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(54) **A METHOD OF PRODUCING STEEL**
EIN STAHLHERSTELLUNGSVERFAHREN
PROCEDE DE PRODUCTION D'ACIER

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Description

[0001] This application claims priority to Australian Patent Application No. PR0479, filed September 29, 2000.

Background and Summary of the Invention

[0002] The present invention relates to a method of producing steel strip and the cast steel strip produced according to the method.

[0003] In particular, the present invention relates to producing steel strip in a continuous strip caster.

[0004] The term "strip" as used in the specification is to be understood to mean a product of 5mm thickness or less.

[0005] The applicant has carried out extensive research and development work in the field of casting steel strip in a continuous strip caster in the form of a twin roll caster.

[0006] In general terms, casting steel strip, continuously in a twin roll caster involves introducing molten steel between a pair of contra-rotated horizontal casting rolls which are internally water cooled so that metal shells solidify on the moving rolls surfaces and are brought together at the nip between them to produce a solidified strip delivered downwardly from the nip between the rolls, the term "nip" being used to refer to the general region at which the rolls are closest together. The molten metal may be poured from a ladle into a smaller vessel from which it flows through a metal delivery nozzle located above the nip so as to direct it into the nip between the rolls, so forming a casting pool of molten metal supported on the casting surfaces of the rolls immediately above the nip and extending along the length of the nip. This casting pool is usually confined between side plates or dams held in sliding engagement with end surfaces of the rolls so as to dam the two ends of the casting pool against outflow, although alternative means such as electromagnetic barriers have also been proposed. The casting of steel strip in twin roll casters of this kind is for example described in United States Patents 5,184,668, 5,277,243 and 5,934,359.

[0007] In a paper entitled "Application of Fundamental Research at Project ’M’ ",presented at the Belton Memorial Symposium, Sydney, Australia on 10-11 January 2000, it was proposed that-strip casting has the potential to produce a broad range of mechanical properties from a single steel chemistry due to the coarse austenitic grain structure which is more responsive to cooling rate changes than is found with typical hot-strip mill product. How to realise this potential was not explained.

[0008] WO-A-98/57767 discloses that in strip casting aluminium killed low carbon steel different combinations of strength, ductility and cold formability properties for the cast strip can be obtained by controlling the chemical analysis of the steel and the in line cooling modes so as to develop suitable final microstructures in the cast strip. Hot reduction of less than 15 % is included in the casting process. It is not described that a broad range of mechanical properties, such as yield strengths up to 450 MPa and above, are possible without a change of chemistry.

[0009] Steel strip is produced of a given composition that has a wide range of microstructures, and therefore a wide range of yield strengths, by continuously casting the strip and thereafter selectively cooling the strip to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C. It is understood that the transformation range is within the range between 850°C and 400°C and not that entire temperature range. The precise transformation temperature range will vary with the chemistry of the steel composition and processing characteristics.

[0010] Specifically, from work carried out on low carbon steel, including low carbon steel that has been silicon/manganese killed, it has been determined that selecting cooling rates in the range of 0.01°C/sec to greater than 100°C/sec to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C, can produce steel strip that has yield strengths that range from 200 MPa to 700 MPa or greater. This is a significant development since, unlike conventional slab casting/hot rolling processes where chemistry changes are necessary to produce a broad range of properties, it has been determined that the same outcome can be achieved with a single chemistry.

[0011] Accordingly, there is provided a method of producing steel strip as defined in claim 1.

[0012] The yield strength may be in excess of 700 MPa. The microstructures that are obtainable include microstructures that are:

(i) a mixture of polygonal ferrite and low temperature transformation products; and

(ii) predominantly low temperature transformation products.

[0013] The term "low temperature transformation products" includes Widmanstatten ferrite, acicular ferrite, bainite and martensite.

[0014] The method may include passing the strip onto a run-out table and step (c) includes controlling cooling of the strip on the run-out table to achieve the selected cooling rate and to complete the transformation from austenite in a temperature range between 850°C and 400°C.

[0015] The cast strip produced in step (a) illustratively has a thickness of no more than 2mm.

