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(54) DRAWLESS PRESS ALUMINIUM ALLOY FIN MATERIAL FOR HEAT EXCHANGER, AND MANUFACTURING METHOD FOR SAME

(57) Aluminum alloy fin material, which is drawless-press fin material, is for a heat exchanger, and exhibits excellent collar-cracking resistance which can suppress the occurrence of collar cracking during a forming process, is formed from aluminum alloy material which contains 0.010 - 0.4 mass% of Fe, the remainder of which is formed from Al and unavoidable impurities, and in which the Al purity is at least 99.30 mass%. The drawless-press aluminum alloy fin material for a heat exchanger is characterized by having a thickness of less than 0.115 mm, having a subgrain average particle diameter of 2.5 μm or less and proof stress of at least 130 N/mm^2. The material is further characterized in that intermetallic compounds having a maximum length which exceeds 3 μm are not more than 2,000/mm^2.

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Description

Technical Field

[0001] The present invention relates to a drawless-press heat-exchanging aluminum alloy fin material for use in heat exchangers; and a manufacturing method for the fin material.

Background Art

[0002] Air conditioners recently employ non-CFC (non-chlorofluorocarbon) refrigerants instead of CFCs to meet controlling of the production and consumption of CFCs. The air conditioners are to have smaller sizes and smaller weights, or to exhibit higher functions. To meet these requirements, heat-exchanging aluminum alloy fin materials for use in heat exchangers typically of air conditioners require smaller and smaller thicknesses. Such fin materials are hereinafter also conveniently referred to as "fin material(s)". For example, some aluminum alloy fin materials have small thicknesses of about 0.15 mm or less, and some recent ones have further smaller thicknesses of down to about 0.09 mm.

[0003] Fin forming processes are categorized as a drawing process, a drawless process, and a drawing-drawless hybrid process (combination process). The draw process includes the steps of bulging, drawing, piercing-burring, and reflaring. The drawless process includes the steps of piercing-burring, ironing, and reflaring. The combination process mainly includes the steps of bulging, drawing, piercing-burring, ironing, and reflaring.

[0004] Any of the forming processes essentially includes the piercing-burring step and reflaring step for the formation of collars around holes for copper tubes to form fins. The forming steps, however, act severely upon fin materials designed to have small thicknesses of 0.15 mm or less. Fin materials having better workability have been developed to meet such reduction requirements in thickness.

[0005] Typically, Patent Literature (PTL) 1 discloses an aluminum alloy fin material having a thickness of 0.15 mm or less and has satisfactory forming workability. Specified are the grain size of intermetallic compounds, and maximum length and average subgrain size of grains with large angle grain boundaries to predetermined levels for this aluminum alloy fin material. PTL 2 discloses a heat-exchanging aluminum alloy fin material having a thickness of less than 0.11 mm, containing Fe and Ti in predetermined contents, having Si and Cu contents controlled to predetermined levels or less, and having a predetermined elongation percentage. This aluminum alloy fin material excels in resistance to the "avec phenomenon" (fin-pitch disorder) and in stacking properties. The "resistance to "avec phenomenon"" refers to resistance to contact with an adjacent fin due to heterogeneous deformation upon tube expansion. PTL 3 discloses a heat-exchanging aluminum alloy fin material having a thickness of less than 0.11 mm and containing predetermined elements in predetermined contents. This aluminum alloy fin material has satisfactory resistance to the "avec phenomenon". PTL 4 discloses a high-strength aluminum alloy thin sheet for the formation of fins by the drawless process, and a manufacturing method of the aluminum alloy thin sheet. The aluminum alloy thin sheet has a thickness of 0.115 mm after cold rolling and contains predetermined elements in predetermined contents.

Citation List

Patent Literatures

[0006]

PTL 1: Japanese Unexamined Patent Application Publication No. 2006-104488
PTL 2: Japanese Patent No. 4275560
PTL 3: Japanese Unexamined Patent Application Publication No. 2005-126799
PTL 4: Japanese Unexamined Patent Application Publication No. S 64-8240

Summary of Invention

Technical Problem

[0007] Those conventional fin materials, however, have disadvantages as follows. While the customary technologies are intended to improve workability, demands are still made to further improve workability. This is because heat exchangers are demanded to have further smaller sizes and lighter weights or to have further higher functions, and thus, fin materials having improved workability are demanded.

[0008] Fin materials may often suffer from cracks called "collar cracks" during forming. Specifically, fine cracks are generated at worked edges during the piercing-burring step and become collar cracks in the final reflare forming. Collar cracks, if generated, may facilitate the occurrence of the so-called "avec phenomenon" in which pitches of stacked fins are extremely narrowed when a copper tube is passed through a collared hole and is expanded in a formed article after fin forming. The avec phenomenon disadvantageously increases draft resistance of the heat exchanger. Specifically, collar cracks disadvantageously not only impair appearance of fins but also cause troubles such as insufficient performance of the heat exchanger to thereby impair the product value. To prevent this, demands have been made to develop a fin material that is resistant to the generation of collar cracks (has collar-cracking resistance). The fin material disclosed in PTL 1 is intended to have better collar-cracking resistance. The fin material, however, may disadvantageously suffer from work hardening due to coarse intermetallic compounds or solute Mn at some Mn contents and/or under some manufacturing conditions. This is because Mn is positively added to the fin material. The fin material is still susceptible to improvement in collar-cracking resistance.

[0009] The present invention has been made in view of these circumstances, and an object thereof is to provide a drawless-press heat-exchanging aluminum alloy fin material which is satisfactorily resistant to collar cracking and less suffers from the generation of collar cracks upon a forming process.

Solution to Problem

[0010] Specifically, the present invention provides a drawless-press heat-exchanging aluminum alloy fin material including an aluminum alloy, the aluminum alloy comprising Fe in a content of 0.010% to 0.4% in mass in a chemical composition thereof, in which the aluminum alloy further comprises Al and inevitable impurities; the aluminum alloy has an Al purity of 99.30% in mass or more; the aluminum alloy fin material has a thickness of less than 0.115 mm; and the aluminum alloy fin material has an average subgrain size of 2.5 μm or less and a yield strength of 130 N/mm^2 or more. In the aluminum alloy fin material, a number density of intermetallic compounds having a maximum length of greater than 3 μm is preferably 2,000 particles/mm^2 or less.

