

METHOD OF MANUFACTURING LEAD-ACID BATTERY ELECTRODE

TECHNICAL FIELD

[0001]

The present invention relates to a method of manufacturing a lead-acid battery electrode, and in particular to a method of filling a paste-like active material onto a grid substrate to fabricate an electrode that has not been chemically converted.

BACKGROUND ART

[0002]

Among secondary batteries that have conventionally been used, lead-acid batteries are advantageous in terms of price and safety. Several types of electrodes for the lead-acid batteries, such as a clad type and a paste type, are available. In particular, electrodes of the paste type can be manufactured at a high productivity and a relatively low cost, and are used in the lead-acid batteries for many purposes. The electrodes of the paste type for the lead-acid batteries are fabricated by filling a paste-like active material onto a grid substrate made of a lead alloy and subjecting an active material-filed electrode to aging and drying.

[0003]

JP 04-2053 A (Patent Document 1) discloses a method of manufacturing a positive electrode for a lead-acid battery. In the method, a paste-like active material to which red lead has been added is filled onto a grid substrate, and thereafter the surface of a positive electrode is caused to react with sulfuric

acid with a concentration of 10% or more by mass and 60% or less by mass to be converted into lead sulfate, thereby maintaining the rate of utilization of the positive active material and suppressing a reduction in cycle characteristics.

[0004]

JP 09-92269 A (Patent Document 2) discloses a method of manufacturing an electrode for a lead-acid battery. In the method, an electrode prepared by filling an active material onto a grid substrate is caused to pass between a pair of soaking rollers containing dilute sulfuric acid in their surfaces, thereby preventing the electrode surface from being cracked in the subsequent step of drying.

BACKGROUND ART DOCUMENTS

PATENT DOCUMENTS

[0005]

Patent Document 1: JP 04-2053 A

Patent Document 2: JP 09-92269 A

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0006]

In the methods disclosed in Patent Documents 1 and 2, the temperature of sulfuric acid during application of sulfuric acid to an active material on the electrode surface and seasonal variations and daytime variations in the atmospheric temperature are not taken into consideration. Therefore, the time required to form a lead sulfate layer on the electrode surface is varied according to the working time of the day, which causes variations

in density and thickness of the lead sulfate layer. Therefore, preliminary drying or primary drying may be performed depending on the manufacturing environment. However, it is necessary to frequently adjust the temperature in a preliminary drying furnace (primary drying furnace) or to reset the time taken for the electrode to pass through the furnace in order to suppress such variations. If the density or the thickness of the lead sulfate layer formed on the electrode surface is not constant, the electrode surface may be cracked or broken. Such cracking and breakage of the electrode surface is conspicuous if preliminary drying (primary drying) is performed. With the methods disclosed in Patent Documents 1 and 2, electrodes may adhere to each other when the electrodes are aged and dried with the electrode surfaces facing each other, and the active material may fall off when the electrodes adhering to each other are separated from each other.

[0007]

An object of the present invention is to provide a method of manufacturing a lead-acid battery electrode that prevents an electrode surface from being cracked or broken.

[0008]

Another object of the present invention is to provide a method of manufacturing a lead-acid battery electrode with which electrodes do not easily adhere to each other during manufacture.

[0009]

A still further object of the present invention is to provide a method of manufacturing an electrode that allows for an increased initial capacity of a lead-acid battery.

SOLUTION TO PROBLEM

[0010]

The present invention aims at improving a method of manufacturing a lead-acid battery electrode. The method includes the steps of filling an active material, pressing, and aging and drying. First, in the step of filling an active material, a paste-like active material is filled (or pasted) onto a grid substrate made of a lead alloy to fabricate an active material-filled electrode. The term "active material-filled electrode" means an electrode that has not been aged or dried, in contrast to a yet-to-be chemically converted electrode (an electrode that has not been chemically converted) that has been aged and dried as discussed later.

[0011]

In the step of pressing, the active material-filled electrode fabricated in the step of filling an active material is pressed. The pressing process may be performed in an arbitrary manner, but using a roll pressing machine as discussed later will facilitate the pressing process.

[0012]

In the step of aging and drying, the active material-filled electrode which has been pressed in the step of pressing is aged and dried to obtain an electrode that has not been chemically converted. The yet-to-be chemically converted electrode, which has been aged and dried, is thereafter subjected to chemical conversion to obtain a lead-acid battery electrode.

[0013]

The manufacturing method according to the present invention further includes the steps of treating with sulfuric acid and preliminarily drying. In the step of treating with sulfuric acid, a surface of the active material-filled electrode fabricated in the step of filling an active material is treated with sulfuric acid that is adjusted to a temperature higher than an ordinary temperature. Lead sulfate crystals are generated on the surface of the active material-filled electrode which has been treated with sulfuric acid due to a reaction between the paste-like active material filled onto the grid substrate and sulfuric acid. The "ordinary temperature" means 25°C. The treatment with sulfuric acid may be performed in an arbitrary manner. Any method may be adopted as long as lead sulfate crystals can be formed on the surface of the active material-filled electrode. The step of treating with sulfuric acid may be performed at any time after the step of filling an active material but before the step of pressing, or during the step of pressing, or at any time after the step of pressing but before the step of preliminarily drying which is discussed later.