[0016] The coarse austenite grains produced in step (a) of 100-300 micron width have a length dependent on the thickness of the cast strip. Generally, the coarse austenite grains are up to slightly less than one-half the thickness of the strip. For example, for cast strip of 2mm thickness, the coarse austenite grains will be up to about 750 microns in length.
[0017] The cast strip produced in step (a) may have austenite grains that are columnar.
[0018] The upper limit of the cooling rate in step (b) is at least 100°C/sec.
[0019] The term slow carbon steel" is understood to be mean steel of the following composition, in weight percent:

C: 0.02-0.08
Si: 0.5 or less;
Mn: 1.0 or less;
residual/incidental impurities: 1.0 or less; and
Fe: balance

[0020] The term "residual/incidental impurities" covers levels of elements, such as copper, tin, zinc, nickel, chromium, and molybdenum, that may be present in relatively small amounts, not as a consequence of specific additions of these elements but as a consequence of standard steel making. By way of example, the elements may be present as a result of using scrap steel to produce low carbon steel.
[0021] If the cooling rate in step (c) is less than 1°C/sec there will be produced a microstructure that is predominantly polygonal ferrite and has a yield strength less than 250 MPa, which is not in accordance with the invention as claimed.
[0022] Additionally, if the cooling rate in step (c) is in the range of 1-15°C/sec there will be produced a microstructure that is a mixture of polygonal ferrite, Widmanstatten ferrite and acicular ferrite and has a yield strength in the range of 250-300 MPa, which is also not in accordance with the invention as claimed.
[0023] The continuous caster may be a twin roll caster.
[0024] There is provided a low carbon steel produced by the method described above having desired microstructure and yield strength.

Brief Description of the Drawings

[0025] In order that the invention may be more fully explained, an example will be described with reference to the accompanying drawings, of which:

Figure 1 illustrates a strip casting installation incorporating an in-line hot rolling mill and coiler; and

Figure 2 illustrates details of the twin roll strip caster; and

Figures 3(a) to 3(d) are photomicrographs of cast strip that illustrate the effect on final microstructure of cooling rates during the austenite to ferrite transformation temperature range.

Detailed Description of the Invention

[0026] The following description of the described embodiments is in the context of continuous casting steel strip using a twin roll caster. The present invention is not limited to the use of twin roll casters and extends to other types of continuous strip casters.
[0027] Figure 1 illustrates successive parts of a production line whereby steel strip can be produced in accordance with the present invention. Figures 1 and 2 illustrate a twin roll caster denoted generally as 11 which produces a cast steel strip 12 that passes in a transit path 10 across a guide table 13 to a pinch roll stand 14 comprising pinch rolls 14A. Immediately after exiting the pinch roll stand 14, the strip passes into a hot rolling mill 16 comprising a pair of reduction rolls 16A and backing rolls 16B by in which it is hot rolled to reduce its thickness. The rolled strip passes onto a run-out table 17 on which it may be cooled by convection by contact with water supplied via water jets 18 (or other suitable means) and by radiation. The rolled strip then passes through a pinch roll stand 20 comprising a pair of pinch rolls 20A and thence to a coiler 19. Final cooling (if necessary) of the strip takes place on the coiler.
[0028] As shown in Figure 2, twin roll caster 11 comprises a main machine frame 21 which supports a pair of parallel casting rolls 22 having a casting surfaces 22A. Molten metal is supplied during a casting operation from a ladle (not shown) to a tundish 23, through a refractory shroud 24 to a distributor 25 and thence through a metal delivery nozzle 26 into the nip 27 between the casting rolls 22. Molten metal thus delivered to the nip 27 forms a pool 30 above the nip and this pool is confined at the ends of the rolls by a pair of side closure dams or plates 28 which are applied to the ends of the rolls by a pair of thrusters (not shown) comprising hydraulic cylinder units connected to the side plate holders. The upper surface of pool 30 (generally referred to as the "meniscus" level) may rise above the lower end of the delivery

nozzle so that the lower end of the delivery nozzle is immersed within this pool.

[0029] Casting rolls 22 are water cooled so that shells solidify on the moving roll surfaces and are brought together at the nip 27 between them to produce the solidified strip 12 which is delivered downwardly from the nip between the rolls.

[0030] The twin roll caster may be of the kind which is illustrated and described in some detail in United States Patents 5,184,668 and 5,277,243 or United States Patent 5,488,988 and reference may be made to those patents for appropriate constructional details which form no part of the present invention.

[0031] The above-described twin roll caster continuously casts strip 12 of no less than 2mm thickness with a microstructure of columnar austenite grains of 100-300 micron width.

