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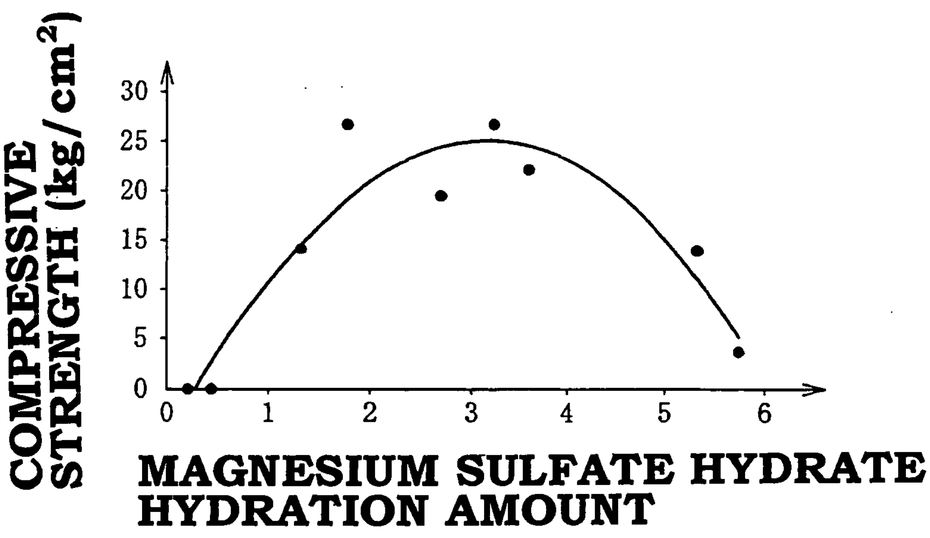
(54) Water-soluble casting mold and method for manufacturing the same

(57) In a water-soluble casting mold according to the present invention, after casting sand is obtained by adding a water-soluble binder containing an inorganic sulfate compound such as magnesium sulfate or the like easily solved in water and water to a refractory granular material for casting sand, the casting sand is dried by microwave radiation or the like in such a manner that the inorganic sulfate compound in the binder is kept retaining at least a portion of crystal water and accordingly, since the inorganic sulfate compound exists in hydrate state in the mold, the mold after drying is provided with good water-solubility and a sufficiently high strength as well, thereby it is possible to recover easily and use repeatedly the binder.

FIG. 1



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Description

[0001] The invention relates to a water-soluble casting mold and a method for manufacturing the mold, more particularly to a technique wherein a binder is water-soluble and repeatedly usable but the strength of a mold can be sufficiently maintained.

[0002] In the case of manufacturing a casting mold, techniques for coating refractory granular materials for casting sand such as siliceous sand with binders have widely been employed. The binders to be used in such cases can broadly be divided into organic binders and inorganic binders. Organic binders, in general, start decomposing at about 400°C, so that it is impossible to repeatedly recover the binders and use them. Therefore, in the case that it is required to recover binders and use them repeatedly, inorganic binders have often been used in many cases. Among the inorganic binders, specifically, if sulfate compounds such as magnesium sulfate that are easy to be dissolved in water are used, a mold can easily be collapsed only by immersing the mold in water after pouring a molten metal into the mold, and the binders can be easily recovered.

[0003] In casting process of an aluminum alloy cast such as a cylinder head or the like of an engine for automobiles, the molten metal pouring temperature reaches about 770°C. Accordingly, when the melting point of an inorganic sulfate compound in a binder to be used for a mold for an aluminum alloy cast is lower than 770°C, the inorganic sulfate compound is melted and vitrified and it becomes impossible to recover the binder after pouring the molten metal. Accordingly, an inorganic sulfate compound having a melting point of 770°C or higher should be used. Here, as such inorganic compound, magnesium sulfate or the like can be exemplified and conventionally, a variety of techniques for using the magnesium sulfate for casting molds has already been proposed.

[0004] For example, Japanese Patent Publication No. 46-4818 (Prior art 1) discloses, in pages 1 and 2 thereof, for example, a technique of forming magnesium sulfate itself as aggregate and using it as a water-soluble core for a high pressure die- casting. Also, Japanese Patent Laid-Open Publication No. 53-119724 (Prior art 2) discloses, in pages 1 and 2 thereof, for example, a technique of using magnesium sulfate as a binder for a refractory granular material for casting sand and mixing the refractory granular material with magnesium sulfate and water, thereafter forcibly drying the obtained mixture at a temperature of 200 to 300°C, thereby obtaining a mold. Further, Japanese Patent Laid-Open Publication No. 11-285777 (Prior art 3) discloses, in pages 3, 4 and Fig. 3 thereof, for example, a technique of obtaining a mold by using calcium sulfate and magnesium sulfate as binders and mixing a refractory granular material such as siliceous sand with the binders and drying the mixture at 350°C for 4 hours.

[0005] However, with respect to the mold described in the above-mentioned Prior art 1, since the magnesium sulfate itself is formed and used as aggregate for molding and the obtained mold is not provided with a sufficient ventilation property, a gas evolved from a metal to be cast at the time of pouring the molten metal cannot be discharged sufficiently. Therefore, obtained cast tends to have defects. With respect to the mold described in the above-mentioned Prior art 2, after the refractory granular material is mixed with magnesium sulfate and water, the mixture is dried forcibly at a temperature of 200 to 300°C, and since magnesium sulfate hydrate is dehydrated at a temperature of 200°C or higher, the magnesium sulfate in the obtained mold is supposed to be an anhydride. However, magnesium sulfate in the anhydride state has a rather decreased strength as compared with that in hydrate state containing crystal water. Therefore, in order to retain a sufficient strength of the mold, the addition amount of magnesium sulfate has to be increased and that is significantly disadvantageous in terms of moldability of the mold, easiness of drying, or recovery of the binder and results in decrease of working efficiency.

[0006] Further, with respect to the mold described in Prior art 3, drying is carried out in a temperature condition as high as 350°C and the bending strength of a test piece is found as extremely low as 0.04 kg/mm^2 in the case where magnesium sulfate is used alone as a binder for the test piece. Therefore, similarly to that of the foregoing Prior art 2, magnesium sulfate in the mold is supposed to be an anhydride. Accordingly, the addition amount of magnesium sulfate has to be considerably increased in order to maintain sufficient strength of the mold. Further, the solubility of calcium sulfate in water is at highest 0.210 g/100 g at 42°C, which is a rather low value, and therefore it cannot be suitable for practical use for the water-soluble mold.

[0007] The basic objects of the present invention are to make recovery of a binder easy and allow repeat use of the binder efficiently by using a binder containing water-soluble sulfate compounds as a main ingredient, and to assure sufficient strength of a mold by using an appropriate amount of the binder.

[0008] In accordance with a first aspect of the invention, there is provided a water-soluble casting mold comprising a refractory granular material for casting sand and a water-soluble binder containing at least one inorganic sulfate compound selected from magnesium sulfate, aluminum sulfate, sodium sulfate, nickel sulfate, manganese sulfate and wherein the inorganic sulfate compound contains crystal water in dry state.

[0009] The magnesium sulfate, aluminum sulfate, sodium sulfate, nickel sulfate, and manganese sulfate to be used as the inorganic sulfate compound contained in the binder for the mold respectively have good solubility in water. Accordingly, a mold obtained using the binder can easily be collapsed only by being submerged and it is possible to recover the binder, thereby it is possible to use the binder repeatedly, even if the mold is used as a core for a casting with a complicated shape. Further, these inorganic sulfate compounds respectively have a melting point of 770°C or higher. Accordingly, even if the mold is used to cast an aluminum alloy casting product such as an automotive part, since the pouring temperature of the molten metal for the aluminum alloy casting is generally at about 770°C, the sulfate compounds are prevented from melting and their vitrification can be avoided, and thus the binder can easily be recovered.

[0010] In general, an inorganic sulfate compound has a high strength in the hydrated state having crystal water as compared with that in the anhydride state having no crystal water. With respect to the water-soluble casting mold according to the present invention, since the inorganic sulfate compound of the binder contains crystal water in dry state, the strength of the mold is extremely high. It is to be noted that the binder is not limited to those containing only one inorganic sulfate compounds among a plurality of kinds of such sulfate compounds. The respective inorganic sulfate compounds show the maximum strength in prescribed hydrated states, and when the quantity of the contained crystal water is fluctuated owing to humidification deterioration or the like, the strength of the respective inorganic sulfate compounds is decreased. Also, at the time of drying the casting sand, it may be possible that the crystal water of the inorganic sulfate compounds is not evenly evaporated in the casting sand. Therefore, a plurality of the inorganic sulfate compounds are mixed at prescribed ratios and at the time of drying the casting sand, they are made to be a mixed crystal to make the peak of the strength moderate in relation to the quantity of the crystal water contained in the binder and consequently, the strength of the entire body of the mold can sufficiently be assured even if the quantity of the crystal water is fluctuated or the content of the crystal water in the mold is uneven.

