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(71) Applicant: **Kabushiki Kaisha Kobe Seiko Sho**
(Kobe Steel, Ltd.)
Kobe-Shi, Hyogo 651-8585 (JP)

(72) Inventors:
• **FUJII Yasuyuki**
Kobe-shi, Hyogo 651-2271 (JP)
• **OKAMOTO Akio**
Tokyo 141-8688 (JP)
• **ITSUMI Yoshio**
Hyogo 676-8670 (JP)
• **FUJITA Akihisa**
Hyogo 676-8670 (JP)

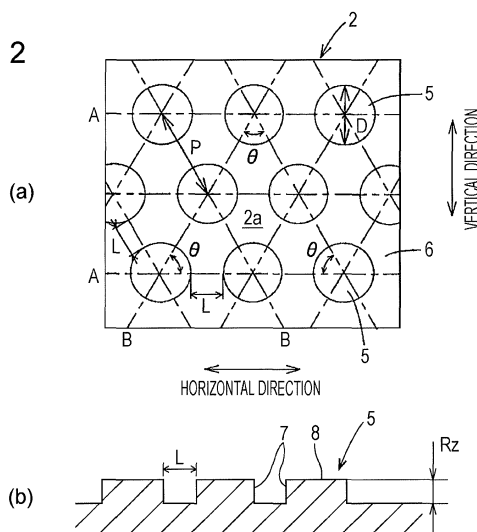
(74) Representative: **TBK**
Bavariaring 4-6
80336 München (DE)

(54) **RAW PLATE MATERIAL FOR HEAT EXCHANGING PLATE, AND HEAT EXCHANGING PLATE USING SAME**

(57) This original plate material for a heat exchanging plate (4) comprises a titanium flat plate material (1) having a minute recess and projections on the surface thereof, and the flat plate material (1) is press-worked to obtain the heat exchanging plate (4). The shape parameter (G1), defined as [height (μm) of the projections] x [width

(μm) of the recess/pitch (μm) of adjacent projections], is 85 μm or less. Relating to this original plate material for a heat exchanging plate (4), the shape parameter (G2), defined as [height (μm) of the projections] x [width (μm) of the recess/pitch (μm) of adjacent projections/angle (deg) of the projections], is 0.94 $\mu\text{m}/\text{deg}$ or less.

FIG. 2



Description

Technical Field

[0001] The present invention relates to an original plate material for a heat-exchanging plate and a heat-exchanging plate using the original plate material.

Background Art

[0002] A good heat transfer characteristics are required for a heat-exchanging plate incorporated in a plate-type heat exchanger or the like described in, for example, Patent Literature 1.

Citation List

Patent Literature

[0003] PTL 1: Japanese Unexamined Patent Application Publication No. 2009-192140

Summary of Invention

Technical Problem

[0004] An object of the present invention is to provide an original plate material for a heat exchanger. The original plate material has a significantly good heat conductivity and a significantly good workability in press forming to be performed in a downstream process, and can be easily formed into a heat-exchanging plate.

Solution to Problem

[0005] An original plate material for a heat-exchanging plate according to the present invention is made by forming a fine recess and fine projections on a surface of a metal flat plate material and is subjected to press working performed as a downstream process so as to be used as a heat-exchanging plate. Regarding the recess and the projections, the recess and the projections are set on a surface of the original plate material such that a shape parameter G1 defined as a height of a projecting part in μm $\times$ [a width of a recessed part in μm /a pitch between the adjacent projecting parts in μm] is equal to or smaller than 85 μm .

[0006] Another original plate material for a heat-exchanging plate according to the present invention is made by forming a fine recess and fine projections on a surface of a metal flat plate material and is subjected to press working performed as a downstream process so as to be used as a heat-exchanging plate. Regarding the recess and the projections, the recess and the projections are set on a surface of the original plate material such that a shape parameter G2 defined as a height of a projecting part in μm $\times$

[0007] [a width of a recessed part in μm /a pitch be-

tween the adjacent projecting parts in μm /an angle of the projecting part in deg] is equal to or smaller than 0.94 $\mu\text{m}/\text{deg}$.

5 Advantageous Effects of Invention

[0008] With the original plate material according to the technology of the present invention, a heat-exchanging plate can be fabricated without the occurrence of breakage or the like in press working. The heat-exchanging plate fabricated with the technology of the present invention has a significantly good heat conductivity. Brief Description of Drawings

15 [Fig. 1] Fig. 1 illustrates a method for fabricating a heat-exchanging plate.

[Fig. 2] Fig. 2 illustrates arrangement of projecting parts formed on a surface of an original plate material.

20 [Fig. 3] Fig. 3 illustrates different arrangement of the projecting parts formed on the surface of the original plate material.

[Fig. 4] Fig. 4 illustrates the relationship between L $\times$ Rz/P and the ratio of concentration of stress.

25 [Fig. 5] Fig. 5 is a reference diagram for calculation of a press formability score.

[Fig. 6] Fig. 6 illustrates the relationship between heat transfer efficiency and the dimensions and shapes of the recessed and projecting shapes formed on the surface of the original plate material, and the relationship between the desirability of the press formability and the dimensions and shapes of the recessed and projecting shapes formed on the surface of the original plate material.

35 [Fig. 7] Fig. 7 illustrates an outline of a device that forms the recessed and projecting shapes on the surface of the original plate material.

[Fig. 8] Fig. 8 is an explanatory diagram illustrating the shape of the projecting part.

40 [Fig. 9] Fig. 9 illustrates the relationship between the angle η of the projecting parts and flows of a fluid.

[Fig. 10] Fig. 10 illustrates the relationship between a shape parameter G2 and the ratio of improvement in heat conductivity.

45 [Fig. 11] Fig. 11 illustrates the relationships among the shape parameter G2, the ratio of improvement in heat conductivity, and the press formability.

[Fig. 12] Fig. 12 illustrates the relationships among the shape parameter G2, the ratio of improvement in heat conductivity, and the press formability.

Description of Embodiments

[0009] The following description is made with an example in which a titanium material is used as a flat plate material 1.

[0010] Titanium is a material having anisotropy. The anisotropy of a material affects its deformation behavior

such as a decrease in thickness or strain gradient in a portion where stress is concentrated. For this reason, titanium has significantly poor press formability and the like compared to other materials not having anisotropy. Furthermore, since titanium easily causes seizure, the titanium material tends to break or become scratched due to contact with a die for pressing or a tool when lubricant film breakdown occurs while being pressed, and accordingly, titanium is not easily processed. Thus, the following successful example with a titanium material can be applied to other metal materials such as stainless steel and aluminum.

[0011] Embodiments of the present invention will be described below with reference to the drawings.

[First Embodiment]

[0012] Fig. 1 is a conceptual view illustrating a method for fabricating a heat-exchanging plate according to a first embodiment.

[0013] Initially, as illustrated in Fig. 1 (a), the flat plate material 1 serving as a raw material is formed to have a specified size. Then, the flat plate material 1 is subjected to press working so as to have fine recessed and projecting shapes on a surface 1a of the flat plate material 1, thereby producing a plate raw sheet (original plate material) having fine recessed and projecting shapes as illustrated in Fig. 1 (b). Next, as illustrated in Fig. 1 (c), the plate raw sheet 2 (original plate material) having the fine recessed and projecting shapes on a surface 2a is pressed so as to form, for example, so called "herringbone", which is a plurality of chevron-shaped grooves having a height of less than 10 mm to less than 10 cm by press-forming. Thus, a heat-exchanging plate 4 is fabricated.

[0014] The flat plate material 1 illustrated in Fig. 1 (a) is made of titanium, and the dimensions and thickness thereof are determined with consideration of dimensions and thickness desired for the heat-exchanging plate 4 as a finished product. The plate raw sheet 2 is fabricated by forming the fine recessed and projecting shapes (made of a plurality of projecting parts 5 and a recessed part 6 interposed therebetween) using a process device 10, which will be described later, on the surface 1a of the flat plate material 1. The plate raw sheet 2 having the recessed and projecting shapes formed thereon has a significantly good heat conductivity (a significantly high heat transfer coefficient). In addition, since the plate raw sheet 2 according to the present invention is made of titanium, the characteristics of which such as corrosion resistance and strength are good and the weight of which is light compared to other metal materials. Thus, the plate raw sheet 2 is preferably used in products for which corrosion resistance and strength are required such as a plate for a plate-type heat exchanger.

[0015] A herringbone 3 formed in the plate raw sheet 2 includes a plurality of chevron-shaped grooves, which appear like a skeleton shape, and the size of the grooves

is from less than 10 mm to less than 10 cm in height. The raw sheet 2 is incorporated in a heat exchanger. Even when a flow of a working fluid in the heat exchanger is not uniform, recesses and projections of inclined grid-like shapes, typical examples of which include the herringbone 3, can serve as walls perpendicular to the working fluid flowing from any direction, and accordingly, contribute to improvement of heat conductivity due to turbulence.