[0032] In accordance with the illustrated embodiment of the method described, the cooling rate of the cast strip to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C is selected to control transformation of austenite into a ferrite microstructure that is required to provide specified yield strength of the cast strip.

[0033] In accordance with the illustrated embodiment, the cooling rate is at least 15°C/sec and may be in excess of 100°C/sec and is selected to transform the steel strip from austenite to ferrite until austenite transformation is completed.

[0034] In the case of low carbon steels, the range of microstructures can produce yield strengths in the range of 300 MPa to in excess of 700 MPa.

[0035] The present disclosure is based in part on experimental work carried out on silicon/manganese killed low carbon steel.

[0036] The table set out below summarises the effect of cooling rate to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C on the microstructure and resultant yield strength of silicon/manganese killed low carbon steel strip. The strips were cast in a twin roll caster of the type described above.

Cooling Rate (°c/sec)	Coiling Temperature (°C)	Microstructure Constituents	Yield Strength (MPa)
0.1	>800	Polygonal ferrite, Pearlite	210
13	670	Polygonal ferrite, Widmanstatten ferrite, acicular ferrite	320
25	580	Polygonal ferrite, Bainite	390
100	<400	Polygonal ferrite, Bainite, Martensite	490

[0037] Figures 3(a) to 3(d) are photomicrographs of the final microstructure of the cast strip.

[0038] It is clear from the table and the photomicrographs that selection and control of the cooling rate had a significant impact on the microstructure and yield strength of the single chemistry cast strip. As noted above, in conventional slab casting/hot rolling processes, a range of different chemistries would be required to achieve the range of yield strength. The range of chemistries was in the past achieved by adding differing amounts of alloys that add considerable cast to the steel production process.

[0039] Control of the cooling rate to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C is achieved by controlling cooling on the run-out table 17 and/or the coiler 19 of the strip casting installation.

[0040] The production of soft materials (yield strength < 350 MPa) requires relatively slow cooling rates through the austenite to ferrite transformation temperature range. In order to achieve the slow cooling rates, it is necessary to complete austenite transformation on the coiler 19.

[0041] The production of harder materials (yields strength > 400 MPa) requires higher cooling rates to transform the strip from austenite to ferrite in a temperature range between 850°C and 400°C. In order to achieve the higher cooling rates the austenite transformation is completed on the run-out table.

[0042] Figures 3(a) to (d) are photomicrographs of the final microstructures of the cast strip.

[0043] Although the invention has been illustrated and described in detail in the foregoing drawings and description with reference to several embodiments, it should be understood that the description is illustrative and not restrictive in character, and that the invention is not limited to the disclosed embodiments. Rather, the present invention covers all variations, modifications and equivalent structures that come within the scope of the invention. Many modifications may be made to the present invention as described above without departing from the scope of the invention.

Claims

1. A method of producing cast steel strip in a strip casting process, comprising the steps of:

   (a) continuously casting molten low carbon steel into a strip of no more than 5mm thickness having austenite grains that are coarse grains of 100-300 micron width, the low carbon steel being a silicon/manganese killed low carbon steel with the following composition by weight:

Carbon 0.02 - 0.08%
Manganese 0.30-0.80%
Silicon 0.10-0.40%
Sulphur 0.002 - 0.05%
Aluminium less than 0.01%

(b) hot rolling the cast strip to a thickness reduction of up to 15%; and
(c) cooling the cast strip and transforming the austenite grains to ferrite in a temperature range between 850°C and 400°C;
(d) the cooling of the cast strip being controlled to provide a desired yield strength in the cast by selecting the cooling rate so that:
(i) the cooling rate in step (c) is in the range of 15-100°C/sec in order to produce cooled strip that has a microstructure that is a mixture of polygonal ferrite and bainite and has a yield strength in the range of 300-450 MPa; or
(ii) the cooling rate in step (c) is at least 100°C/sec in order to produce cooled strip that has a microstructure that is a mixture of polygonal ferrite, bainite and martensite and has a yield strength of a least 450 MPa.

2. The method of in claim 1 wherein the cast strip produced in step (a) has a thickness of no more than 2mm.

3. The method of in claim 1 or claim 2 wherein the austenite grains produced in step (a) are columnar.

4. The method of any one of the preceding claims further includes passing the cast strip produced in step (a) onto a run-out table and step (c) includes controlling cooling of the strip on the run-out table to achieve the selected cooling rate and complete the transformation from the austenite grains in a temperature range between 850°C and 400°C.