[0011] In accordance with a second aspect of the invention, there is provided a water-soluble casting mold comprising 100 parts by weight of a refractory granular material for casting sand and a binder containing 0.5 to 10.0 parts by weight on the basis of magnesium sulfate equivalent to hepta-hydrate and wherein the magnesium sulfate contains crystal water in dry state. Since magnesium sulfate has good solubility in water, it is easy to recover a binder by collapsing the mold only by adding water after pouring molten metal. Further, the melting point of magnesium sulfate is 1,185°C and even if the mold is used to cast an aluminum alloy casting product such as an automotive part, since the pouring temperature of the molten metal of the aluminum alloy casting is generally about 770°C, magnesium sulfate is prevented from melting and its vitrification can be avoided, and thus the binder can easily be recovered.

[0012] Further, since the binder contains 0.5 to 10.0 parts by weight of magnesium sulfate, a sufficient strength of the mold can be assured with an appropriate amount of magnesium sulfate. That is, if the amount of magnesium sulfate is less than 0.5 parts by weight, the mold cannot be provided with a sufficient strength. On the other hand, if the amount of magnesium sulfate is more than 10.0 parts by weight, in the case of mixing the binder with the refractory granular material for casting sand, a large quantity of water for dissolving magnesium sulfate has to be added. This results in deterioration of the filling property of the casting sand in a die for molding the casting sand, and void formation of the mold because of evaporation of the large quantity of water contained in the casting sand when the casting sand is dried after the molding; and consequent strength decrease of the mold.

[0013] In one embodiment of the present invention, preferably, the magnesium sulfate contains crystal water equivalent to mono- to penta-hydrate in dry state. Since magnesium sulfate shows higher strength in the hydrate state than that in anhydride state, a sufficient strength of the mold can be assured by making magnesium sulfate have crystal water equivalent to mono- to penta-hydrate in dry state. Further, since magnesium sulfate exhibits the maximum strength in a form of tri- to tetra-hydrate, it is further preferable that magnesium sulfate in the mold has crystal water equivalent to tri to tetra-hydrate in dry state.

[0014] In one embodiment of the present invention, preferably, the binder contains the inorganic sulfate compounds and not more than 75% by weight of at least one of sodium dihydrogen phosphate and potassium dihydrogen phosphate. At the time of pouring molten metal, a portion of the mold becomes locally a high temperature and crystal water of the inorganic sulfate compounds is isolated, evaporated, and dehydrated. Thereby, the inorganic sulfate compounds become anhydrides to result in decrease of the strength. Consequently, at least one of sodium dihydrogen phosphate and potassium dihydrogen phosphate in an amount of 75% or less by weight is added to the inorganic sulfate compounds so as to retain the water-solubility of the mold and improve the heat resistance property

[0015] In one embodiment of the present invention, preferably, the binder contains the inorganic sulfate compounds and not more than 50% by weight of at least one of tricalcium phosphate, aluminum phosphate, trisodium phosphate, sodium diphosphate, and disodium hydrogen phosphate dodecahydrate. At the time of pouring molten metal, a portion of the mold becomes locally a high temperature and crystal water of the inorganic sulfate compounds is isolated, evaporated, and dehydrated. Thereby, the inorganic sulfate compounds become anhydrides to result in decrease of the strength. Consequently, at least one of tricalcium phosphate, aluminum phosphate, trisodium phosphate, sodium diphosphate, and disodium hydrogen phosphate dodecahydrate in an amount of 50% or less by weight is added to the inorganic sulfate compounds so as to retain the water-solubility of the mold and improve the heat resistance.

[0016] In one embodiment of the present invention, preferably, the binder contains the inorganic sulfate compounds and not more than 75% by weight of magnesium chloride. At the time of pouring molten metal, a portion of the mold becomes locally a high temperature and crystal water of the inorganic sulfate compounds is isolated, evaporated, and dehydrated. Thereby, the inorganic sulfate compounds become anhydrides to result in decrease of the strength. Consequently, magnesium chloride in an amount of 75% or less by weight is added to the inorganic sulfate compounds so as to retain the water-solubility of the mold and improve the heat resistance.

[0017] In accordance with a third aspect of the invention, there is provided a method for manufacturing a water-soluble casting mold including a first step of obtaining casting sand by mixing a refractory granular material for casting sand with a water-soluble binder containing at least one inorganic sulfate compound selected from magnesium sulfate, aluminum sulfate, sodium sulfate, nickel sulfate, and manganese sulfate and water; a second step of forming a mold with the resulting casting sand; and a third step of obtaining a casting mold by drying the casting sand in such a manner that the inorganic sulfate compound in the casting sand is kept retaining at least a portion of the crystal water.

[0018] In the case of producing the mold, first of all, in the first step, a water-soluble binder containing at least one inorganic sulfate compound selected from magnesium sulfate, aluminum sulfate, sodium sulfate, nickel sulfate, and manganese sulfate and water by which the binder is dissolved are added to and mixed with a refractory granular material such as siliceous sand or the like to obtain casting sand. In the second step, the obtained casting sand is formed into a prescribed mold. Further, in the third step, the molded casting sand is dried by heating or the like to remove water from the casting sand, and at that time, since the casting sand is dried in the state that the inorganic sulfate compound therein is kept retaining at least a portion of crystal water, the inorganic sulfate compound exists in hydrate state in the mold after the drying and consequently, the strength of the mold can be obtained.

[0019] Incidentally, in the third step, a method for drying the casting sand is preferably a method of evaporating water in the casting sand with a higher dielectric constant than that of the crystal water by irradiating microwave to the casting sand since water has to be removed while at least a portion of the crystal water being kept in the inorganic sulfate compound. However, unless the inorganic sulfate compound becomes an anhydride, any method other than such a method using microwave can be employed. Practically, a method for evaporating water with heat by supplying hot air to the mold, a method for hardening the casting sand by filling a heated die with the sand, a method for evaporating water by decreasing pressure after a mold is filled with the casting sand, and the like can be exemplified. Further, these methods can be employed in combination.

[0020] In accordance with a fourth aspect of the invention, there is provided a method for manufacturing a water-soluble casting mold including a first step of obtaining casting sand by mixing 100 parts by weight of a refractory granular material for casting sand with a binder containing 0.5 to 10.0 parts by weight of magnesium sulfate equivalent to hepta-hydrate and water in an amount sufficient to completely dissolve the magnesium sulfate in the binder; a second step of forming the resulting casting sand; and a third step of obtaining a mold by drying the casting sand in such a manner that the magnesium sulfate in the casting sand is kept retaining at least a portion of the crystal water.

[0021] In the case of manufacturing the mold, first of all, in the first step, a water-soluble binder containing magnesium sulfate heptahydrate in an amount of 0.5 to 10.0 parts by weight and water in an amount sufficient to completely dissolve the magnesium sulfate in the binder are added to and mixed with 100 parts by weight of a refractory granular material for casting sand such as siliceous sand or the like to obtain casting sand. In the second step, the obtained casting sand is formed into a prescribed mold. Further, in the third step, the molded casting sand is dried by heating or the like to remove water from the casting sand and at that time, since the casting sand is dried in the state that the magnesium sulfate therein is kept retaining at least a portion of crystal water, the magnesium sulfate exists in hydrate state in the mold after the drying and consequently, the strength of the mold can be obtained.

[0022] Further, in this case, since a proper quantity of water is added to completely dissolve magnesium sulfate, the binder is sufficiently mixed with the refractory granular material for casting sand and the refractory granular material for casting sand is reliably coated with the binder.

[0023] In addition, as explained above, a variety of methods employing microwave, hot air and the like can be applicable as a method for drying the casting sand.

[0024] In one embodiment of the present invention, preferably, the binder contains the inorganic sulfate compound and not more than 75% by weight of at least one of sodium dihydrogen phosphate and potassium dihydrogen phosphate. The water-solubility of the mold can be retained and the heat resistance is improved, by adding at least one of sodium dihydrogen phosphate and potassium dihydrogen phosphate in an amount of 75% or less by weight to the inorganic sulfate compound.

[0025] In one embodiment of the present invention, preferably, the binder contains the inorganic sulfate compound and not more than 50% by weight of at least one of tricalcium phosphate, aluminum phosphate, trisodium phosphate, sodium diphosphate, and disodium hydrogen phosphate dodecahydrate. The water-solubility of the mold can be retained and the heat resistance is improved, by adding at least one of tricalcium phosphate, aluminum phosphate, trisodium phosphate, sodium diphosphate, and disodium hydrogen phosphate dodecahydrate in an amount of 50% or less by weight to the inorganic sulfate compound.

[0026] In one embodiment of the present invention, preferably, the binder contains the inorganic sulfate compound and not more than 75% by weight of magnesium chloride. The water-solubility of the mold can be retained and the heat resistance is improved by adding magnesium chloride in an amount of 75% or less by weight to the inorganic sulfate compound.

