(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 2 638 982 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
**18.09.2013 Bulletin 2013/38**

(21) Application number: **11849189.3**

(22) Date of filing: **13.12.2011**

(51) Int Cl.:
***B21D 5/01*** *(2006.01)* ***B21D 51/10*** *(2006.01)*

(86) International application number:
**PCT/JP2011/079273**

(87) International publication number:
**WO 2012/081717 (21.06.2012 Gazette 2012/25)**

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

(30) Priority: **14.12.2010 JP 2010277923**

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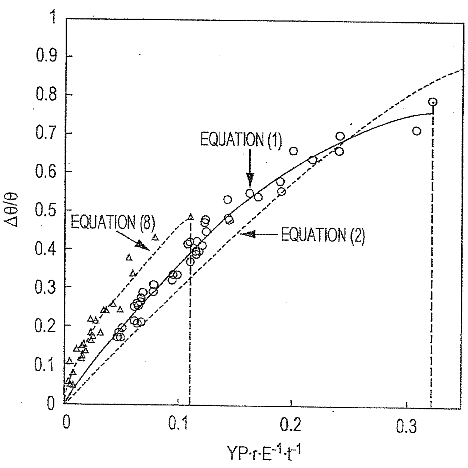
(54) **METHOD OF DESIGNING MATERIAL FOR CYLINDER FORMATION PROCESS, AND CYLINDER FORMATION PROCESSED PRODUCT**

(57) An object of the present invention is to provide a method for designing a metal material having mechanical properties with which a specified spring back angle can be achieved after any one of metal materials having a wide variety of mechanical properties and thicknesses has been formed by performing cylinder forming and a product formed by using the method. A method for designing a material to be subjected to cylinder forming, the method including, in the design of a metal material to be subjected to cylinder forming in which the metal material is formed by performing bending forming, calculating the yield strength YP, the Young's modulus E and the thickness t of the metal material so that a spring back angle $\Delta\theta$ becomes a specified value when cylinder forming is performed under conditions of a radius of curvature of bending r of 5 mm or more and a bending angle $\theta$ of 90 degrees or more and 180 degrees or less and designing the metal material so that the metal material has the calculated yield strength YP and Young's modulus E.

FIG. 2

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Printed by Jouve, 75001 PARIS (FR)

## Description

[Technical Field]

**[0001]** The present invention relates to a method for designing a metal material in which a spring back angle in cylinder forming can be controlled to a specified value and a product formed by performing cylinder forming.

[Background Art]

**[0002]** A cylindrically formed product which is manufactured by performing cylinder forming in which a metal material is formed by performing bending forming (hereinafter, called cylinder forming) is used for a food container, a medical device, a metal container, an equipment part and so forth. For example, in the case of a three-piece can which consists of an end, a body and a bottom end, a cylinder product formed by performing cylinder forming is used for the body.

**[0003]** In general, spring back occurs due to elastic recovery when a metal material (a metal sheet) is subjected to cylinder forming and then unloaded, which results in a change in the shape of the cylinder. Therefore, when cylinder forming is performed, it is necessary to determine the conditions under which cylinder forming is performed in consideration of spring back in advance.

**[0004]** Nowadays, there is a tendency to require reduction of the thickness (hereinafter, also called thickness reduction) of a metal material in order to reduce material cost. However, there is a problem in that thickness reduction causes an increase in a spring back angle, which makes it impossible to achieve a specified shape of a cylinder, that is, a specified lapping width. Here, a spring back angle is defined in terms of an amount of change in a bending angle from the loaded state to the unloaded state in bending forming. In addition, a lapping width is, as illustrated in Fig. 1, defined in the following manner in terms of a distance between one edge and another of the metal sheet which is made into the shape of a cylinder by performing cylinder forming: a lapping width has a value of 0 in the case where both edges butt each other, a positive value in the case where both edges are separated by a gap and a negative value in the case where both edges overlap each other.