[0016] The details of the recessed and projecting shapes on the surface of the plate raw sheet 2 will be described below.

[0017] As illustrated in Fig. 2 (a), the projecting parts 5 formed on a surface 2a of the plate raw sheet 2 each have a substantially circular shape in plan view and a diameter D of equal to or greater than 400 μm . The projecting parts 5 are arranged in a staggered manner in plan view. Here, arrangement in a staggered manner (staggered arrangement) means that the centers of the projecting parts 5 adjacent to each other in a vertical and horizontal direction are non-collinear with each other.

[0018] Specifically, the projecting parts 5 adjacent to each other in the vertical direction may be shifted to each other by a half pitch in the horizontal direction in the plate raw sheet 2. Furthermore, the projecting parts 5 may be arranged such that a line (dotted-chain line) A connecting the centers of the adjacent projecting parts 5 to one another in the horizontal direction forms an angle θ of 60° with a line (dotted-chain line) B connecting the centers of the adjacent projecting parts 5 to one another in the vertical direction (Y-direction).

[0019] As described above, even when a flow of a working fluid in the heat exchanger is not uniform, by arranging the projecting parts 5 in an staggered manner, the recess and projections can serve as walls perpendicular to the working fluid flowing from any direction, and accordingly, contribute to improvement of heat conductivity due to turbulence. Also, concentration of stress due to anisotropy of titanium or other materials having anisotropy can be addressed.

[0020] Preferably, the distance L between the projecting parts 5 (width L of the recessed part 6) adjacent to each other in the vertical or horizontal direction is equal to or greater than 200 μm . The width L of the recessed part 6 is the shortest distance between the adjacent projecting parts 5 in the horizontal or vertical direction and defined by the following expression: width L of recessed part 6 = pitch P between adjacent projecting parts 5 - (diameter D of projecting part 5/2 x 2). Here, the pitch P between the adjacent projecting parts 5 means the distance between the centers of the projecting parts 5 most closely adjacent to each other in the horizontal or vertical direction (distance between the centers of the projecting parts 5 spaced apart from each other by the shortest distance).

[0021] The width L of the recessed part 6 illustrated in Fig. 2 (a) is the same in the vertical and horizontal directions. That is, the distance between the projecting parts

5 adjacent to each other in the vertical direction and the distance between the projecting parts 5 adjacent to each other in the horizontal direction are the same. Preferably, the pitch P (distance between the centers of the projecting parts 5) of the adjacent projecting parts 5 is equal to or greater than 600 μm .

[0022] As illustrated in Fig. 2 (b), the projecting parts 5 formed on the surface of the plate raw sheet 2 each have a substantially trapezoidal shape in sectional view having a side wall 7 that extend upward and a front wall 8 that closes an upper edge of the side wall 7 in a direction parallel to the surface 2a. In other words, the projecting parts 5 have a flat portion at its top. The height Rz of the projecting parts 5 (side wall 7) expressed as ten-point average roughness (may also be referred to as height Rz hereafter) is equal to or greater than 5 μm , and equal to or smaller than 1/10 (one tenth) of the thickness t of the plate raw sheet 2.

[0023] The above-described range of the height Rz of the projecting parts 5 is determined since, when the recessed and projecting shapes are excessively large relative to the thickness, during roll transfer using the process device 10, which will be described later, flatness (shape) cannot be ensured, and accordingly, stability in rolling cannot be obtained. Furthermore, when a plate is press-formed in a downstream process, if the flatness of the plate is not ensured, stress distribution occurs, and accordingly, the plate breaks in portions of the plate where stress is higher. That is, the projecting parts 5 having an excessively large height Rz cause (become the starting points of) breaks in press working and cause scratches. In contrast, when the height Rz is excessively small (equal to or smaller than 5 μm), the heat transfer efficiency cannot be improved.

[0024] The shape of the projecting part 5 in plan view includes not only a perfect circle but also an ellipse, with a flattening of up to about 0.2. Although the projecting part 5 having a polygonal shape or another shape in plan view also seems possible, the projecting part 5 preferably has a substantially circular shape in plan view from the viewpoint of avoiding concentration of stress in press working to be performed in a downstream process.

[0025] The staggered arrangement of the projecting parts 5 is not limited to that illustrated in Fig. 2.

[0026] For example, as illustrated in Fig. 3, the projecting parts 5 may be arranged such that a line (dotted-chain line) A' connecting the centers of the adjacent projecting parts 5 to one another in the horizontal direction forms an angle θ of 45° with a line (dotted-chain line) B' connecting the centers of the adjacent projecting parts 5 to one another in the vertical direction. The angle θ may be other than 45°.

[0027] The recessed and projecting shapes of the plate raw sheet 2 as described above are based on the findings as follows.

[0028] In fabricating the plate raw sheet 2, in order for the height Rz of the projecting parts 5, the number of the projecting parts 5 (the width L of the recessed part 6),

and the pitch P between the adjacent projecting parts formed on the surface of the plate raw sheet 2 to satisfy desirable requirements (such as heat transfer characteristics), the inventors have found the following shape parameter G1 of the recessed and projecting shapes including the above-described dimensions and the like: "height Rz of projecting part 5 x (width L of recessed part 6/pitch P between adjacent projecting parts)".

[0029] Initially, in the above-described shape parameter G1, when it is assumed that the height Rz of the projecting parts 5 is fixed and width L of recessed part 6/pitch P between adjacent projecting parts (L/P) is changed, as illustrated in Fig. 4, the ratio of concentration of stress tends to increase as L/P increases. That is, an excessively large width L of the recessed part 6 or an excessively small pitch P between the projecting parts leads to concentration of stress, thereby allowing breakage to easily occur at such time as when press-forming (press working in which the herringbone or the like is formed) is performed.

[0030] In the above-described shape parameter G1, when assuming that the height Rz of the projecting parts 5 is increased, similarly to the case where the width L of the recessed part 6 or the pitch P between the adjacent projecting parts 5 is changed, stress may be unevenly distributed and breakage may occur in portions where stress is higher when press-forming is performed.

[0031] Accordingly, with consideration of press formability of the plate raw sheet 2, in an optimum case, the height Rz of the projecting parts 5 or the width L of the recessed part 6 is not excessively large and the pitch P between the projecting parts is not excessively small. Thus, the shape parameter G1 that represents these is thought to have an upper limit.

[0032] The inventors have clarified the relationships between the shape parameter G1 defined as "[height Rz of projecting parts 5 x (width L of recessed part 6/pitch P between adjacent projecting parts)]" and press formability for the plate raw sheet 2 formed of titanium and having a variety of the recessed and projecting shapes through experiments and the like.

[0033] In an evaluation test to evaluate the formability in press working (press formability), as illustrated in Fig. 5, the herringbone (grooves) 3 is initially formed in the original plate raw sheet 2 so as to form the heat-exchanging plate 4. In this fabrication, a piece of die for formation is initially prepared in accordance with the working conditions of the heat exchanger. Then, the herringbone 3 is formed in the plate raw sheet 2 by using the die. A plurality of the heat-exchanging plates 4 are fabricated. The plurality of heat-exchanging plates 4 are fabricated such that the heat-exchanging plates 4 having a formation height that is incremented by 0.1 mm from one plate to another. Among the fabricated evaluation plates (heat-exchanging plates 4), a formation limit height of the die with which no necking occurs (maximum formation height without the occurrence of necking) is evaluated as an indentation amount.

[0034] In the above-described evaluation test, when the indentation amount is large, necking does not easily occur and it can be said that press formability is good; when the indentation amount is small, the necking easily occurs and it can be said that press formability is bad. As described above, the formation depth from which necking starts and the amount of strain at which formation can be performed can be evaluated in the evaluation test.

[0035] Fig. 6 illustrates a press formability score, which is the above-described indentation amount having been normalized. The inventors have confirmed that, when the press formability score is equal to or greater than 1, press-forming can be reliably performed while the occurrence of necking is prevented.

[0036] As illustrated in Fig. 6, as the shape parameter G1 increases, the press formability score decreases. However, when the shape parameter G1 is equal to or smaller than 85 μm , the press formability score can be equal to or greater than 1. Thus, the occurrence of necking can be prevented. That is, when the shape parameter G1 is equal to or smaller than 85 μm , the occurrence of necking can be prevented, and accordingly, a decrease in press formability can be avoided.

[0037] When the shape parameter G1 is equal to or smaller than 65 μm , seizure or an increase in local bearing pressure occurring due to non-uniform distribution of a lubricating state caused by an increase in the height of the recess and projection can be further prevented. Because of this, it has been confirmed by the inventors through an experiment and the like that the heat-exchanging plate 4 can be reliably fabricated without troubles with press working.

