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(54) ALUMINUM PLAIN BEARING ALLOY

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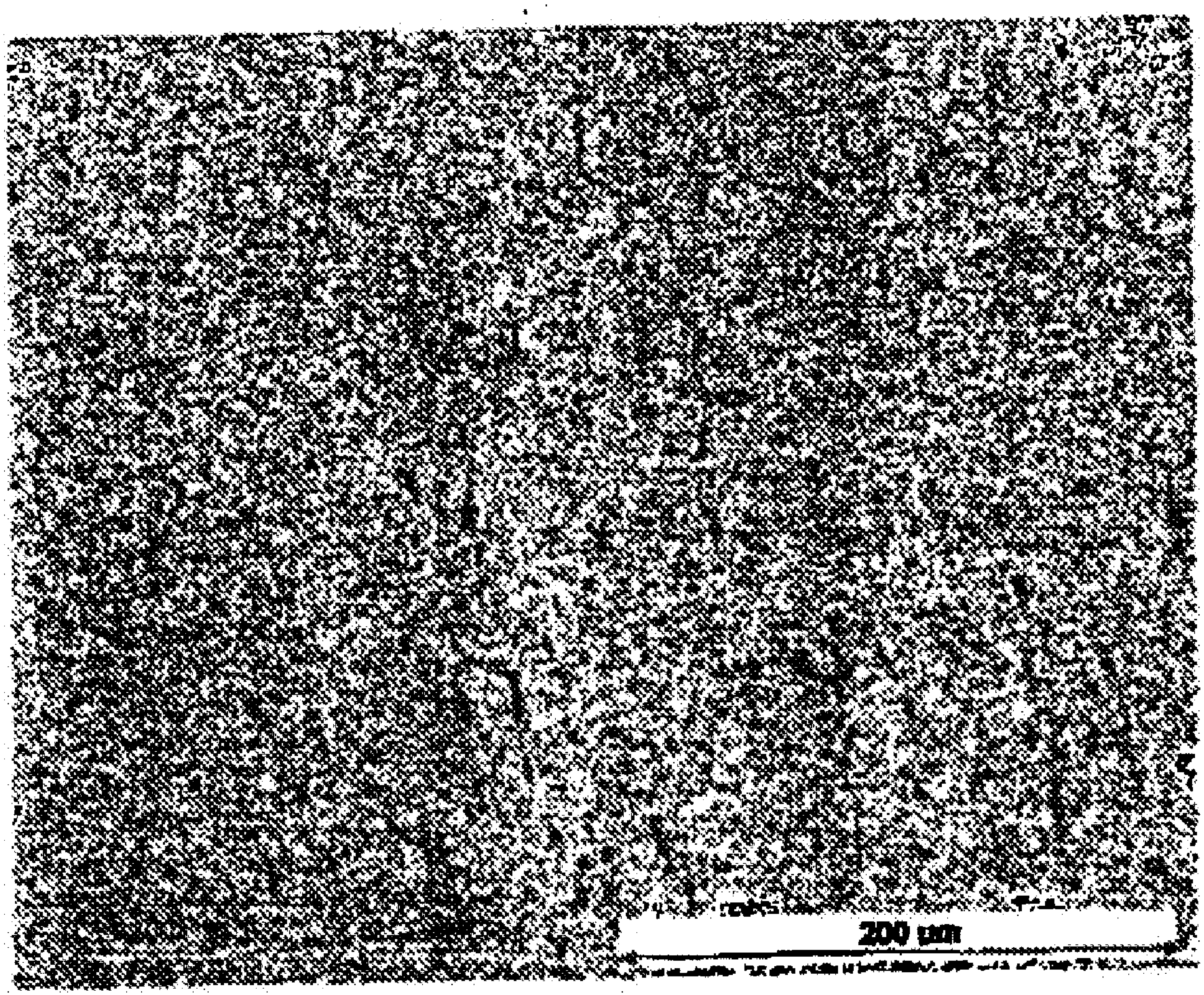
(57) **ABSTRACT**

The invention relates to a monotectic aluminium plain bearing alloy, comprising 5 to 20 wt. % bismuth, 3 to 20 wt. % zinc, 1 to 4 wt. % copper and additionally several of the components manganese, vanadium, niobium, nickel, molybdenum, cobalt, iron, tungsten, chromium, silver, calcium, scandium, cerium, beryllium, antimony, boron, titanium, carbon and zirconium in amounts up to 5 wt. % and aluminium to make 100 wt. %, produced by strip casting and during the subsequent production process for plain bearings, after rolling or roll-bonding, subjected to a heat treatment at ca. 270 to 400° C. Long bismuth particles or sheets, produced by rolling or roll-bonding can thus be recoagulated to give finely-distributed spherical drops with a size in the 20 μm range and smaller.