[0011] The aluminum alloy fin material having this configuration exhibits advantages as follows. Specifically, Fe as added in a predetermined content forms Al-Fe intermetallic compounds or dissolves as a solute in the aluminum matrix. This allows subgrains to be finer upon press forming and suppresses work hardening. Control of the Al purity suppresses increase in intermetallic compounds. Control of the average subgrain size to 2.5 μm or less helps the fin material having a thickness of less than 0.115 mm to exhibit a higher elongation. Control of the yield strength of 130 N/mm^2 or more helps the fin material to have an appropriate strength as a fin material for use in drawless-press. Control of intermetallic compounds each having a maximum length of greater than 3 μm to a number density of 2,000 particles/mm^2 or less prevents the generation of collar cracks that occur from coarse intermetallic compounds.

[0012] In a preferred embodiment of the drawless-press heat-exchanging aluminum alloy fin material according to the present invention, the aluminum alloy may further contain Cu in a content of 0.005% to 0.05% in mass and be controlled to have a Si content of 0.15% in mass or less, a Mn content of less than 0.015% in mass, and a Cr content of 0.015% in mass or less.

[0013] The aluminum alloy fin material having this configuration, as containing Cu in a predetermined content, may have satisfactory rigidity even when having a small thickness. The aluminum alloy fin material, as having Si, Mn, and Cr contents controlled to equal to or less than predetermined levels, or less than a predetermined level, may less suffer from coarsening of precipitates (i.e., intermetallic compounds).

[0014] In the drawless-press heat-exchanging aluminum alloy fin material according to the present invention, the aluminum alloy may further contain Ti in a content of 0.01% to 0.05% in mass in the chemical composition. The fin material having this configuration, as containing Ti in a predetermined content, may have a finer structure derived from the ingot.

[0015] The drawless-press heat-exchanging aluminum alloy fin material according to the present invention may have a surface-treatment coating on a surface thereof. The surface-treatment coating may be exemplified by a corrosion-resistant coating, a hydrophilic coating, and a lubricative coating. The fin material having this configuration can have a better property, such as corrosion resistance, hydrophilicity, or formability, according to a service condition or intended use.

[0016] In addition and advantageously, the present invention provides a method for manufacturing the drawless-press heat-exchanging aluminum alloy fin material according to an embodiment of the present invention (one having no surface-treatment coating). The method includes the steps of: heat-treating an aluminum alloy ingot at a temperature of 450°C to 500°C for a duration of one hour or longer, the aluminum alloy ingot having the chemical composition of the aluminum alloy; hot-rolling the aluminum alloy ingot as a material after the heat treatment so that a finishing mill delivery temperature in hot rolling be from 250°C to lower than 300°C; cold-working the aluminum alloy material after the hot rolling to a cold working ratio of 96% or more; and temper-annealing the aluminum alloy material after the cold working by holding at a temperature of 230°C or lower for a duration of 1 to 6 hours.

[0017] The manufacturing method serves as follows. The heat treatment step homogenizes the ingot structure. The hot rolling step rolls the ingot into a hot-rolled sheet without causing the hot-rolled sheet to have a recrystallized structure.

The cold working step allows the sheet to have a thickness of less than 0.115 mm without causing coarsening of subgrains after the temper annealing. The temper annealing step refine the cold working material.

Advantageous Effects of Invention

[0018] The drawless-press heat-exchanging aluminum alloy fin material according to the present invention is resistant to collar cracks upon a forming process and is protected from disadvantages such as poor appearances of fins and insufficient performance of heat exchangers.

[0019] The method for manufacturing a drawless-press heat-exchanging aluminum alloy fin material according to an embodiment of the present invention can give a heat-exchanging aluminum alloy fin material having satisfactory resistance to collar cracking.

Description of Embodiments

[0020] Some embodiments of the drawless-press heat-exchanging aluminum alloy fin material according to the present invention (hereinafter also conveniently referred to as "fin material") and the manufacturing method of the fin material are explained below.

(Fin Material)

[0021] A fin material according to an embodiment of the present invention includes an aluminum alloy. The aluminum alloy contains Fe in a predetermined content, further contains Al and inevitable impurities, and has an Al purity of 99.30% in mass or more. The fin material may be used in drawless pressing. The fin material has a thickness of less than 0.115 mm and is controlled to have an average subgrain size of 2.5 μm or less and a yield strength of 130 N/mm^2 or more. A number density of intermetallic compounds having a size of greater than 3 μm is specified to be 2,000 particles/mm^2 or less. In a preferred embodiment according to necessity, the chemical composition of the aluminum alloy further contains Cu in a predetermined content; and, of inevitable impurities in the aluminum alloy, Si, Mn, and Cr are controlled to equal to or less than a predetermined level, or to less than a predetermined level. In another preferred embodiment, the fin material may further contain Ti in a predetermined content according to necessity.

[0022] Hereinafter the chemical composition is described first, followed by description of other configurations.

(Fe: 0.010% to 0.4% in mass)

[0023] Iron (Fe) element forms Al-Fe intermetallic compounds or dissolves as a solute in the aluminum matrix and contributes to refinement of subgrains upon press forming. This element thereby contributes to smaller work hardening and effectively reduces collar cracking defects. The element also effectively contributes to control of subgrain sizes and to improvement in strength of the aluminum alloy sheet (fin material). An aluminum alloy fin material having an Fe content of less than 0.010% in mass may not enjoy the effects and may have inferior collar-cracking resistance upon press forming. In contrast, an aluminum alloy fin material having an Fe content of greater than 0.4% in mass may have an excessively high strength and have insufficient collar-cracking resistance due to formation of coarse intermetallic compounds. To prevent these, the Fe content is specified to be 0.010% to 0.4% in mass.

(Cu: 0.005% to 0.05% in mass)

[0024] To exhibit certain rigidity when having a small thickness, the aluminum alloy preferably further contains Cu. The effect may be obtained at a Cu content of 0.005% in mass or more. In contrast, Cu in a content of greater than 0.05% in mass may invite work hardening and cause the fin material to have inferior resistance to the "avec phenomenon" and to have insufficient collar-cracking resistance and corrosion resistance. The content of Cu, when added to provide certain rigidity, is preferably 0.005% to 0.05% in mass and more preferably 0.01% to 0.05% in mass.