[0038] As described above, when the shape parameter G1 is equal to or smaller than 85 μm , the decrease in press formability can be avoided. However, the plate raw sheet 2 according to the present invention is a material of a plate that is part the heat exchanger, specifically, a material processed to form a bulkhead for exchanging heat. Thus, the plate raw sheet 2 according to the present invention is also required to have a large heat transfer coefficient (large heat transfer efficiency).

[0039] Here, thinking of heat transfer efficiency of a plate having recessed or projecting shapes (heat-exchanging plate) compared to heat transfer efficiency of "a flat plate without recessed and projecting shapes", which is assumed to be 1.00, the heat transfer efficiency of the heat-exchanging plate needs to be greater than 1.00. Furthermore, in order to produce significant effects on an actual heat exchanger, it is desirable that the heat transfer efficiency be equal to or greater than 1.05.

[0040] Here, the relationship between the heat transfer efficiency and the shape parameter G1 is discussed. For example, when the height Rz of the projecting parts 5 or the width L of the recessed part 6 is decreased, or the pitch P between the projecting parts is increased, the shape parameter G1 gradually decreases from 85 μm . As the shape parameter G1 gradually decreases as described above, the heat transfer efficiency also gradually

decreases as illustrated in Fig. 6. This makes the heat transfer efficiency become closer to that of the flat plate without the recessed or projecting parts formed thereon. However, when the shape parameter G1 is equal to or greater than 4 μm , the heat transfer efficiency required for the actual heat exchanger (equal to or greater than 1.05) can be ensured.

[0041] Thus, from the viewpoint of the heat transfer efficiency, it is preferable that the shape parameter G1 be equal to or greater than 4 μm when fabricating the plate raw sheet 2. It is more preferable that the shape parameter G1 be greater than 12 μm , and specifically, the shape parameter G1 be greater than 12 μm and equal to or smaller than 85 μm .

[0042] As the width L of the recessed part 6 is decreased, the shape parameter G1 decreases. When thinking from the viewpoint of a thermal boundary layer in the case where a fluid flows, the recessed part 6 having an excessively small width L causes heat conductivity to be decreased. Thus, it is desirable that the width L of the recessed part 6 of a certain degree of size be ensured. That is, it is thought to be necessary that the shape parameter G1 also be of a certain degree of magnitude.

[0043] As described above, also from the viewpoint of the relationship between the thermal boundary layer and the width L of the recessed part 6, the shape parameter G1 of a certain degree of magnitude needs to be ensured while the shape parameter G1 is equal to or smaller than 85 μm . Specifically, as described above, it is thought that the shape parameter needs to be equal to or greater than 4 μm . By setting the shape parameter G1 to a value in a range from 4 μm to 85 μm , and as described above, setting the height Rz of the projecting parts 5 expressed as ten-point average roughness Rz to equal to or greater than 5 μm and to (thickness of flat plate material $\times$ 0.1) μm , the width L of the recessed part 6 (or the pitch P between the projecting parts 5) is automatically determined (found).

[0044] In addition, with consideration of prevention of deformation of the projecting parts 5 and workability in pressing operation to be performed in a downstream process, it is preferable the ratio S of pressure contact areas in the plate raw sheet 2 satisfy an expression (1) for the recessed and projecting shapes illustrated in Fig. 2 (a): Yield stress σ_y of flat plate material (titanium) > bearing pressure (P/S) applied to projecting part in pressing (1).

$$\text{Here, } S1 = P \cdot P \cdot \tan(\theta/180 \pi)/4,$$

$$S2 = \pi/4 \cdot D \cdot D/2,$$

$$S = \text{ratio of pressure contact areas} = S2/S1, \text{ and}$$

$$P = \text{load in press working.}$$

In the expression (1), S1 is an area of a plane in Fig. 2 (area of a triangle surrounded by the line A and the lines B in Fig. 2). In an expression (2), S2 is the area of the projecting parts 5 in Fig. 2 (area of the projecting parts existing within the above-described triangle).

[0045] By using the titanium original plate material 2, on the surface of which the recessed and projecting parts are formed so as to have the shape parameter G1 of 4 μm to 85 μm as described above, the heat-exchanging plate 4, which is part of the heat exchanger, can be fabricated without the occurrence of breakage or the like during press working. The heat-exchanging plate 4 fabricated as described above has a heat exchanger effectiveness of equal to or greater than 1.05 and exhibits a significantly good heat conductivity. A heat exchanger in which this heat-exchanging plate 4 is incorporated has a significantly high heat exchanger efficiency.

[0046] The above-described plate raw sheet 2 can be formed using the process device 10 as illustrated in Fig. 7. The process device 10 includes transport rollers 11, a process roller 12, and a support roller 13. The transport rollers 11 transport the flat plate material 1 and are disposed on the upstream side and the downstream side of the process roller 12.

[0047] The process roller 12 forms a recess and projections in the order of micrometers (smaller than 10 μm to smaller than one mm) on the surface of the flat plate material 1 being transported. Specifically, the process roller 12 forms the recessed and projecting parts 5 and 6 on the surface 1a of the flat plate material 1 such that the shape parameter G1 of the plate raw sheet 2 after processing is within a range from 4 μm to 85 μm . That is, the height Rz of the projecting parts 5, the width L of the recessed part 6, and the pitch P between the adjacent projecting parts 5 are set in the process roller 12 in order to form the recessed and projecting parts 5 and 6 so as to satisfy the shape parameter G1 in the range from 4 to 85 μm .

[0048] Process portions 14 each having a projecting shape (a trapezoidal projection) are formed over a whole area of an outer peripheral surface of the process roller 12 by etching or electro-discharge texturing. The height of the process portions 14 is set such that the height Rz of the projecting parts 5 in the plate raw sheet 2 after processing is equal to or greater than 5 μm and equal to or smaller than (thickness t of flat plate material $\times$ 0.1) μm . It is desirable that a surface layer of the process roller 12 be Cr-plated or tungsten-carbide coated from the viewpoint of load bearing characteristics and wear resistance.

[0049] The process device 10 presses the process portions 14 provided on the process roller 12 against the surface of the flat plate material 1 while the process roller 12 is being rotated. By doing this, the recessed part 6 and projecting parts 5, which are complementarily shaped with respect to the process portions 14, is formed on the surface of the flat plate material 1. That is, by using the process device 10, the plate raw sheet 2 having the recessed and projecting shapes can be formed, the shape parameter G1 of which is from 4 μm to 85 μm and the height Rz of which is equal to or greater than 5 μm and equal to or smaller than 10% of the plate thickness t. The method of forming the projecting parts 5 is not

limited to machining using the above-described process device or the like. The projecting parts 5 may be formed by chemical processing such as etching.

[0050] The heat-exchanging plate 4 is fabricated in press working performed on the plate raw sheet 2 according to the present invention. This press working performed on the plate raw sheet 2 may be any press working and not limited to the foregoing press working that forms the herringbone.

[0051] Regarding the recess and projections formed on the plate raw sheet 2, it is sufficient that the range from 4 μm to 85 μm of the shape parameter G1 be satisfied in at least part of the plate raw sheet 2, and it is preferable that this range of the shape parameter G1 be satisfied over the entirety of the plate raw sheet 2.

[Second Embodiment]

[0052] A second embodiment is described below. Description common to the above-described first embodiment and the second embodiment is omitted as appropriate.

[0053] The details of the recessed and projecting shapes of the surface of the plate raw sheet 2 are described below.

[0054] As illustrated in Fig. 8, the projecting parts 5 formed on the surface 2a of the plate raw sheet 2 each have the side wall 7 and the front wall 8. The side wall 7 stands erect in the thickness direction (thickness direction of the plate raw sheet 2). The front wall 8 closes the upper end (upper edge) of the side wall 7. In other words, the projecting parts 5 have a flat portion at its top. In the case where the projecting parts 5 have a cylindrical shape or a conical shape, the projecting parts 5 have a single side wall 7. In the case where the projecting parts 5 have a square rod shape or a pyramid shape, the projecting parts 5 have a plurality of side walls 7.

[0055] As illustrated in Fig. 2 (a), the projecting parts 5 formed on the surface 2a of the plate raw sheet 2 each have a substantially circular shape in plan view and a diameter D of equal to or greater than 400 μm . It is preferable that the projecting parts 5 be arranged in a staggered manner in plan view as is the case with the first embodiment, and the pitch P between the adjacent projecting parts 5 (the distance between the centers of the projecting parts 5, that is, the distance between the centers of the front walls 8), be equal to or greater than 600 μm .

[0056] As is the case with the first embodiment, the projecting parts 5 formed on the surface of the plate raw sheet 2 have a substantially trapezoidal shape as illustrated in Fig. 2 (b). The height (height Rz) of the projecting parts 5 (side wall 7) expressed as ten-point average roughness Rz is equal to or greater than 5 μm , and equal to or smaller than 1/10 (one tenth) of the thickness t of the plate raw sheet 2. Rz of the projecting parts 5 of the plate raw sheet 2 is, for example, about 25 μm (about 10 μm when expressed as Ra).