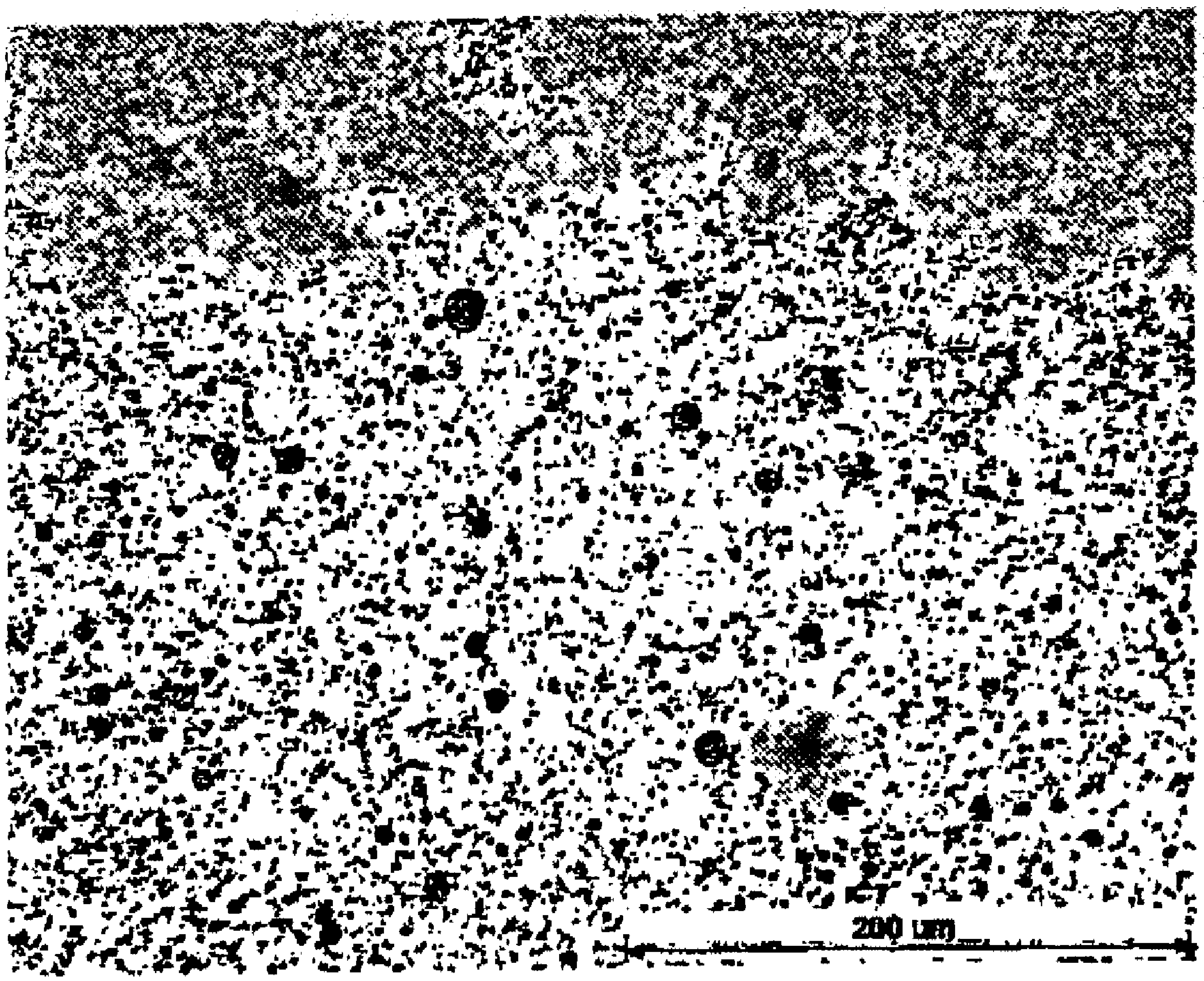


Fig. 1

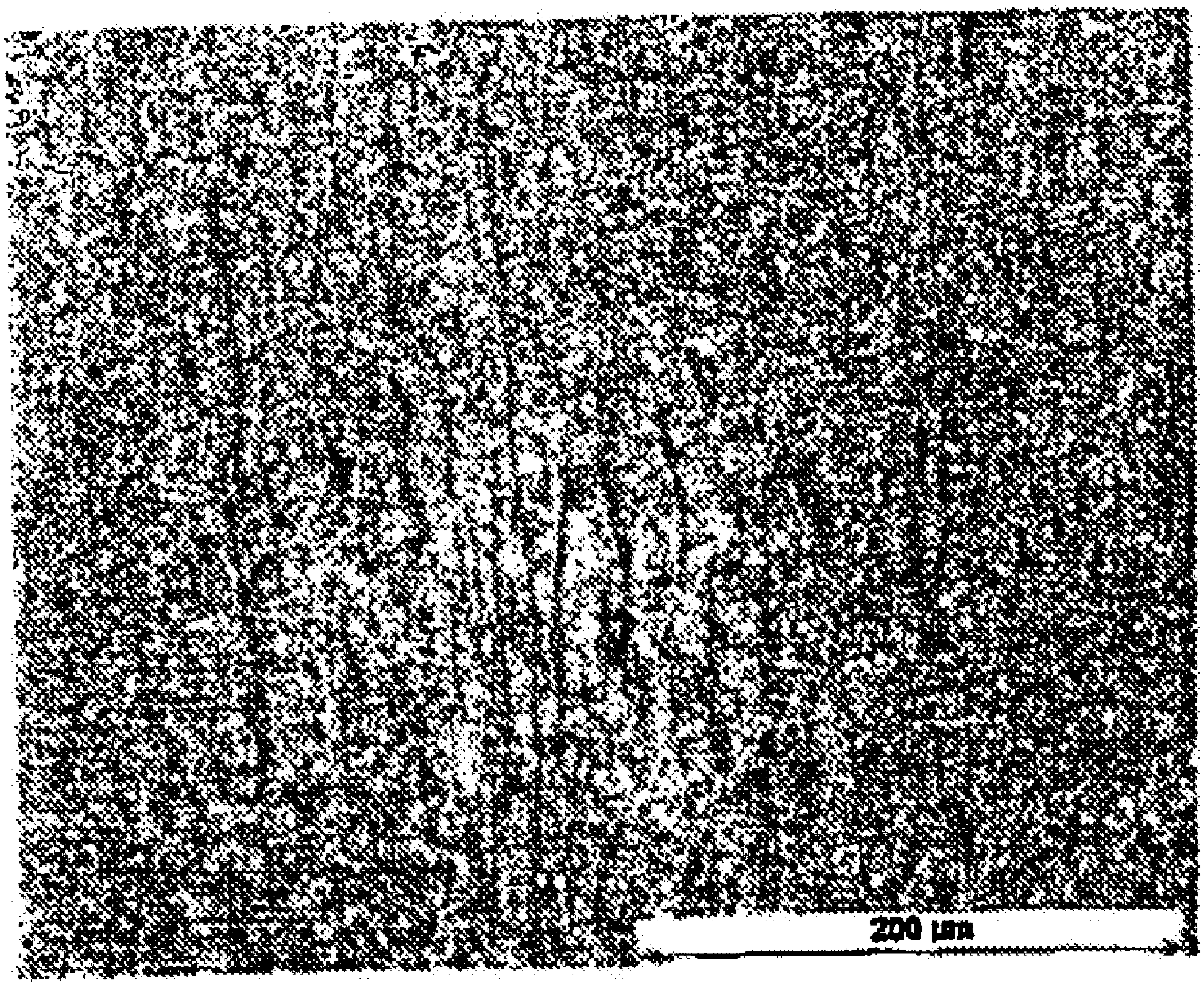


Fig. 2

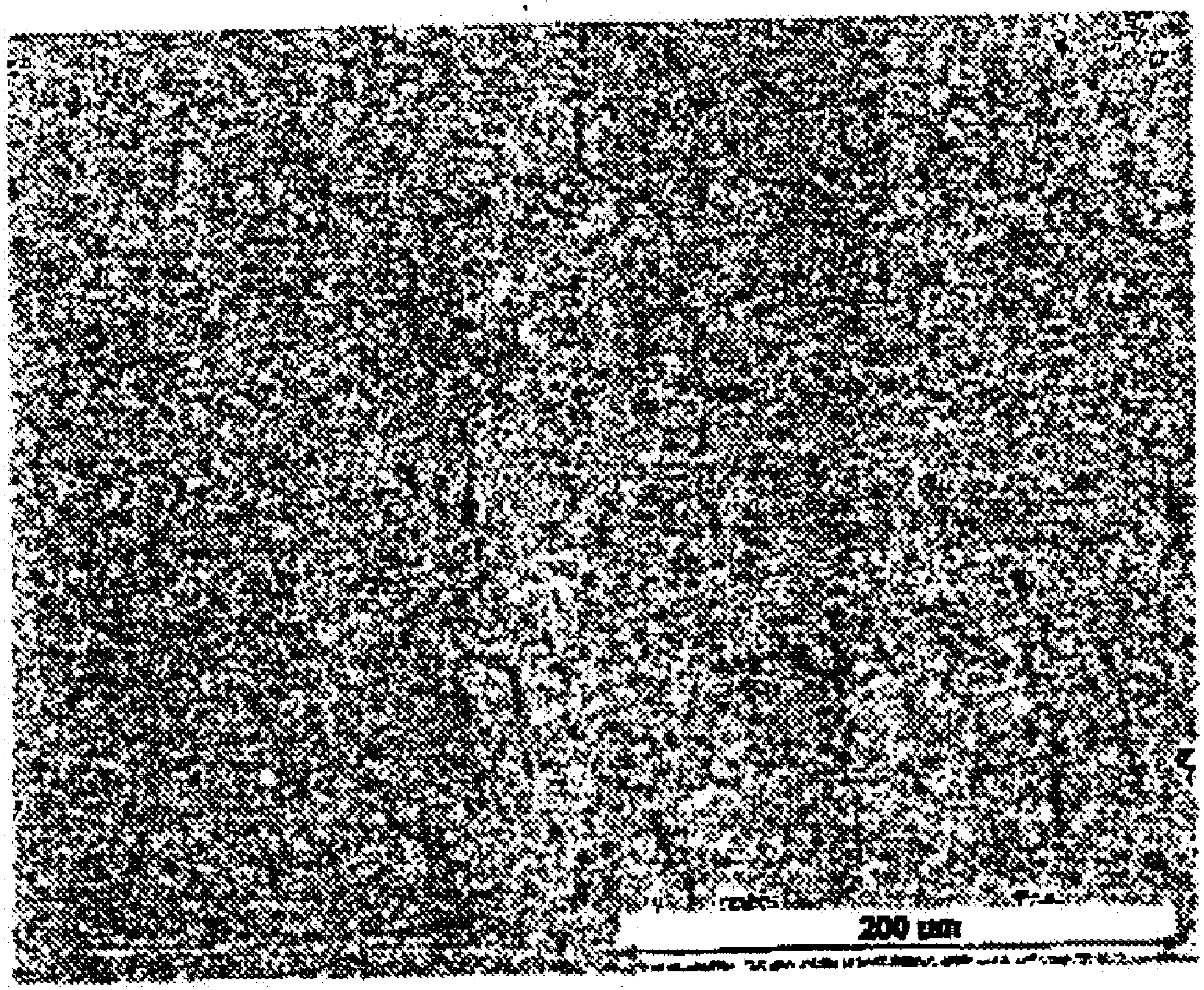


Fig.3

ALUMINUM PLAIN BEARING ALLOY

[0001] The invention relates to a heavy-duty aluminum plain bearing alloy, in particular for multilayer bearings, to a process for its production and to associated plain bearing shells and plain bearings.

[0002] Heavy-duty plain bearings are made up of a number of layers to meet the variety of requirements that are demanded of the bearings and to some extent conflict. Steel-aluminum composite materials are predominantly used. While the steel supporting shell ensures that mechanical loads are absorbed and that there is a firm fit, the materials of the plain bearing have to withstand the diverse tribological loads and be resistant to fatigue. In order to meet this requirement, the materials of the plain bearing in the aluminum matrix contain on the one hand hard phases, such as for instance silicon and intermetallic precipitates, and on the other hand soft phases, such as for example lead or tin. The heavy-duty multilayer bearings often additionally have a sliding layer with a high lead content that is galvanically applied on the functional layer. This soft sliding layer provides the good emergency-running properties of the bearing. It can embed abrasion particles and so remove them from the sliding surface.