(Si: 0% to 0.15% in mass)

[0025] Silicon (Si) is contaminated as an inevitable impurity. Si, if contained in a content of more than 0.15 percent by mass, may cause precipitates (intermetallic compounds) to be coarse, and such coarse precipitates may act as stress concentration points to cause cracks upon a forming process. To prevent this, the content of Si is preferably controlled to equal to or less than 0.15% in mass. The Si content may be reduced down to 0% in mass.

(Mn: 0% to less than 0.015% in mass)

[0026] Manganese (Mn) element is contaminated as an inevitable impurity. Mn, if contained in a content of 0.015% in mass or more, may cause precipitates (intermetallic compounds) to be coarse, and such coarse precipitates may act as stress concentration points to cause cracks upon a forming process. To prevent this, the content of Mn is preferably controlled to less than 0.015% in mass and more preferably less than 0.005% in mass. The Mn content may be reduced down to 0% in mass.

(Cr: 0% to 0.015% in mass)

[0027] Chromium (Cr) element is contaminated as an inevitable impurity. Cr, if contained in a content of greater than 0.015% in mass may cause precipitates (intermetallic compounds) to be coarse, and such coarse precipitates may act as stress concentration points to cause cracks upon a forming process. To prevent this, the content of Cr is preferably controlled to equal to or less than 0.015% in mass. The Cr content may be reduced down to 0% in mass.

(Ti: 0.01% to 0.05% in mass)

[0028] Ti may be added as an Al-Ti-B intermediate alloy to help the ingot to have a finer structure. Specifically, an Al-Ti-B ingot refiner having a ratio of Ti to B of 5:1 or 5:0.2 in the form of a waffle or rod may be added to a molten metal. The molten metal is one in any stage before slab solidification, such as one charged into a melting furnace, an inclusion filter, a degasser, or a molten-metal flow rate controller. Ti may be contained in a content of up to 0.05% in mass. Ti, if contained in a content of less than 0.01% in mass, may fail to effectively contribute to refinement of the ingot structure. In contrast, Ti, if contained in a content of greater than 0.05% in mass, may cause precipitates (intermetallic compounds) to be coarse, and such coarse precipitates may act as stress concentration points to cause cracks upon a forming process. To prevent this, the content of Ti, when added, is preferably from 0.01% to 0.05% in mass.

(Remainder: Al and inevitable impurities)

[0029] The fin material contains the above chemical compositions (elements) and further contains Al and inevitable impurities. The inevitable impurities are typified by the aforementioned elements, i.e., Si, Mn, and Cr, as well as other elements such as Mg, Zn, Zr, Ce, Ga, V, and Ni. These elements may be contained in the ingot and/or in the intermediate alloy within generally known ranges. They may be contained each in a content of up to 0.05% in mass, unless the Al purity be less than 99.30% in mass.

(Al purity: 99.30% in mass or more)

[0030] A fin material having an Al purity of less than 99.30% in mass may suffer from increasing collar cracks with increasing intermetallic compounds. To prevent this, the Al purity is specified to be 99.30% in mass or more.

(Thickness: less than 0.115 mm)

[0031] The present invention is applied to fin materials having a thickness of less than 0.115 mm, so as to allow the fin materials to have smaller thicknesses to meet the recent requirements of heat exchangers, such as reduction in size and weight, and higher functions. The fin material according to the present invention therefore has a thickness of less than 0.115 mm.

(Average subgrain size: 2.5 μm or less)

[0032] To exhibit a higher elongation, the fin material having a small thickness of less than 0.115 mm should have an average subgrain size of 2.5 μm or less in the aluminum alloy. A fin material having an average subgrain size of greater than 2.5 μm may not have a sufficient elongation. To prevent this, the average subgrain size is specified to be 2.5 μm or less. The average subgrain size is not critical in its lower limit, but may be 0 μm (namely, the fin material does not have to contain subgrains). The fin material, as having an average subgrain size within this range, less suffers from the generation of collar cracks, even when undergoing work hardening by the action typically of solute Mn and/or solute Cu.

[0033] Next, how to measure the average subgrain size and the number density of intermetallic compounds is described.

[0034] Initially, a scanning electron microscopic (SEM) image of a structure is subjected to an orientation analysis by an electron backscattered diffraction pattern (EBSP) technique. In the EBSP technique, a specimen is irradiated with electron beams, and crystal orientations are identified using an electron backscattered diffraction pattern (Kikuchi pattern) formed upon irradiation. The crystal orientations can be analyzed typically with an OIM (Orientation Imaging Microscopy™) supplied by TexSEM Laboratories, Inc.

[0035] An average subgrain size is determined by calculating the number of grains based on SEM/EBSP measurement data, dividing the total area of the fin material by the number of grains to give an area of each grain, approximating the area of each grain to a circle, determining the diameter of the circle, and defining the diameter as the average subgrain size.

[0036] The average subgrain size and the number density of intermetallic compounds can be controlled by the chemical composition and manufacturing conditions mentioned later. Specifically, the average subgrain size may be controlled typically by contents of respective elements, soaking conditions (temperature and time), finishing mill delivery temperature (end temperature) of hot finish rolling, cold working ratio, and temper annealing conditions (temperature and time). The number density of intermetallic compounds may be controlled typically by contents of respective elements and soaking conditions (temperature and time).

(Yield strength: 130 N/mm^2 or more)

[0037] The fin material according to the present invention is for use in drawless-press and should have a yield strength of 130 N/mm^2 or more. A fin material having a yield strength of less than 130 N/mm^2 may have an insufficient strength and suffer from collar cracks upon drawless-press forming. To prevent these, the yield strength is specified to be 130 N/mm^2 or more. The yield strength is preferably more than 130 N/mm^2. Further, a fin material having an excessively high strength suffers from collar cracks upon drawless-press forming. The upper limit of yield strength is preferably 170 N/mm^2.

[0038] The yield strength may be measured by cutting out a Japanese Industrial Standard (JIS) Number 5 tensile specimen from a sample fin material so that the tensile direction be parallel to the rolling direction, and subjecting the tensile specimen to a tensile test according to JIS Z 2241.