[0057] The recessed and projecting shapes of the plate raw sheet 2 according to the second embodiment are based on the findings as follows.

[0058] In fabricating the plate raw sheet 2, in order to optimize the height R_z of the projecting parts 5, the number of the projecting parts 5 (the width L of the recessed part 6), the pitch P between the adjacent projecting parts, and the angle η of the projecting parts formed on the surface of the plate raw sheet 2, the inventors have focused on the following shape parameter $G2$ of the recessed and projecting shapes including the above-described values: "height R_z of projecting part 5 x (width L of recessed part 6/pitch P between adjacent projecting parts)/angle η of projecting part".

[0059] Initially, in the above-described shape parameter $G2$, when it is assumed that the height R_z of the projecting parts 5 is fixed and the width L of recessed part 6/pitch P between adjacent projecting parts (L/P) is changed, as illustrated in Fig. 4, the ratio of concentration of stress tends to increase as L/P increases. That is, an excessively large width L of the recessed part 6 or an excessively small pitch P between the projecting parts leads to concentration of stress, thereby allowing breakage to easily occur at such time as when press-forming (press working in which the herringbone or the like is formed) is performed.

[0060] In the above-described shape parameter $G2$, when assuming that the height R_z of the projecting parts 5 is changed to an increased value, similarly to the case where the width L of the recessed part 6 or the pitch P between the adjacent projecting parts 5 is changed, stress may be unevenly distributed and breakage may occur in portions where stress is higher when press-forming is performed.

[0061] Accordingly, with consideration of press formability of the plate raw sheet 2, it is thought to be optimum that the height R_z of the projecting parts 5 or the width L of the recessed part 6 is not excessively large and the pitch P between the projecting parts is not excessively small, and a parameter that expresses these values has an upper limit.

[0062] Fig. 6 summarizes the relationship between the press formability and the heat transfer efficiency when the parameter defined as "height R_z of projecting part 5 x (width L of recessed part 6/pitch P between adjacent projecting parts)", which does not include the above-described rising angle η of the projecting parts, is changed. The press formability score illustrated in Fig. 6 represents the normalized indentation amount described below.

[0063] Here, an evaluation test for evaluating the formability in press working (press formability) is the same as that of the first embodiment and description thereof is omitted.

[0064] As illustrated in Fig. 6, as the parameter increases, the press formability score decreases. However, when the parameter is $85\ \mu\text{m}$ or smaller, the press formability score can be equal to or greater than 1. Thus, press-forming can be reliably performed while the occur-

rence of necking is prevented.

[0065] As described above, the plate raw sheet 2 according to the present invention is a material of a plate that is part the heat exchanger, specifically, a material processed to form a bulkhead for exchanging heat. Thus, in order to produce significant effects on an actual heat exchanger with the plate raw sheet 2 according to the present invention, it is desirable that the heat transfer efficiency be equal to or greater than 1.05.

[0066] Here, the relationship between the heat transfer efficiency and the parameter is discussed. For example, when the height R_z of the projecting parts 5 or the width L of the recessed part 6 is decreased, or the pitch P between the projecting parts is increased, the parameter gradually decreases from $85\ \mu\text{m}$. As the parameter gradually decreases, the heat transfer efficiency also gradually decreases as illustrated in Fig. 6. This makes the heat transfer efficiency become closer to that of the flat plate without the recessed or projecting parts formed thereon. However, when the parameter is equal to or greater than $4\ \mu\text{m}$, the heat transfer efficiency required for the actual heat exchanger (equal to or greater than 1.05) can be ensured. Thus, from the viewpoint of the heat transfer efficiency, in fabricating the plate raw sheet 2, it is preferable that the parameter defined as "height R_z of projecting part 5 x width L of recessed part 6/pitch P between adjacent projecting parts" be from $4\ \mu\text{m}$ to $85\ \mu\text{m}$.

[0067] As described above, by setting the height R_z of the projecting parts 5, the width L of the recessed part 6, and the pitch P between the adjacent projecting parts 5, the plate raw sheet 2 having a good press formability and a good heat conductivity can be fabricated.

[0068] Here, assuming that fluids are caused to flow on both sides of the heat-exchanging plate 4 as follows: a fluid, the temperature of which is high (high-temperature fluid) is caused to flow on a rear side (one side); and a fluid, the temperature of which is low (low-temperature fluid), is caused to flow on a front side (the other side and a side on which the recessed and projecting surface is formed). Here, the low-temperature fluid may be changed from a gas to a liquid (condensed) or remain in a liquid state. In either case, in order to increase the heat transfer efficiency of the heat-exchanging plate 4, it is important to cause turbulence or forced convection on the low-temperature fluid (liquid) side. Thus, in fabricating the plate raw sheet 2 as the original material of the heat-exchanging plate, the inventors have also examined the shape of the projecting part 5, with which turbulence or forced convection is easily caused, by considering not only the height R_z of the projecting parts 5, the width L of the recessed part 6, and the pitch P between the projecting parts 5, but also the angle η of the projecting parts 5 (rising angle η of the side walls 7).

[0069] Fig. 9 (a) schematically illustrates a flow of the fluid when the angle η of the projecting parts 5 is large. Fig. 9 (b) schematically illustrates a flow of the fluid when the angle η of the projecting parts 5 is smaller than that

illustrated in Fig. 9 (a).

[0070] As illustrated in Fig. 9 (a), when the angle η of the projecting parts, in other word, the angle η formed between a bottom wall 6a of the recessed part 6 and the side walls 7 is comparatively large (the side walls 7 gently rise), the fluid easily flows over the projecting parts 5 and turbulence is not easily caused. In contrast, as illustrated in Fig. 9 (b), when the angle η of the projecting parts 5 is comparatively small (the side walls 7 steeply rise), the fluid easily strikes the projecting parts 5, and the turbulence is easily caused. As described above, the angle η of the projecting parts 5 is a factor that affects turbulence, thereby changing heat conductivity. That is, as the angle η of the projecting parts 5 increases, the heat conductivity tends to decrease. In contrast, as the angle η of the projecting parts 5 decreases, the heat conductivity increases. Based on this finding, the inventors have studied the more suitable shape parameter G2 that includes the angle η of the projecting parts 5, which affects heat conductivity, in addition to the height Rz of the projecting parts 5, the width L of the recessed part 6, and the pitch P between the projecting parts 5.

[0071] That is, the shape parameter G2 defined as "height Rz of projecting part 5 x (width L of recessed part 6/pitch P between adjacent projecting parts)/angle η (deg) of projecting part 5" is obtained by dividing the above-described parameter defined as "height Rz of projecting part 5 x (width L of recessed part 6/pitch P between adjacent projecting parts)" by the angle η of the projecting parts 5.

[0072] Fig. 10 summarizes the relationship between the shape parameter G2 and the ratio of improvement in heat conductivity.

[0073] As illustrated in Fig. 10, it is observed that the tendency of the heat transfer efficiency in condensation when the shape parameter G2 is increased and decreased is similar to the tendency of the heat transfer efficiency in forced convection. From this, it can be said that the above-described shape parameter G2 is most suitable for representing heat transfer characteristics in condensation and forced convection.

[0074] Furthermore, press formability, which is one of basic requirements as described above, is considered with respect to the shape parameter G2, which can suitably represent heat transfer characteristics in condensation and forced convection. Fig. 11 summarizes the relationship between the press formability and the heat transfer efficiency when the shape parameter G2 defined as "height Rz of projecting part 5 x (width L of recessed part 6/pitch P between adjacent projecting parts)/angle η (deg) of projecting part", which includes the rising angle η of the projecting parts, is changed.

[0075] As illustrated in Fig. 11, as the shape parameter G2 increases, the press formability score decreases. However, when the shape parameter G2 is equal to or smaller than 0.94 $\mu\text{m}/\text{deg}$, the press formability score can be equal to or greater than 1. Thus, press-forming can be reliably performed while the occurrence of neck-

ing is prevented. That is, when the shape parameter for also considering condensation and forced convection is equal to or smaller than 0.94 $\mu\text{m}/\text{deg}$, the occurrence of necking can be prevented and a reduction in press formability can be avoided.

[0076] That is, by forming the recess and projections such that the shape parameter G2, which is obtained by multiplying the parameter defined as "height Rz of projecting part 5 x (width L of recessed part 6/pitch P between adjacent projecting parts)" by the angle η of the projecting parts 5, is equal to or smaller than 0.94 $\mu\text{m}/\text{deg}$, the plate raw sheet 2 having a significantly good heat conductivity and suitable for press-forming can be fabricated. As described for parameters other than the angle η of the projecting parts, when a lower limit is considered also for the shape parameter G2 (to ensure a heat transfer efficiency of 1.05 or higher), as illustrated in Fig. 11, the shape parameter G2 needs to be equal to or greater than 0.14 $\mu\text{m}/\text{deg}$. Preferably, the shape parameter G2 is equal to or greater than 0.16 $\mu\text{m}/\text{deg}$, and more preferably, the shape parameter G2 is equal to or greater than 0.2 $\mu\text{m}/\text{deg}$.