**[0005]** Since a change in lapping width due to thickness reduction hampers the succeeding processes (such as a process in which a metal sheet is made into the body of a three-piece can by welding the edges of the metal sheet), it is necessary to prevent a change in lapping width due to thickness reduction. Therefore, in the case where a thick metal material is replaced by a thin metal material in a cylinder forming process, it is necessary to readjust forming conditions or remodel a forming apparatus, which is an obstacle to the improvement of productivity and the reduction of cost.

**[0006]** Therefore, if a metal material can be designed so that a specified shape of a cylinder (lapping width) can be obtained even if the thickness of the material is reduced, it is not necessary to readjust forming conditions or remodel a forming apparatus. That is to say, it is necessary to design a metal material with which a spring back angle equivalent to that of a metal material before the thickness is changed can be obtained even after the thickness has been changed.

**[0007]** Incidentally, if it is assumed that a material which is used for forming is an elastic- perfectly plastic solid which does not exhibit work- hardening behavior, a spring back angle can be theoretically calculated by the following equation (2) (refer to Non Patent Literature 1) :

$$\Delta\theta/\theta = 3(YP\cdot r)/(E\cdot t)-4[(YP\cdot r)/(E\cdot t)]^3 \cdots (2),$$

where, $\Delta\theta$: spring back angle (degrees) , $\theta$: bending angle (degrees) , r: radius of curvature of bending (mm) , t: thickness (mm) , YP: yield strength (MPa) and E: Young's modulus (MPa) .

**[0008]** Therefore, it is appropriate that designing a metal material having the required mechanical properties (a Young's modulus and a yield strength) which are calculated by the equation (2) in accordance with a target thickness and a target spring back angle.

**[0009]** However, as Non Patent Literature 2 reports that, the theoretical equation (2) does not necessarily correctly replicate experimental findings. Moreover, although Non Patent Literature 2 proposes an empirical equation regarding a stainless steel sheet, since the target metal material is limited to a stainless steel sheet, it cannot be said that it is suitable for a wide variety of metal materials and there is a problem left from the viewpoint of versatility.

[Citation List]

**[0010]**

[NPL 1] Baba and Hashida: Tetsu-to-Hagané (The bulletin of The Iron and Steel Institute of Japan), vol. 49(3) (1963),

p. 507.
[NPL 2] Sugimoto, Hukui, Mitsui, Watanabe and Nakamura: Tetsu- to- Hagané, vol. 66 (1980) , S 976.

[Summary of Invention]

[Technical Problem]

**[0011]** The present invention has been completed in view of the situation described above. The inventors found a new method for calculating a spring back angle which occurs when metal materials having a wide variety of mechanical properties and thicknesses are formed by performing cylinder forming, and an object of the present invention is to provide a method for designing a metal material having a material quality (mechanical properties) with which a specified spring back angle can be achieved by using this calculating method and a formed product which is manufactured by performing cylinder forming from the metal material which is designed by using the designing method.

[Solution to Problem]

**[0012]** The subject matter of the present invention will be described as follows.

[1] A method for designing a material to be subjected to cylinder forming, the method including, in the design of a metal material to be subjected to cylinder forming in which the metal material is formed by performing bending forming, calculating the yield strength YP, the Young's modulus E and the thickness t of the metal material on the basis of equation (1) below so that a spring back angle $\Delta\theta$ becomes a specified value when cylinder forming is performed under conditions of a radius of curvature of bending r of 5 mm or more and a bending angle $\theta$ of 90 degrees or more and 180 degrees or less and designing the metal material so that the metal material has the calculated yield strength YP and Young's modulus E:

$$\Delta\theta/\theta = -5.52[(YP\cdot r)/(E\cdot t)]^2+4.13(YP\cdot r)/(E\cdot t) \quad \cdots \quad (1),$$

where, $\Delta\theta$: spring back angle (degrees), $\theta$: bending angle (degrees), YP: yield strength (MPa), E: Young's modulus (MPa), t: thickness (mm), r: radius of curvature of bending (mm).

[2] A product formed by performing cylinder forming, the product being manufactured by performing cylinder forming in which the metal material designed by using the method according to item [1] is subjected to bending forming.