[0039] The average subgrain size, yield strength, and number density of intermetallic compounds may be controlled by the chemical composition and manufacturing conditions. Specifically, the average subgrain size may be controlled typically by the contents of respective elements, soaking conditions (temperature and time), finishing mill delivery temperature in hot rolling, cold working ratio, and temper annealing conditions (temperature and time). The yield strength may be controlled typically by the contents of respective elements, soaking conditions (temperature and time), and temper annealing conditions (temperature and time). The number density of intermetallic compounds may be controlled typically by the contents of respective elements and soaking conditions (temperature and time).

[0040] The fin material according to the present invention may further have a surface-treatment coating on a surface thereof. The term "surface" of the fin material refers to one side or both sides of the fin material.

(Surface-treatment Coating)

[0041] The surface-treatment coating may be typified by chemical conversion coatings, resin coatings, and inorganic coatings as chosen according to the service condition and intended use. Each of these coatings may be employed in combination. Specifically, a resin coating and/or an inorganic coating may be provided on a chemical conversion coating. The resin coatings and the inorganic coatings are typified by corrosion resistant resin coatings, hydrophilic resin coatings, hydrophilic inorganic coatings, and lubricative resin coatings, and each of them may be employed in combination according to necessity.

[0042] The chemical conversion coatings are exemplified by phosphate-chromate coatings. The corrosion resistant resin coatings are exemplified by coatings of resins such as epoxy, urethane, acrylic, and polyester resins. These coatings preferably have a thickness of 0.5 to 5 μm. The hydrophilic coatings are typified by coatings of water-glass inorganic substances; resins containing a poly (acrylic acid) or a poly (acrylic acid salt); and resins containing a sulfonic group or a sulfonic group derivative. These coatings preferably have a thickness of 0.05 to 10 μm. The lubricative resin coatings are typified by coatings of resins containing a polyetherpolyol and preferably have a thickness of 0.1 to 10 μm.

[0043] When two or more of such a corrosion resistant resin coating, a hydrophilic resin coating, a hydrophilic inorganic coating, and a lubricative resin coating are employed in combination, it is preferred that a hydrophilic resin coating is provided on a corrosion resistant resin coating; and that a lubricative resin coating is provided on a hydrophilic resin coating or hydrophilic inorganic coating.

(Manufacturing Method for Fin Material)

[0044] A method for manufacturing a fin material according to an embodiment of the present invention is a method for manufacturing the fin material and includes the steps of heat treatment, hot rolling, cold working, and temper annealing. Where necessary, the method may further include an ingot-making step and/or a surface treatment step.

[0045] The respective steps are described below.

(Ingot-making Step)

[0046] The ingot-making step is the step of melting and casting an aluminum alloy to make an aluminum alloy ingot. In the ingot-making step, an aluminum alloy having the aforementioned chemical composition is melted to give a molten metal, and the molten metal is cast into an ingot having a predetermined shape. The aluminum alloy may be melted and cast according to any known procedures. Typically, the aluminum alloy may be melted in a vacuum induction furnace and cast through continuous casting or semi-continuous casting.

(Heat Treatment Step)

[0047] The heat treatment step is the step of subjecting an aluminum alloy ingot having the chemical composition of the aluminum alloy to a heat treatment (soaking) at a temperature of 450°C to 500°C for a duration of one hour or longer. A heat treatment at a temperature lower than 450°C may insufficiently homogenize (soak) the ingot structure, invite insufficient hot workability, and cause large-sized subgrains. In contrast, a heat treatment at a temperature of higher than 500°C may cause intermetallic compounds, which will have smaller grain sizes during heating, to be coarse and cause coarse subgrains, resulting in insufficient elongation. This heat treatment may also cause excessively high yield strength and a large amount of solid solution (solutes). To prevent these, the heat treatment may be performed at a temperature of 450°C to 500°C. There is no need for specifying the upper limit of the holding time in the heat treatment because the heat treatment can exhibit the effects as long as performed for a holding time of one hour or longer. However, a heat treatment for a holding time longer than 10 hours may exhibit saturated effects. From the economical viewpoint, the heat treatment is preferably performed for a holding time of not longer than 24 hours.

(Hot Rolling Step)

[0048] The hot rolling step is the step of subjecting the material after the heat treatment to hot rolling under such conditions that a finishing mill delivery temperature in hot rolling be from 250°C to lower than 300°C. A hot rolling performed at a finishing mill delivery temperature of lower than 250°C may cause insufficient rolling properties of the material, and this may impede rolling itself or impede the thickness control, resulting in poor productivity. In contrast, a hot rolling performed at a finishing mill delivery temperature of 300°C or higher may cause the resulting hot-rolled sheet to have a recrystallized structure, and the recrystallized structure may form a group of fibrous crystals having an identical crystal orientation to cause necking in the piercing and burring step. This hot finish rolling may also cause the fin material to include large-sized subgrains and its yield strength smaller than the lower limit. To prevent these, the hot rolling may be performed at a finishing mill delivery temperature of from 250°C to lower than 300°C and is more preferably performed at a finishing mill delivery temperature of from 260°C to 290°C.

(Cold Working Step)

[0049] The cold working step is the step of subjecting the material after the hot rolling to a cold working (cold rolling) to a cold working ratio of 96% or more. After the completion of the hot rolling, the cold working is performed once or multiple times to allow the fin material to have a desired final thickness. However, a cold working performed to a cold working ratio of less than 96% may cause the fin material to include coarse subgrains after the temper annealing and to suffer from insufficient yield strength. To prevent this, the cold working is preferably performed to a cold working ratio of 96% or more. If a process annealing is performed in the middle of cold working, the term "cold working ratio" refers to a cold working ratio after the process annealing down to the final thickness. Accordingly, a process annealing is not employed herein because a cold working ratio of 96% or more may not be achieved if a process annealing is performed. The upper limit of the cold working ratio is not critical, because the higher cold working ratio is, the better.

