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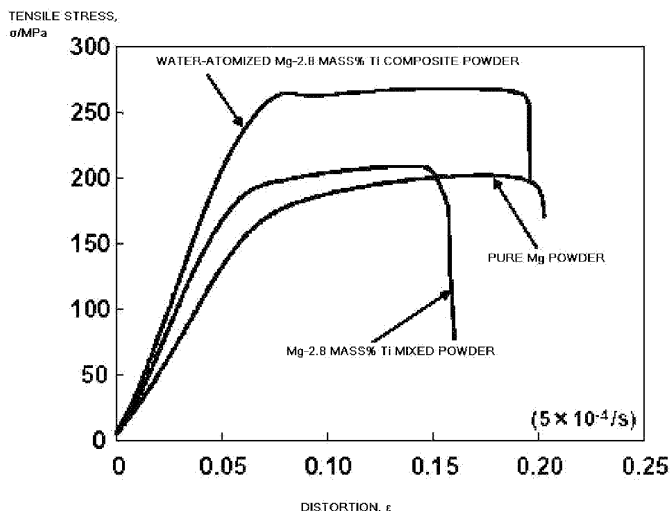
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(54) **MAGNESIUM-BASED COMPOSITE MATERIAL HAVING TI PARTICLES DISPERSED THEREIN, AND METHOD FOR PRODUCTION THEREOF**

(57) A Ti particle-dispersed magnesium-based composite material is a material having titanium particles uniformly dispersed in a magnesium matrix. Magnesium that forms the matrix and titanium particles are bonded to-

gether,) with satisfactory wettability without titanium oxide at an interface therebetween. The Ti particle-dispersed magnesium-based composite material has a tensile strength of 230 MPa or more.

FIG. 6



Description

TECHNICAL FIELD

[0001] The present invention relates to magnesium alloys, and more particularly to titanium (Ti) particle-dispersed magnesium-based composite materials that can be used in various fields such as household electric appliances, automotive parts, and aircraft members by increasing both strength and ductility, and manufacturing methods thereof.

BACKGROUND ART

[0002] Due to the lowest specific gravity of magnesium (Mg) among metal materials for industrial use, magnesium is expected to be used for parts and members of two-wheeled vehicles, automobiles, aircrafts, etc. for which reduction in weight is strongly desired. However, the use of magnesium alloys is limited as magnesium is not strong enough as compared to conventional industrial materials such as ferrous materials and aluminum alloys.

[0003] Composite materials in which particles, fibers, etc. having higher strength and hardness characteristics than those of magnesium are dispersed as a second phase have been developed in order to solve this problem. One example of an effective second phase to be dispersed is titanium (Ti). The rigidity of Mg is 45 GPa, whereas the rigidity of Ti is 105 GPa. The hardness of Mg is 35 to 45 Hv (Vickers hardness), whereas the hardness of Ti is 110 to 120 Hv. Thus, dispersing titanium particles in a magnesium matrix can be expected to increase the strength and hardness of magnesium-based composite materials.

[0004] In conventional composite materials, ceramic particles and ceramic fibers such as oxides, carbides, and nitrides are commonly dispersed. Such particles and fibers have high rigidity and high hardness, but have poor ductility. Thus, dispersing these particles and fibers in magnesium alloys reduces the ductility (e.g., breaking elongation) of the resultant composite materials. On the other hand, since titanium is a metal and has high ductility, adding and dispersing titanium particles does not reduce the ductility of the resultant composite materials.

[0005] However, magnesium has lower corrosion resistance. Magnesium has less noble characteristics (base metal), and has, e.g., a standard electrode potential E_s (the standard hydrogen (H) electrode is zero volt) as low as -2.356 V. If a small amount of iron (Fe: $E_s = -0.44$ V) or copper (Cu: $E_s = +0.34$ V) is contained in magnesium, a galvanic corrosion phenomenon occurs due to the potential difference between Mg and Fe and between Mg and Cu. On the other hand, titanium has a standard electrode potential of -1.75 V, and the potential difference between Mg and Ti is smaller than that between Mg and aluminum (Al: $E_s = -1.676$ V) as an element that is added to Mg. That is, dispersing titanium in magnesium does not significantly affect the corrosion phenomenon.

[0006] Thus, it is effective to use titanium particles as a dispersion strengthening material in magnesium matrix.

[0007] For example, the following non-patent documents have been reported as techniques related to Ti particle-dispersed magnesium composite materials. Non-Patent Document 1: Collected Abstracts of the 2008 Spring Meeting of the Japan Institute of Metals (March 26, 2008), p. 355, No. 464 (Kataoka and Kitazono: Effect of Microstructure on Mechanical Characteristics of Ti Particle-Dispersed Mg-Based Composite Material). Non-Patent Document 2: Collected Abstracts of the 2008 Spring Meeting of the Japan Institute of Light Metals (May 11, 2008), p. 13, No. 7 (Kitazono, Kataoka, and Komazu: Effect of Addition of Titanium Particles on Mechanical Characteristics of Magnesium). Non-Patent Document 3: Abstracts of Spring Meeting of Japan Society of Powder and Powder Metallurgy, 2007 (June 6, 2007), p. 148, No. 2-51 A (Enami, Fujita, Ohara, and Igarashi: Development of Magnesium Composite Material by Bulk Mechanical Alloying Method). Non-Patent Document 4: Journal of Japan Society of Powder and Powder Metallurgy, Vol. 55, No. 4 (2008), p. 244 (Enami, Fujita, Hone, Ohara, Igarashi, and Kondo: Development of Magnesium Composite Material by Bulk Mechanical Alloying Method). Non-Patent Document 5: Journal of Japan Institute of Light Metals, Vol. 54, No. 11 (2004), p. 522-526 (Sato, Watanabe, Miura, and Miura: Development of Titanium Particle-Dispersed Magnesium-Based Functionally Graded Material by Centrifugal Solid-Particle Method).