[0027] In one embodiment of the present invention, preferably, the casting sand is dried by microwave or heating with hot air in the third step. When microwave is radiated to the casting sand, since water in the casting sand has a higher dielectric constant than that of the crystal water of the inorganic sulfate compound, the water in the casting sand is easily evaporated than that of the crystal water. Accordingly, the water can be removed while the inorganic sulfate compound is kept retaining at least a portion of the crystal water.

[0028] In the case where the casting sand is heated by blowing hot air to the casting sand, if the temperature of the hot air is set to be a prescribed temperature (e.g. 200°C) or lower at which the crystal water contained in the inorganic sulfate compound is not completely dehydrated, the water in the casting sand is evaporated prior at 100°C under a normal pressure condition and therefore, similarly to the above-mentioned drying by using microwave, the water can be removed while the inorganic sulfate compound is kept retaining at least a portion of the crystal water.

[0029] In one embodiment of the present invention, preferably, the second step of forming the casting sand is carried out by filling a cavity of a ventilative ceramic mold with the casting sand. Accordingly, at the time of drying the casting sand in the third step, the evaporated water can be released evenly to the outside from the ceramic mold, so that the strength of the manufactured mold can be made uniform.

Fig. 1 is a graph showing a correlation between a magnesium sulfate hydrate according to an embodiment of the invention and the compressive strength;
Fig. 2 is a graph showing a solubility of magnesium sulfate heptahydrate in water;
Fig. 3 is an explanatory drawing showing the filling work of casting sand into a die in the second step;
Fig. 4 is an explanatory drawing showing the drying work by microwave in the third step;
Fig. 5 is an explanatory drawing showing the filling work by hot air blow in the third step.

[0030] Hereinafter, the embodiments of the invention will be described. The embodiments are examples of the inventions applied to a casting mold of an aluminum alloy casting product and its manufacturing method. At first, a water-soluble casting mold according to the invention will be explained.

[0031] Firstly, a water-soluble casting mold containing a binder that contains magnesium sulfate hydrate which is to be mixed with a refractory granular material for casting sand such as flatterry siliceous sand or the like (hereinafter, referred to as a refractory granular material) will be described. In the case of manufacturing such a casting mold, magnesium sulfate heptahydrate and water sufficient to completely dissolve the magnesium sulfate heptahydrate are added to and mixed with the refractory granular material to coat the refractory granular material with the binder and obtain the casting sand. After the casting sand is formed into a prescribed shape by filling a mold with the sand, water in the casting sand is evaporated to obtain a mold.

[0032] In magnesium sulfate, the strength considerably fluctuates depending on the quantity of the crystal water contained therein. Fig. 1 shows the correlation between the hydration quantity of magnesium sulfate and the strength of the casting mold. It was obtained by the following experiments. That is, 100 parts by weight of flatterry siliceous sand is used as the refractory granular material and 3 parts by weight of magnesium sulfate heptahydrate and water are added thereto to obtain casting sand. Each specimen of the casting sand with a diameter of 30 mm and a height of 50 mm is formed by using a specimen beating and hardening apparatus standardized according to JIS Z 2601. Each specimen is formed by beating and hardening three times using the apparatus. The specimen is then dried by irradiating microwave of 700 W output. At that time, the drying duration (microwave radiation duration) is adjusted so as to alter the quantity of the crystal water contained in the magnesium sulfate in the specimen and the compressive strength of each specimen is measured. The quantity of the crystal water contained in magnesium sulfate of each specimen is determined by drying further magnesium sulfate at 300°C after drying with microwave until it becomes completely anhydride, assuming decrease of the weight of the specimen before and after the drying to be the crystal water contained in magnesium sulfate in the specimen, and carrying out calculation by mole ratio from the amount of magnesium sulfate added.

[0033] Hydrates of magnesium sulfates include mono, tetra, hepta, and dodeca hydrates and as shown in Fig. 1, about mono- to hexa-hydrates are applicable for a casting mold. Further, mono to penta-hydrates are preferable to provide strength. Accordingly, it is desirable for magnesium sulfate in the mold in dry state to have crystal water equivalent to mono to penta hydrates. Further, it is more desirable for magnesium sulfate to have crystal water equivalent to tri to tetra hydrates.

[0034] Next, the correlations of the addition amount of magnesium sulfate heptahydrate with compressive strength of the mold and the quantity of crystal water of magnesium sulfate will be described. Here, water is evaporated from each specimen, which is formed in the same manner as mentioned above, by a method of irradiating microwave of 700 W output for a prescribed duration and also by a method of blowing hot air at 200°C for 1 hour and then the strength of the specimen and the crystal water in magnesium sulfate are measured. Since the dielectric constant of water in the specimen is higher than that of the crystal water of magnesium sulfate, in the case of radiating microwave to the specimen, water is easily evaporated prior to the crystal water. Accordingly, the quantity of the crystal water contained in magnesium sulfate can be changed by adjusting the duration of microwave radiation. The results are shown in Table 1.

[Table 1]

	Drying method	Compressive strength kg/cm^2	Crystal water %	Conversion into hydrate	Remarks
magnesium sulfate heptahydrate 0.5 parts by weight	Microwave drying for 1 minute	0.6	0.23	3.09	In the case of using molten ceramic sand, 1.7 kg/cm^2 (microwave drying for 1 minute)
	Microwave drying for 3 minutes	0.2	0.1	1.34	
water 0.4 parts by weight	Drying at 200°C for 1 hour	0.0	0.01	0.13	
magnesium sulfate heptahydrate 1.0 parts by weight	Microwave drying for 1 minute	2.5	0.44	2.97	
	Microwave drying for 3 minutes	0.2	0.19	1.28	
water 0.8 parts by weight	Drying at 200°C for 1 hour	0.0	0.02	0.14	
magnesium sulfate heptahydrate 3.0 parts by weight	Microwave drying for 1 minute	25.8	0.76	1.75	
	Microwave drying for 3 minutes	13.8	0.57	1.31	
water 2.4 parts by weight	Drying at 200°C for 1 hour	0.0	0.1	0.23	
magnesium sulfate heptahydrate 5.0 parts by weight	Microwave drying for 1 minute	30.7	1.06	1.49	
	Microwave drying for 3 minutes	26.6	0.65	0.91	
water 4.0 parts by weight	Drying at 200°C for 1 hour	0.6	0.14	0.20	
magnesium sulfate heptahydrate 10 parts by weight	Microwave drying for 1 minute	57.0	2.12	1.56	
	Microwave drying for 3 minutes	28.9	1.09	0.80	
water 8.0 parts by weight	Drying at 200°C for 1 hour	1.0	0.32	0.24	
magnesium sulfate heptahydrate 12.5 parts by weight	Microwave drying for 1 minute	24.1	-	-	No normal specimen obtained at the time of drying. Voids existing in the inside
	Microwave drying for 3 minutes	27.0	-	-	
water 10 parts by weight	Drying at 200°C for 1 hour	0.0	-	-	
magnesium sulfate heptahydrate 15 parts by weight	Microwave drying for 1 minute	1.3	-	-	No normal specimen obtained at the time of drying. Voids existing in the inside
	Microwave drying for 3 minutes	15.9	-	-	
water 12 parts by weight	Drying at 200°C for 1 hour	8.0	-	-	
magnesium sulfate heptahydrate 20 parts by weight	Microwave drying for 1 minute	forming impossible	-	-	
	Microwave drying for 3 minutes	forming impossible	-	-	
water 16 parts by weight	Drying at 200°C for 1 hour	forming impossible	-	-	

[0035] As shown in Table 1, high compressive strength is obtained in the case of microwave drying for 1 minute and the quantity of crystal water in such a case is found equivalent to mono to trihydrate on the basis of hydrate. Specimens subjected to drying at 200°C for 1 hour are scarcely provided with compressive strength and the quantity of crystal water is less than monohydrate. The crystal water is supposed to be water absorbed from atmospheric air. In the case where the addition amount of magnesium sulfate heptahydrate is 0.5 parts by weight, the strength approximately same as that of a green sand mold is obtained. In the case where the addition amount of magnesium sulfate heptahydrate is 12.5 parts by weight or more, voids are formed in the inside of the specimens owing to evaporation of a large quantity of free water existing in the specimens at the time of drying of the specimens and consequently the strength is decreased.

[0036] On the other hand, in the case where the addition amount of magnesium sulfate heptahydrate is increased, the amount of water to be added so as to dissolve the magnesium sulfate heptahydrate is inevitably increased. Consequently, in the case of forming the casting sand, the filling property of the casting sand into a mold is significantly deteriorated. Especially, when a core with a complicated shape just like a core for a water jacket in an automotive engine is manufactured, the filling property is a particularly important matter. The strength needed for a casting mold and excellent filling property into a mold can be obtained in the case where the addition amount of the magnesium sulfate heptahydrate is in a range of 0.5 parts by weight to 10 parts by weight.