[0014]

In the step of preliminarily drying, the active material-filled electrode, which has been treated with the sulfuric acid in the step of treating with sulfuric acid, is preliminarily dried. The preliminary drying is intended to preliminarily dry the active material-filled electrode before it is aged in the subsequent step of aging and drying. The preliminary drying is alternatively referred to as "primary drying" in

contrast to drying after aging. In the step of preliminarily drying (primary drying), extra water on the active material surface is removed, and lead sulfate crystals generated by a chemical reaction between the sulfuric acid and the active material are grown to form an appropriate lead sulfate layer. The temperature adjustment for the drying furnace, the drying time, and the drying method are important factors. If the preliminary drying temperature is too high, water contained in the paste-like active material is excessively evaporated, thereby hindering a chemical reaction in the subsequent step of aging and drying. Conversely, if the preliminary drying temperature is too low, it takes time to achieve an appropriate dry state, thereby lowering the production efficiency. The preliminary drying is performed by heating the inside of the drying furnace. The inside of the drying furnace is heated using an electric heater or hot air. If the electric heater is used, the temperature of the paste-like active material filled on the electrode is abruptly raised, and therefore it is difficult to appropriately maintain the amount of water contained in the paste-like active material and adjust the inside of the drying furnace to an appropriate temperature for forming a lead sulfate layer. If the drying furnace is heated using hot air, the active material surface is also dried by air, and therefore the amount of water contained in the paste-like active material can be kept at a prescribed level even if the temperature of the hot air is set to be low. Therefore, drying using hot air makes it relatively easy to form a lead sulfate layer on the active material surface and remove water on the active

material surface to an extent that the active material on the surface does not fall off.

[0015]

By using the method of manufacturing according to the present invention, it is possible to prevent the surface of an electrode that has not been chemically converted from being cracked or broken. Especially, even when preliminary drying (primary drying) is performed, it is possible to prevent the surface of an active material-filled electrode from being cracked or broken. Further, when the active material-filled electrodes are arranged to face each other in the step of aging and drying, the active materials do not easily adhere to each other when the surfaces of the adjacent active material-filled electrodes contact each other. Even if the active materials adhere to each other, the active materials can be prevented from falling off when the active materials adhering to each other are separated from each other. By treating the surface of the active material-filled electrode with sulfuric acid having a temperature higher than an ordinary temperature as in the present invention, the progress of a reaction between the surface (paste-like active material) of the active material-filled electrode and sulfuric acid can be sped up even if there are seasonal variations and daytime variations in atmospheric temperature (in particular, when the atmospheric temperature is in a range equal to or less than an ordinary temperature). As a result, lead sulfate crystals with high crystallinity are generated on the surface of the active material-filled electrode to form a uniform lead sulfate layer.

The thus formed lead sulfate layer has a robust crystal structure as compared to the surface of the active material immediately after being filled onto the grid substrate, and therefore is considered to provide the effect described above.

[0016]

Preferably, the temperature of sulfuric acid used in the step of treating with sulfuric acid is adjusted in the range of 40°C to 60°C. If the surface of the active material-filled electrode is treated with sulfuric acid adjusted to such a temperature range, the amount of generated lead sulfate and the growth of crystals do not significantly vary and the reaction rapidly progresses as compared to when the surface of the active material-filled electrode is treated with sulfuric acid having an ordinary temperature. Thus, it is possible to obtain an electrode, the surface of which is not easily cracked or broken, even if the drying temperature in the subsequent step of preliminarily drying is set to be low as compared to that in the related art and the drying time is set to be short. If the temperature of sulfuric acid for treatment of the surface of the active material-filled electrode is higher than 60°C, large crystals of lead sulfate are precipitated on the electrode surface, thereby retarding the aging reaction. Consequently, the capacity of the lead-acid battery tends to be smaller. If the temperature of sulfuric acid is lower than 40°C, fine lead sulfate crystals are easily precipitated on the electrode surface. Such crystals hinder permeation and diffusion of an electrolyte from the electrode surface into the active material when the lead-acid

battery is in use, which tends to reduce the capacity of the lead-acid battery.

[0017]

Preferably, the specific gravity of sulfuric acid used in the step of treating with sulfuric acid is adjusted in the range of 1.10 to 1.30 at a temperature of 20°C. If the specific gravity of sulfuric acid is higher than 1.30, that is, if the concentration of sulfuric acid is high, fine lead sulfate crystals are precipitated, thereby hindering permeation and diffusion of an electrolyte from the active material surface into the active material. Consequently, the capacity of the lead-acid battery tends to be smaller. If the specific gravity of sulfuric acid is lower than 1.10, that is, if the concentration of sulfuric acid is low, large crystals of lead sulfate are precipitated, thereby retarding the progress of the aging reaction. Consequently, the capacity of the lead-acid battery tends to be smaller.