[0008] Non-Patent Documents 1 and 2 disclose production of a Ti particle-dispersed magnesium-based composite material by the following method. Pure titanium particles are applied to the surface of a pure magnesium plate, and another pure magnesium plate is placed thereon. In this state, the pure magnesium plates are heated and pressed to produce a composite material having the titanium particles interposed between the pure magnesium plates. A plurality of such composite materials are superposed on each other, and are heated and pressed to produce a Ti particle-dispersed magnesium-based composite material having the titanium particles arranged in the direction of the plane of the plates.

[0009] Non-Patent Documents 3 and 4 disclose production of a Ti particle-dispersed magnesium-based composite material by the following method. Magnesium alloy powder is mixed with pure titanium powder, and molds are filled with the mixed powder. In this state, the mixed powder is continuously subjected to a severe plastic working process, and is then subjected to a hot extrusion process to produce a Ti particle-dispersed magnesium-based composite material.

[0010] In each of Non-Patent Documents 1 to 4, the heating temperature is sufficiently lower than the melting point of magnesium, and composite materials are produced in a completely solid-phase temperature range without melting.

The tensile test result of the composite materials shows that the strength is increased by about 5 to 10% but the ductility (breaking elongation) is reduced by about 20 to 30%, as compared to materials containing no Ti particle. Since magnesium and titanium do not form a compound, the bonding interface strength therebetween is not sufficient, and thus the strength is not increased sufficiently. On the other hand, a stress concentrates on the interface, whereby the ductility is reduced.

[0011] Thus, adhesion at the Mg-Ti interface needs to be increased in order to significantly increase both the strength and ductility of titanium particle-dispersed magnesium-based composite materials.

[0012] Non-Patent Document 5 describes a manufacturing method in which molten magnesium or a molten magnesium alloy (AZ91 D) containing titanium particles that are present as a solid phase is subjected to a centrifugal force, and a composition gradient is controlled by using the difference in traveling speed which is caused by the difference in centrifugal force due to the difference in density between the dispersed particles and the molten magnesium or the molten magnesium alloy. Since the specific gravity of titanium is at least twice that of magnesium, it is difficult to uniformly disperse titanium particles in the molten magnesium or the molten magnesium alloy by the centrifugal solid-particle method disclosed in Non-Patent Document 5. In fact, this document describes that "it was found difficult to disperse titanium particles by this method." This document also describes that, in the case of adding titanium particles to a molten magnesium alloy (AZ91D) containing aluminum, and using the centrifugal solid-particle method, the aluminum concentration is very high in a portion where the titanium particles are aggregated, and regions where aluminum is solid-solved are also present in the outer periphery of the titanium particles. As a reason for this, this document describes that "there is a possibility that the initial melt having a high aluminum concentration may have penetrated the gaps between the titanium particles due to a capillary phenomenon, and may have been involved in aggregation and sintering of the titanium particles. Thus, it was found that the use of the centrifugal solid-particle method in the AZ91D alloy containing aluminum is problematic in view of the composition of the melt."

DISCLOSURE OF THE INVENTION

[0013] The present invention was developed to solve the above problems, and it is an object of the present invention to provide a Ti particle-dispersed magnesium-based composite material having high strength by uniformly dispersing titanium particles in a magnesium matrix, and increasing adhesion at the interface between titanium and magnesium.

[0014] A Ti particle-dispersed magnesium-based composite material according to the present invention is a material having titanium particles uniformly dispersed in a magnesium matrix. The Ti particle-dispersed magnesium-based composite material is characterized in that magnesium that forms the matrix and titanium particles are bonded together with satisfactory wettability without titanium oxide at an interface between the titanium particles and the magnesium matrix, and the magnesium-based composite material has a tensile strength of 230 MPa or more.

[0015] According to the present invention, since a proper amount of titanium particles are uniformly dispersed in the magnesium matrix with satisfactory wettability, a magnesium-based composite material having a tensile strength as high as 230 MPa or more can be obtained.

[0016] One embodiment of the present invention is directed to powder for manufacturing the Ti particle-dispersed magnesium-based composite material. This powder is produced by making a cast material, which has the titanium particles uniformly dispersed in the magnesium matrix, into powder by a machining process.

[0017] Powder according to another embodiment of the present invention is powder for manufacturing the Ti particle-dispersed magnesium-based composite material. The powder is produced by solidifying molten magnesium, which has the titanium particles uniformly dispersed therein, into powder by using an atomization process.

[0018] A method for manufacturing a Ti particle-dispersed magnesium-based composite material according to the present invention includes the steps of: placing titanium particles into molten magnesium; stirring the molten magnesium so that the titanium particles are uniformly dispersed therein; producing a composite material having the titanium particles uniformly dispersed in a magnesium matrix by solidifying the molten magnesium; and producing a magnesium-based composite material having a tensile strength of 230 MPa or more by subjecting the composite material to a hot plastic working process.

[0019] In one embodiment, the step of producing the composite material includes solidifying the molten magnesium to produce a cast material having the titanium particles dispersed in the magnesium matrix, machining the cast material so as to make the cast material into powder, and compacting and solidifying the powder to produce a compacted body.

[0020] In another embodiment, the step of producing the composite material includes solidifying the molten magnesium into powder by using an atomization process, and compacting and solidifying the powder to produce a compacted body.

[0021] According to another aspect of the present invention, a method for manufacturing a Ti particle-dispersed magnesium-based composite material according to the present invention includes the steps of: mixing magnesium powder with titanium particles; holding the mixed powder at a temperature higher than a liquid phase transition temperature of the magnesium powder; sintering and solidifying the mixed powder held at the high temperature; and producing a magnesium-based composite material having a tensile strength of 230 MPa or more by subjecting the sintered solidified body to a hot plastic formation process.