[Advantageous Effects of Invention]

**[0013]** According to the present invention, a metal material with which a spring back angle can be controlled to a specified value can be easily designed and there is a large contribution to the improvement of productivity and the reduction of cost of a cylinder forming process.

[Brief Description of Drawings]

**[0014]**

[Fig. 1] Fig. 1 is a schematic diagram illustrating a lapping width.
[Fig. 2] Fig. 2 is a diagram illustrating the relationship between $\Delta\theta/\theta$ and (YP·r) / (E·t) .

[Description of Embodiments]

**[0015]** In the case where metal materials having the same mechanical properties and different thicknesses are subjected to cylinder forming under the same conditions, the spring back angles of the materials vary each other depending on the thicknesses and thus it is difficult to achieve a specified lapping width (the shape of a cylinder). Therefore, in the case where cylinder forming is performed in a practical production site, it is necessary to remodel the forming apparatus every time a thickness is changed or to change forming conditions in accordance with the thickness, which hampers productivity. In order to solve this problem, it is thought to be effective to change a material to one having different mechanical properties depending on thickness. That is to say, in the case where thickness is changed from $t_1$ to $t_2$, a formed product can be obtained without change in lapping width after cylinder forming has been performed, if a metal material having mechanical properties with which a spring back angle equivalent to that of a metal material having a thickness of $t_1$ is achieved is used.

**[0016]** In order to realize this, it is necessary to clarify the influence of various factors such as the thickness and mechanical properties of a metal material and forming conditions on a spring back angle. Therefore, firstly, the present inventors conducted investigations regarding what kinds of factors among the various factors have an influence on the spring back angle, and, as a result, confirmed that such kinds of factors are a bending angle, a radius of curvature of bending, a thickness, a yield strength and a Young's modulus.

**[0017]** Secondly, an empirical equation which represents the relationship between a spring back angle and such kinds of factors was derived by quantitatively evaluating the influence of each of the factors by observing the spring back angles when bending forming was performed under the conditions in which each of the factors were varied. The details will be described hereafter.

**[0018]** As described above, usually, when a metal material is unloaded after having been subjected to bending forming, the shape of the material changes slightly from the shape in the loaded state due to elastic recovery. This phenomenon is called spring back. A spring back angle $\Delta\theta$ (degrees) is represented by equation (3) in the case where a bending angle $\theta$ (degrees) changes into $\theta'$ (degrees) due to spring back. In addition, in bending forming, the relationship represented by the equation (4) below is obtained in the case where a radius of curvature of a plane at which there is no change in strain in the circumferential direction changes from r (mm) to r' (mm).

$$\Delta\theta = \theta - \theta' \quad \cdots \quad (3)$$

$$\Delta\theta/\theta = (1/r - 1/r')/(1/r') \quad \cdots \quad (4)$$

**[0019]** In the case where there is the plane at which there is no change in strain in the circumferential direction at the position of the center in the thickness direction as stated above, the equation (5) below holds regarding the change in curvature due to unloading by using equation (4).

$$\Delta\theta/\theta = (M\cdot r)/(E\cdot I) \quad \cdots \quad (5),$$

where, M is a bending moment ($MPa\cdot mm^3$) and I is an area moment of inertia ($mm^4$).

**[0020]** According to the theory of a beam in simple flexure, since a bending moment is represented by equation (6) below, equation (7) is derived by substituting equation (6) into equation (5) described above. Incidentally, in the case where it is assumed that a metal material is an elastic-perfectly plastic solid which does not exhibit work hardening behavior, since n (work hardening coefficient) = 0, equation (2) described above is derived from equation (7). However, it is not reasonable to assume n = 0 in an actual metal material and the value of n varies depending on the kind of metal material.