[0018]

When preliminary drying (primary drying) is performed after the surface of the active material-filled electrode has been treated with sulfuric acid having the above-mentioned adjusted temperature range and specific gravity range, the thickness of the lead sulfate layer formed on the surface of the active material-filled electrode is in the range of 100 μm to 800 μm . In other words, by controlling the treatment with sulfuric acid in the step of treating with sulfuric acid such that the lead sulfate layer formed on the surface of the active material-filled electrode after the preliminary drying has a thickness in the

range of 100 μm to 800 μm , it is possible to reliably prevent the surface of an electrode, which has not been chemically converted, from being cracked or broken, and also to prevent electrodes superposed on each other from adhering to each other. Preferably, the treatment with sulfuric acid in the step of treating with sulfuric acid is controlled such that the thickness of the lead sulfate layer formed on the electrode surface is in the range of 100 μm to 500 μm . When the thickness of the lead sulfate layer is in the range of 100 μm to 500 μm , it is possible not only to prevent the surface of an electrode, which has not been chemically converted, from being cracked or broken and to prevent electrodes superposed on each other from adhering to each other, but also to maintain the battery capacity.

[0019]

If the thickness of the lead sulfate layer is in the range of 100 μm or more, there will be no water on the electrode surface, and it is accordingly considered that the electrodes do not adhere to each other. In other words, if the thickness of the lead sulfate layer is less than 100 μm , the amount of water on the electrode surface will be larger, which makes the electrodes easily adhere to each other and may adversely affect the battery performance. If the thickness of the lead sulfate layer is more than 500 μm , the battery performance may be affected. If the thickness of the lead sulfate layer is more than 800 μm , the battery performance may be significantly affected (that is, the higher the sulfuric acid specific gravity is, the thicker the lead sulfate layer will be, which may lower the battery performance).

[0020]

Preferably, the step of treating with sulfuric acid is included in the step of pressing. That is, the treatment with sulfuric acid in the step of treating with sulfuric acid and the pressing in the step of pressing are preferably performed at the same time. In this case, in the step of pressing, a roll pressing machine provided with a pair of rollers is used to press the active material-filled electrode by causing the active material-filled electrode to pass between the pair of rollers. Pressing surfaces of the pair of rollers have been immersed in advance into sulfuric acid for use in the treatment with sulfuric acid. With this, when the active material-filled electrode is caused to pass between the pair of rollers, sulfuric acid is applied to the surface of the active material-filled electrode. Thus, while the active material-filled electrode is pressed, the surface of the active material-filled electrode is treated with sulfuric acid.

[0021]

As described above, if the step of treating with sulfuric acid is included in the step of pressing to apply the sulfuric acid to the surface of the active material-filled electrode, it is possible to reliably treat the surface of the active material-filled electrode with sulfuric acid without significantly changing the manufacturing line. Since the treatment with sulfuric acid is performed at the same time as the pressing, it is possible to form a robust lead sulfate layer having a uniform thickness on the surface of the active material-filled electrode. Therefore, it is possible to reliably prevent the

surface of the active material-filled electrode from being cracked during preliminary drying (primary drying), and also prevent the active materials from adhering to each other during aging.

EFFECT OF INVENTION

[0022]

In the present invention, the surface of the active material-filled electrode is treated with sulfuric acid that is adjusted to a temperature higher than an ordinary temperature. This prevents the electrode surface from being cracked or broken. If the electrodes are arranged to face each other in the process of aging, the adjacent electrodes do not easily adhere to each other. Even if the electrodes adhere to each other, the active materials can be prevented from falling off when the active materials are separated from each other.

BRIEF DESCRIPTION OF DRAWINGS

[0023]

Fig. 1 is a schematic diagram illustrating an example process of manufacturing a lead-acid battery electrode according to an embodiment of the present invention.

Fig. 2 is a graph indicating the relationship between the specific gravity of sulfuric acid used in the treatment with sulfuric acid (a specific gravity of sulfuric acid for immersion) and the thickness of a lead sulfate layer formed on a surface of an active material-filled electrode by the treatment with sulfuric acid (a thickness of a layer intruded with or immersed in sulfuric acid).

Figs. 3A to 3C are photomicrographs of a section of an active material-filled electrode treated with sulfuric acid having a specific gravity of 1.10 to 1.30, as taken in the vicinity of the surface of the electrode. The photomicrographs are captured using an optical digital metallurgical microscope and enlarged at a magnification of 100 times.

DESCRIPTION OF EMBODIMENTS

[0024]

An embodiment of the present invention will be described in detail below. Fig. 1 illustrates an example process of manufacturing a lead-acid battery electrode according to an embodiment of the present invention. In this example, a grid substrate 3 is mounted onto a belt conveyor 1. The grid substrate 3 may be a cast grid substrate or an expanded grid substrate. The grid substrate contains lead as a main component, and may also contain tin, calcium, antimony, or the like as additional components. In this example, a grid substrate made of a lead alloy containing calcium and tin is used. Addition of calcium can decrease the rate of self-discharge. Further, addition of tin can suppress corrosion of the electrode, which may likely occur when calcium is added.