[0022] The technical significance or the functions and effects of the above structures of the present invention will be described in detail in the following sections.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023]

- Fig. 1 shows a graph and images for evaluating the wettability between pure magnesium and pure titanium.
 Fig. 2 shows scanning electron microscope (SEM) images of the interface between pure magnesium and pure titanium.
 Fig. 3 shows an SEM image of the interface between pure magnesium and pure titanium in a composite material obtained by heating and pressing mixed powder of pure titanium powder and pure magnesium powder.
 Fig. 4 shows an example of an image of the structure of magnesium-based composite powder having titanium particles dispersed therein.
 Fig. 5 shows images of the appearance and the structure of Ti particle-dispersed magnesium base composite powder obtained by using a water atomization process.
 Fig. 6 is a graph showing a stress-distortion curve of extruded materials using pure magnesium powder containing no titanium particle, and two kinds of Ti particle-dispersed magnesium-based composite powder produced by two manufacturing methods.
 Fig. 7 is a graph showing a change in tensile strength (TS) and yield strength (YS) of protruded materials with respect to the amount of titanium added.
 Fig. 8 shows optical microscope images of protruded materials having different contents of titanium particles.

BEST MODE FOR CARRYING OUT THE INVENTION

[0024] In order to develop titanium particle-dispersed magnesium composite materials capable of increasing adhesion at the interface between titanium and magnesium, the inventors of the present application focused on wettability between titanium and magnesium, and evaluated characteristics of the wettability and examined manufacturing methods of composite materials by using high wettability.

(1) Wettability between Pure Magnesium and Pure Titanium

[0025] The inventors of the present application examined wettability between pure titanium plates and pure magnesium droplets. Specifically, pure magnesium droplets (held at 800°C) melted in a high vacuum state were statically discharged from the tip of a nozzle made of magnesium oxide (MgO) onto the surface of a pure titanium plate, and the wettability between pure Mg and pure Ti at 800°C was evaluated by continuous shooting. The result is shown in Fig. 1.

[0026] As shown in Fig. 1, the wetting angle (contact angle) was about 50° when pure magnesium contacted the Ti plate surface ($t = 0$ seconds). The wetting angle decreased with time, and decreased to 13° after 6 minutes. In general, it is determined that the wetting phenomenon has occurred if the wetting angle becomes smaller than 90°. The wettability increases as the wetting angle becomes closer to 0°. In view of the fact that titanium carbide (TiC), which is said to have satisfactory wettability with magnesium, has a wetting angle of about 33° at 900°C (reference: A. Contrerasa et al., Scripta Materialia, 48 (2003) 1625-1630), it is recognized that the wettability between pure Mg and pure Ti is highly satisfactory.

[0027] After evaluating the wettability, the interface between the solidified pure Mg and the titanium plate of a test piece was observed by using a scanning electron microscope (SEM). The result is shown in Fig. 2. It is recognized that the molten Mg closely contacts the titanium plate in a satisfactory manner with no gap or void therebetween, in the entire region where the molten Mg contacts the titanium plate.

[0028] For comparison, such composite materials as reported in related art (Non-Patent Documents 1 to 4) were produced. That is, composite materials were produced by heating and pressing mixed powder of pure titanium powder and pure magnesium powder at a solid phase temperature of magnesium powder, and the bonding interface between pure magnesium and pure titanium was observed. The result is shown in Fig. 3. In producing the composite materials, the heating temperature was 520°C, which is lower than the melting point (650°C) of pure magnesium so as to obtain a completely solid phase state. As shown by arrows, many gaps or voids were observed at the interface between the Ti particles and the Mg matrix, which shows that adhesion is not sufficient. Thus, in the manufacturing methods disclosed in related art, since heating and sintering are performed at a solid phase temperature that is lower than the melting point of Mg, adhesion between Mg and Ti is not sufficient, whereby strength and ductility of the composite materials are not increased.

(2) Composite Materials Using Ti Particle-Dispersed Molten Magnesium

[0029] Based on the above result, the inventors produced Ti particle-dispersed magnesium-based composite materials by the following method in order to increase adhesion between a magnesium matrix and Ti particles. First, molten magnesium was held at a temperature higher than the melting point of magnesium or a magnesium alloy that forms a matrix, and a proper amount of Ti particles was added to the molten magnesium or magnesium alloy. After sufficiently stirring the molten magnesium or magnesium alloy so that the titanium particles were uniformly dispersed therein, the molten magnesium or magnesium alloy was solidified. In the magnesium-based composite materials produced by this manufacturing method, magnesium that forms the matrix and titanium particles are bonded together, with high adhesion due to satisfactory wettability, without titanium oxide at the interface between the titanium particles and the magnesium matrix. These magnesium-based composite materials were subjected to a hot plastic working process, whereby Ti particle-dispersed magnesium-based composite materials having a tensile strength of 230 MPa or more were able to be obtained.

[0030] Composite materials having titanium particles uniformly dispersed in a magnesium matrix can also be manufactured by conventional methods such as a casting method and a die casting method. The cast materials can be made into powder by a machining process such as a cutting process or a crushing process. In the magnesium-based composite powder thus obtained, the titanium particles are uniformly dispersed in the magnesium matrix. Fig. 4 shows an example of an image of the structure of this magnesium-based composite powder. As can be seen from Fig. 4, there is no void at the interface between the Ti particles and the Mg matrix, and satisfactory adhesion is obtained.

[0031] Magnesium-based composite powder having titanium particles uniformly dispersed in a magnesium matrix can also be obtained by solidifying molten magnesium having titanium particles uniformly dispersed therein by using an atomization process. Specifically, the inventors obtained solidified powder by the following method. Pure magnesium is melted in a carbon crucible, and 3 mass% of pure titanium powder (average particle size: 29.8 μm) is added to the molten pure magnesium. After stirring sufficiently, the melt is discharged from the bottom of the crucible as a molten flow, and high pressure water is ejected to the molten flow (a water atomization process) to obtain solidified powder. Fig. 5 shows an image of the appearance of the obtained powder, and the observation result of the inner structure of the powder. It is recognized that, in this water atomized powder as well, there is no void at the interface between the Ti particles and the Mg matrix, and satisfactory adhesion is obtained.

[0032] As described above, either in the case where a magnesium-based composite material is produced by adding titanium particles to molten magnesium, and after sufficient uniform stirring, performing a casting method or a die casting method, or in the case where molten magnesium having titanium particles uniformly dispersed therein is directly made into powder by using an atomization process, magnesium that forms the matrix and titanium particles are bonded together, without void and with satisfactory adhesion due to high wettability.