[Equation 1]

$$M = \frac{EI}{r}\left\{\frac{3}{2+n}\left(\frac{2r\cdot YP}{Et}\right)^{1-n} - \frac{1-n}{2+n}\left(\frac{2r\cdot YP}{Et}\right)^{3}\right\} \quad \cdots \quad (6)$$

[Equation 2]

$$\frac{\Delta\theta}{\theta} = \frac{3}{2+n}\left(\frac{2r\cdot YP}{E\cdot t}\right)^{1-n} - \frac{1-n}{2+n}\left(\frac{2r\cdot YP}{E\cdot t}\right)^{3} \quad \cdots \quad (7)$$

**[0021]** According to Non Patent Literature 2 above, it was found that there is a correlation between $\Delta\theta/\theta$ and $(YP\cdot r)/(E\cdot t)$, and equation (8) is derived. However, since the target metal material is limited to a stainless steel sheet, the range of a factor with which $\Delta\theta/\theta$ is determined is narrow ($0 < (YP\cdot r)/(E\cdot t) \leq 0.11$), which results in a lack of versatility.

$$\Delta\theta/\theta = 1.9[(YP\cdot r)/(E\cdot t)]^{0.62} \cdots (8)$$

**[0022]** Therefore, the present inventors observed a spring back angle by actually performing bending forming with a wide variety of metal materials (an aluminum sheet, a copper sheet, a stainless steel sheet and a steel sheet) and thickness conditions, where the radius of curvature of bending was in the range of 5 mm or more, the bending angle was in the range of 90 degrees or more and 180 degrees or less and the thickness was in the range of 0.1 mm or more and 2.0 mm or less. This is because these ranges can sufficiently satisfy the requirements for practical use of these materials in the fields of a food container, a medical device, a metal container, an equipment part and so forth, which means that there is versatility.

**[0023]** Fig. 2 illustrates investigation results regarding the relationship between $\Delta\theta/\theta$ and $(YP\cdot r)/(E\cdot t)$ . In the figure, O denotes the result of this observation. A regression equation which correctly replicates these observation results was derived and equation (1) described above was obtained (refer to the solid line in the figure) . This equation (1) can be applied to the range in which $(YP\cdot r)/(E\cdot t)$ is 0.33 or less and which is much wider than the application range described in Non Patent Literature 2. That is to say, this equation (1) can be applied to a wide variety of metal materials and, by using this equation, mechanical properties (YP and E) with which a specified spring back angle can be achieved can be calculated in accordance with a specified thickness. Then, it is appropriate that a metal material having the calculated mechanical properties is designed. In addition, a thickness with which a specified spring back angle can be achieved can be calculated for a metal material having specified mechanical properties. Moreover, it is possible to calculate a spring back angle from a specified thickness and specified mechanical properties. Incidentally, in Fig. 2, $\Delta$ denotes the observed data in Non Patent Literature 2 and dotted lines denote equation (8) and theoretical equation (2) .

**[0024]** In the case where the thickness of a metal material to be subjected to cylinder forming is reduced, a procedure in which a metal material is designed so that a spring back angle is not changed (a lapping width is not changed) even if a thickness is changed will be described hereafter.

**[0025]** Firstly, a spring back angle $\Delta\theta$ before a thickness is changed is observed. A test piece having arbitrary dimensions is subjected to bending forming under the conditions of, for example, a radius of curvature of bending of 12.7 mm and a bending angle of 180 degrees. Then, a bending angle $\theta'$ of the test piece in the unloaded state is observed and a spring back angle $\Delta\theta$ is calculated by using equation (3) described above. This procedure may be omitted in the case where a spring back angle $\Delta\theta$ exists as stored data.

**[0026]** By substituting the spring back angle $\Delta\theta$ and the bending angle $\theta$ (=180°) obtained as described above into equation (1), the value to be taken by the ratio of a yield strength to a Young's modulus (YP/E) is determined, since a radius of curvature of bending r and a thickness t are already known on the right-hand side of the equation. Then, in consideration of the specification of a metal material to be subjected to cylinder forming, a yield strength YP and a Young's modulus E are determined from the YP/E obtained as described above, and then a metal material having these mechanical properties is designed. Incidentally, in the design of a metal material, a metal material having the mechanical properties described above may be selected from a database of a metal material, or a new material may be designed in accordance with the YP and E as indexes in the case where the database cannot be found.