[0025]

An active material is filled or pasted onto the grid substrate 3 mounted on the belt conveyor 1 using a filler (or a pasting machine) 5 to fabricate an active material-filled electrode 7 (in the step of filling an active material). A paste-like active material is used since it is easy to be filled

onto the grid substrate 3 mentioned above. The composition of the paste-like active material is not specifically limited. The paste-like active material is preferably fabricated by kneading lead powder containing lead monoxide, and water, sulfuric acid, and so forth (occasionally with additives such as cut carbon fiber pieces, carbon powder, lignin, barium sulfate, and red lead depending on the characteristics of positive and negative electrodes). The paste-like active material is filled onto the grid substrate in at least such an amount that the grid of the grid substrate 3 is completely covered. Preferably, the paste-like active material is filled in such an amount that the thickness of the paste-like active material reaches or exceeds the thickness of the frame at the outermost peripheral portion of the grid substrate 3.

[0026]

The active material-filled electrode 7, which has been fabricated by filling the paste-like active material onto the grid substrate 3, is shaped by pressing (in the step of pressing). In this example, a roll pressing machine 9 provided with a pair of rollers 9A and 9B is used. Specifically, the active material-filled electrode 7 is caused to pass through a gap between the pair of rollers 9A and 9B of the roll pressing machine 9 for pressing. The pair of rollers 9A and 9B may each include at least one roller. In this example, in order that the paste-like active material is sufficiently pressed to be filled on the substrate, the pair of rollers 9A and 9B each include three rollers as illustrated in Fig. 1.

[0027]

In this example, a surface of the active material-filled electrode 7 is treated with sulfuric acid that is adjusted to a temperature higher than an ordinary temperature (in the step of treating with sulfuric acid). The sulfuric acid is stored in a sulfuric acid bath 11 made of a resin such as polypropylene or polyethylene which is chemically resistant, or made of a resin or metal coated with a fluorine resin. The sulfuric acid in the sulfuric acid bath 11 is heated to a preset temperature by a heating device 13. The heating device 13 includes a silica glass heater. The silica glass heater is immersed into the sulfuric acid bath 11 to heat the sulfuric acid. The temperature of sulfuric acid is measured using a K thermocouple, not illustrated, which is coated with a fluorine resin. A signal indicative of the measured temperature is transferred to a temperature controller, not illustrated, to control the temperature of the silica glass heater. In this example, the capacity of the sulfuric acid bath 11 is 2 m³, and three silica glass heaters 13 with a heater capacity of 2 kW are used. As the heating device 13, heaters coated with a fluorine resin may be used in place of the silica glass heaters described above. In this example, the sulfuric acid is heated to a temperature higher than an ordinary temperature as described above.

[0028]

In this example, a specific gravity measurement instrument, not illustrated, is used to measure the specific gravity of the sulfuric acid. Reserve tanks, not illustrated, of concentrated

sulfuric acid and pure water are connected to the sulfuric acid bath 11. Open-close valves for the reserve tanks are controlled to maintain a predetermined specific gravity of the sulfuric acid. [0029]

In this example, the step of treating with sulfuric acid is included in the step of pressing. That is, the step of treating a surface of the active material-filled electrode 7 with sulfuric acid is performed along with the step of pressing the active material-filled electrode 7. In this case, pressing surfaces of the pair of rollers have been immersed in advance into the sulfuric acid having a temperature higher than an ordinary temperature for use in the treatment with sulfuric acid. Specifically, the sulfuric acid is pumped up from the sulfuric acid bath 11 by an acid-resistant pump, not illustrated. Then, the pumped-up sulfuric acid is transferred using a tube 14, and dropped onto the pressing surfaces of the roll pressing machine 9 (pair of rollers 9A and 9B) to infiltrate the pressing surfaces with the sulfuric acid. The pressing surfaces may be covered with a cloth to infiltrate the pressing surfaces of the pair of rollers 9A and 9B with the sulfuric acid. A porous material or the like may be used to retain a sufficient amount of the sulfuric acid. For example, fluororubber, a porous material of an ultra-high molecular polyethylene material, a sintered porous material of a fluorine resin, or the like may be used. In this example, the peripheral surfaces of the pair of rollers, which are disposed respectively at upper and lower positions, are covered with a woven fabric made of polyester.

[0030]

The pump includes control means for adjusting the flow rate of the sulfuric acid for controlling the discharge amount as appropriate. Specifically, the discharge amount is controlled so as to be variable in the range of 1 dm³/minute to 10 dm³/minute by a controller, not illustrated. In this example, an acid-resistant self-suction pump is used, and the discharge amount is set to 5 dm³/minute. The sulfuric acid bath 11 is controlled such that the specific gravity of the sulfuric acid is within a preset range. The liquid amount of the sulfuric acid in the sulfuric acid bath 11 is controlled to a preset range by a liquid level gauge, not illustrated.

[0031]

As mentioned above, the sulfuric acid is dropped onto the pressing surfaces of the roll pressing machine 9 (pair of rollers 9A and 9B) to infiltrate the pressing surfaces of the pair of rollers 9A and 9B with the sulfuric acid. In this state, the active material-filled electrode 7 is caused to pass through the gap between the pair of rollers 9A and 9B. Thus, the sulfuric acid with which the pressing surfaces are infiltrated is applied to the surface of the active material-filled electrode 7 while the active material-filled electrode 7 is being pressed. In other words, crystals of the lead sulfate can be generated on the surface of the active material-filled electrode 7 while the pressing process improves the filling performance of the paste-like active material onto the active material-filled electrode 7.