(Temper Annealing Step)

[0050] The temper annealing step is the step of subjecting the material after the cold working to a temper annealing (finish annealing) by holding at a temperature of 230°C or lower for a duration of 1 to 6 hours. A temper annealing at a temperature of higher than 230°C may cause accelerate work hardening through ironing step, and may cause cracking and also suppress yield strength. To prevent these, the temper annealing is performed at a temperature of 230°C or lower, preferably lower than 180°C. There is no need for specifying the lower limit of the temperature in the temper annealing. However, to have the effects of the step, temper annealing is preferably conducted at the temperature of 100°C or higher. The temper annealing is performed for a holding time of 1 to 6 hours. This is because such temper annealing is generally performed for a holding time of one hour or longer, but, if it is performed for a holding time of longer than 6 hours, the effects may be saturated.

(Surface Treatment Step)

[0051] The surface treatment step is the step of subjecting the fin material after the temper annealing to a surface treatment. A chemical conversion coating, when to be formed in the surface treatment step, may be formed by a chemical conversion treatment using a common coat-type or reactive agent. A resin coating, when to be formed, may be formed by applying a resin composition using a roll coater and drying the applied film. The resin coating is typified by a corrosion resistant resin coating, a hydrophilic resin coating, and a lubricative resin coating.

[0052] The method according to the present invention may further include one or more other steps between, before, or after the respective steps within ranges not adversely affecting the respective steps. Typically, the method may further include one or more of steps such as foreign substance removing step of removing foreign substances such as dust; facing step of applying facing to the ingot; and machining step of suitably performing machining so as to provide a fin material. The machining step may be performed after the temper annealing step or the surface treatment step.

[0053] The resulting fin material is subjected to a forming process by a drawless forming. The drawless forming (drawless press) includes the steps of piercing and burring (piercing-burring forming) in a first step; ironing in a second step and a third step; and reflaring in a fourth step. The fin material according to the present invention has superior collar-cracking resistance and less suffers from the generation of collar cracks upon a forming process by drawless forming.

EXAMPLES

[0054] While having been described with reference to embodiments thereof, the present invention will be illustrated in further detail with reference to several working examples exhibiting advantageous effects of the present invention, in comparison to comparative examples not satisfying the conditions specified in the present invention. It should be noted, however, that these examples are never construed to limit the scope of the present invention.

(Preparation of Specimens)

(Examples Nos. 1 to 10 and Comparative Examples Nos. 11 to 21)

[0055] Aluminum alloys having compositions given in Table 1 were melted and cast into ingots, and the ingots were subjected to facing and subsequently to soaking at 480°C for 4 hours. The soaked (homogenized) ingots were subjected to hot rolling controlled so as to perform hot finish rolling at a finishing mill delivery temperature of 270°C, and yielded hot-rolled sheets having a thickness of 3.0 mm. The hot-rolled sheets were respectively subjected to cold rolling to a cold working ratio of about 97.0% or about 97.3% so as to have a thickness of 90 μm or 80 μm, subjected to temper annealing at temperatures for holding times each given in Table 1, and yielded fin materials.

(Examples Nos. 22 to 27 and Comparative Examples Nos. 28 to 34)

[0056] Aluminum alloys given in Table 2 (corresponding to Alloys A, B, and C in Table 1) were melted and cast into ingots, the ingots were subjected sequentially to facing, soaking, and hot rolling, and thereby yielded hot-rolled sheets having a thickness of 3.0 mm. The samples other than No. 34 were respectively subjected to cold rolling to a cold working ratio of about 97.0% or about 97.3% so as to have a thickness of 90 μm or 80 μm, subjected to temper annealing, and thereby yielded fin materials. In Sample No. 34, the hot-rolled sheets having a thickness of 3.0 mm were subjected to cold rolling to a cold working ratio of 50%, and then subjected to a process annealing in a batch furnace at 360°C for 3 hours. The sheets were respectively subjected to cold rolling to a cold working ratio of about 94.0% or about 94.7% so as to have a thickness of 90 μm or 80 μm, respectively, subjected to temper annealing, and yielded fin materials. Soaking conditions, finishing mill delivery temperature in hot rolling, and temper annealing conditions are as indicated in Table 2. Sample No. 30 was impossible to give a fin material.

(Examples Nos. 35 to 38 and Comparative Examples Nos. 39 to 42)

[0057] Surface treatments (Nos. 1 to 4) were performed on fin materials of Nos. 35 and 36 corresponding to No. 22 in Table 2; fin materials of Nos. 37 and 38 corresponding to No. 27 in Table 2; fin materials of Nos. 39 and 40 corresponding to No. 29 in Table 2; and fin materials of Nos. 41 and 42 corresponding to No. 32 in Table 2.

[0058]

Surface Treatment No. 1: Surface treatment under the same conditions as Comparative Example 1 in Japanese Unexamined Patent Application Publication No. 2010-223520 (to provide a chemical conversion coating, a hydrophilic coating, and a lubricative coating in this order)

Surface Treatment No. 2: Surface treatment under the same conditions as Example 1 in Japanese Patent No. 3383914 (to provide a chemical conversion coating, a hydrophilic coating, and a lubricative resin coating in this order)

Surface Treatment No. 3: Surface treatment under the same conditions as Example 1 in Japanese Unexamined Patent Application Publication No. 2008-224204 (to provide a chemical conversion coating, a corrosion resistant resin coating, and a hydrophilic coating in this order)

Surface Treatment No. 4: Surface treatment under the same conditions as Comparative Example 21 in Japanese Unexamined Patent Application Publication No. 2010-223514 (to provide a chemical conversion coating and a corrosion resistant resin coating in this order)

[0059] The chemical compositions are shown in Table 1, and manufacturing conditions are described in Tables 2 and 3. In these tables, data not falling within a range specified in the present invention are underlined, and a composition (element) not contained is indicated by "-". Sample No. 30 was impossible to give a fin material and is indicated by "-" in temper annealing. Sample No. 16 corresponds to an aluminum alloy fin material described in PTL 1 (Inventive Example 1 in Table 2), except that Inventive Example 1 employed a hot rolling at a different finishing mill delivery temperature, a different thickness after hot rolling (3.5 mm), and a different temper annealing temperature. Sample No. 13 corresponds to an aluminum alloy fin material described in PTL 2 (Inventive Example 4 in Table 1), except that Inventive Example 4 employed a different forming process (drawing process). Sample No. 17 corresponds to aluminum alloy fin material described in PTL 3 (Inventive Example 3 in Table 1), except that Inventive Example 3 employed a different forming process (drawless process). Sample No. 33 corresponds to an aluminum alloy fin material described in PTL 4 (Inventive Example 11 in Table 2), except that Inventive Example 11 employed a different thickness (0.115 mm) after cold rolling.