[0003] An environmentally friendly alternative to aluminum plain bearing alloys that contain lead are plain bearings based on aluminum-tin, which are used without an additional sliding layer. However, there are limits to the mechanical properties of these alloys, for example the fatigue resistance and heat resistance. The relatively high tin content results during casting in the formation of a tin network joined together at the grain boundaries, which considerably impairs the load-bearing capacity of these alloys, especially at relatively high temperatures.

[0004] By contrast with tin, bismuth has several advantages as the soft phase in the aluminum matrix. For instance, bismuth has a higher melting point and can be used at higher temperatures. In addition, it is possible by special casting and heat treatment measures to avoid a massive enrichment of the bismuth at the grain boundaries of the plain bearing alloys and to obtain a sufficiently uniform and fine distribution of the bismuth droplets in the microstructure, which ultimately results in an improvement in its load-bearing capacity and the tribological properties in comparison with aluminum-tin alloys.

[0005] So it has been proposed in DE 4003018 A1 that an aluminum alloy may contain one or more of the components 1 to 50% by weight, preferably 5 to 30% by weight, lead, 3 to 50% by weight, preferably 5 to 30% by weight, bismuth and 15 to 50% by weight indium and additionally one or more of the components 0.1 to 20% by weight silicon, 0.1 to 20% by weight tin, 0.1 to 10% by weight zinc, 0.1 to 5% by weight magnesium, 0.1 to 5% by weight copper, 0.05 to 3% by weight iron, 0.05 to 3% by weight manganese, 0.05 to 3% by weight nickel and 0.001 to 0.30% by weight titanium. This alloy, known from DE 4003018 A1, is cast by continuous casting vertically into a strip or wire of 5 to 20 mm in thickness or diameter, the melt being cast at a cooling rate of 300 to 1500 K/s. The rapid cooling rate is intended to prevent large-volume precipitates of a minority phase from forming in the time between the temperature falling below the segregation temperature and the complete solidification of the matrix metal. However, it is known from practical experience with the continuous casting of aluminum alloys that the very high cooling rates have the consequence that there is a considerable risk of crack formation and that the process stability required for mass production can only be ensured with difficulty.

[0006] The process described in EP 0 940 474 A1 allows a monotectic aluminum plain bearing alloy that is difficult to cast, comprising up to 15% by weight bismuth and at least one element from the group comprising silicon, tin and lead in total of 0.5 to 15% by weight and possible additions from the group comprising copper, manganese, magnesium, nickel, chromium, zinc and antimony to an extent of in total up to 3%, to be cast with reproducible quality by strip casting. A homogeneous distribution of the minority phase is in this case achieved by intensive stirring of the melt in the electromagnetic field. By adding grain refiners, the microstructure of this alloy is additionally refined. Among the effects this has is also an advantageous effect on the size of the bismuth precipitates in the form of drops, which in the cast state have a diameter of at most 40 μm. The added amount of grain refiners is calculated according to EP 0 940 474 A1 by a formula that allows for the bismuth content in the melt. This invention does not contain any indications of the kind of grain refining additions that are used to obtain the results described in the patent.

[0007] EP 0 190 691 discloses an alloy comprising 4 to 7% by weight bismuth, 1 to 4.5% by weight silicon, 0 to 1.7% by weight copper, 0 to 2.5% by weight lead and at least one element from the group comprising nickel, manganese and chromium to an extent of in total up to 1% and additionally at least one element from the group comprising tin, zinc and antimony of in total up to 5% by weight. Although high silicon contents strengthen the aluminum matrix, they have an adverse influence on the size of the minority phase and lead to a distinct worsening of the drop distribution in the strand. During the rolling of such a cast structure, the originally spherical lead or bismuth phase is deformed into very thick filaments, which considerably reduce the mechanical load-bearing capacity and the tribological properties of the material.

[0008] One possible solution for setting the desired material properties is to transform the elongate precipitates of the minority phase into compact structural forms by a subsequent heat treatment. For example, according to DE 4014430 A1, a monotectic aluminum-silicon-bismuth alloy is heat-treated at temperatures of from 575° C. to 585° C. in order to achieve a fine distribution of the bismuth phase, stretched in the form of lamellae after rolling.

[0009] As a further advantage, the heat treatment offers the possibility of improving the strength values of the aluminum plain bearing alloy by hardening effects. The elements suitable for achieving the possible hardening effects are, for example, silicon, magnesium, zinc and zirconium. The addition of copper increases the hardening rate and can be used in combination with these elements.