[0077] Thus, it is preferable that the shape parameter G2 defined as "height Rz of projecting part 5 x (width L of recessed part 6/pitch P between adjacent projecting parts)/angle η (deg) of projecting part 5", be from 0.14 to 0.94 $\mu\text{m}/\text{deg}$.

[0078] Here, with consideration of prevention of deformation in forming the projecting parts 5, it is preferable that the ratio S of pressure contact areas in the plate raw sheet 2 satisfy the expression (1) for the recessed and projecting shapes illustrated in Fig. 2 (a).

[0079] Yield stress σ_y of flat plate material (titanium) > Bearing pressure (P/S) applied to projecting part in pressing (1).

Here,

[0080]

$$S1 = P \cdot P \cdot \tan(\theta/180 \pi)/4,$$

$$S2 = \pi/4 \cdot D \cdot D/2,$$

$$S = \text{ratio of pressure contact areas} = S2/S1, \text{ and}$$

$$P = \text{load in press working.}$$

[0081] In the expression (1), S1 is an area of a plane in Fig. 2 (area of the triangle surrounded by the line A and the lines B in Fig. 2). In an expression (2), S2 is the area of the projecting parts 5 in Fig. 2 (area of the projecting parts existing within the above-described triangle).

[0082] By using the original plate material 2 made of titanium, on the surface of which the recessed and projecting parts are formed so as to have the shape parameter G2 of 0.14 to 0.94 $\mu\text{m}/\text{deg}$ as described above, the heat-exchanging plate 4, which is part of the heat exchanger, can be fabricated without the occurrence of breakage or the like during press working. The heat-ex-

changing plate 4 fabricated as above has a significantly good heat conductivity and can be used as a gas-liquid heat-exchanging plate and a liquid-liquid heat-exchanging plate.

[0083] The above-described plate raw sheet 2 can be formed using the process device 10 as illustrated in Fig. 7 similarly to the first embodiment. The height R_z of the projecting parts 5, the width L of the recessed part 6, the pitch P between the adjacent projecting parts 5, and the angle η of the projecting parts are set in the process roller 12 in order to form the recessed and projecting parts 5 and 6 so as to satisfy the shape parameter G_2 in the range from 0.14 to 0.94 $\mu\text{m}/\text{deg}$.

[Third Embodiment]

[0084] In the above-described second embodiment, the shape parameter G_2 including the rising angle η of the projecting parts 5 is 0.14 to 0.94 $\mu\text{m}/\text{deg}$. In a third embodiment, the shape parameter G_2 is further examined through an experience and the like. Description of the same structures as those of the second embodiment is omitted.

[0085] Fig. 12 summarizes the relationship between the press formability and the heat transfer efficiency when the shape parameter G_2 defined as "height R_z of projecting part 5 $\times$ (width L of recessed part 6/pitch P between adjacent projecting parts)/angle η (deg) of projecting part", which includes the rising angle η of the projecting parts, is changed.

[0086] As illustrated in Fig. 12, as the shape parameter G_2 increases, the press formability score decreases. However, when the shape parameter G_2 is equal to or smaller than 0.94 $\mu\text{m}/\text{deg}$, the press formability score can be equal to or greater than 1. Thus, press-forming can be reliably performed while the occurrence of necking is prevented. That is, when the shape parameter G_2 for also considering condensation and forced convection is equal to or smaller than 0.94 $\mu\text{m}/\text{deg}$, the occurrence of necking can be prevented and a reduction in press formability can be avoided. That is, as a result of the examination, the upper limit of the shape parameter G_2 needs to be equal to or smaller than 0.94 $\mu\text{m}/\text{deg}$. Thus, the result of the third embodiment is the same as that of the second embodiment.

[0087] In order to use the heat-exchanging plate 4 in a variety of applications, as described above, the heat transfer efficiency needs to be equal to or greater than 1.05. However, when the heat-exchanging plate 4 is also used as, for example, a gas-liquid or liquid-liquid heat-exchanging plate, it is sufficient that the heat transfer efficiency of equal to or greater than 1.03 be ensured. As illustrated in Fig. 12, when the shape parameter G_2 is equal to or greater than 0.028 $\mu\text{m}/\text{deg}$, the heat transfer efficiency can be equal to or greater than 1.03. Thus, it is preferable that the lower limit of the shape parameter G_2 be 0.028 $\mu\text{m}/\text{deg}$. In Fig. 12, the filled circles representing forced convection are superposed with the hollow

circles representing condensation, and values in forced convection are substantially the same as values in condensation.

[0088] In fabricating the plate raw sheet 2, the recess and projections are formed by using the process device 10 (process roller 12) such that the shape parameter G_2 is 0.028 to 0.94 $\mu\text{m}/\text{deg}$. The details of the fabricating method are the same as the above-described embodiments and description thereof is omitted.

[0089] Regarding the recess and projections formed on the plate raw sheet 2, it is sufficient that the range from 0.14 to 0.94 $\mu\text{m}/\text{deg}$ of the shape parameter G_2 be satisfied in at least part of the plate raw sheet 2, and it is preferable that this range of the shape parameter G_2 be satisfied over the entirety of the plate raw sheet 2.

[0090] Although the embodiments of the present invention have been described, the present invention is not limited to the embodiments described above, and implementation of the present invention with a variety of changes is possible without departing from contents described in the claims. The present application is applied based on Japanese Patent Application No. 2011-203422 filed on September 16, 2011, Japanese Patent Application No. 2011-203423 filed on September 16, 2011, Japanese Patent Application No. 2011-246574 filed on November 10, 2011, and Japanese Patent Application No. 2011-284605 filed on December 27, 2011, the entire contents of which are incorporated herein by reference.

Industrial Applicability

[0091] The original plate material for a heat-exchanging plate according to the present invention and the heat-exchanging plate using the original plate material is preferable as the original plate for a plate of a heat exchanger used for electric generation by temperature difference and the like and a heat-exchanging plate using the original plate. Reference Signs List

- 1 flat plate material
- 1a surface of flat plate material
- 2 plate raw sheet (original plate material)
- 2a surface of plate raw sheet
- 3 groove
- 4 heat-exchanging plate
- 5 projecting part
- 6 recessed part
- 7 side wall
- 8 front wall

- 10 process device
- 11 transfer roller
- 12 process roller
- 13 support roller

Claims

1. An original plate material for a heat-exchanging plate, the original plate material being subjected to press working so as to be used as a heat-exchanging plate, the original plate material being made by forming a fine recess and fine projections on a surface of a metal flat plate material as a raw material, wherein the recess and the projections are formed such that a shape parameter G1 defined as a height of a projecting part in μm x [a width of a recessed part in μm /a pitch between the adjacent projecting parts in μm] is equal to or smaller than 85 μm .
2. The original plate material for a heat-exchanging plate according to Claim 1, wherein the recess and the projections are formed on a surface of the original plate material such that the shape parameter G1 is equal to or greater than 4 μm .
3. The original plate material for a heat-exchanging plate according to Claim 1 or 2, wherein the projecting parts each have a circular shape in plan view and are arranged on the surface of the flat plate material in a staggered manner.
4. The original plate material for a heat-exchanging plate according to Claim 1 or 2, wherein the height of the projecting parts is equal to or greater than 5 μm expressed as ten-point average roughness Rz and equal to or smaller than 0.1 x a thickness of the flat plate material in μm .
5. The heat-exchanging plate according to Claim 1 or 2, wherein the heat-exchanging plate is formed by press working performed on the original plate material for a heat-exchanging plate.
6. An original plate material for a heat-exchanging plate, the original plate material being subjected to press working so as to be used as a heat-exchanging plate, the original plate material being made by forming a fine recess and fine projections on a surface of a metal flat plate material as a raw material, wherein the recess and the projections are formed such that a shape parameter G2 defined as a height of a projecting part in μm x [a width of a recessed

part in μm /a pitch between the adjacent projecting parts in μm /an angle of the projecting part in deg] is equal to or smaller than 0.94 $\mu\text{m}/\text{deg}$.

7. The original plate material for a heat-exchanging plate according to Claim 6, wherein the recess and the projections are formed on a surface of the original plate material such that the shape parameter G2 is equal to or greater than 0.14 $\mu\text{m}/\text{deg}$.
8. The original plate material for a heat-exchanging plate according to Claim 6, wherein the recess and the projections are formed on a surface of the original plate material such that the shape parameter G2 is equal to or greater than 0.028 $\mu\text{m}/\text{deg}$.
9. The original plate material for a heat-exchanging plate according to any one of Claims 6 to 8, wherein the height of the projecting parts is equal to or greater than 5 μm expressed as ten-point average roughness Rz and equal to or smaller than 0.1 x a thickness of the flat plate material in μm .
10. The heat-exchanging plate according to any one of Claims 6 to 8, wherein the heat-exchanging plate is formed by press working performed on the original plate material for a heat-exchanging plate.