[0037] If magnesium sulfate heptahydrate is added alone, as shown in Fig. 1, the compressive strength becomes the maximum when the content of crystal water is a prescribed amount (crystal water equivalent to tri to tetrahydrate) and the crystal water in the casting mold is not necessarily evaporated uniformly at the time of drying. Further, magnesium sulfate has a problem that the amount of crystal water is fluctuated owing to moisture absorption to result in decrease of the strength. Therefore, investigations have been made so as to find whether it is possible or not that an inorganic sulfate compound is used in combination with magnesium sulfate to form a mixed crystal at the time of drying and the strength can be obtained with different mole ratios in relation to the crystal water and whether it is possible that the strength is hardly decreased at the time of moisture absorption. Table 2 shows the strength of each specimen after microwave drying, the compressive strength after moisture absorption, and results of a water-solubility test at 600°C.

[Table 2]

	water parts by weight	Compressive strength kg/cm²				600°C x 15 min firing, water-solubility test, dissolution state
		immediately after drying		after moisture absorption		
		Microwave (700W)		Microwave (700W)		
		1 minute	3minutes	1 minute	3minutes	
magnesium sulfate heptahydrate 3 parts by weight	2.4	28.7	16.3	15.8	14.2	collapsed in 4.1 seconds
magnesium sulfate heptahydrate 2.7 parts by weight aluminum sulfate dodecahydrate 0.3 parts by weight	2.4	26.9	26.7	18.4	22.1	collapsed in 8.5 seconds
magnesium sulfate heptahydrate 2.7 parts by weight aluminum sulfate 0.3 parts by weight	2.4	25.2	23.1	22.3	20.5	collapsed in 8.3 seconds
magnesium sulfate heptahydrate 2.7 parts by weight sodium sulfate decahydrate 0.3 parts by weight	2.4	17.2	25.2	10.1	11.1	collapsed in 4.9 seconds
magnesium sulfate heptahydrate 2.7 parts by weight nickel sulfate hexahydrate 0.3 parts by weight	2.4	26.3	24.2	20.9	20.2	collapsed in 14.0 seconds
magnesium sulfate heptahydrate 2.7 parts by weight manganese sulfate pentahydrate 0.3 parts by weight	2.4	17.3	22.9	19.9	18.2	collapsed in 4.3 seconds

[0038] Here, as another inorganic sulfate compound, aluminum sulfate dodecahydrate, aluminum sulfate, sodium sulfate decahydrate, nickel sulfate hexahydrate, and manganese sulfate pentahydrate are used. As the refractory granular material, flatterry siliceous sand is used. As a binder, magnesium sulfate heptahydrate 2.7 parts by weight and another inorganic sulfate compound 0.3 parts by weight are added to the refractory granular material and further water 2.4 parts by weight is added to obtain casting sand. The forming is carried out in the same manner as described above to obtain each specimen with a diameter of 30 mm and a height of 50 mm. Microwave radiation duration is set to be 1 minute and 3 minutes and the compressive strength is measured immediately after drying. Further, in order to absorb moisture in each specimen, the specimen after microwave drying is left for 24 hours in a desiccator containing water and after moisture absorption of the specimen in such a manner, the compressive strength is again measured.

[0039] The compressive strength is deteriorated after 3-minute microwave radiation in the case of using magnesium sulfate heptahydrate alone, meanwhile the strength decrease is prevented by using another inorganic sulfate compound in combination. Further, the strength after moisture absorption is more increased by adding aluminum sulfate dodecahydrate, aluminum sulfate, nickel sulfate hexahydrate, or manganese sulfate pentahydrate than adding solely magnesium sulfate heptahydrate and thus it is confirmed that the strength is improved after moisture absorption.

[0040] As another inorganic compound to be combined with magnesium sulfate, the following inorganic sulfates shown in Table 3 are preferable. They have a melting point of 770°C or higher, an average molten metal pouring temperature of an aluminum alloy casting product, and are thus not melted at the time of the pouring molten metal and are easy to be dissolved in water and to form a mixed crystal with magnesium sulfate.

[Table 3]

	solubility in 100 g of water	melting point
Magnesium sulfate	26.9g/100g (0°C)	1185 °C
Aluminum sulfate dodecahydrate	36.2g/100g (20°C)	770 °C
Aluminum sulfate	36.2g/100g (20°C)	770 °C
sodium sulfate decahydrate	19.4g/100g (20°C)	884 °C
nickel sulfate hexahydrate	39.7g/100g (20°C)	840 °C
Manganese sulfate pentahydrate	75.3g/100g (25°C)	850 °C

[0041] Specimens of casting molds containing binders containing these inorganic sulfate compounds, as shown in Table 2, are easily collapsed in water in a 600°C water-solubility test. The 600°C water-solubility test is carried out by firing each specimen subjected to 1-minute microwave radiation at 600°C for 15 minutes and immersing the specimen in water after cooling to find whether the specimen is collapsed or not. Incidentally, any inorganic compound may be used if it has a melting point of 770°C or higher and, similarly to the inorganic sulfate compounds shown in Table 3, has a high water-solubility at lowest 19.4 g (at 20°C), the minimum value of the solubility in 100 g water.

[0042] Further, Table4 to Table 7 show the compressive strength and the result of the 600°C water-solubility test of each specimen in the case where other inorganic sulfate compounds are added at different mixing ratios to magnesium sulfate heptahydrate.

[Table 4]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	aluminum sulfate dodecahydrate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	24.5	27.2	0.0	collapsed by stirring for 60 seconds or longer
50	50	32.7	37.6	0.0	collapsed by stirring for 60 seconds or longer

[Table 4] (continued)

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	aluminum sulfate dodecahydrate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
75	25	42	47.1	0.0	collapsed by stirring for 60 seconds or longer
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[Table 5]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	sodium sulfate decahydrate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	1.41	1.77	0.0	collapsed in 1.8 seconds
50	50	21.7	28.1	0.0	collapsed in 3.4 seconds
75	25	35.1	35.2	0.0	collapsed in 5.5 seconds
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[Table 6]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	nickel sulfate hexahydrate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	28.3	35.3	0.0	collapsed by stirring for 60 seconds or longer
50	50	26.5	32.3	0.0	collapsed by stirring for 60 seconds or longer

[Table 6] (continued)

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	nickel sulfate hexahydrate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
75	25	25.4	30.3	0.0	collapsed by stirring for 60 seconds or longer
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[Table 7]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min Bring, water-solubility test, dissolution state
magnesium sulfate heptahydrate	manganese sulfate pentahydrate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	0.4	1.5	1.5	collapsed in 2.3 seconds
50	50	22.5	14.4	0.2	collapsed in 3.6 seconds
75	25	19.4	23.6	0.0	collapsed in 5.1 seconds
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[0043] As the refractory granular material, flatterry siliceous sand is used and a binder 3 parts by weight in total and water 2.4 parts by weight are added to produce specimens. And a compressive test is carried out after the specimens are dried by microwave radiation and 1-hour drying at 200°C for reference data to find compressive strength. Even in the case where aluminum sulfate dodecahydrate, sodium sulfate decahydrate, nickel sulfate hexahydrate, and manganese sulfate pentahydrate are used alone as a binder, the strength is provided by drying with microwave radiation and also in the case where they are added to magnesium sulfate heptahydrate, the strength can be obtained. In any combination, the results of the 600°C water-solubility test are excellent and molds containing binders using those inorganic compounds in combination can easily be collapsed while being submerged. As being made clear from Table 4 to Table 7, especially in the case of mixing magnesium sulfate and aluminum sulfate, a high compressive strength can be obtained.

[0044] From the fact that no strength is exhibited in all of the combinations in the case of 1-hour drying at 200°C, it can be understood that crystal water is important to be left in the inorganic sulfate compound since no strength is obtained in the anhydride state. Also, it is no need to say that even if an anhydride of an inorganic sulfate compound is used for a binder, since a hydrate can be obtained at the time of water addition and therefore the same effect can be obtained.

[0045] Next, the case another inorganic compound is added to magnesium sulfate heptahydrate will be described. The average molten metal pouring temperature of an aluminum alloy cast is about 770°C and a portion of a mold locally becomes high temperature at the time of pouring molten metal, however crystal water of magnesium sulfate is isolated, evaporated, and dehydrated at 200°C or higher, and magnesium sulfate becomes an anhydride, so that the strength is decreased locally. For that, together with magnesium sulfate heptahydrate, another inorganic compound as described below is added to the refractory granular material so as to improve the heat resistance.

[0046] Table 8 and Table 9 show the compressive strength and the results of the 600°C water-solubility test given in the case of casting molds using sodium dihydrogen phosphate or potassium dihydrogen phosphate in combination with magnesium sulfate heptahydrate.