**[0027]** As another embodiment of the present invention, the case where the mechanical properties of a metal material to be subjected to cylinder forming are changed will be described hereafter. Firstly, a metal material is subjected to bending forming and a spring back angle is observed before the mechanical properties of the metal material are changed. Then, a thickness t is calculated by using equation (1) using the spring back angle described above, a yield strength YP and a Young's modulus E which are specified in advance and the conditions of bending forming (a radius of curvature of bending and a bending angle). The lapping width which is the same as that of the metal material before the mechanical properties of the metal material is changed can be achieved by forming the metal material having this thickness and these mechanical properties by performing cylinder forming.

**[0028]** According to the present invention, as described above, in the case where required properties (a thickness and mechanical properties) of a metal material are changed, a specified lapping width can be achieved after cylinder forming has been performed, firstly by making the spring back angle of the metal material clear before the change, and then, by determining the properties of the metal material one after another under conditions in which equation (1) is satisfied.

[EXAMPLES]

**[0029]** Under conditions in which the thickness of a metal material to be subjected to cylinder forming was reduced, a metal material with which a lapping width equivalent to that of a metal material before the thickness was reduced can be achieved was designed. Firstly, in the case where the specifications of a steel sheet before the thickness was reduced were t = 0.153 mm, YP = 400 MPa, E = 206000 MPa, $\Delta\theta$ = 96 degrees, $\theta$ = 180 degrees, r = 12.7 mm and lapping width was -10.5 mm or more and -9.0 mm or less (the mean value:-9.6 mm) and where the thickness was reduced to t = 0.117

mm, an example in which the optimization of a yield strength YP was investigated in order to keep a spring back angle constant will be described. The result that the object is satisfied with a YP of about 310 MPa was obtained by substituting $\Delta\theta$ = 96 degrees, E = 206000 MPa and t = 0.117 mm into equation (1).

**[0030]** On the basis of this result, two kinds of steel sheets which had a thickness of 0.117 mm and different yield strengths YP's were made, then 10 test pieces of 165.4 mm × 136.5 mm were cut out of each steel sheet, and then cylinder forming was performed under the same conditions as before the thickness was reduced. The observation results of a lapping width after cylinder forming had been performed are given in Table 1. The criteria for judging whether or not the product was satisfactory, regarding whether the same lapping width as before the thickness was reduced was achieved, was decided so that the case where the observed lapping width was within the range of -10% or more and +10% or less of the mean lapping width of the material before the thickness was reduced was judged to be satisfactory in consideration of the variability of a lapping width. The mean value of the lapping width after cylinder forming had been performed on a steel sheet (No. 2) having YP = 300 MPa was -10.5 mm, which means that a lapping width equivalent to that of the metal material before the thickness was reduced was achieved in consideration of the variability of lapping width. On the other hand, the mean value of the lapping width after cylinder forming had been performed on a steel sheet (No. 3) having YP = 362 MPa was +5.0 mm, which means that a lapping width equivalent to that of the metal material before the thickness was reduced was not achieved.

[Table 1]

| No. | Thickness (mm) | YP (Mpa) | E (Mpa) | r (mm) | $\theta$ (degrees) | $\Delta\theta$ (degrees) | Wrapping Width (mm) | Saticfactory or Not | Note |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.153 | 400 | 206000 | 12.7 | 180 | 96.0 | -9.6 | - | Conventional Material |
| 2 | 0.117 | 300 | 206000 | 12.7 | 180 | 94.5 | -10.5 | ○ | Example |
| 3 | 0.117 | 362 | 206000 | 12.7 | 180 | 105.0 | + 5.0 | × | Comparative Example |

**[0031]** Secondly, in the case where the specifications of a steel sheet before the thickness was reduced were t = 0.242 mm, YP = 310 MPa, E = 206000 MPa, $\Delta\theta$ = 54.3 degrees, $\theta$ = 180 degrees, r = 12.7 mm and lapping width was- 12.0 mm or more and- 8.0 mm or less (a mean value:- 10.0 mm) and where the thickness was reduced to t = 0.226 mm, an example in which the optimization of a Young's modulus was investigated in order to keep a spring back angle constant will be described. The result that the object is satisfied with an E of about 230000 MPa was obtained by substituting $\Delta\theta$ = 54.3 degrees, YP = 310 MPa or more and 320 MPa or less and t = 0.226 mm into equation (1) .