[0032]

A portion of the sulfuric acid dropped onto the pressing surfaces of the roll pressing machine 9 (pair of rollers 9A and 9B) is not applied to the surface of the active material-filled electrode 7. Such sulfuric acid (including sulfuric acid which is not infiltrated into the pair of rollers 9A and 9B) is dropped into a sulfuric acid recovery bath 15, and recovered and delivered to the sulfuric acid bath 11 through a tube 16 by an acid-resistant self-suction pump, not illustrated, capable of adjusting the discharge amount.

[0033]

An unwanted muddy substance such as an active material and lead sulfate is present in the recovered sulfuric acid. Thus, a filter may be provided in the sulfuric acid recovery bath 15 to remove such a muddy substance. The muddy substance in the sulfuric acid has a high specific gravity, and is precipitated at the bottom portion of the sulfuric acid bath 11. Therefore, the sulfuric acid may be pumped up from the vicinity of the liquid surface of the sulfuric acid bath 11 and be supplied to the roll pressing machine 9.

[0034]

The active material-filled electrode 7 which has been subjected to the pressing and the treatment with sulfuric acid is preliminarily dried (in the step of preliminarily drying) before being aged and dried. Specifically, the active material-filled electrode 7 which has been pressed and applied with the sulfuric acid at the same time as illustrated in Fig. 1 is caused to pass through a preliminary drying furnace 17

provided on a belt conveyor 2 that is adjacent to the belt conveyor 1. In this example, a circulatory hot-air drying furnace is used as the preliminary drying furnace 17. The temperature in the furnace is adjusted to 100°C to 150°C, the drying time is set to 15 seconds to 25 seconds, and the amount of water contained in the paste-like active material is set to 8% to 11% by mass.

[0035]

The active material-filled electrode 7 which has been subjected to the preliminary drying is aged and dried under predetermined conditions as discussed later (in the step of aging and drying). Then, an electrode that has not been chemically converted is obtained.

Examples

[0036]

Examples according to the present invention will be described in detail below.

[0037]

<Fabrication of Positive Paste-like Active Material>

1000 kg of lead powder containing lead monoxide as a main component and 2 kg of PET fibers [fineness: 2.0 D (denier); fiber length: 3.0 mm] were mixed. Water was added to the mixture. After that, slurry prepared by adding 300 kg of red lead to 200 kg of dilute sulfuric acid (specific gravity: 1.260 at a temperature of 20°C) and stirring them was added to the mixture, and the resulting mixture was kneaded to fabricate a positive paste-like active material.

[0038]

The amount of the water to be added was adjusted such that the hardness of the paste-like active material was constant in consideration of the filling performance of the paste-like active material onto the grid substrate.

[0039]

<Fabrication of Positive Electrode>

The positive paste-like active material fabricated by the method discussed above was filled onto the grid substrate 3 to fabricate a paste-type positive electrode 7 that has not been chemically converted. That is, the positive paste-like active material was filled onto a cast grid substrate made of a lead-calcium alloy in a grid shape having a length of 240 mm, a width of 140 mm, and a thickness of 4.3 mm such that the electrode had a thickness of 4.4 mm. After that, the active material-filled electrode 7 was caused to pass between the pair of rollers 9A and 9B while sulfuric acid having a temperature and a specific gravity set to predetermined values were constantly dropped onto the pressing surfaces of the roll pressing machine (a pair of rollers). Subsequently, the active material-filled electrode 7 was dried for 20 seconds in the circulatory hot-air drying furnace (the preliminary drying furnace) 17 at a temperature adjusted to 130°C for preliminary drying (primary drying).

[0040]

After that, the active material-filled electrode 7 was aged and dried under the following conditions to fabricate a paste-type positive electrode that had not been chemically converted.

[0041]

(Primary resting): four to eight hours at an atmospheric temperature of 75°C to 85°C and at a relative humidity of 95% to 98%

(Secondary resting): 20 hours or more at an atmospheric temperature of 50°C to 65°C and at a relative humidity of 50% or more

(Drying): 24 hours or more at a temperature of 55°C to 65°C
<Fabrication of Negative Paste-like Active Material>

900 kg of lead powder containing lead monoxide as a main component and 2.7 kg of PET fibers [fineness: 2.0 D (denier); fiber length: 3.0 mm], 4.5 kg of barium sulfate, and 1.8 kg of lignin were mixed. Water was added to the mixture. After that, 100 kg of dilute sulfuric acid was added to the mixture, and the resulting mixture was kneaded to fabricate a negative paste-like active material.

[0042]

The amount of the water to be added was adjusted such that the hardness of the paste-like active material was constant in consideration of the filling performance of the paste-like active material onto the grid substrate.