[0060] Next, the average subgrain size and the number density of intermetallic compounds of a size of greater than 3 μm were measured as structural morphologies of the fin materials by methods below. The strength and elongation of the fin materials were also measured by methods as follows.

(Average Subgrain Size)

[0061] An average subgrain size was measured in the following manner. The structure of a sample fin material surface was imaged in the observation under a scanning electron microscope (SEM) at a 1,000-fold magnification, orientations of which were analyzed by EBSP at measurement intervals of 0.10 μm to give data, and the data were automatically calculated on OIM (Orientation Imaging Microscopy™) software supplied by TexSEM Laboratories, Inc. to give an average subgrain size. Specifically, the number of grains was counted based on the SEM/EBSP measured data, the total area of the sample fin material was divided by the number of grains, the area of each grain was approximated to a circle, and a diameter of the circle was defined as the average subgrain size. The number of grains was counted so that a grain surrounded by grain boundaries with a difference in orientation between adjacent grains of 2° or less is defined as one grain.

(Number Density of Intermetallic Compounds Having Size of Greater than 3 μm)

[0062] A number density of compounds having a size of greater than 3 μm was measured by imaging a structure-of a sample surface in an area of 1.0 mm^2 in the observation under a scanning electron microscope (SEM) at a 500-fold magnification, and analyzing the image. As used herein the term "size" of a compound refers to a maximum length of the respective compound.

(Strength and Elongation)

[0063] From the fin materials, JIS No. 5 tensile specimens were cut so that the tensile direction be parallel to the rolling direction. The specimens were subjected to tensile tests according to JIS Z 2241 to measure a tensile strength, a 0.2%-yield strength, and an elongation. The tensile tests for the evaluation of the examples and comparative examples were performed at a tensile speed of 5 mm/min.

(Evaluation)

[0064] The prepared fin materials were stamped (press-formed) through drawless forming, whereby their collar-cracking resistance was evaluated.

[0065] The collar-cracking resistance was evaluated by visually counting cracks generated in collars around 400 holes formed by stamping.

[0066] A frequency of collar cracking was calculated according to the expression: "(Number of cracks)/400×100 (%)".

A specimen having a frequency of less than 3% was evaluated as "◎"; a specimen having a frequency of from 3 % to less than 5% was evaluated as "○"; and a specimen having a frequency of 5% or more was evaluated as "×". A sample evaluated as "◎" or "○" in all the specimens having thicknesses of 90 μm and 80 μm was evaluated as accepted.

[0067] The results of measurements and evaluations are indicated in Tables 1 to 3. In Tables 1 to 3, data out of a range specified in the present invention are underlined, and data on a sample which was impossible to give a fin material and was immeasurable and unevaluable is indicated by "-".

[Table 1]

Category	No.	Alloy type	Chemical composition								Temper Annealing	Density of precipitates with maximum length > 3 µm	Average subgrain size	Mechanical properties			Collar cracking resistance	
			Si	Fe	Cu	Ti	Mn	Cr	Other	Al				Tensile strength	0.2% yield strength	Elongation	Drawless press	
			(mass%)	(mass%)	(mass%)	(mass%)	(mass%)	(mass%)	(mass%)	(mass%)	(°C x hr)	(particles/mm²)	(µm)	(MPa)	(MPa)	(%)	90 µm	80 µm
Example	1	A	0.08	0.3	0.05	—	—	—	—	99.55	160×4	1020	1.4	157	153	3.2	◎	○
	2		—	0.1	0.008	—	—	—	—	99.77	200×4	not measured	2.2	132	130	7.8	○	○
	3		—	0.3	—	—	—	—	—	99.50	160×4	1340	1.0	148	135	2.5	◎	◎
	4	B	0.07	0.2	0.03	0.02	—	—	—	99.52	160×4	1210	1.1	155	149	3.5	◎	◎
	5		0.15	0.01	0.05	—	0.003	—	—	99.71	180×4	not measured	1.3	143	139	2.8	○	○
	6		0.11	0.2	0.04	—	—	0.015	—	99.62	180×4	not measured	1.2	140	135	2.6	○	○
	7		0.08	0.1	0.01	0.01	0.002	—	—	99.45	160×4	1210	1.2	150	142	2.9	◎	◎
	8		0.02	0.3	—	—	0.014	0.002	—	99.59	160×4	1150	1.3	145	134	2.2	◎	○
	9		0.05	0.2	0.02	0.01	—	0.002	—	99.68	160×4	1250	1.1	153	147	3.5	◎	○
	10		0.03	0.4	0.02	0.05	0.01	0.01	—	99.45	160×4	not measured	1.0	155	148	2.1	○	○
Comparative Example	11		0.20	0.3	0.04	—	—	—	—	99.40	180×4	not measured	1.2	142	137	2.4	×	×
	12		0.04	0.002	0.03	—	—	—	—	99.86	180×4	710	2.8	142	135	3.0	×	×
	13		0.06	0.74	0.03	0.015	—	—	※1	99.10	220×6	2830	2.0	132	130	11.2	×	×
	14		0.15	0.4	0.05	0.04	0.01	0.01	—	99.25	180×4	2780	1.1	135	131	10.5	×	×
	15		0.04	0.3	0.08	—	—	—	—	99.50	200×4	1930	1.2	145	140	2.5	×	×
	16		0.1	0.2	0.01	0.01	0.33	0.01	—	99.31	220×4	not measured	1.8	170	165	2.2	×	×
	17		0.10	0.3	0.02	0.02	0.2	—	※2	99.30	275×6	2740	1.5	135	128	14.2	×	×
	18		0.07	0.3	0.03	—	—	0.017	—	99.50	180×4	2220	1.4	145	138	5.2	×	×
	19		0.06	0.3	0.03	0.07	—	—	—	99.45	160×4	not measured	1.1	155	147	1.8	×	×
	20	C	0.09	0.3	0.01	0.10	0.01	—	※3	99.35	180×4	not measured	1.8	139	132	4.0	×	×
	21		—	0.5	—	—	—	—	—	99.45	180×4	2130	1.6	136	131	7.5	×	×