[Table 8]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	sodium dihydrogen phosphate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	7.5	11.1	4.8	Insoluble
10	90	11.3	12.0	7.2	Insoluble
25	75	29.9	31.9	32.2	collapsed by pressurizing for 60 seconds or longer
50	50	34.6	44.9	47.8	collapsed by pressurizing for 60 seconds or longer
66.7	33.3	32.3	40.4	31.1	collapsed by pressurizing for 60 seconds or longer
75	25	36.8	41.7	19.3	collapsed by pressurizing for 60 seconds or longer
90	10	25.2	31.8	13.2	collapsed by pressurizing for 60 seconds or longer
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[Table 9]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	potassium dihydrogen phosphate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	10.5	14.2	12.2	Insoluble
10	90	12.2	16.1	10.9	Insoluble
25	75	18.8	32.2	24.4	collapsed by pressurizing for 60 seconds or longer

[Table 9] (continued)

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	potassium dihydrogen phosphate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
50	50	24.9	30.0	21.3	collapsed by pressurizing for 60 seconds or longer
66.7	33.3	31.5	27.7	10.3	collapsed by pressurizing for 60 seconds or longer
75	25	30.4	25.1	10.6	collapsed by pressurizing for 60 seconds or longer
90	10	31.7	23.1	2.6	collapsed by pressurizing for 60 seconds or longer
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[0047] As the refractory granular material, flatterry siliceous sand is used and a binder 3 parts by weight in total and water 2.4 parts by weight are added to produce specimens and a compressive test is carried out after the specimens are dried by microwave radiation and 1-hour drying at 200°C for reference data to find compressive strength. Both of sodium dihydrogen phosphate and potassium dihydrogen phosphate are effective to give the strength even in the case of using them alone and therefore they are usable as a binder, however specimens become water-insoluble in the 600°C water-solubility test. If they are added in an amount of 75% or less by weight to magnesium sulfate heptahydrate, the specimens are collapsed into sand particles by stirring the specimens in water under pressurizing condition (described as collapsed by pressurizing for 60 seconds or longer) and show water-solubility. Further, since strength is exhibited even after 1-hour drying at 200°C, the heat resistance is excellent and various problems such as washing, deformation, cracking and the like of molds at the time of pouring molten metal can be solved. In addition, since both of sodium dihydrogen phosphate and potassium dihydrogen phosphate contribute to heat resistance improvement as described above, they can be mixed and in such a case, both are preferable to be added in an amount of 75% or less by weight to magnesium sulfate heptahydrate.

[0048] Next, Table 10 to Table 14 show the compressive strength and the results of the 600°C water-solubility test given in the case where molds are produced by using other inorganic phosphate compounds in combination with magnesium sulfate heptahydrate.

[Table 10]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	tricalcium phosphate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	0.0	0.0	0.0	--

[Table 10] (continued)

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	tricalcium phosphate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
50	50	6.2	4.3	0.5	collapsed by pressurizing for 60 seconds or longer
66.7	33.3	9.4	7.1	5.8	collapsed by pressurizing for 60 seconds or longer
75	25	12.6	15.2	4.2	collapsed by pressurizing for 60 seconds or longer
90	10	22.6	12.4	1.2	collapsed by pressurizing for 60 seconds or longer
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[Table 11]

mixing ratio of binder (%)		compressive strength kg/cm^2			
magnesium sulfate heptahydrate	aluminum phosphate	microwave drying		1-hour drying at 200°C	600°C × 15 min firing, water-solubility test, dissolution state
		1 minute	3 minutes		
0	100	0.0	0.0	0.0	--
50	50	5.9	4.0	0.9	collapsed by pressurizing for 60 seconds or longer
66.7	33.3	7.3	6.4	0.9	collapsed by pressurizing for 60 seconds or longer
75	25	12.9	9.7	0.7	collapsed by pressurizing for 60 seconds or longer
90	10	15.1	13.7	0.5	collapsed by pressurizing for 60 seconds or longer
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[Table 12]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	trisodium phosphate dodecahydrate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	0.0	0.0	0.0	--
50	50	0.7	0.6	0.3	collapsed by pressurizing for 60 seconds or longer
66.7	33.3	0.9	1.0	0.4	collapsed by pressurizing for 60 seconds or longer
75	25	5.4	3.2	0.3	collapsed by pressurizing for 60 seconds or longer
90	10	15.6	11.1	0.3	collapsed by pressurizing for 60 seconds or longer
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[Table 13]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	sodium diphosphate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	0.0	0.0	0.0	--
50	50	6.2	6.4	2.1	collapsed by pressurizing for 60 seconds or longer
66.7	33.3	17.7	23.3	4.2	collapsed by pressurizing for 60 seconds or longer
75	25	16.5	17.1	3.0	collapsed by pressurizing for 60 seconds or longer
90	10	19.8	15.0	1.4	collapsed by pressurizing for 60 seconds or longer
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[Table 14]

mixing ratio of binder (%)		compressive strength kg/cm^2			600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	disodium hydrogen phosphate dodecahydrate	microwave drying		1-hour drying at 200°C	
		1 minute	3 minutes		
0	100	0.2	0.1	0.1	--
50	50	3.2	2.9	0.9	collapsed by pressurizing for 60 seconds or longer
66.7	33.3	4.1	0.5	1.2	collapsed by pressurizing for 60 seconds or longer
75	25	7.2	3.2	2.3	collapsed by pressurizing for 60 seconds or longer
90	10	15.8	16.0	3.4	collapsed by pressurizing for 60 seconds or longer
100	0	25.8	13.8	0.0	collapsed in 4.1 seconds

[0049] As other inorganic phosphate compounds, tricalcium phosphate, aluminum phosphate, trisodium phosphate dodecahydrate, sodium diphosphate, and disodium hydrogen phosphate dodecahydrate are used. These phosphate compounds cannot give the strength if they are used alone and therefore, they cannot solely be used as a binder. However, in the case of mixing them in an amount of 50% or less by weight to magnesium sulfate, they give the compressive strength and assure the water-solubility in both cases; microwave drying and 1-hour drying at 200°C and therefore, they can be used as a binder.

[0050] Further, Table 15 shows the compressive strength test and the results of the 600°C water-solubility test given in the case where molds are produced by using magnesium chloride in combination with magnesium sulfate heptahydrate.

[Table 15]

mixing ratio of binder (%)		compressive strength kg/cm^2				600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	magnesium chloride	microwave drying			1-hour drying at 200°C	
		30 seconds	1 minute	3 minutes		
0	100	25.0	19.7	12.6	3.5	Insoluble
10	90	26.5	21.7	13.3	3.2	Insoluble
25	75	18.3	17.6	10.4	3.2	collapsed by pressurizing for 60 seconds or longer

[Table 15] (continued)

mixing ratio of binder (%)		compressive strength kg/cm^2				600°C × 15 min firing, water-solubility test, dissolution state
magnesium sulfate heptahydrate	magnesium chloride	microwave drying			1-hour drying at 200°C	
		30 seconds	1 minute	3 minutes		
50	50	19.0	12.6	6.0	2.9	collapsed by pressurizing for 60 seconds or longer
66.7	33.3	14.9	12.1	9.2	1.6	collapsed by pressurizing for 60 seconds or longer
75	25	10.5	9.9	7.2	0.6	collapsed by pressurizing for 60 seconds or longer
90	10	10.7	18.4	9.4	0.6	collapsed by pressurizing for 60 seconds or longer
100	0	3.7	25.8	13.8	0.0	collapsed in 4.1 seconds

[0051] Also, in the case of using magnesium chloride alone, the strength can be given and therefore magnesium chloride can be used alone as a binder, however the specimen becomes water-insoluble in the 600°C water-solubility test. On the other hand, in the case of using magnesium chloride in an amount of 75% or less by weight in combination with magnesium sulfate heptahydrate, water solubility is assured. Further, the strength is given even after 1-hour drying at 200°C and the heat resistance is thus improved and various problems such as washing, deformation, cracking and the like of casting molds at the time of pouring molten metal can be solved. In addition, in the case of drying with microwave radiation, high strength can be given by radiation for a duration as short as 30 seconds, the productivity of forming the molds can be improved.

[0052] With respect to the water-soluble casting molds described above, Table 16 shows the compressive strength in the case of producing molds by using magnesium sulfate heptahydrate alone for a variety of refractory granular materials, which are used commonly, or adding other inorganic sulfate compounds having a melting point of 770°C or higher and showing water-solubility at various mixing ratios to magnesium sulfate heptahydrate and drying in various drying manners. As reference example, Table 17 shows the results of a confirmation test for the molds described in the foregoing Prior art 2.