FIG. 1

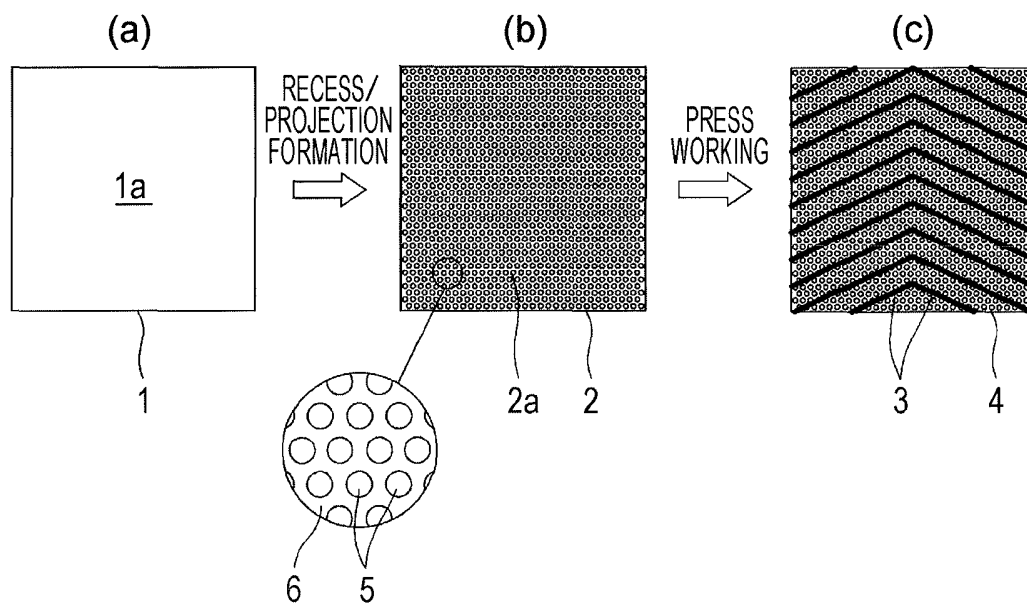


FIG. 2

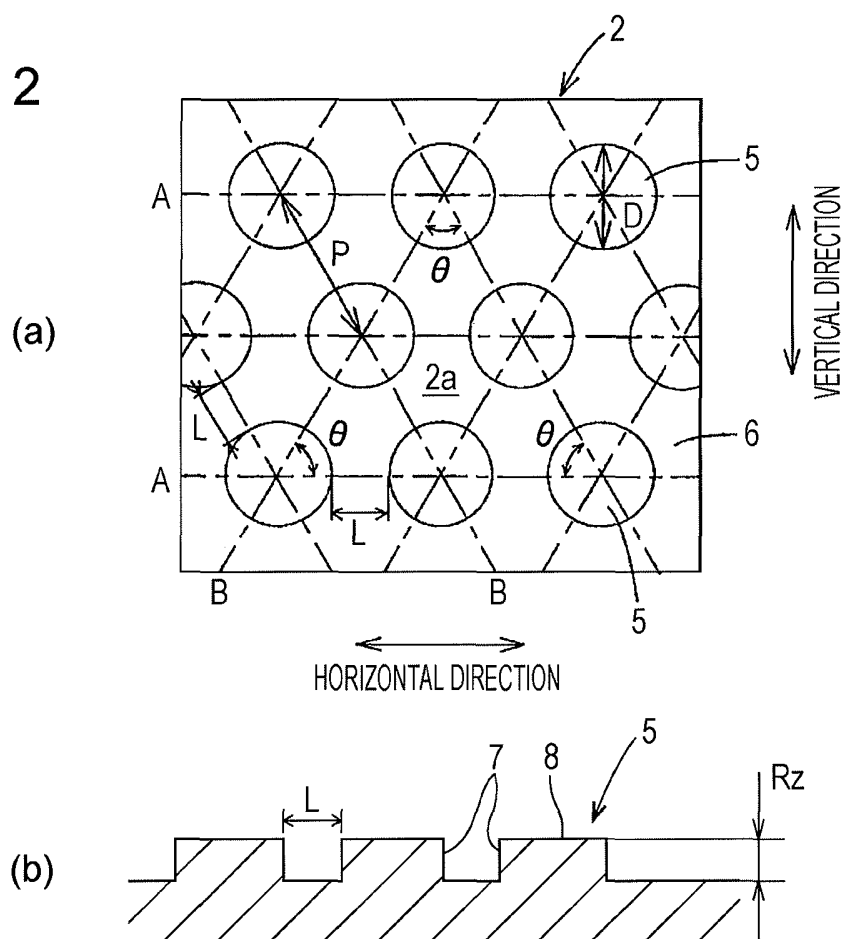


FIG. 3

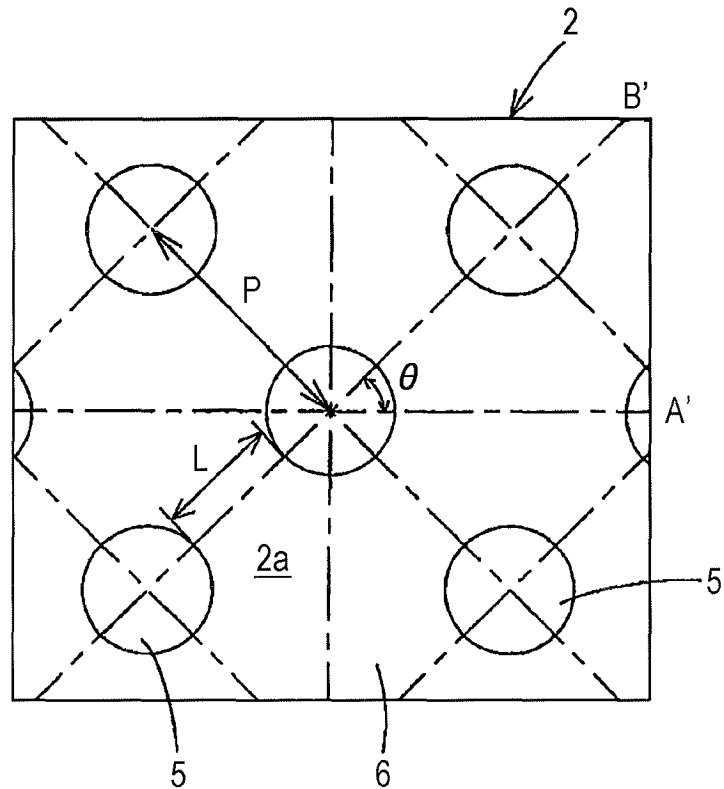


FIG. 4

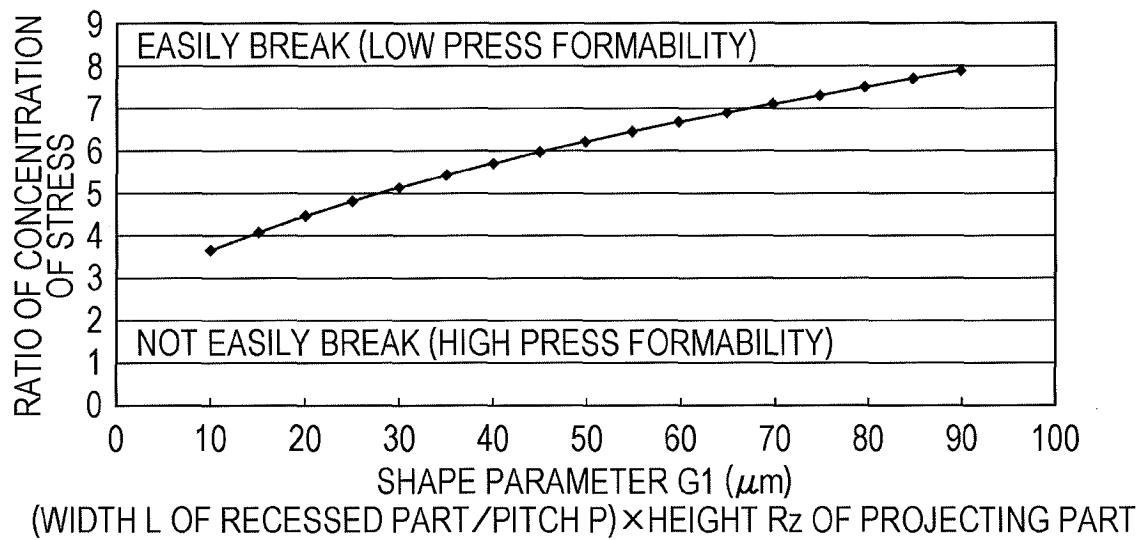


FIG. 5