※1: containing 0.01 mass% of Mg

※2: containing 0.03 mass% of Zr and 0.01 mass% of Mg

※3: containing 0.01 mass% of Zn, 0.01% of Mg, and 0.05mass% of Ce

[Table 2]

Category	No.	Alloy type	Soaking	Hot rolling finishing mill delivery temperature	Process annealing	Temper annealing	Density of precipitates with maximum length > 3 µm	Average subgrain size	Mechanical properties			Collar cracking resistance	
									Tensile strength	0.2% yield strength	Elongation	Drawless press	
			(°C x hr)	(°C)		(°C x hr)	(particles/mm²)	(µm)	(MPa)	(MPa)	(%)	90 µm	80 µm
Example	22	A	450×4	277	not conducted	180×4	not measured	1.2	140	131	2.0	○	○
	23	A	500×4	297	not conducted	200×4	not measured	1.3	140	132	5.0	◎	○
	24	A	470×4	277	not conducted	160×4	not measured	1.2	155	145	2.2	◎	○
	25	B	500×4	252	not conducted	200×4	1330	1.1	138	131	6.3	○	○
	26	B	450×24	265	not conducted	170×4	not measured	1.0	145	135	4.6	◎	○
	27	B	450×4	270	not conducted	200×4	1220	1.2	142	132	5.2	◎	○
Comparative Example	28	A	400×4	277	not conducted	180×4	not measured	1.8	130	120	7.5	×	×
	29	B	560×4	290	not conducted	200×4	2310	2.8	147	137	1.0	×	×
	30	B	500×4	245	not conducted	—	—	—	—	—	—	—	—
	31	B	480×4	320	not conducted	200×4	1320	2.6	135	125	8.2	×	×
	32	B	460×4	274	not conducted	240×4	not measured	2.2	101	99	27.2	×	×
	33	C	560×4	290	not conducted	200×4	2460	2.9	147	137	1.0	×	×
	34	B	460×4	274	conducted※	230×4	not measured	5.4	105	100	19.5	×	×

※: Annealing at 360°C for 3 hours in a batch furnace was conducted after cold working to a cold working ratio of 50%

[Table 3]

Category	No.	Alloy type	Temper annealing	Hot rolling finishing mill delivery temperature	Process annealing	Temper annealing	Surface treatment number	Density of precipitates with maximum length > 3 μm	Average subgrain size	Mechanical properties			Collar cracking resistance	
										Tensile strength	0.2% yield strength	Elongation	Drawless press	
			(°C x hr)	(°C)		(°C x hr)	No.	(particles/mm^2)	(μm)	(MPa)	(MPa)	(%)	90 μm	80 μm
Example	35	A	450×4	277	not conducted	180×4	1	not measured	1.2	140	131	2.0	○	○
	36						2	not measured	1.2	140	131	2.0	○	○
	37	B	450×4	270	not conducted	200×4	3	1220	1.2	142	135	5.2	◎	○
	38						4	1220	1.2	142	135	5.2	◎	○
Comparative Example	39	B	560×4	290	not conducted	200×4	1	2310	2.8	147	137	1.0	×	×
	40						2	2310	2.8	147	137	1.0	×	×
	41	B	460×4	274	not conducted	240×4	3	not measured	2.2	101	99	27.2	×	×
	42						4	not measured	2.2	101	99	27.2	×	×

Surface treatment

No.1: Surface treatment under the condition of Comparative Example 1 in Japanese Unexamined Patent Application Publication No. 2010-223520

No.2: Surface treatment under the condition of Example 1 in Japanese Patent No. 3383914

No.3: Surface treatment under the condition of Example 1 in Japanese Unexamined Patent Application Publication No. 2008-224204

No.4: Surface treatment under the condition of Comparative Example 21 in Japanese Unexamined Patent Application Publication No. 2010-223514

(Evaluation Based on Chemical Composition)

[0068] Table 1 demonstrates as follows. Samples Nos. 1 to 10 as the examples had chemical compositions within ranges specified in the present invention and exhibited satisfactory collar-cracking resistance.

[0069] By contrast, Samples Nos. 11 to 21 as the comparative examples had chemical compositions out of the ranges specified in the present invention and had disadvantages as follows. Sample No. 11 had a Si content of higher than the upper limit, included coarse intermetallic compounds in a large number density, and had poor collar-cracking resistance.

[0070] Sample No. 12 had an Fe content of lower than the lower limit, had a large subgrain size, and had poor collar-cracking resistance. Sample No. 13 had an Fe content of higher than the upper limit and an Al purity of lower than the lower limit, included coarse intermetallic compounds in a large number density. This sample exhibited poor collar-cracking resistance. Sample No. 14 had an Al purity of lower than the lower limit, included coarse intermetallic compounds in a large number density. This sample exhibited poor collar-cracking resistance.

[0071] Sample No. 15 had a Cu content of higher than the upper limit to cause work hardening and exhibited poor collar-cracking resistance. Sample No. 16 had a Mn content of higher than the upper limit, included coarse intermetallic compounds in a large number density, and exhibited poor collar-cracking resistance. Sample No. 17 had a Mn content of higher than the upper limit and included coarse intermetallic compounds in a large number density. This sample underwent temper annealing at a temperature of higher than the upper limit, suffered from excessive work hardening, had a yield strength of lower than the lower limit, and exhibited poor collar-cracking resistance.

[0072] Sample No. 18 had a Cr content of higher than the upper limit, included coarse intermetallic compounds in a large number density, and exhibited poor collar-cracking resistance. Sample No. 19 had a Ti content of higher than the upper limit, included coarse intermetallic compounds in a large number density, and exhibited poor collar-cracking resistance. Sample No. 20 had a Ti content of higher than the upper limit, included coarse intermetallic compounds in a large number density, and exhibited poor collar-cracking resistance. Sample No. 21 had an Fe content of higher than the upper limit, included coarse intermetallic compounds in a large number density. This sample exhibited poor collar-cracking resistance.