[Table 16]

	refractory granular material for casting sand	binder		water parts by weight	drying method	compressive strength kg/cm^2
		type of binder	parts by weight			
Example-1	melted ceramic sand 100 parts by weight	magnesium sulfate heptahydrate 100%	1.5	1.2	1-minute microwave drying	17.6
Example-2	flatterry siliceous sand 100 parts by weight	magnesium sulfate heptahydrate 100%	5.0	---	after vapor ventilation, 1-minute microwave drying	44.4
Example-3	flatterry siliceous sand 100 parts by weight	magnesium sulfate heptahydrate 100%	3.0	1.0	1-minute microwave drying after addition of a solution containing a binder and water after heating to 100°C.	15.4
Example-4	flatterry siliceous sand 100 parts by weight	magnesium sulfate heptahydrate 100%	3.0	2.0	1-minute microwave drying after addition of a binder and water to casting sand heated at 100°C.	15.0
Example-5	flatterry siliceous sand 100 parts by weight	magnesium sulfate heptahydrate 100%	3.0	1.0	adding a binder and water at 100°C to casting sand at 100°C and then purging heated air..	12.2
Example-6	flatterry siliceous sand 100 parts by weight	magnesium sulfate heptahydrate 100%	3.0	1.8	3-minute heating of casting sand at 100°C in a mold at 120°C and then at purging heated air.	9.9

[Table 16] (continued)

	refractory granular material for casting sand	binder		water parts by weight	drying method	compressive strength kg/cm^2
		type of binder	parts by weight			
Example-7	flatterry siliceous sand flatterry siliceous sand 100 parts by weight	magnesium sulfate heptahydrate 100%	3.0	1.0	adding a binder and water at 100°C to casting sand at 100°C and then purging heated air.	11.3
Example-8	flatterry siliceous sand 100 parts by weight	magnesium sulfate heptahydrate 100%	3.0	1.0	adding a binder and water at 100°C to casting sand at 100°C and then dehydrating by reducing pressure.	9.0
Example-9	melted ceramic sand 100 parts by weight	magnesium sulfate heptahydrate 75% aluminum sulfate dodecahydrate 25%	1.5	1.2	1-minute microwave drying	20.9
Example-10	melted ceramic sand 100 parts by weight	magnesium sulfate heptahydrate aluminum sulfate dodecahydrate 50% 25% sodium sulfate decahydrate 25%	1.5	1.2	1-minute microwave drying	24.7
Example-11	melted ceramic sand 100 parts by weight	magnesium sulfate heptahydrate sodium dihydrogen phosphate 75% 25%	1.5	1.2	1-minute microwave drying	28.9

[Table 16] (continued)

	refractory granular material for casting sand	binder		water parts by weight	drying method	compressive strength kg/cm^2
		type of binder	parts by weight			
Example-12	melted ceramic sand 100 parts by weight	magnesium sulfate heptahydrate 50% aluminum sulfate dodecahydrate 25% sodium dihydrogen phosphate 25%	1.5	1.2	1-minute microwave drying	27.3

[Table 17]

	refractory granular material for casting sand	binder		water parts by weight	drying method	compressive strength kg/cm^2
		type of binder	parts by weight			
Comparative Example-1	Albany siliceous sand 100 parts by weight	magnesium sulfate heptahydrate 100%	10.0	3.0	drying at 200°C	0.0
Comparative Example-2	Albany siliceous sand 100 parts by weight	magnesium sulfate heptahydrate 100%	20.0	5.0	drying at 300°C after addition of a solution containing a binder and water to casting sand heated at 80°C	0.8

[0053] From the results shown in Table 16 and Table 17, it is confirmed that molds in the scope of the invention are produced with a small amount of a binder and are provided with sufficiently high compressive strength as compared with molds described in Prior art 2. As mixing examples of the binder in the invention, based on the data of the compressive strength and the collapsing property of molds of the respective tables, the mixture of magnesium sulfate and aluminum sulfate, the mixtures of magnesium sulfate with sodium dihydrogen phosphate and potassium dihydrogen phosphate, the mixtures of magnesium sulfate with aluminum sulfate, sodium dihydrogen phosphate and potassium dihydrogen phosphate are preferable examples.

[0054] Incidentally, as the refractory granular material, any type can be used if it can be used as casting sand and has a particle size satisfying an average particle diameter in a range from about 0.05 mm (280 mesh) to 1 mm (16 mesh). The following are examples of a variety of refractory granular materials for casting sand such as domestically produced siliceous sand, imported siliceous sand, zircon sand, chromite sand, olivine sand, slag sand, carbon sand, mullite sand, alumina sand, chamotte sand, ceramic sand, porous ceramic sand, melted ceramic sand, various glass sand, hollow glass spherical sand, crushed materials of various refractory materials, metal granular materials such as shot beads, and their reproduced sand.

[0055] The casting sand or the binder may also contain a prescribed amount of a rouge, an iron powder, a coal powder, a graphite powder, a wood powder, a talc, a starch powder, a grain powder, a silica flour, a zircon flour, an olivine flour and the like, which are commonly added to casting sand for preventing casting defects.

[0056] Further, the casting sand or the binder may contain a prescribed amount of tungsten disulfide and molybdenum disulfide as an inorganic lubricant and a hydrocarbon-based lubricant, polyalkylene glycol, a silicone-based lubricant, a fluoro type lubricant, phenyl ether, and a phosphoric acid ester type lubricant as an organic lubricant for improving the filling property into a mold.

[0057] Further, materials generally applied to the surface of a casting mold such as an alcohol-based mold wash, a water-based mold wash, a powder-based mold wash, a surface stabilizer, a tellurium powder for preventing shrinkage can be used.

[0058] Next, a method for manufacturing a casting mold by using a water-soluble binder containing the above-mentioned various inorganic sulfate compounds will be described. The mold manufacturing method is an example in which the invention is applied as a core for aluminum alloy casting.

[0059] The mold manufacturing method include a first step of obtaining casting sand by mixing a refractory casting sand with the above-mentioned water-soluble binder containing inorganic sulfate compounds and water; a second step of forming the resulting casting sand; and a third step of obtaining a mold by drying the casting sand in such a manner that the inorganic sulfate compounds in the casting sand are kept retaining at least a portion of the crystal water.

[0060] At first, in the first step, the binder to be added to the refractory casting sand includes inorganic sulfate compounds having a melting point equal to or higher than the average molten metal pouring temperature (770°C) of aluminum alloy casting. Practically, as described above, the binder includes magnesium sulfate heptahydrate alone; mixtures of magnesium sulfate heptahydrate with other inorganic sulfate compounds such as aluminum sulfate or the like; or solely another inorganic sulfate compound. Further, mixtures containing a variety of the foregoing phosphate compounds such as sodium dihydrogen phosphate or the like and magnesium chloride in a prescribed amount with which the water-solubility can be assured may be used in order to improve the heat resistance of the binder.

[0061] The addition amount of water is desirable to be satisfactory to dissolve the binder. That is because the binder can be applied evenly to the refractory granular material and gives high strength only in the case where the binder is dissolved. However, the solubility differs depending on the temperature. For example, in the case where the refractory granular material is previously heated at 200°C (the temperature at which crystal water in the inorganic sulfate compounds is dehydrated) or lower or in the case where the mold is dried by heating at 200°C or lower, the solubility of the binder is increased because water is heated. Accordingly, the minimum amount of water to be added in the first step is an amount sufficient to completely dissolve the binder at 200°C and the maximum amount is the amount sufficient to completely dissolve the binder at around a normal temperature.

[0062] The boiling point of water in atmospheric air is 100°C, however the boiling point is increased by pressurization. Fig. 2 shows the solubility of magnesium sulfate heptahydrate in water at different water temperatures. As being understood, the solubility of magnesium sulfate is also increased as the temperature of water is increased. For example, the solubility at 0°C is 53.9% and in such a case, the ratio of water to be added is 46.1 to a binder 53.9. On the other hand, the solubility at 200°C is 95.5% and the ratio of water is 4.5 to a binder 95.5 to make it possible to considerably decrease the water addition amount. However, since it is rather industrially difficult to assemble an apparatus for pressurizing water and increasing the boiling point of water to 200°C in a molding machine, around 100°C is supposed to be the maximum limit. The concentration at 100°C is 74.7% and in such a case, the water content is 15.3 to a binder 74.7.

[0063] Next, as shown in Fig. 3, in the second step, the casting sand S obtained in the first step is blown to a cavity 2 of a ventilative ceramic die 1 for forming a core. The ceramic die 1 is composed of an upper and a lower separate die parts 1a and 1b. The ceramic die is covered with a case member 3 made of an aluminum. When the casting sand S is packed in the cavity 2, pressurized air is supplied to a blow head 4 installed on the top part of the ceramic die 1 and the casting sand S is blown into the cavity 2 of the ceramic die 1 for forming a core through the blow nozzle 5 and thus the casting sand S is compressed and filled into the cavity 2 to form the casting sand S in a prescribed shape.