[0033] The Ti particle-dispersed magnesium-based composite material produced by a casting method or a die casting method may be heated to a predetermined temperature, and then the composite material may be subjected to a hot plastic working process such as a hot extrusion process, a hot rolling process, or a forging process. This reduces the crystal grain size of the matrix, and further increases the strength of the composite material. For example, the tensile strength of the composite material is 230 MPa or more.

[0034] The Ti particle-dispersed magnesium-based composite material produced from the cast material by a machining process such as a cutting process, or the Ti particle-dispersed magnesium-based composite powder obtained by ejecting high pressure water or high pressure gas to the molten magnesium flow, may be compacted and solidified to produce a compacted body or a sintered solidified body. Subsequently, the compacted body or the sintered solidified body may be subjected to a hot plastic working process such as a hot extrusion process, a hot rolling process, or a forging process, as necessary. A Ti particle-dispersed magnesium-based composite material having particles of the composite powder metallurgically bonded or sintered together can be produced in this manner.

[0035] Although a proper amount of titanium particles is added to molten magnesium in the above embodiment, a Ti particle-dispersed magnesium-based composite material can also be obtained by the following manufacturing method as another embodiment. In this embodiment, magnesium powder is mixed with titanium particles, and the mixed powder is sintered and solidified while being held at a predetermined temperature. The important thing is to hold the mixed powder at a temperature higher than a liquid phase transition temperature of the magnesium powder. By holding the mixed powder at such a high temperature, magnesium that forms the matrix and the titanium particles are bonded together in the sintered solidified body with high adhesion due to satisfactory wettability, without titanium oxide at the interface between the titanium particles and the magnesium matrix. This sintered solidified body is subjected to a hot plastic working process, whereby a Ti particle-dispersed magnesium-based composite material having a tensile strength of 230 MPa or more can be obtained.

Example 1

[0036] A mass of pure magnesium having a purity of 99.8%, and titanium powder having an average particle size of 29.8 μm were prepared as starting materials. The pure magnesium mass was melted by heating to 750°C in a carbon crucible, and three different amounts of the titanium particle, namely 0.5 mass%, 1.5 mass%, and 2.8 mass% in a weight percentage relative to the total weight, were added to the molten magnesium. After sufficiently uniformly stirring the resultant molten magnesium to prevent segregation of the Ti particles and sedimentation thereof at the bottom, a water atomization process was performed to produce Ti particle-dispersed magnesium-based composite powder.

[0037] For comparison, pure magnesium powder having a purity of 99.9% (average particle size: 162 μm) was prepared, and the pure magnesium powder and the above Ti powder was weighed so that the ratio of the Ti powder was 0.5 mass%, 1.5 mass%, and 2.8 mass%. Then, the pure magnesium powder was mixed with the Ti powder by using a dry ball mill, thereby producing Mg-Ti mixed powder.

[0038] The two kinds of powder thus produced were placed in carbon molds, and were pressed at 550°C for 30 minutes (pressure: 30 MPa) in a vacuum atmosphere by using a discharge plasma sintering apparatus to sinter and solidify the particles of the powder together, thereby producing extrusion billets having a diameter of 45 mm. These Ti particle-dispersed magnesium powder billets were held at 200°C for 5 minutes in an argon gas atmosphere, and then immediately subjected to a hot extrusion process (extrusion ratio: 37) to produce round-bar shaped extruded materials having a diameter of 7 mm.

[0039] Note that for comparison, round-bar shaped extruded materials were also produced from pure magnesium powder containing no Ti particle, based on the above manufacturing procedures.

[0040] Tensile test pieces were obtained from the three types of magnesium powder extruded materials thus produced, and a tensile strength test was performed at normal temperature. Fig. 6 shows a stress-distortion curve of the extruded materials using the pure Mg powder containing no Ti particle, and the extruded materials using the Mg powder containing 2.8 mass% of Ti particles, which were produced by the two manufacturing methods.

[0041] As compared to the strength and the elongation property of the pure magnesium powder extruded materials containing no Ti particle, the tensile strength and the yield strength of the Ti particle-dispersed magnesium-based composite powder extruded materials using the water atomization process of the present invention increased by about 35 to 40%, and the breaking elongation thereof was as high as 15% or more, which is about the same as the pure magnesium powder extruded materials containing no Ti particle.

[0042] On the other hand, in the extruded materials produced by using the mixed powder of Ti particles and Mg powder as comparative materials, the tensile strength and the yield strength increased by about 3 to 6%, but the breaking elongation reduced to less than 10%. Observation of the broken faces of the test pieces after the tensile test showed that, in the comparative materials, cracks developed at the interface between the Ti particles and the magnesium matrix. Thus, it is recognized that adding the Ti particles did not increase the strength due to insufficient adhesion therebetween.

[0043] Fig. 7 shows a change in tensile strength (TS) and yield strength (YS) of each extruded material with respect to the amount of Ti added. In the Ti particle-dispersed magnesium-based composite powder extruded materials using the water atomization process according to the present invention, both the tensile strength and the yield strength increase as the content of Ti particles increases, and it is verified that the strength is increased by uniform diffusion of the Ti particles. As described above, this is because adhesion between the Ti particles and magnesium in the molten magnesium is increased due to high wettability therebetween.

[0044] On the other hand, in the conventional manufacturing methods in which sintering/extrusion and solidification are performed in a solid phase temperature range by using mixed powder of Ti powder and Mg powder, the tensile strength and the yield strength of the extruded materials tend to decrease as the amount of Ti particles added increases. Thus, it is recognized that dispersion strengthening by Ti particles is not sufficient.