[0010] U.S. Pat. No. 5,286,445 discloses an aluminum plain bearing alloy with a bismuth content of from 2 to 15% by weight, 0.05 to 1% by weight zirconium and a copper content and/or magnesium content of up to 1.5%. In addition, this alloy contains at least one element from the group comprising tin, lead and indium in a total of 0.05 to 2% by weight or at least one element from the group comprising silicon, manganese, vanadium, antimony, niobium, molybdenum, cobalt, iron, titanium and chromium in a total of 0.05 to 5% by weight. The additions of tin, lead and indium assist the re-coagulation of stretched bismuth drops to finer precipitates at temperatures of from 200° C. to 350° C. The elements zirconium, silicon and magnesium bring about the actual hardening effect after annealing in the temperature range of 480° C. to 525° C., which according to U.S. Pat. No. 5,286,445 is carried out shortly before the roll-cladding operation. The transition elements are intended to ensure an additional increase in the mechanical load-bearing capacity of the material.

[0011] The unfavorable effect of silicon on the size and distribution of the minority phase has already been reported. The addition of magnesium is additionally accompanied by the disadvantage that magnesium preferentially forms with bismuth the intermetallic compound Mg_3Bi_2. This is intercalated in the bismuth drops and distinctly reduces the ability of the bismuth drops to embed abrasion particles. Adding tin considerably impairs the mechanical load-bearing capacity of the plain bearing material at higher temperatures. Furthermore, the temperatures for the heat treatment of over 480° C. that are proposed in DE 40144 30 A1 and in U.S. Pat. No. 5,286,445, are very unfavorably chosen with regard to the formation of brittle intermetallic phases between the steel supporting shell and the aluminum. According to the prior art, the temperature range that is acceptable for cladding aluminum with steel lies below 400° C.

[0012] None of the bismuth-containing alloys described above have so far gained any practical significance, since it has not yet been possible to master adequately the complex processes that occur during their production by continuous casting and subsequent further processing to form the plain bearing shell. Apart from a fine distribution of the minority phase in the cast state, a pre-requisite for optimum characteristics of the aluminum plain bearing alloys is in particular the possibility of being able to establish a fine distribution of the minority phase even after the necessary forming and roll-cladding operations. Other requirements are high strength, mechanical load-bearing capacity—including at high temperatures—wear resistance of the aluminum matrix and good formability.

[0013] The invention is consequently based on the object of providing a heavy-duty aluminum plain bearing alloy that avoids the disadvantages of the prior art and makes it possible to achieve a uniform and fine distribution of the bismuth phase and to preserve and possibly improve this during the subsequent further processing of the strips in the production phase to form the plain bearing shell.

[0014] This object is achieved by an aluminum plain bearing alloy containing the following constituents: about 5 to 20% by weight bismuth, about 3 to 20% by weight zinc, about 1 to 4% by weight copper and additionally one or more of the components manganese, vanadium, niobium, nickel, molybdenum, cobalt, iron, tungsten, chromium, silver, calcium, scandium, cerium, antimony, boron, beryllium, titanium, carbon and zirconium in a total of up to about 5% by weight and the remainder aluminum, but without tin, lead and silicon, apart from in an amount caused by smelting-related impurities, or in an amount of up to at most 1% by weight of each. This means that it is intended in principle that the alloy according to the invention should not contain tin and silicon as alloying constituents. However, not only tin (Sn) but also lead (Pb) and silicon (Si) may be present in amounts caused by impurities of up to about 0.3% by weight, or otherwise in small amounts of up to about 1% by weight, but better up to about 0.5% by weight, without impairing the advantages of the invention too much. The plain bearing alloy according to the invention is preferably continuously cast and is already distinguished in the cast state by a fine distribution of the bismuth phase, which is largely independent of the drawing-off and cooling rate. Long bismuth lamellae created in the course of a further treatment when rolling and roll-cladding can subsequently be re-coagulated completely by a heat treatment at temperatures of from 270° C. to 400° C. to form finely distributed spherical drops, which are smaller than 20 μm if the process is conducted appropriately.

[0015] The alloy preferably contains between about 7 and 12% by weight bismuth. The zinc content may preferably lie between about 3 and 6% by weight, that of copper between about 2 and 4, in particular between about 2 and 3% by weight. The contents of the various elements are variable independently of one another within the given limits.