[0043]

<Fabrication of Negative Electrode>

The negative paste-like active material fabricated by the method discussed above was filled onto the grid substrate to fabricate a paste-type negative electrode that has not been chemically converted. That is, the negative paste-like active material was filled onto a cast grid substrate made of a

lead-calcium alloy in a grid shape having a length of 240 mm, a width of 140 mm, and a thickness of 2.5 mm such that the electrode had a thickness of 2.6 mm. After that, the active material-filled electrode was caused to pass between the rollers while sulfuric acid having a temperature and a specific gravity set to predetermined values were constantly dropped onto the pressing surfaces of the rollers. Subsequently, the active material-filled electrode was dried for 20 seconds in a circulatory hot-air drying furnace at a temperature adjusted to 130°C for preliminary drying (primary drying).

[0044]

After that, the active material-filled electrode was aged and dried under the following conditions to fabricate a paste-type negative electrode that had not been chemically converted.

[0045]

(Primary resting): 24 hours at an atmospheric temperature of 37°C to 43°C and at a relative humidity of 92% to 98%

(Secondary resting): 16 hours or more at an atmospheric temperature of 37°C to 43°C and at a relative humidity of 50% or more

(Drying): 8 hours at a temperature of 35°C to 45°C, and 12 hours at a temperature of 65°C to 75°C

[Examples 1 to 5 and Comparative Example 1]

Sulfuric acid was applied to the surfaces of the positive electrode and the negative electrode described above while varying the temperature and the specific gravity of the sulfuric acid to be dropped onto the pressing surfaces of the rollers as

indicated in Table 1. Subsequently, the electrodes were subjected to preliminary drying (primary drying), and aging and drying to obtain electrodes that had not been chemically converted. It was verified whether or not the electrodes adhered to each other. The initial capacity of a lead-acid battery assembled using the electrodes that had not been chemically converted was also verified.

[0046]

<Evaluation Test 1>

For the not-yet-to be chemically converted electrode that were fabricated under the conditions of Examples 1 to 5 and Comparative Example 1, it was verified whether or not the electrodes, which had been subjected to aging and drying, adhered to each other as follows. The active material-filled electrodes which had been subjected to preliminary drying (primary drying) were stacked to be superposed on each other, and left as they were for two hours without applying a load thereto. After that, when the upper electrode was lifted up by hand, if the lower electrode was in tight contact with the upper electrode and lifted up together, even though slightly, the electrodes were evaluated to adhere to each other, which is indicated with a symbol "x"; a symbol "o" is given otherwise. The result of this test is shown in Table 1.

[0047]

<Evaluation Test 2>

A lead-acid battery was assembled using the electrodes fabricated in Examples 1 to 5, and subjected to a 1.0 CA discharge

test under test conditions based on the JIS standard C 8704-2-1 to verify the high-rate discharge capacity. The discharge time before the final voltage was reached is also shown in Table 1.

[Table 1]

	Set values for sulfuric acid		Whether or not electrodes adhered to each other	Discharge time (min.)
	Temperature (°C)	Specific gravity (g/cm ³)		
Ex. 1	50	1.20	o	30
Ex. 2	40		o	28
Ex. 3	60		o	28
Ex. 4	30		o	26
Ex. 5	70		o	22
Comp. Ex. 1	25		x	-

[0048]

As shown in Table 1, the electrodes adhered to each other in Comparative Example 1 in which the sulfuric acid temperature was 25°C or less, but the electrodes did not adhere to each other in Examples 1 to 5 in which the sulfuric acid temperature was higher than 25°C.

[0049]

In Examples 1 to 5 and Comparative Example 1, the electrodes were subjected to preliminary drying (primary drying), aging, and drying under the same condition after sulfuric acid was applied to the surfaces of the electrodes. It is considered that the electrodes did not adhere to each other when the sulfuric acid

temperature was higher than 25°C (Examples 1 to 5) because the density of lead sulfate crystals was appropriate and the lead sulfate layer was appropriately formed when the step of preliminarily drying (primary drying) was finished, as compared to when the sulfuric acid temperature was 25°C or less (Comparative Example 1). When the sulfuric acid temperature is 25°C or less, it is necessary to grow lead sulfate crystals by raising the preliminary drying (primary drying) temperature and extending the drying time. When the sulfuric acid temperature is higher than 25°C, the preliminary drying (primary drying) can be completed in a shorter time as compared to when the sulfuric acid temperature is 25°C or less, thereby reducing the amount of energy for maintaining the temperature in the preliminary drying (primary drying) furnace.

[0050]

From the comparison between Examples 1 to 3 and Examples 4 and 5, it is observed that the high-rate discharge capacity was larger when the sulfuric acid temperature was set to 40°C to 60°C as compared to when the sulfuric acid temperature was lower than 40°C or higher than 60°C. When the sulfuric acid temperature is set to be high, large lead sulfate crystals are precipitated, which hinders the progress of the aging reaction. When the sulfuric acid temperature is set to be low, fine lead sulfate crystals are precipitated, and the lead sulfate layer hinders permeation and diffusion of sulfuric acid working as an electrolyte into the active material. Therefore, the initial capacity is considered to be lowered in either case. For this

reason, the condition that the sulfuric acid temperature is 40°C to 60°C (Examples 1 to 3) is particularly preferable in order to form a lead sulfate layer on an active material surface layer after the active material is filled.