Example 2

[0045] As in Example 1, a mass of pure magnesium having a purity of 99.8%, and titanium powder having an average particle size of 29.8 μm were prepared as starting materials. The magnesium mass was melted by heating to 750°C in a carbon crucible, and three different amounts of the titanium particles, namely 1 mass%, 3 mass%, and 5 mass% in a weight percentage relative to the total weight, were added to the molten magnesium. After sufficiently uniformly stirring the resultant molten magnesium to prevent segregation of the Ti particles and sedimentation thereof at the bottom, the molten magnesium was cast into cylindrical molds to produce billets having a diameter of 60 mm. The cast billets were machined to produce extrusion billets having a diameter of 45 mm. These billets were held at 200°C for 5 minutes in an argon gas atmosphere, and then immediately subjected to a hot extrusion process (extrusion ratio: 37) to produce round-bar shaped extruded materials having a diameter of 7 mm,

[0046] Fig. 8 shows the observation result of the extruded materials by using an optical microscope. The proportion of Ti particles in the extruded material increases as the amount of Ti particles added increases. Even when 5 mass%

of Ti particles was added, no aggregation/segregation phenomenon of the Ti particles is observed, and the Ti particles are uniformly dispersed in the magnesium matrix.

[0047] The tensile test result of the extruded materials is shown in Table 1.

[0048]

[Table 1]

Amount of Ti Particles (mass%)	0	1	3	5
Tensile Strength (MPa)	196	237	278	302
Yield Strength (MPa)	161	228	261	289
Breaking Elongation (%)	17.2	16.1	14.8	13.2

[0049] As in Example 1, in the extruded materials obtained by extruding the Ti particle-dispersed magnesium-based composite material produced by a casting method according to the present invention, the tensile strength and the yield strength increase and the breaking elongation does not significantly decrease as the content of Ti particles increases. The above result shows that in the Ti parties-dispersed magnesium-based composite material of the present invention, the strength of the magnesium matrix can be increased by adding the Ti particles without causing aggregation and segregation of the Ti particles.

Example 3

[0050] As in Example 1, a mass of pure magnesium having a purity of 99.8%, and titanium powder having an average particle size of 29.8 μm were prepared as starting materials. The magnesium mass was melted by heating to 750°C in a carbon crucible, and different amounts of the titanium particles, namely 2 mass% and 4 mass% in a weight percentage relative to the total weight, were added to the molten magnesium. After sufficiently uniformly stirring the resultant molten magnesium to prevent segregation of the Ti particles and sedimentation thereof at the bottom, the molten magnesium was cast into cylindrical molds to produce billets having a diameter of 60 mm. Chips having a total length of about 1 to 4 mm were produced from the cast billets by a cutting process.

[0051] The observation result of the chips shows that the Ti particles are uniformly dispersed in the Mg matrix without aggregation and segregation. Then, SKD11 molds were filled with the chips, and were pressed with a pressure of 600 MPa by a hydraulic press to produce billets of a powder molded body having a diameter of 45 mm. The billets were held at 300°C for 5 minutes in an argon gas atmosphere, and then immediately subjected to a hot extrusion process (extrusion ratio: 37) to produce round-bar shaped extruded materials having a diameter of 7 mm.

[0052] Tensile test pieces were obtained from the magnesium powder extruded materials, and a tensile strength test was performed at normal temperature. The result shows that the extruded material using the chips containing 2 mass% of Ti has a tensile strength of 264 MPa and breaking elongation of 15.4%, and the extruded material using the chips containing 4 mass% of Ti has a tensile strength of 294 MPa and breaking elongation of 13.74%. As the amount of Ti particles added increases, the tensile strength increases without causing a significant decrease in breaking elongation. As compared with the characteristics of the comparative materials described in Example 1, it is apparent that the tensile strength and the yield strength are increased even if the same amount of Ti particles is contained.

[0053] The above result shows that in the Ti particle-dispersed magnesium-based composite material obtained by the manufacturing method of the present invention, the strength of the magnesium matrix can be increased by adding the Ti particles without causing aggregation and segregation of the Ti particles.

Example 4

[0054] As in Example 1, a mass of pure magnesium having a purity of 99.8%, and titanium alloy powder having an average particle size of 22.8 μm (Ti-6.1Al%-3.8V/mass%) were prepared as starting materials. The magnesium mass was melted by heating to 750°C in a carbon crucible, and three different amounts of the Ti alloy particles, namely 1 mass%, 3 mass%, and 5 mass% in a weight percentage relative to the total weight, were added to the molten magnesium. After sufficiently uniformly stirring the resultant molten magnesium to prevent segregation of the Ti alloy particles and sedimentation thereof at the bottom, the molten magnesium was cast into cylindrical molds to produce billets having a diameter of 60 mm.

[0055] The cast billets were machined to produce extrusion billets having a diameter of 45 mm. These billets were held at 200°C for 5 minutes in an argon gas atmosphere, and then immediately subjected to a hot extrusion process (extrusion ratio: 37) to produce round-bar shaped extruded materials having a diameter of 7 mm. Tensile test pieces

were obtained from these magnesium powder extruded materials, and a tensile strength test was performed at normal temperature.

[0056] The result is shown in Table 2. Note that the tensile strength of the extruded materials using the pure Ti particles as described in Example 2 was used as comparative values.

[0057]

[Table 2]

Amount of Ti Particles (mass%)	0	1	3	5
Ti-6Al-4V Powder	196	248	296	327
Pure Ti Powder	196	237	278	302

[0058] Even when the Ti-6Al-4V alloy particles are used, the Ti alloy particles are uniformly dispersed in the matrix in the Ti particle-dispersed magnesium-based composite material of the present invention, without causing aggregation and segregation of the Ti particles. The tensile strength increases as the amount of Ti alloy particles added increases. Moreover, the amount of increase in tensile strength is increased as compared to the case where the pure Ti particles are added. That is, the strength of the magnesium composite material is further increased as the hardness and strength of the particles that are dispersed are further increased.

[0059] Although the embodiments of the present invention are described above with reference to the drawings, the present invention is not limited to the illustrated embodiments. Various modifications and variations can be made to the illustrated embodiments within a scope that is the same as, or equivalent to the present invention.