[0016] The alloy according to the invention differs from the known alloys by the use of bismuth as a single soft phase former, i.e. there is no combination of bismuth with lead and/or tin, and by a zinc content increased up to a maximum of 20% by weight and a copper content increased up to a maximum of 4% by weight. Although the stated amounts of added zinc and copper lead to a slight worsening in the size of the bismuth drops in the cast state in comparison with binary Al—Bi alloys, they permit a complete re-coagulation of the highly stretched bismuth filaments after the cladding pass to form fine spherical drops of up to 20 μm in size. For this purpose, annealing operations of up to 400° C. are provided. The annealing time depends on the chemical composition. In addition, increased copper contents bring about an increase in the strength of the aluminum matrix and in our experience improve the corrosion resistance of the bismuth-containing plain bearing material.

[0017] It has been found that use of the commercially available grain refiner AlTi5B1 or AlTi3CO,15 in added amounts of about 0.3 to 2% by weight have a great grain-refining effect on the alloy according to the invention and reliably prevent the formation of heat cracks during continuous casting at different cooling rates. The addition of the grain refiners mentioned has the additional effect of distinctly reducing the size of the minority phase. It has been possible by the use of grain refining additions to reduce the maximum diameter of the bismuth drops in the cast state to less than 30 μm, even with relatively low cooling rates of about 5 K/s.

[0018] With the aid of the elements manganese, vanadium, niobium, nickel, molybdenum, cobalt, iron, tungsten, chromium, silver, calcium, scandium, cerium, beryllium, antimony, boron, titanium, zirconium and carbon, it is possible to adapt the properties of the alloy according to the invention specifically to the respective intended use.

[0019] The invention further comprises a process for producing an aluminum plain bearing alloy using the composition according to the invention as described above. With preference, the alloying constituents are combined to form an alloy in a casting process in which the cooling rate is 5 to 1000 K/s. The alloy can otherwise also be produced by other customary production processes, in particular by other casting processes. Production by continuous casting is currently preferred. The conditions are then to be adapted in such a way that preferably bismuth intercalations in drop form are created. During the continuous casting, the drawing-off rate is preferably 2 to 15 mm/s.

[0020] According to a preferred embodiment of this invention, the alloy obtained by casting is subjected to at least one heat treatment at temperatures between about 270 and 400° C. in the course of subsequent forming processes. Such a heat treatment preferably follows a rolling and/or roll-cladding operation, it being possible for a number of rolling and/or cladding operations to be carried out within the production process between the casting of the alloy and the end product, and at least one heat treatment to follow on after the final rolling and/or roll-cladding operation or else after a number of or all of these operations.

[0021] For the preparation of a semifinished product or in the course of the production of products such as for instance plain bearings, the cast alloy may be provided with at least one supporting layer. The supporting layer may be in particular a steel layer. Further layers, for example adhesion promoting layers or coatings, may be added.

[0022] The invention further comprises a plain bearing shell which contains an alloy according to the invention as one of the materials used in it or consists of this alloy.

[0023] Finally, the invention comprises a plain bearing with such a plain bearing shell or the use of the plain bearing shell according to the invention in a plain bearing.

[0024] The invention is explained in more detail below on the basis of an exemplary embodiment.

[0025] In the drawing:

[0026] FIG. **1** shows a cast structure of an AlZn5Cu3Bi7 alloy,

[0027] FIG. **2** shows a rolled structure of an AlZn5Cu3Bi7 alloy, total forming degree 94%, before the heat treatment,

[0028] FIG. **3** shows a rolled structure of an AlZn5Cu3Bi7 alloy, total forming degree 94%, after the heat treatment at 360° C./3 h.

[0029] To produce the plain bearing material, in this example cast strips with a cross section of 10 mm×100 mm are created on a vertical continuous casting installation, as known in the prior art, with the addition of 0.6% by weight AlTi5B1. In the production of the strips, the drawing-off rate is 8 mm/s and the cooling rate is 600 K/s. The strands are initially milled horizontally on the wide sides to a thickness of approximately 8 mm.

[0030] Subsequently, a brushed and degreased adhesion promoter of an aluminum alloy is clad onto the likewise brushed and degreased AlZn5Cu3Bi7 alloy with the first rolling pass in the rolling stand. The thickness of the clad raw material strip is 4 mm. This is subsequently rolled to 1.3 mm in a number of rolling passes. Five rolling passes are necessary for this. In order to improve the cladding properties of the aluminum bearing material strip, it is subjected to a recovery annealing operation at 370° C. for up to 3 hours. In the next processing step, the steel strip and the aluminum bearing material strip are bonded to one another in a cladding rolling mill.