(Evaluation Based on Manufacturing Method)

[0073] Table 2 demonstrates as follows. Samples Nos. 22 to 27 as the examples were manufactured by methods under conditions within ranges specified in the present invention and exhibited satisfactory collar-cracking resistance.

[0074] By contrast, Samples Nos. 28 to 34 as the comparative examples were manufactured by methods under conditions out of the ranges specified in the present invention and showed unsatisfactory results as follows. Sample No. 28 underwent soaking at a temperature of lower than the lower limit, suffered from insufficient soaking and a yield strength of lower than the lower limit, and exhibited poor collar-cracking resistance. Sample No. 29 underwent temper annealing at a temperature of higher than the upper limit and suffered from excessively large-sized subgrains. This sample exhibited poor collar-cracking resistance.

[0075] Sample No. 30 underwent hot rolling at a finishing mill delivery temperature of lower than the lower limit. This impeded rolling itself and inhibited manufacturing a fin material. Sample No. 31 underwent hot rolling at a finishing mill delivery temperature of higher than the upper limit, suffered from excessively large-sized subgrains and yield strength of lower than the lower limit, and exhibited poor collar-cracking resistance. Sample No. 32 underwent temper annealing at a temperature of higher than the upper limit, suffered from excessive work hardening, and had yield strength of lower than the lower limit. This sample exhibited poor collar-cracking resistance.

[0076] Sample No. 33 underwent soaking at a temperature of higher than the upper limit, had a yield strength of higher than the upper limit, and suffered from excessively large-sized subgrains. This sample exhibited poor collar-cracking resistance. Sample No. 34 underwent process annealing and had a cold working ratio of lower than the lower limit. This sample thereby had an average subgrain size of higher than the upper limit and yield strength of lower than the lower limit, and exhibited poor collar-cracking resistance.

(Evaluation of Samples Subjected to Surface Treatments)

[0077] Samples Nos. 35 to 42 as fin materials each subjected to a surface treatment exhibited collar-cracking resistance similar to that of corresponding fin materials which underwent no surface treatment.

[0078] The fin materials of Samples Nos. 16, 13, 17, and 33 simulated customary aluminum alloy fin materials disclosed in PTL 1, 2, 3, and 4, respectively, as an experimental example. As is demonstrated by the experimental example, the customary aluminum alloy fin materials do not meet the predetermined levels in the evaluations. The experimental example therefore objectively demonstrates that the drawless-press heat-exchanging aluminum alloy fin materials according to the present invention are superior to the customary aluminum alloy fin materials.

Claims

1. A drawless-press heat-exchanging aluminum alloy fin material comprising an aluminum alloy, the aluminum alloy comprising Fe in a content of 0.010% to 0.4% in mass in a chemical composition thereof, wherein:

   the aluminum alloy further comprises Al and inevitable impurities;
   the aluminum alloy has an Al purity of 99.30% in mass or more;
   the fin material has a thickness of less than 0.115 mm; and
   the fin material has an average subgrain size of 2.5 μm or less and a yield strength of 130 N/mm^2 or more.

2. The drawless-press heat-exchanging aluminum alloy fin material of claim 1, wherein a number density of intermetallic compounds having a maximum length of greater than 3 μm is 2,000 particles/mm^2 or less.

3. The drawless-press heat-exchanging aluminum alloy fin material of one of claims 1 and 2, wherein:

   the aluminum alloy further comprises Cu in a content of from 0.005% to 0.05% in mass in the chemical composition; and
   the aluminum alloy is controlled to have a Si content of 0.15% in mass or less, a Mn content of less than 0.015% in mass, and a Cr content of 0.015% in mass or less.

4. The drawless-press heat-exchanging aluminum alloy fin material of any one of claims 1 to 3, wherein the aluminum alloy further comprises Ti in a content of 0.01% to 0.05% in mass in the chemical composition.

5. The drawless-press heat-exchanging aluminum alloy fin material of any one of claims 1 to 4, wherein the fin material comprises a surface-treatment coating on a surface thereof.

6. A method of manufacturing the drawless-press heat-exchanging aluminum alloy fin material of any one of claims 1 to 4, the method comprising the steps of:

   heat-treating an aluminum alloy ingot at a temperature of 450°C to 500°C for a duration of one hour or longer, the aluminum alloy ingot having the chemical composition of the aluminum alloy;
   hot-rolling the aluminum alloy ingot as a material after the heat treatment so that a finishing mill delivery temperature in hot rolling be from 250°C to lower than 300°C;
   cold-working the aluminum alloy material after the hot rolling to a cold working ratio of 96% or more; and
   temper-annealing the aluminum alloy material after the cold working by holding at a temperature of 230°C or lower for a duration of 1 to 6 hours.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/055659

A. CLASSIFICATION OF SUBJECT MATTER
C22C21/00(2006.01)i, *C22F1/04*(2006.01)i, *F28F21/08*(2006.01)i, *C22F1/00*(2006.01)n

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C21/00-21/18, C22F1/04-1/057, F28F21/08, C22F1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2006-104488 A (Kobe Steel, Ltd.), 20 April 2006 (20.04.2006), claims 1 to 3; paragraphs [0003], [0004], [0036], [0043], [0050] to [0055]; tables 1, 2 (Family: none)	1-6
A	JP 3-2343 A (Kobe Steel, Ltd.), 08 January 1991 (08.01.1991), claims; page 2, upper right column, line 11 to page 3, left column, line 10 (Family: none)	1-6
A	JP 8-313191 A (The Furukawa Electric Co., Ltd.), 29 November 1996 (29.11.1996), claims 1 to 5 (Family: none)	5

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search 23 May, 2012 (23.05.12)	Date of mailing of the international search report 05 June, 2012 (05.06.12)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/055659

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2009-250510 A (Mitsubishi Electric Corp.), 29 October 2009 (29.10.2009), claims 5, 8 (Family: none)	5
A	JP 2006-283114 A (Kobe Steel, Ltd.), 19 October 2006 (19.10.2006), claims 1 to 3; tables 1 to 4 (Family: none)	1-6
E,A	WO 2012/29594 A1 (Kobe Steel, Ltd.), 08 March 2012 (08.03.2012), claims 1 to 4; tables 1 to 3 (Family: none)	1-6

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2008224204 A **[0058]**
- JP 2010223514 A **[0058]**