[0051]

[Examples 6 to 9]

An electrode that had not been chemically converted was manufactured through the same steps as those for Example 1 except that the temperature and the specific gravity of the sulfuric acid to be dropped onto the peripheral surfaces of the rollers were varied as indicated in Table 2. It was verified whether or not the manufactured electrodes adhered to each other. The battery capacity of the lead-acid battery assembled using the electrodes was also verified.

[0052]

Whether or not the manufactured electrodes adhered to each other was evaluated in the same manner as in the evaluation test 1 discussed above.

[0053]

<Evaluation Test 3>

For the electrodes fabricated in Examples 1 and 6 to 9, a 0.1 CA discharge test was conducted under test conditions based on the JIS standard C 8704-2-1 to verify the low-rate discharge capacity. The discharge time before the final voltage was reached is also shown in Table 2 together with whether or not the electrodes adhered to each other.

[Table 2]

	Set values for sulfuric acid		Whether or not electrodes adhered to each other	Discharge time (min.)
	Temperature (°C)	Specific gravity (g/cm ³)		
Ex. 1	50	1.20	o	10.0
Ex. 6		1.10	o	9.9
Ex. 7		1.30	o	9.8
Ex. 8		1.05	o	9.4
Ex. 9		1.35	o	9.5

[0054]

As shown in Table 2, the electrodes did not adhere to each other when the sulfuric acid temperature was 50°C (constant) and the specific gravity was varied from 1.05 to 1.35 (Examples 1 and 6 to 9).

[0055]

From the comparison between Examples 1, 6, and 7 and Examples 8 and 9, it is observed that the low-rate discharge capacity was larger when the specific gravity of the sulfuric acid was set to 1.10 to 1.30 as compared to when the specific gravity of the sulfuric acid was lower or higher than that range. When the sulfuric acid specific gravity is set to be lower than 1.10 or set to be higher than 1.30, the low-rate discharge capacity tends to be lowered. When the sulfuric acid specific gravity is high, fine lead sulfate crystals are precipitated, and the lead sulfate hinders permeation and diffusion of sulfuric acid working as an electrolyte into the active material. When the sulfuric acid

specific gravity is low, large lead sulfate crystals are precipitated, which hinders the progress of the aging reaction. Therefore, the capacity is considered to be lowered in either case.

[0056]

As can be known from the results of Examples 1 to 9 and Comparative Example 1, it is the most preferable to apply sulfuric acid having a specific gravity of 1.10 to 1.30 and a temperature of 40°C to 60°C to the electrodes in order to suppress adhesion between the electrodes after filling of the active material and maintain the battery characteristics.

[0057]

[Examples 10 to 14 and Comparative Examples 2 to 5]

As the treatment of the active material-filled electrode with sulfuric acid, the surface of the active material-filled electrode, which had been pressed before the treatment with sulfuric acid, was immersed into sulfuric acid with varied conditions of the temperature and the specific gravity as indicated in Table 3 shown below. Thus, a lead sulfate layer was formed on the surface of the active material-filled electrode. An electrode that had not been chemically converted was manufactured through the same steps as those in Example 1 except for the step described above. In these examples, the thickness of the lead sulfate layer formed on the electrode surface was verified with respect to the specific gravity of the sulfuric acid. In addition, it was verified whether or not the manufactured electrodes adhered to each other. The battery capacity of the

lead-acid battery assembled using the electrodes was also verified.

[0058]

Whether or not the manufactured electrodes adhered to each other was evaluated in the same manner as in the evaluation test 1 discussed above. For the battery capacity, the low-rate discharge capacity was verified as in the evaluation test 3 discussed above.

[0059]

<Evaluation Test 4>

The sections of the electrodes fabricated in Examples 10 to 14 and Comparative Examples 2 to 5 were observed using an optical digital metallurgical microscope (MX-1200II manufactured by Nakaden International and having a magnification of 100 times), and the observed state was verified. From the verified state of the vicinity of the surface of the electrode, the relationship between the specific gravity of the sulfuric acid used in the treatment with sulfuric acid (the specific gravity of the sulfuric acid used for immersion) and the thickness of the lead sulfate layer formed on the electrode surface (the thickness of the acid-immersed layer due to intrusion of sulfuric acid) was verified. The results are indicated in Figs. 2 and 3 and Table 3 together with the corresponding sulfuric acid specific gravities.

[Table 3]

	Set values for sulfuric acid		Thicknes s of lead sulfate layer on electrod e surface (mm)	Whether or not electrodes adhered to each other	Discharge time (min.)
	Temperature (°C)	Specific gravity (g/cm ³)			
Comp. Ex. 2	40	1.00	0	X	9.3
Comp. Ex. 3		1.02	0.03	X	9.3
Comp. Ex. 4		1.05	0.06	X	9.4
Comp. Ex. 5		1.08	0.09	X	9.5
Ex. 10		1.10	0.12	o	9.9
Ex. 11		1.20	0.35	o	10.0
Ex. 12		1.30	0.48	o	9.8
Ex. 13		1.40	0.62	o	9.5
Ex. 14		1.50	0.79	o	9.4

[0060]

From Fig. 2 and Table 3, it was found that the thickness of the lead sulfate layer formed on the electrode surface was varied according to the specific gravity of sulfuric acid used in the treatment with sulfuric acid. From Figs. 2 and 3 and Table 3, adhesion between the electrodes was not observed when the thickness of the lead sulfate layer formed on the electrode surface was in the range of 100 μm to 800 μm (0.1 mm to 0.8 mm) (Examples 10 to 14). It was also found that the electrodes did not adhere to each other and a good discharge time was obtained

particularly when the thickness of the lead sulfate layer formed on the electrode surface was in the range of 100 μm to 500 μm (0.1 mm to 0.5 mm) (Examples 10 to 12).