[0031] Subsequently, the material combination created is subjected to a heat treatment at a temperature of 360° C. lasting three hours, the bond between the steel and the aluminum bearing material being increased by a diffusion process and the highly stretched bismuth filaments after the cladding in the aluminum-zinc-copper matrix being completely reformed into fine spherical drops of up to 20 μm in size. The high degree of hardness likewise resulting from the heat treatment, of at least 43 HB 2.5/62.5/30, is also of advantage. After this heat treatment, the clad strip can be subdivided and formed into bearing shells.

[0032] FIGS. **1** to **3** show by way of example how an alloy according to the invention, here an AlZn5Cu3Bi7 alloy, changes in its microstructure during the working. FIG. **1** shows the microstructure of the alloy after the production by continuous casting. The bismuth phase, which is in the form of droplets, is shown as dark.

[0033] FIG. **2** shows the microstructure of the alloy after the rolling. The bismuth lamellae elongated by the rolling can be seen in the rolled structure.

[0034] FIG. **3** shows the rolled structure after a heat treatment at 360° C. for 3 hours. It has been possible for the elongated Bi lamellae to be effectively re-coagulated by the heat treatment. Larger drops, isolated instances of which can still be seen in FIG. **1**, have been broken down by the stretching and re-coagulating, so that the overall degree of fine distribution is increased by the treatment.

[0035] It should be mentioned that the example merely serves the purpose of illustration and does not restrict the invention. A person skilled in the art also knows how plain bearings and bearing shells are produced and how the production of the alloy according to the invention can consequently be incorporated in the customary bearing production processes.

1. A monotectic aluminum plain bearing alloy comprising 5 to 20% by weight bismuth, 3 to 20% by weight zinc, 1 to 4% by weight copper and additionally one or more of the components manganese, vanadium, niobium, nickel, molybdenum, cobalt, iron, tungsten, chromium, silver, calcium, scandium, cerium, beryllium, antimony, boron, titanium, carbon and zirconium in a total of up to 5% by weight and aluminum to make it up to 100% by weight.

2. The monotectic aluminum plain bearing alloy as claimed in claim **1**, characterized in that the alloy contains between 7 and 12% by weight bismuth.

3. The monotectic aluminum plain bearing alloy as claimed in claim **1**, characterized in that the alloy contains between 3 and 6% by weight zinc.

4. The monotectic aluminum plain bearing alloy as claimed in claim **1**, characterized in that the alloy contains between 2 and 4% by weight, in particular between 2 and 3% by weight, copper.

5. The monotectic aluminum plain bearing alloy as claimed in claim **1**, characterized in that the alloy contains up to 2% by weight Al—Ti—B or Al—Ti—C grain refiner.

6. A process for producing an aluminum plain bearing alloy using the composition as claimed in claim **1**, characterized in that the alloying constituents are combined to form an alloy in a casting process in which the cooling rate is 5 to 1000 K/s.

7. The process as claimed in claim **6**, characterized in that the drawing-off rate is 2 to 15 mm/s.

8. The process as claimed in claim **6**, characterized in that a continuous casting process is used as the casting process.

9. The process as claimed in claim **6**, characterized in that, for the preparation of a semifinished product, the alloy is provided with at least one supporting layer.

10. The process as claimed in claim **6**, characterized in that at least one heat treatment at temperatures of from 270° C. to 400° C. is performed on the alloy in the course of subsequent forming processes.

11. The process as claimed in claim **10**, characterized in that the heat treatment follows a rolling and/or roll-cladding operation.

12. A plain bearing shell which contains an alloy comprising 5 to 20% by weight bismuth, 3 to 20% by weight zinc, 1 to 4% by weight copper and additionally one or more of the components manganese, vanadium, niobium, nickel, molybdenum, cobalt, iron, tungsten, chromium, silver, calcium, scandium, cerium, beryllium, antimony, boron, titanium, carbon and zirconium in a total of up to 5% by weight and aluminum to make it up to 100% by weight as one of the materials used in it or consists of this alloy.

13. A plain bearing with a shell which contains an alloy comprising 5 to 20% by weight bismuth, 3 to 20% by weight zinc, 1 to 4% by weight copper and additionally one or more of the components manganese, vanadium, niobium, nickel, molybdenum, cobalt, iron, tungsten, chromium, silver, calcium, scandium, cerium, beryllium, antimony, boron, titanium, carbon and zirconium in a total of up to 5% by weight and aluminum to make it up to 100% by weight as one of the materials used in it or consists of this alloy.

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