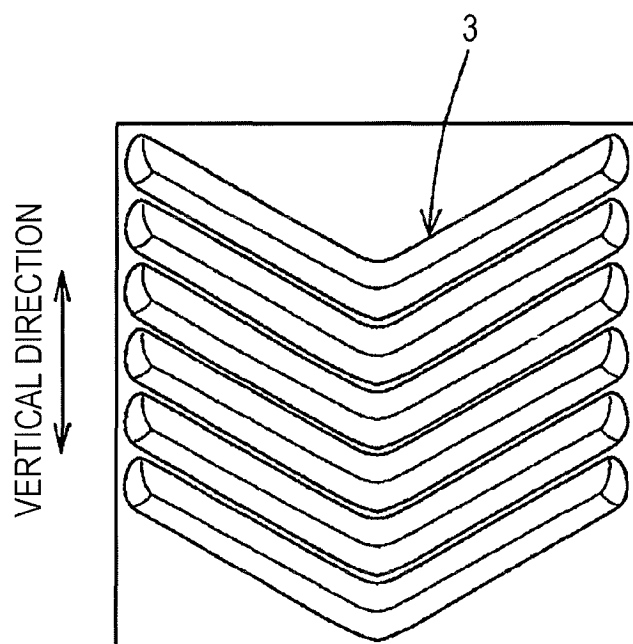


FIG. 6

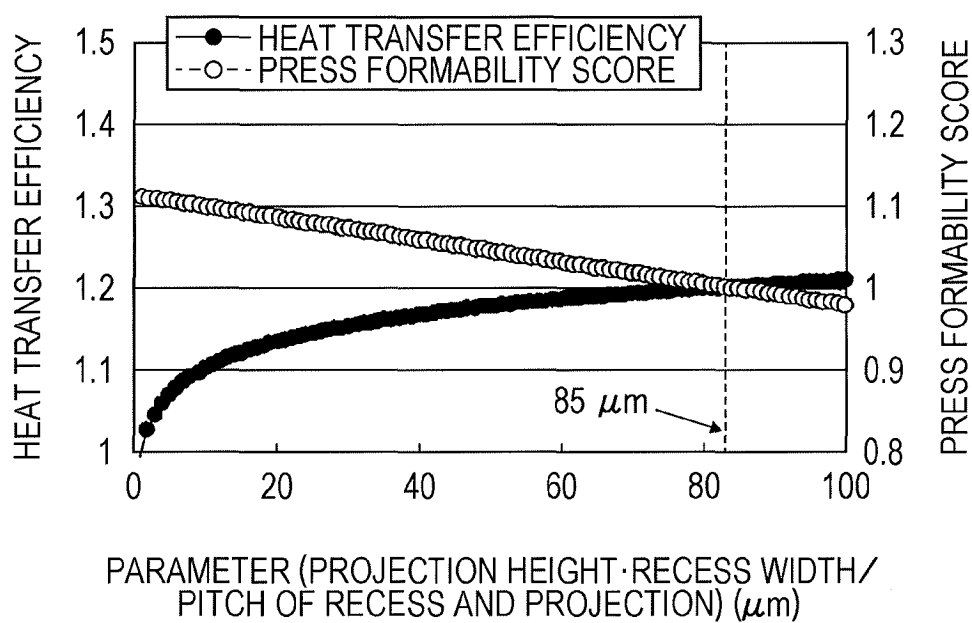


FIG. 7

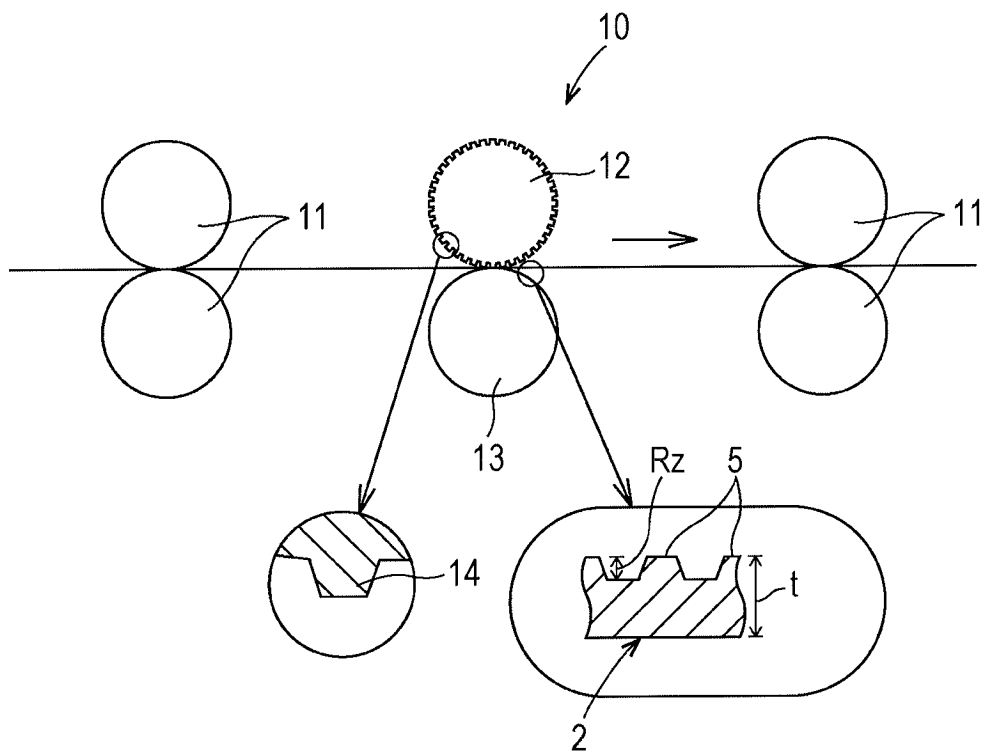


FIG. 8

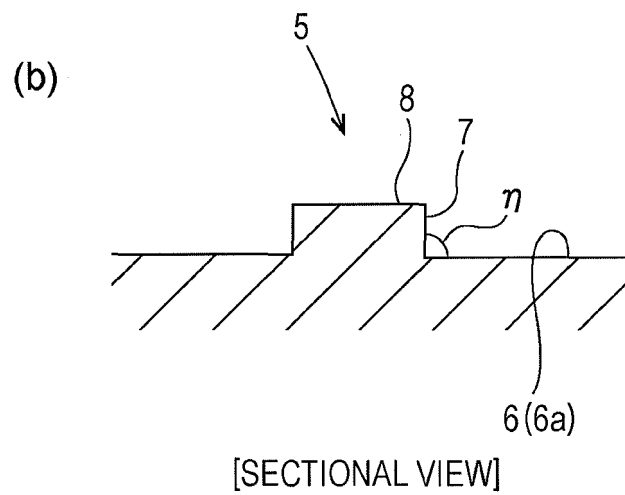
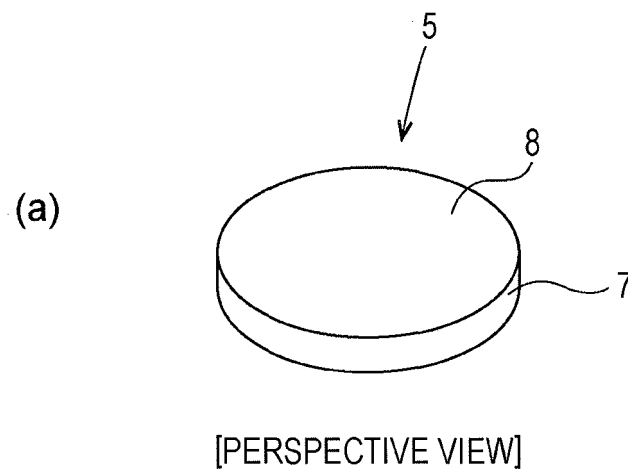