INDUSTRIAL APPLICABILITY

[0060] The present invention can be advantageously used as a Ti particle-dispersed magnesium-based composite material having high strength, and a manufacturing method thereof.

Claims

1. A Ti particle-dispersed magnesium-based composite material having titanium particles uniformly dispersed in a magnesium matrix, **characterized in that** magnesium that forms the matrix and titanium particles are bonded together, with satisfactory wettability without titanium oxide at an interface between the titanium particles and the magnesium matrix, and the Ti particle-dispersed magnesium-based composite material has a tensile strength of 230 MPa or more.
2. Powder for manufacturing the Ti particle-dispersed magnesium-based composite material according to claim 1, wherein the powder is produced by making a cast material, which has the titanium particles uniformly dispersed in the magnesium matrix, into powder by a machining process.
3. Powder for manufacturing the Ti particle-dispersed magnesium-based composite material according to claim 1, wherein the powder is produced by solidifying molten magnesium, which has the titanium particles uniformly dispersed therein, into powder by using an atomization process.
4. A method for manufacturing a Ti particle-dispersed magnesium-based composite material, comprising the steps of:
 - placing titanium particles into molten magnesium;
 - stirring the molten magnesium so that the titanium particles are uniformly dispersed therein;
 - producing a composite material having the titanium particles uniformly dispersed in a magnesium matrix, by solidifying the molten magnesium; and
 - producing a magnesium-based composite material having a tensile strength of 230 MPa or more, by subjecting the composite material to a hot plastic working process.
5. The method according to claim 4, wherein the step of producing the composite material includes

solidifying the molten magnesium to produce a cast material having the titanium particles dispersed in the magnesium matrix,
machining the cast material to make the cast material into powder, and
compacting and solidifying the powder to produce a compacted body.

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6. The method according to claim 4, wherein
the step of producing the composite material includes
solidifying the molten magnesium into powder by using an atomization process, and
compacting and solidifying the powder to produce a compacted body.
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7. A method for manufacturing a Ti particle-dispersed magnesium-based composite material, comprising the steps of:
- mixing magnesium powder with titanium particles;
holding the mixed powder at a temperature higher than a liquid phase transition temperature of the magnesium
powder;
sintering and solidifying the mixed powder held at the high temperature; and
producing a magnesium-based composite material having a tensile strength of 230 MPa or more, by subjecting
the sintered solidified body to a hot plastic working process to.
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FIG. 1