**[0032]** On the basis of this result, two kinds of steel sheets which had a thickness of 0.226 mm and different Young's moduli E's were made, then 10 test pieces of 165.4 mm × 136.5 mm were cut out of each steel sheet, and then cylinder forming was performed under the same conditions as before the thickness was reduced. The observation results of a lapping width after cylinder forming had been performed are given in Table 2. The criteria for judging whether or not the product was satisfactory, regarding whether the same lapping width as before the thickness was reduced was achieved, was decided so that the case where the observed lapping width was within the range of -10% or more and +10% or less of the mean lapping width of the material before the thickness was reduced was judged to be satisfactory in consideration of the variability of a lapping width. The mean value of the lapping width after cylinder forming had been performed on a steel sheet (No. 2) having E = 231000 MPa was -10.5 mm, which means that the lapping width equivalent to that of the metal material before the thickness was reduced was achieved in consideration of the variability of lapping width. On the other hand, the mean value of the lapping width after cylinder forming had been performed on a steel sheet (No. 3) having E = 214000 MPa was -2.4 mm, which means that a lapping width equivalent to that of the metal material before the thickness was reduced was not achieved.

[Table 2]

| No. | Thickness (mm) | YP (Mpa) | E (Mpa) | r (mm) | $\theta$ (degrees) | $\Delta\theta$ (degrees) | Wrapping Width (mm) | Saticfactory or Not | Note |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.242 | 310 | 206000 | 12.7 | 180 | 54.3 | -10.0 | - | Conventional Material |
| 2 | 0.226 | 319 | 231000 | 12.7 | 180 | 53.5 | -10.5 | ○ | Example |

(continued)

| No. | Thickness (mm) | YP (Mpa) | E (Mpa) | r (mm) | θ (degrees) | Δθ (degrees) | Wrapping Width (mm) | Saticfactory or Not | Note |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 0.226 | 319 | 214000 | 12.7 | 180 | 57.9 | -2.4 | × | Comparative Example |

**[0033]** Although, in the examples described above, the cases where one of a yield strength and a Young's modulus was fixed and the other was optimized in order to reduce a thickness were described, both may be changed. In addition, although in the examples described above, the cases where a yield strength or a Young's modulus was optimized in order to keep the spring back angle (lapping width) unchanged before and after a thickness was reduced were described, the spring back angle may be changed to a certain value. Moreover, a spring back angle can be calculated in the case where a thickness is changed while a yield strength and a Young's modulus are kept unchanged. Alternatively, a thickness with which a specified spring back angle can be achieved while a yield strength and a Young's modulus are kept unchanged can be calculated.

## Claims

1. A method for designing a material to be subjected to cylinder forming, the method comprising, in the design of a metal material to be subjected to cylinder forming in which the metal material is formed by performing bending forming, calculating the yield strength YP, the Young's modulus E and the thickness t of the metal material on the basis of equation (1) below so that a spring back angle Δθ becomes a specified value when cylinder forming is performed under conditions of a radius of curvature of bending r of 5 mm or more and a bending angle θ of 90 degrees or more and 180 degrees or less and designing the metal material so that the metal material has the calculated yield strength YP and Young's modulus E:

$$\Delta\theta/\theta = -5.52[(YP\cdot r)/(E\cdot t)]^2+4.13(YP\cdot r)/(E\cdot t) \cdots (1),$$

where, Δθ: spring back angle (degrees), θ: bending angle (degrees), YP: yield strength (MPa), E: Young's modulus (MPa), t: thickness (mm), r: radius of curvature of bending (mm).

2. A product formed by performing cylinder forming, the product being manufactured by performing cylinder forming in which the metal material designed by using the method according to Claim 1 is subjected to bending forming.