[0064] Further, as shown in Fig. 4, in the third step, while a stirrer 6 being rotated so as to evenly radiate microwave to the ceramic die 1 filled with the casting sand S, microwave is radiated for a prescribed period from a magnetron 7. Being transmitted through the ceramic die 1, the microwave works on the casting sand S in the cavity 2. At that time, although water exists in two states; free water and crystal water of inorganic sulfate compounds; since free water has a higher dielectric constant than that of the crystal water, free water is easily evaporated prior to crystal water and accordingly, free water in the casting sand S can be evaporated in such a state that the inorganic sulfate compounds in the casting sand are kept retaining at least a portion of crystal water. The moisture generated by evaporation is discharged to the outside of the ceramic die by a suction pump 8 through a suction hood 9 and a suction hose 10. Since the inorganic sulfate compounds in the binder contain crystal water even in dry state by drying the casting sand in such a manner to result in exhibition of strength, the resulting mold obtained by such drying can surely be provided with a sufficient strength.

[0065] Since the ceramic die 1 has the ventilation property, the evaporated moisture can be released uniformly to the outside from the ventilative ceramic die 1. Therefore, unevenness in the quantity of crystal water contained in the inorganic sulfate compounds can be restrained as small as possible and the strength of the obtained mold can be made uniform.

[0066] A die forming the cavity 2 is not necessarily limited to the ceramic die 1 and may be any die made of another material such as a die made of a synthetic resin if it can transmit microwave.

[0067] In the third step, the casting sand S may be dried by supplying hot air to the die filled with the casting sand S and heating the casting sand S by the hot air. That is, as shown in Fig. 5, hot air is supplied through an air hose 12 to an air hood 11 formed in the upper part of the die 1 and hot air is supplied to the die 1 from the air hood 11 to heat the casting sand S packed in the cavity 2 of the die 1. In that case, it is required to supply the hot air at a proper temperature (for example, 200°C or lower) for a sufficient supply time to avoid dehydration of the inorganic sulfate compounds in the casting sand S.

[0068] The following methods are also applicable: a method for filling the casting sand into a die heated to 200 °C or lower, thereby hardening the casting sand; a method for packing the casting sand heated at 200°C or lower in a die so as to evaporate water and thereby hardening the casting sand; a method for packing the casting sand in a die and then evaporating water by decreasing the pressure; and the like. Any method can be employed if the method is capable of drying the casting sand in such a manner that the inorganic sulfate compounds contained in the binder are kept retaining crystal water.

[0069] The following effects can be provided by a water-soluble casting mold of the invention and a method for manufacturing the casting mold.

1) Since a water-soluble casting mold is constituted by using a binder containing inorganic sulfate compounds having high solubility in water, the mold can easily be collapsed by being submerged into water, and it is possible to recover easily the binder and make the binder repeatedly usable at a high efficiency. Further, since the melting point of the inorganic sulfate compounds is 770°C or higher, when the mold is used for molding an aluminum alloy castings, the inorganic sulfate compounds are prevented from melting and vitrification. Therefore, the binder can easily be recovered. Further, the gas generated at the time of casting is only steam and therefore, the casting work can be carried out in safe environmental conditions.

The inorganic sulfate compounds have higher strength in the hydrate state containing crystal water than that in the anhydride state, and in the dry state of the water-soluble casting mold of the invention, since the inorganic sulfate compounds of the binder contain crystal water, sufficiently high strength of the mold can be assured. Further, a plurality of types of inorganic sulfate compounds are mixed at prescribed ratios to form a mixed crystal at the time of drying the casting sand, so that the peak for exhibiting the strength in the entire binder can be moderated and the strength can be obtained in a wide range of mole ratios and accordingly, even if the quantity of the crystal water fluctuates or the content of the crystal water in the mold is rather variable, the strength of the entire body of the mold can sufficiently be retained.

2) Since the binder contains 0.5 to 10.0 parts by weight of magnesium sulfate, the mold is provided with sufficient strength with a proper amount of magnesium sulfate and the amount of water to be added to dissolve magnesium sulfate can be suppressed and therefore, the filling property of the casting sand is kept excellent. Further, since magnesium sulfate can bring strength more in hydrate state, particularly in form of tri to tetrahydrate state, than in dehydrated state, proper strength of the mold can be assured by setting magnesium sulfate in the mold to contain crystal water equivalent to mono- to pentahydrate in dry state.

3) Use of a binder obtained by mixing at prescribed ratios of phosphate compounds and magnesium chloride with the inorganic sulfate compounds makes it possible to assure the water-solubility of the mold and improve the heat resistance at the time of pouring molten metal.

4) At the time of manufacturing a water-soluble casting mold, casting sand obtained by adding a water-soluble binder containing inorganic sulfate compounds and water in a proper amount to solve the inorganic sulfate compounds to the refractory granular material is dried by radiating microwave, so that free water in the casting sand which has a higher dielectric constant than crystal water contained in the inorganic sulfate compounds can easily be evaporated prior and the casting sand can be dried in such a manner that the inorganic sulfate compounds are kept retaining at least a portion of crystal water. The same effects can be obtained by supplying hot air to the casting sand at a prescribed temperature or lower at which the inorganic sulfate compounds are dehydrated.

5) At the time of manufacturing a water-soluble casting mold, the casting sand is formed by filling a cavity of a ventilative ceramic die with the casting sand and in the case of drying the casting sand after formation, the evaporated moisture can be released evenly to the outside from the ventilative ceramic die. Accordingly, unevenness in the content of crystal water in the inorganic sulfate compounds can be restrained as small as possible and consequently, the strength of the mold can be made uniform.

Claims

1. A water-soluble casting mold comprising a refractory granular material for casting sand and a water-soluble binder containing at least one inorganic sulfate compound selected from magnesium sulfate, aluminum sulfate, sodium sulfate, nickel sulfate, manganese sulfate, wherein the inorganic sulfate compound has crystal water in dry state.

2. A water-soluble casting mold comprising 100 parts by weight of a refractory granular material for casting sand and a binder containing 0.5 to 10.0 parts by weight of magnesium sulfate heptahydrate, wherein the magnesium sulfate has crystal water in dry state.

3. The water-soluble casting mold according to claim 2, wherein the magnesium sulfate has crystal water equivalent to mono- to penta-hydrate in dry state.

4. The water-soluble casting mold according to claim 1, wherein the binder contains the inorganic sulfate compound and not more than 75% by weight of at least one of sodium dihydrogen phosphate and potassium dihydrogen phosphate.

5. The water-soluble casting mold according to claim 1, wherein the binder contains the inorganic sulfate compound and not more than 50% by weight of at least one of tricalcium phosphate, aluminum phosphate, trisodium phosphate, sodium diphosphate, and disodium hydrogen phosphate dodecahydrate.

6. The water-soluble casting mold according to claim 1, wherein the binder is a mixture of the inorganic sulfate compound and not more than 75% by weight of magnesium chloride.

7. A method for manufacturing a water-soluble casting mold including a first step of obtaining casting sand by mixing a refractory granular material for casting sand with a water-soluble binder containing at least one inorganic sulfate compound selected from magnesium sulfate, aluminum sulfate, sodium sulfate, nickel sulfate, and manganese sulfate and water; a second step of forming the resulting casting sand; and a third step of obtaining a mold by drying the casting sand in such a manner that the inorganic sulfate compound in the casting sand is kept retaining at least a portion of the crystal water.

8. A method for manufacturing a water-soluble casting mold including a first step of obtaining casting sand by mixing 100 parts by weight of a refractory granular material for casting sand with a binder containing 0.5 to 10.0 parts by weight on the basis of magnesium sulfate heptahydrate and water in an amount sufficient to completely dissolve the magnesium sulfate in the binder; a second step of forming the resulting casting sand; and a third step of obtaining a mold by drying the casting sand in such a manner that the magnesium sulfate in the casting sand is kept retaining at least a portion of the crystal water.

9. The method for manufacturing a water-soluble casting mold according to claim 7, wherein the binder contains the inorganic sulfate compound and not more than 75% by weight of at least one of sodium dihydrogen phosphate and potassium dihydrogen phosphate.

10. The method for manufacturing a water-soluble casting mold according to claim 7, the binder contains the inorganic sulfate compound and not more than 50% by weight of at least one of tricalcium phosphate, aluminum phosphate, trisodium phosphate, sodium diphosphate, and disodium hydrogen phosphate dodecahydrate.

11. The method for manufacturing a water-soluble casting mold according to claim 7, wherein the binder is a mixture of the inorganic sulfate compound and not more than 75% by weight of magnesium chloride.

12. The method for manufacturing a water-soluble casting mold according to any one of claims 7 to 11, wherein the third step is carried out by drying the casting sand with microwave or hot air heating.

13. The method for manufacturing a water-soluble casting mold according to any one of claims 7 to 12, wherein forming in the second step is carried out by filling a cavity of a ventilative ceramic mold with the casting sand.