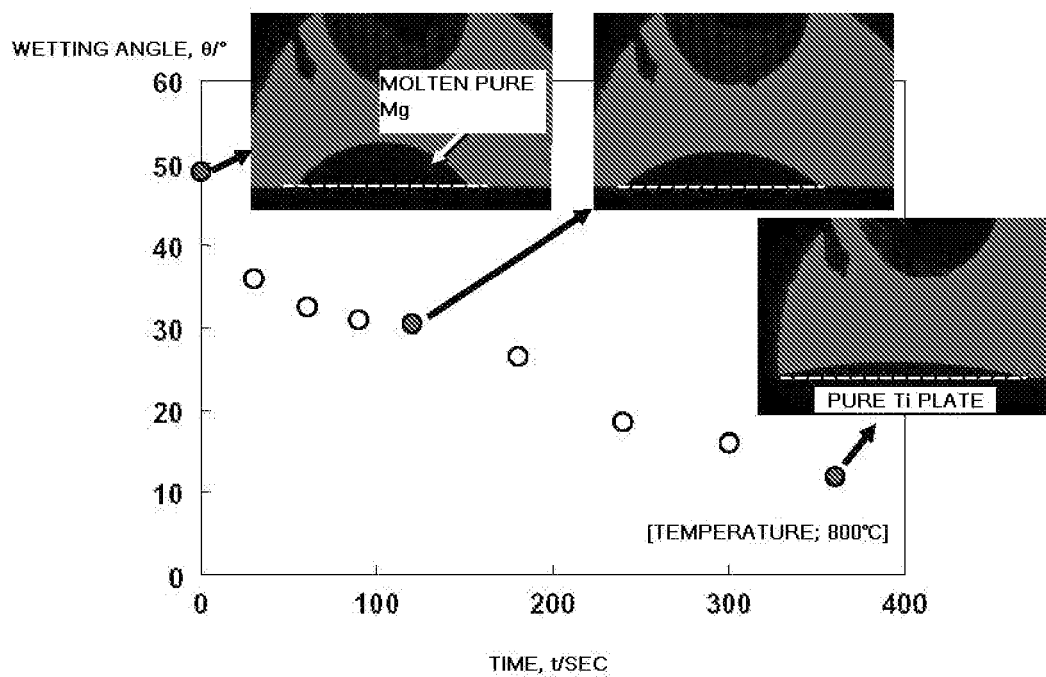


FIG. 2

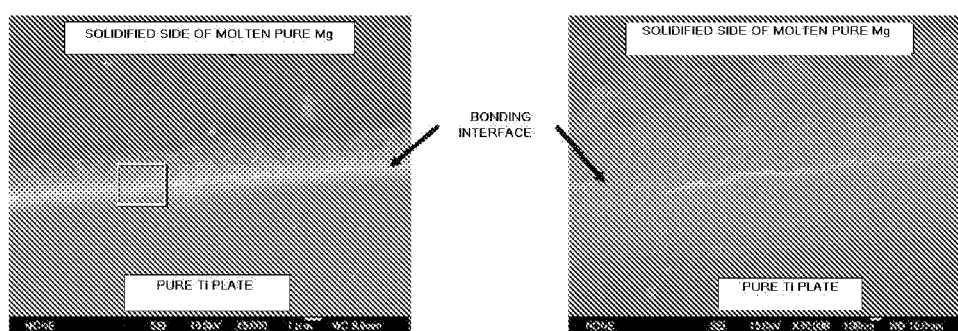


FIG. 3

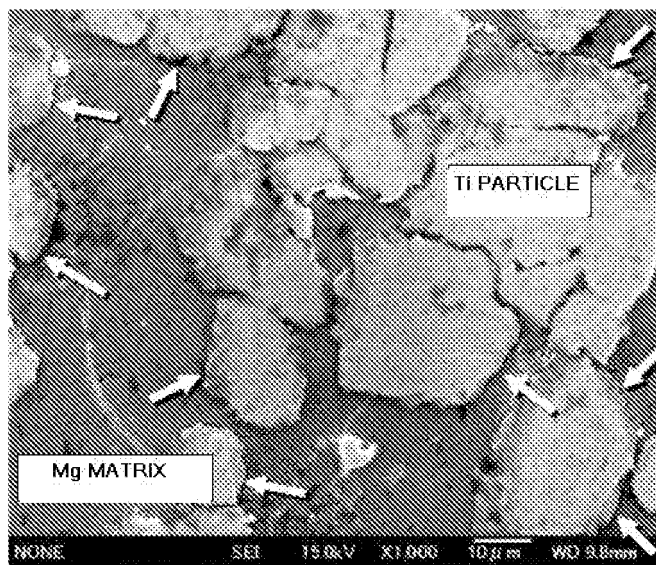


FIG. 4

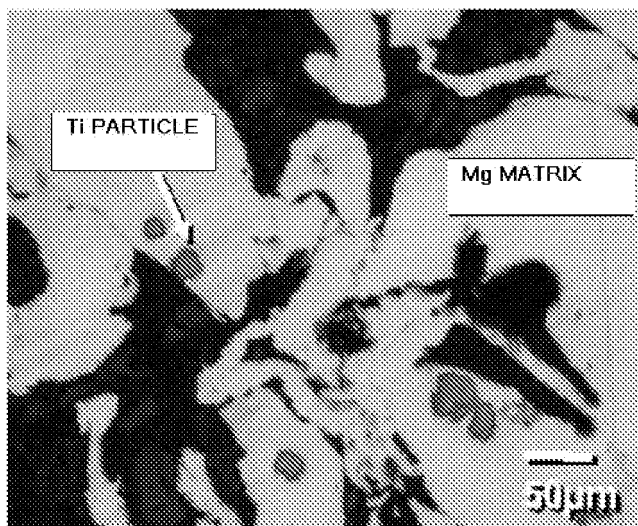


FIG. 5

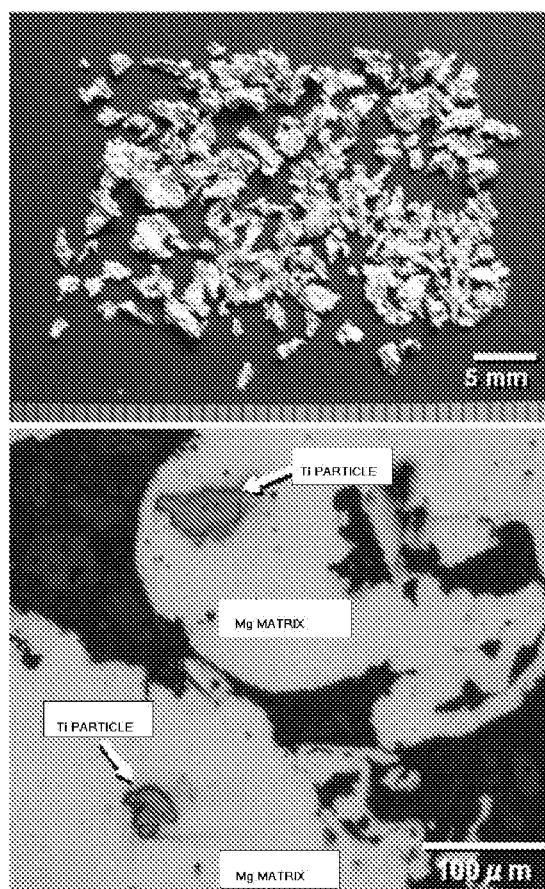


FIG. 6

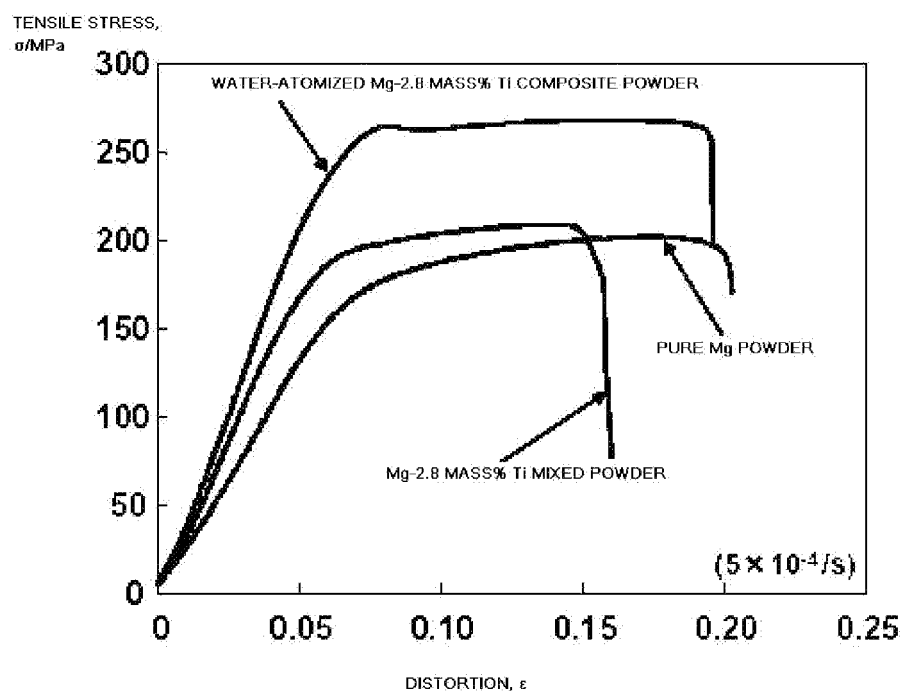


FIG. 7

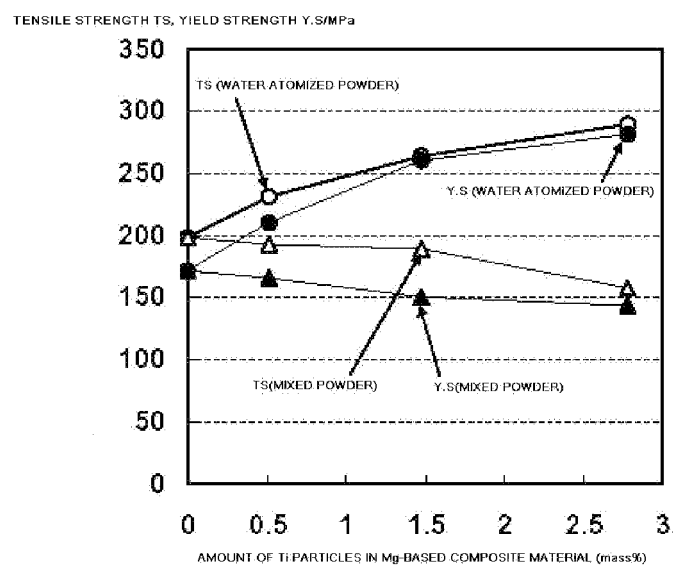
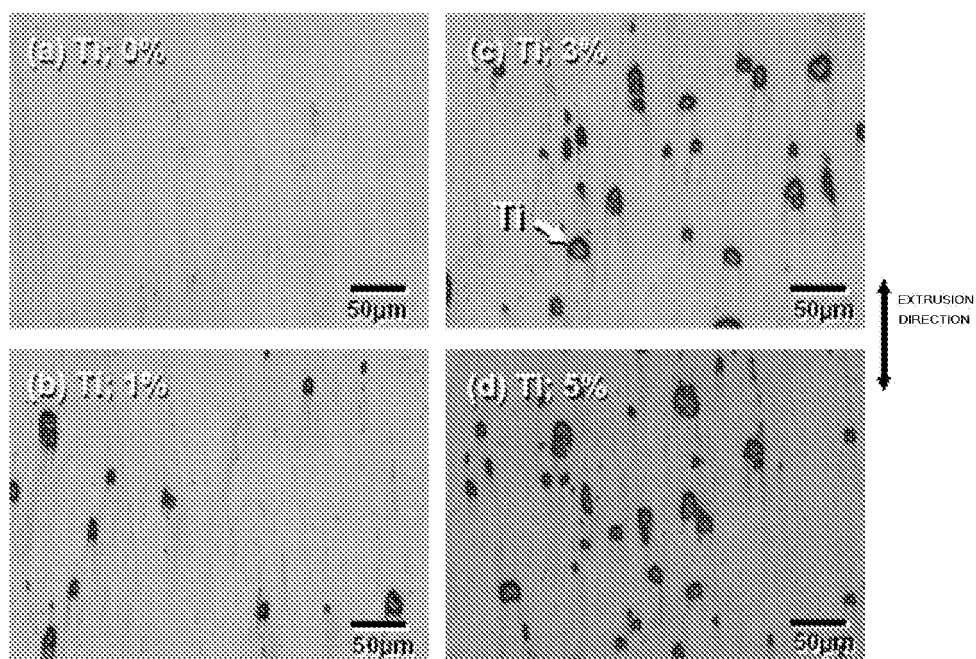


FIG. 8



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2009/055026

A. CLASSIFICATION OF SUBJECT MATTER C22C23/00(2006.01)i, B22F1/00(2006.01)i, B22F9/04(2006.01)i, B22F9/08(2006.01)i, C22C1/00(2006.01)i, C22C1/02(2006.01)i, C22C1/04(2006.01)i, C22F1/06(2006.01)i, C22F1/00(2006.01)n, C22F1/02(2006.01)n According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) C22C23/00, B22F1/00, B22F9/04, B22F9/08, C22C1/00, C22C1/02, C22C1/04, C22F1/06, C22F1/00, C22F1/02 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2009 Kokai Jitsuyo Shinan Koho 1971-2009 Toroku Jitsuyo Shinan Koho 1994-2009 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2002-105575 A (Hokkaido Technology Licensing Office Co., Ltd.), 10 April, 2002 (10.04.02), Claims 1 to 3; Par. Nos. [0029] to [0035] (Family: none)	1-6
Y	JP 5-214477 A (Suzuki Motor Corp.), 24 August, 1993 (24.08.93), Claims 1, 2; Par. Nos. [0005], [0007] (Family: none)	1-6
Y	JP 2008-163361 A (Mitsubishi Aluminum Co., Ltd.), 17 July, 2008 (17.07.08), Claims 1, 2; Par. Nos. [0007], [0021] (Family: none)	1-7
☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
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Date of the actual completion of the international search 03 June, 2009 (03.06.09)		Date of mailing of the international search report 16 June, 2009 (16.06.09)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2009/055026

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2-129329 A (Masahiro NISHIYAMA), 17 May, 1990 (17.05.90), Claims; page 7, upper left column, line 20 to upper right column, line 10 (Family: none)	1, 7
Y	Toshiyuki NISHIO et al., "Magnesium Gokin Funmatsu o Riyo shita MMC-zai no Seikei Oyobi Kikaiteki Seishitsu", Japanese Foundry Engineering Society, Reports of the JFS Meeting, 15 October, 1998 (15.10.98), Dai 133 Kai, page 71	1, 7
A	JP 2008-195978 A (Topy Industries Ltd.), 28 August, 2008 (28.08.08), Claims 1 to 11 (Family: none)	1-7
A	JP 10-102163 A (Hiroshima-Ken), 21 April, 1998 (21.04.98), Claims 1 to 9 (Family: none)	1-7

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REFERENCES CITED IN THE DESCRIPTION

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- **Enami ; Fujita ; Ohara ; Igarashi.** Development of Magnesium Composite Material by Bulk Mechanical Alloying Method. *Abstracts of Spring Meeting of Japan Society of Powder and Powder Metallurgy*, 06 June 2007, 148 [0007]
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