5. The method of any one of the preceding claims wherein the continuous casting is done with a twin roll caster

Patentansprüche

1. Verfahren zur Herstellung eines Gussstahlbandes in einem Bandgussverfahren, umfassend die Schritte:

(a) kontinuierliches Gießen von geschmolzenem kohlenstoffarmen Stahl zu einem Band mit nicht mehr als 5 mm Dicke mit Austenitkörnern, welche grobe Körner mit 100-300 μm Breite sind, wobei der kohlenstoffarme Stahl ein Silizium/Mangan beruhigter kohlenstoffarmer Stahl mit der folgenden Zusammensetzung in Bezug auf das Gewicht ist:

Kohlenstoff	0,02-0,08%
Mangan	0,30-0,80%
Silizium	0,10-0,40%
Schwefel	0,002 -0,05 %
Aluminium	weniger als 0,01%

(b) Warmwalzen des gegossenen Bandes auf eine Dickenverringerung von bis zu 15 %; und
(c) Abkühlen des gegossenen Bandes und Umwandeln der Austenitkörner zu Ferrit in einem Temperaturbereich zwischen 850°C und 400°C;
(d) wobei das Abkühlen des gegossenen Bandes gesteuert wird, um eine gewünschte Dehngrenze des gegossenen Bandes zu erzielen, indem die Abkühlrate so gewählt wird, dass:
(i) die Abkühlrate in dem Schritt (c) in dem Bereich von 15 - 100°C/ Sekunde liegt, um ein abgekühltes Band zu erzeugen, welches eine Mikrostruktur aufweist, die eine Mischung aus polygonalem Ferrit und Bainit ist und eine Dehngrenze in dem Bereich von 300 - 450 MPa aufweist; oder
(ii) die Abkühlrate in dem Schritt (c) in dem Bereich wenigstens 100°C/ Sekunde beträgt, um ein abgekühltes Band zu erzeugen, welches eine Mikrostruktur aufweist, die eine Mischung aus polygonalem Ferrit, Bainit und Martensit ist und eine Dehngrenze von wenigstens 450 MPa aufweist.

2. Verfahren nach Anspruch 1, wobei das in Schritt (a) hergestellt gegossene Band eine Dicke von nicht mehr als 2 mm aufweist.

3. Verfahren nach Anspruch 1 oder 2, wobei die in Schritt (a) erzeugten Austenitkörner säulenartig sind.

4. Verfahren nach einem der vorangehenden Ansprüche, des weiteren umfassend das Führen des in Schritt (a) hergestellten gegossenen Bandes auf ein Auslauftisch und wobei der Schritt (c) das Steuern des Abkühlens des Bandes auf dem Auslauftisch umfasst, um die ausgewählte Abkühlrate zu erzielen und die Umwandlung der Austenitkörner in einem Temperaturbereich zwischen 850°C und 400°C zu erzielen.

5. Verfahren nach einem der vorangehenden Ansprüche, wobei das kontinuierliche Gießen mit einem Twin-Roll-Caster durchgeführt wird.

Revendications

1. Méthode de production de bandes d'acier coulé lors d'un procédé de coulée en bande, comprenant les étapes consistant à :

   (a) couler en continu de l'acier liquide à faible teneur en carbone en une bande d'épaisseur inférieure ou égale à 5 mm ayant des grains d'austénite qui sont de gros grains d'une largeur allant de 100 à 300 microns, l'acier à faible teneur en carbone étant un acier à faible teneur en carbone calmé au silicium/manganèse ayant la composition suivante en poins :

   Carbone 0,02 à 0,08 %
   Manganèse 0,30 à 0,80 %
   Silicium 0,10 à 0,40 %
   Soufre 0,002 à 0,05 %
   Aluminium moins de 0,01 %

   (b) laminer à chaud la bande coulée pour obtenir une réduction de l'épaisseur atteignant 15 % ; et
   (c) refroidir la bande coulée et transformer les grains d'austénite en ferrite dans une plage de température allant de 850°C à 400°C ;
   (d) le refroidissement de la bande coulée étant régulé pour assurer une limite d'élasticité voulue dans la bande coulée en sélectionnant la vitesse de refroidissement de manière à ce qui :
   (i) la vitesse de refroidissement à l'étape (c) soit dans la plage de 15 à 100°C/s afin de produire une bande refroidie dont la microstructure soit un mélange de ferrite polygonale et de bainite et qui ait une limite d'élasticité dans la plage de 300 à 450 MPa; ou
   (ii) la vitesse de refroidissement à l'étape (c) soit supérieure ou égale à 100°C/s afin de produire une bande refroidie dont la microstructure soit un mélange de ferrite polygonale, de bainite et de martensite et qui ait une limite d'élasticité supérieure ou égale à 450 MPa.

