, where the boride particles are complexed with the iron or steel matrix in order to suppress strains which occur during elastic deformation, thereby realising a high value of Young's modulus. For this a uniform distribution of coarser TiB_2 particles, typically of one to several microns in size, is necessary (see the Examples of the application, for example on page 7, lines 36 to 38). The person skilled in the art wishing to improve the Young's modulus of iron and conventional steels would not consult document D2 either.

5. *Workability of the invention*

The Board is satisfied that the invention is capable of being worked over the entire scope of the claims, and in particular that conventional ferritic, austenitic, or martensitic steel compositions may be used to prepare the claimed high-modulus iron-based alloys. Such steels may include the usual components such as carbon, silicon, manganese, and even Group VI elements such as molybdenum. However, these components will react with the iron rather than with the boron and there will be no exchange thereof with the Group IVa element such as titanium so as to impair the value of Young's modulus.

Similarly, a small addition of carbon is permitted by the application (samples 7 and 10 include 0.4 wt% carbon), the important point being that the amount should be such as not to allow the formation of any carbide or boro-carbide (see the paragraph linking pages 6 and 7 of the A2 publication). The amount of carbon permissible depends on the other constituents of the steel, particularly boron, there being a direct correlation between the boron content and Young's modulus, see Tables 1 to 3 of the application, so that the more boron there is the more the carbon content may be increased before the Young's modulus is degraded to value below that defined in the claims (see Example 3). In any given case the permissible amount of carbon can be easily determined by experimentation.

Although the claims define an upper limit for the size of the boride particles in the alloy, no lower limit thereof is defined, despite the fact that the Examples illustrate the case of the boride size only being between one to several microns in diameter. Again this depends on the boron content which may be so high as to permit the boride size to be below 1 micron without the Young's modulus falling below 23,120 kgf/mm^2.

In all these cases a limited amount of experimentation is necessary to determine the permissible amounts of the other components for a given amount of boron, for which thermodynamic stability of the borides is assured and the Young's modulus is at least 23,120 kgf/mm^2.

Order

For these reasons it is decided that:

1. The decision under appeal is set aside.

2. The case is remitted to the first instance with the order to grant a patent on the basis of claims 1 to 10 as filed at the oral proceedings, Figures as originally filed, and a description still to be adapted.

The Registrar: The Chairman:

V. Commare W. D. Weiß