FIG. 9

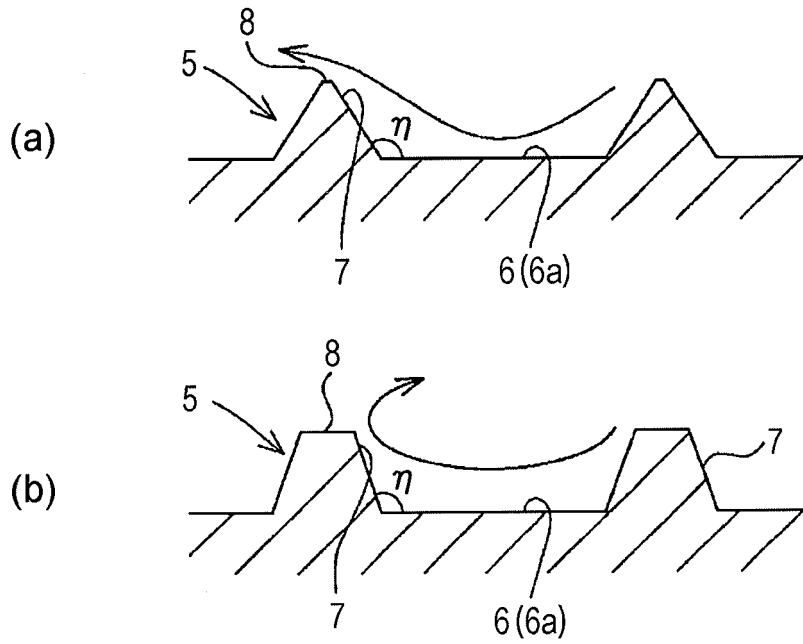


FIG. 10

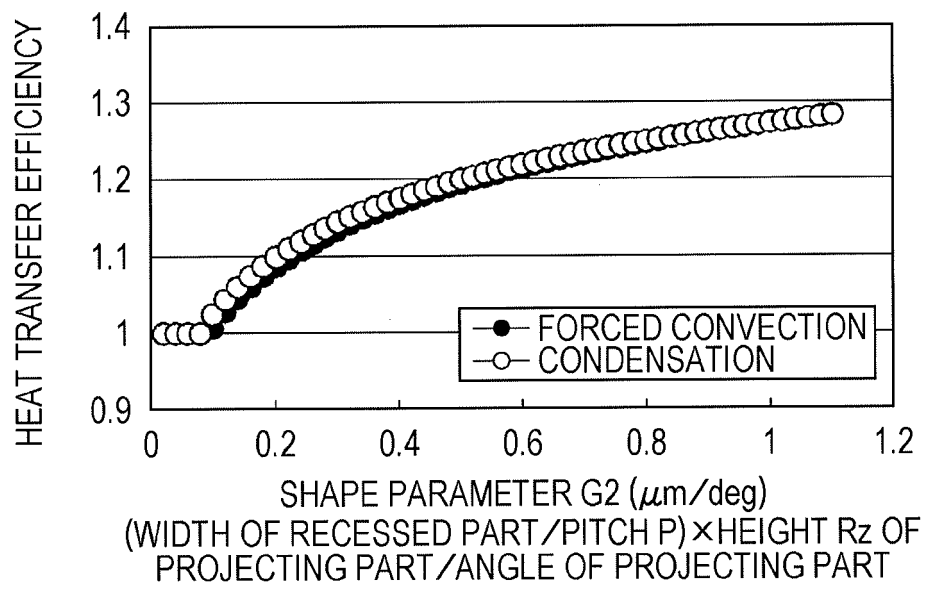


FIG. 11

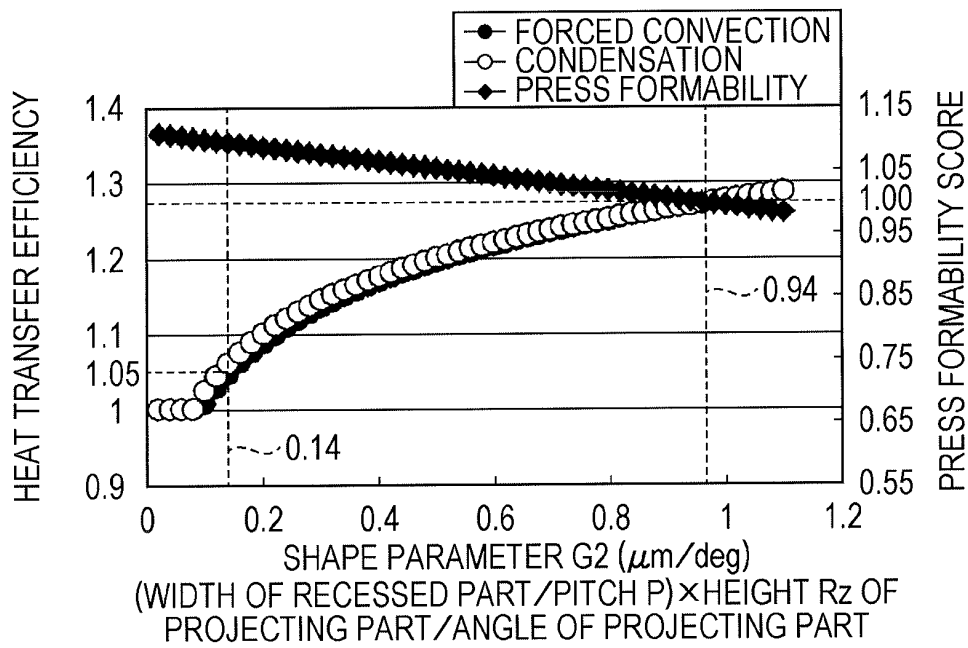
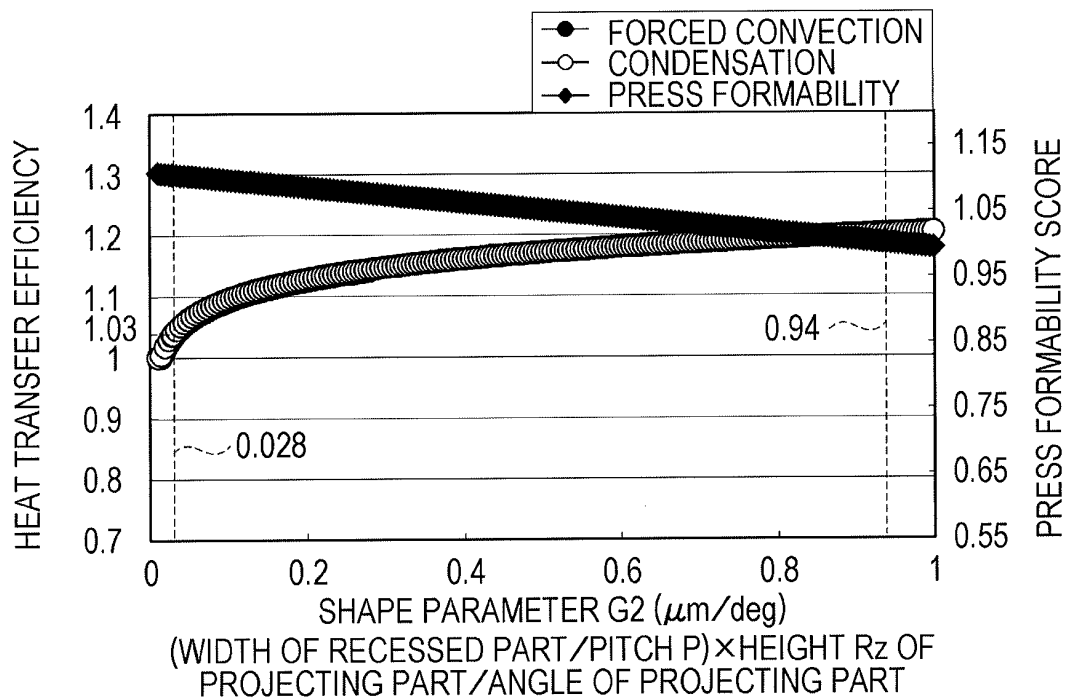


FIG. 12



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/073661

A. CLASSIFICATION OF SUBJECT MATTER

F28F13/02(2006.01)i, B21D31/00(2006.01)i, B21D53/04(2006.01)i, F28F1/12(2006.01)i, F28F3/04(2006.01)i, F28F21/08(2006.01)i

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)

F28F13/02, B21D31/00, B21D53/04, F28F1/12, F28F3/04, F28F21/08

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.
Y	US 2003/0136547 A1 (Dieter GOLLAN), 24 July 2003 (24.07.2003), fig. 1 to 12, 14; paragraphs [0068], [0075] to [0077] & EP 1318371 A2 & DE 10159860 A & AT 384237 T & ES 2300414 T	1-10
Y	WO 2010/143564 A1 (Kobe Steel, Ltd.), 16 December 2010 (16.12.2010), fig. 1 to 5; paragraphs [0010] to [0037] & EP 2442059 A1 & WO 2010/143564 A1 & CN 102460057 A & KR 10-2012-0024719 A	1-10

☒ 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
11 October, 2012 (11.10.12)

Date of mailing of the international search report
23 October, 2012 (23.10.12)

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/073661

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0057941 A2 (NORANDA MINES LTD.), 18 August 1982 (18.08.1982), entire text; all drawings & JP 57-139294 A & NO 820103 A & AU 7914681 A & CA 1155107 A	1-10
A	US 2003/0080478 A1 (Joon-Shik PARK), 01 May 2003 (01.05.2003), fig. 1b, 6a, 6b, 6c; paragraphs [0048] to [0052] & KR 10-2003-0035089 A	1-10

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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- JP 2011246574 A [0090]
- JP 2011284605 A [0090]