FIG. 1

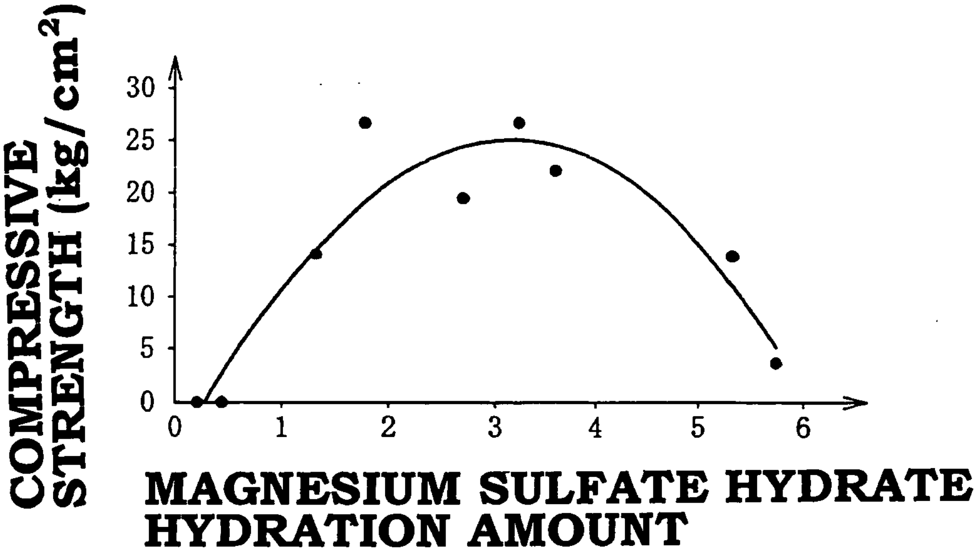

COMPRESSIVE STRENGTH (kg/cm²)
30
25
20
15
10
5
0
0
1
2
3
4
5
6
MAGNESIUM SULFATE HYDRATE HYDRATION AMOUNT

FIG. 2

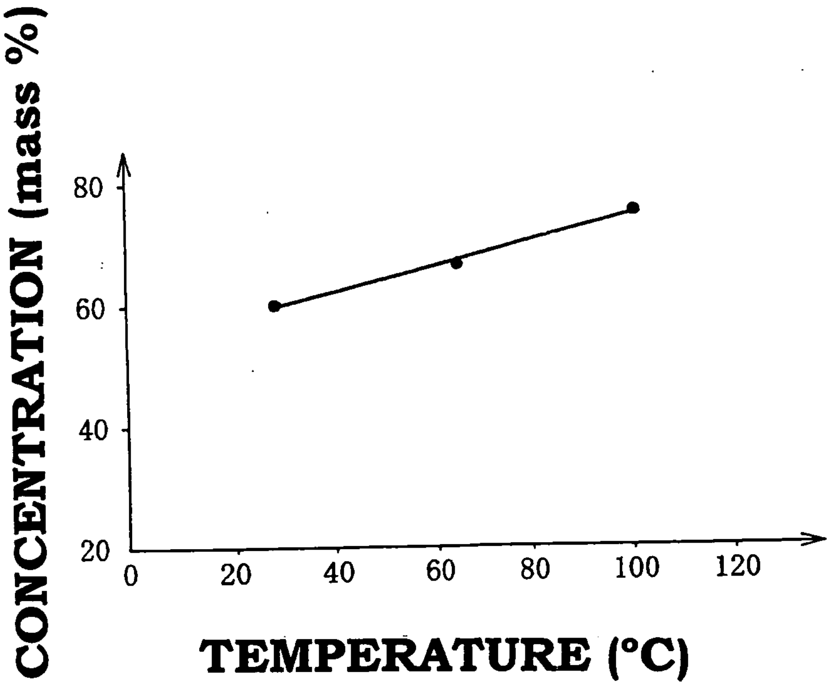

CONCENTRATION (mass %)
80
60
40
20
0
20
40
60
80
100
120
TEMPERATURE (°C)

FIG. 3

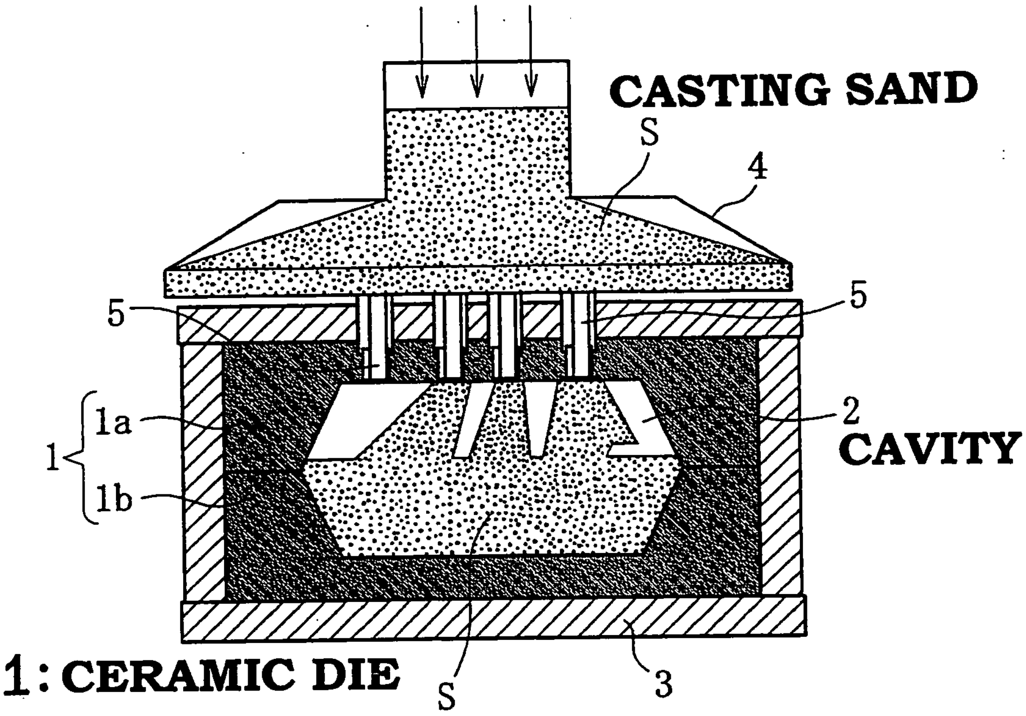

CASTING SAND
S
4
5
5
1a
1
1b
2
CAVITY
1: CERAMIC DIE
S
3

FIG. 4

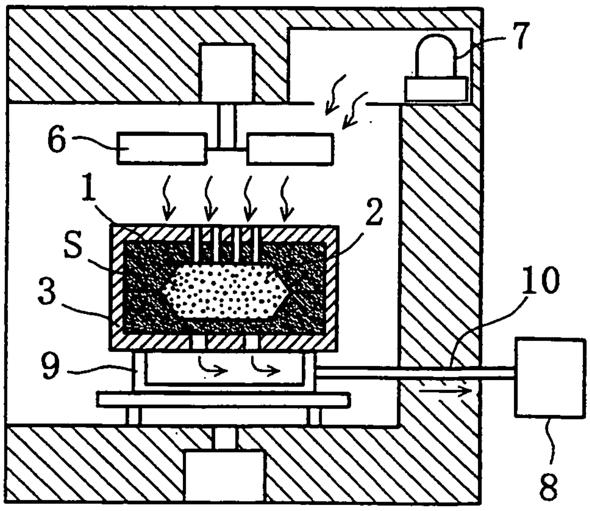
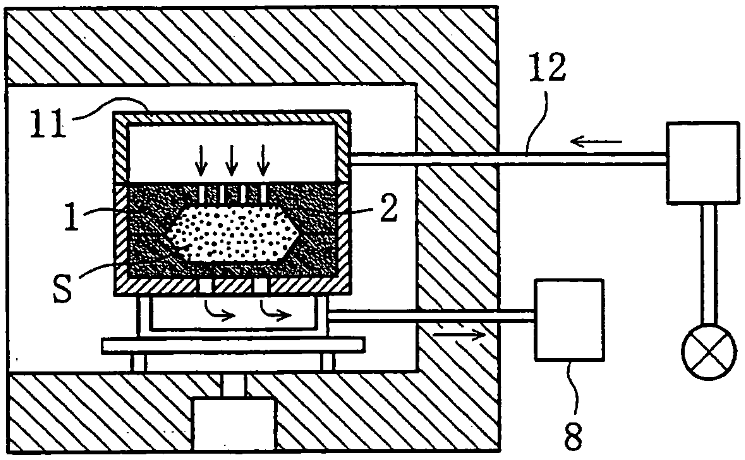

7
6
1
2
S
3
10
9
8

FIG. 5



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EUROPEAN SEARCH REPORT

Application Number
EP 04 00 3620

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	4 May 2004	Lombois, T

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
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