FIG. 1

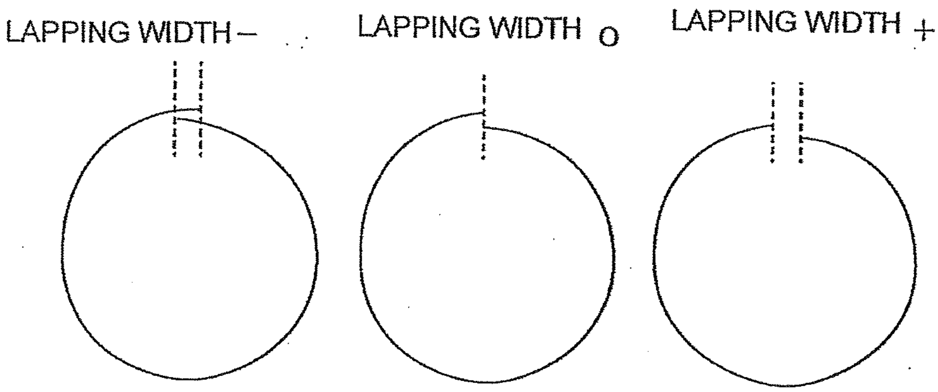
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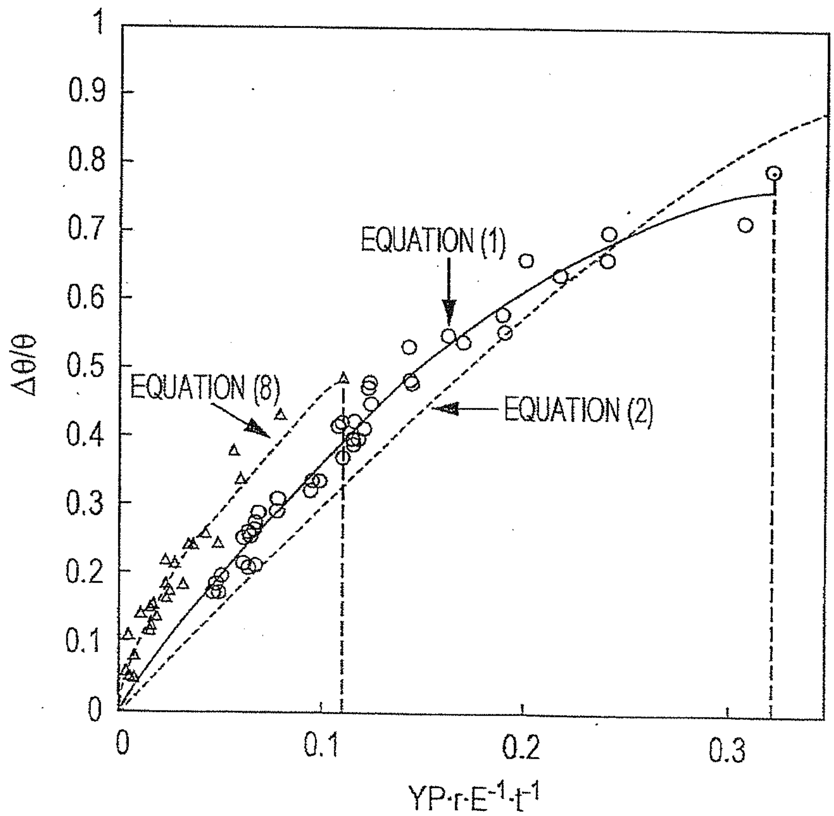
FIG. 2


Δθ/θ
YP·r·E-1·t-1
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EQUATION (8)
EQUATION (2)
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0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.2
0.3

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/079273

A. CLASSIFICATION OF SUBJECT MATTER
*B21D5/01*(2006.01)i, *B21D51/10*(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)
B21D5/01, B21D51/10

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 2004-261845 A (JFE Steel Corp.), 24 September 2004 (24.09.2004), entire text; all drawings (Family: none) | 1,2 |

☐ 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 | Date of mailing of the international search report |
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| 29 February, 2012 (29.02.12) | 13 March, 2012 (13.03.12) |

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## REFERENCES CITED IN THE DESCRIPTION

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### Non-patent literature cited in the description


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