[0061]

As can be known from the foregoing, the results of Examples 10 to 14 and Comparative Examples 2 to 5 indicate that the electrodes can be prevented from adhering to each other by controlling the treatment with sulfuric acid such that the thickness of the lead sulfate layer formed on the electrode surface after the preliminary drying is in the range of 100 μm to 800 μm . The results further indicate that the electrodes can be prevented from adhering to each other while maintaining the battery characteristics by controlling the treatment with sulfuric acid such that the thickness of the lead sulfate layer formed on the electrode surface after the preliminary drying is in the range of 100 μm to 500 μm (see Fig. 3).

[0062]

Although an embodiment of the present invention has been specifically described above, the present invention is not limited to the embodiment and the examples described herein. That is, the conditions described in the embodiment and the examples described above may be changed or modified based on the technical concept of the present invention unless specifically stated otherwise.

SIGN LISTING

[0063]

1, 2 Belt conveyor

3	Grid substrate
5	Filler
7	Active material-filled electrode
9A, 9B	Roller
11	Sulfuric acid bath
13	Heater (quartz glass heater)
14, 16	Tube
15	Sulfuric acid recovery tank
17	Preliminary drying furnace (Primary drying furnace)

CLAIMS

1. A method of manufacturing a lead-acid battery electrode, comprising the steps of:

filling a paste-like active material onto a grid substrate made of a lead alloy to fabricate an active material-filled electrode;

pressing the active material-filled electrode;

aging and drying the active material-filled electrode which has been pressed in the step of pressing to obtain an electrode that has not been chemically converted; wherein:

the method further comprises the steps of:

treating a surface of the active material-filled electrode with sulfuric acid that has a constant temperature higher than an ordinary temperature; and

preliminarily drying the active material-filled electrode which has been treated with the sulfuric acid in the step of treating with sulfuric acid before the active material-filled electrode is aged in the step of aging and drying;

the sulfuric acid used in the step of treating with sulfuric acid has a constant temperature adjusted in the range of 40°C to 60°C, and has a specific gravity adjusted in the range of 1.10 to 1.30 (at a temperature of 20°C);

the step of treating with sulfuric acid is included in the step of pressing;

in the step of pressing, a roll pressing machine provided with a pair of rollers having pressing surfaces is used to press the active material-filled electrode by causing the active

material-filled electrode to pass between the pair of rollers;
and

the sulfuric acid is infiltrated into the press surfaces of the pair of rollers and the sulfuric acid is applied to the surface of the active material-filled electrode when the active material-filled electrode passes between the pair of rollers.

2. A method of manufacturing a lead-acid battery electrode, comprising the steps of:

filling a paste-like active material onto a grid substrate made of a lead alloy to fabricate an active material-filled electrode;

pressing the active material-filled electrode; and

aging and drying the active material-filled electrode which has been pressed in the step of pressing to obtain an electrode that has not been chemically converted, wherein:

the method further comprises:

treating a surface of the active material-filled electrode with sulfuric acid that is adjusted to a constant temperature higher than an ordinary temperature; and

preliminarily drying the active material-filled electrode, the surface of which has been treated with the sulfuric acid in the step of treating with sulfuric acid, before the active material-filled electrode is aged in the step of aging and drying, wherein

the sulfuric acid used in the step of treating with sulfuric acid has a temperature that is adjusted in the range of 40°C to

60°C, and has a specific gravity that is adjusted in the range of 1.10 to 1.30 (at a temperature of 20°C).

3. The method of manufacturing a lead-acid battery electrode according to claim 2, wherein

a lead sulfate layer formed on the surface of the active material-filled electrode which has been preliminarily dried in the step of preliminarily drying has a thickness of 100 μm to 800 μm .

4. The method of manufacturing a lead-acid battery electrode according to claim 2, wherein

a lead sulfate layer formed on the surface of the active material-filled electrode which has been preliminarily dried in the step of preliminarily drying has a thickness of 100 μm to 500 μm .

5. The method of manufacturing a lead-acid battery electrode according to claim 2, 3, or 4, wherein the step of treating with sulfuric acid is performed at the same time as the step of pressing.

6. The method of manufacturing a lead-acid battery electrode according to claim 2, 3, or 4, wherein:

the step of treating with sulfuric acid is included in the step of pressing;

in the step of pressing, a roll pressing machine provided with a pair of rollers having pressing surfaces is used to press the active material-filled electrode by causing the active material-filled electrode to pass between the pair of rollers; and

the sulfuric acid is infiltrated into the press surfaces of the pair of rollers and the sulfuric acid is applied to the surface of the active material-filled electrode when the active material-filled electrode passes between the pair of rollers.