2. Méthode selon la revendication 1, dans laquelle la bande coulée produite à l'étape (a) a une épaisseur inférieure ou égale à 2 mm.

3. Méthode selon la revendication 1 ou 2, dans laquelle les grains d'austénite produits à l'étape (a) sont basaltiques.

4. Méthode selon l'une quelconque des revendications précédentes, comprenant en outre l'étape consistant à transférer la bande coulée produite à l'étape (a) sur une table de sortie, et dans laquelle l'étape (c) comprend la régulation du refroidissement de la bande sur la table de sortie pour atteindre la vitesse de refroidissement sélectionnée et achever la transformation des grains d'austénite dans une plage de températures allant de 850°C à 400°C.

5. Méthode selon l'une quelconque des revendications précédentes, dans laquelle la coulée continue est réalisée entre cylindres.

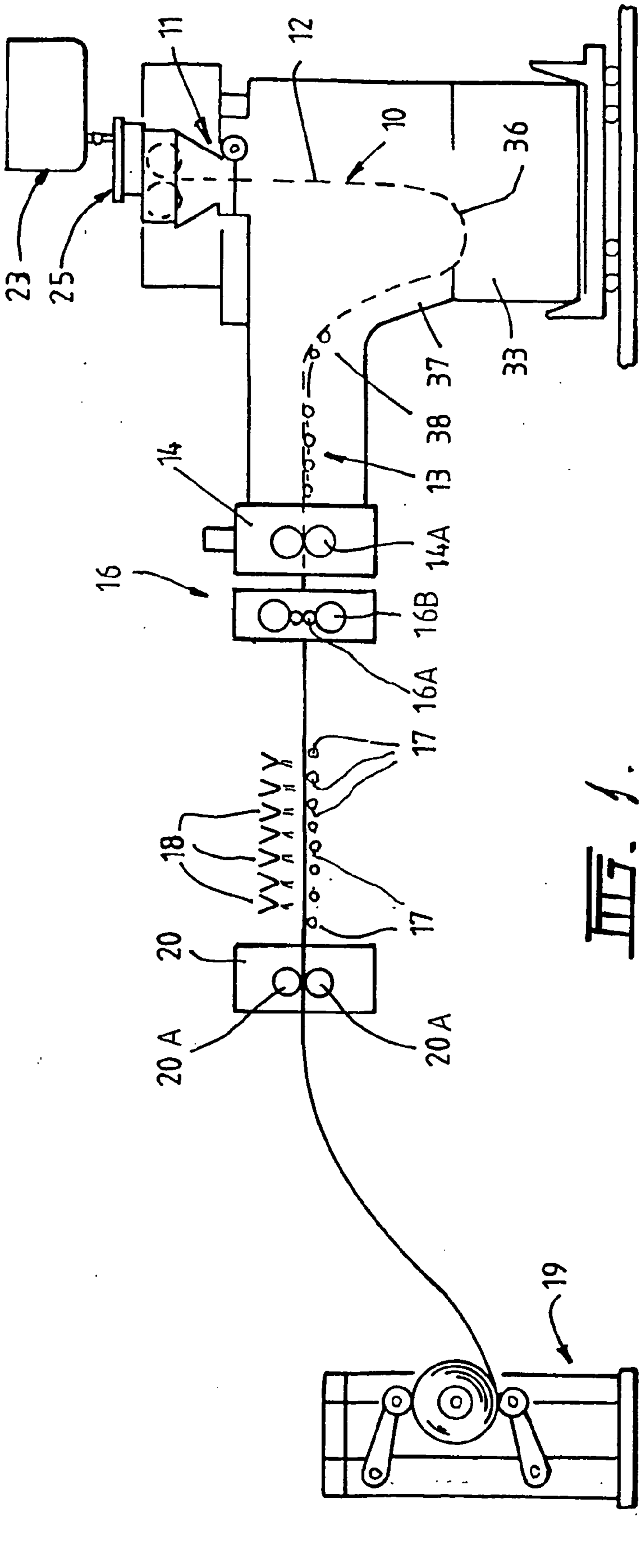

Fig. 1

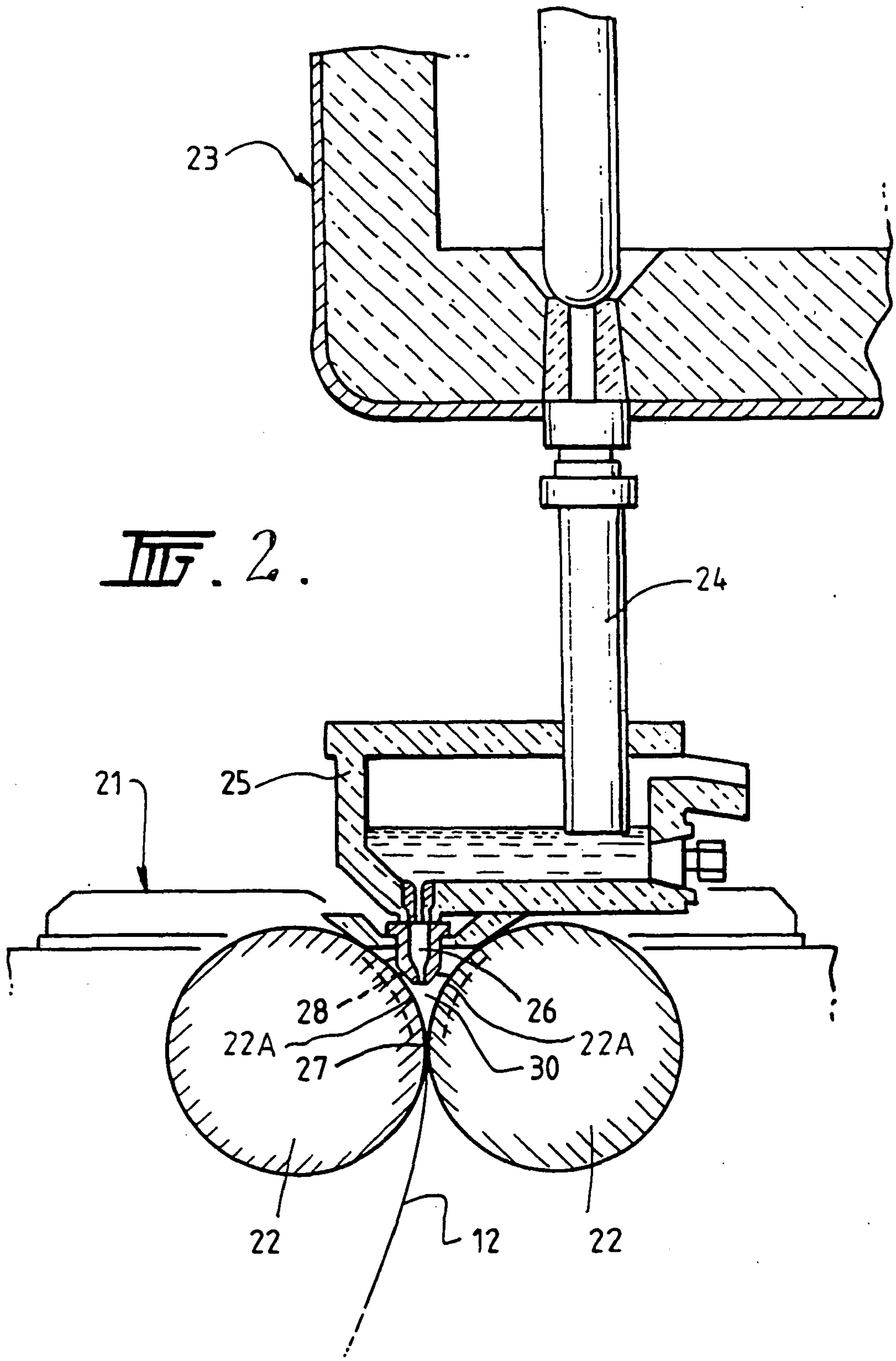

FIG. 2.

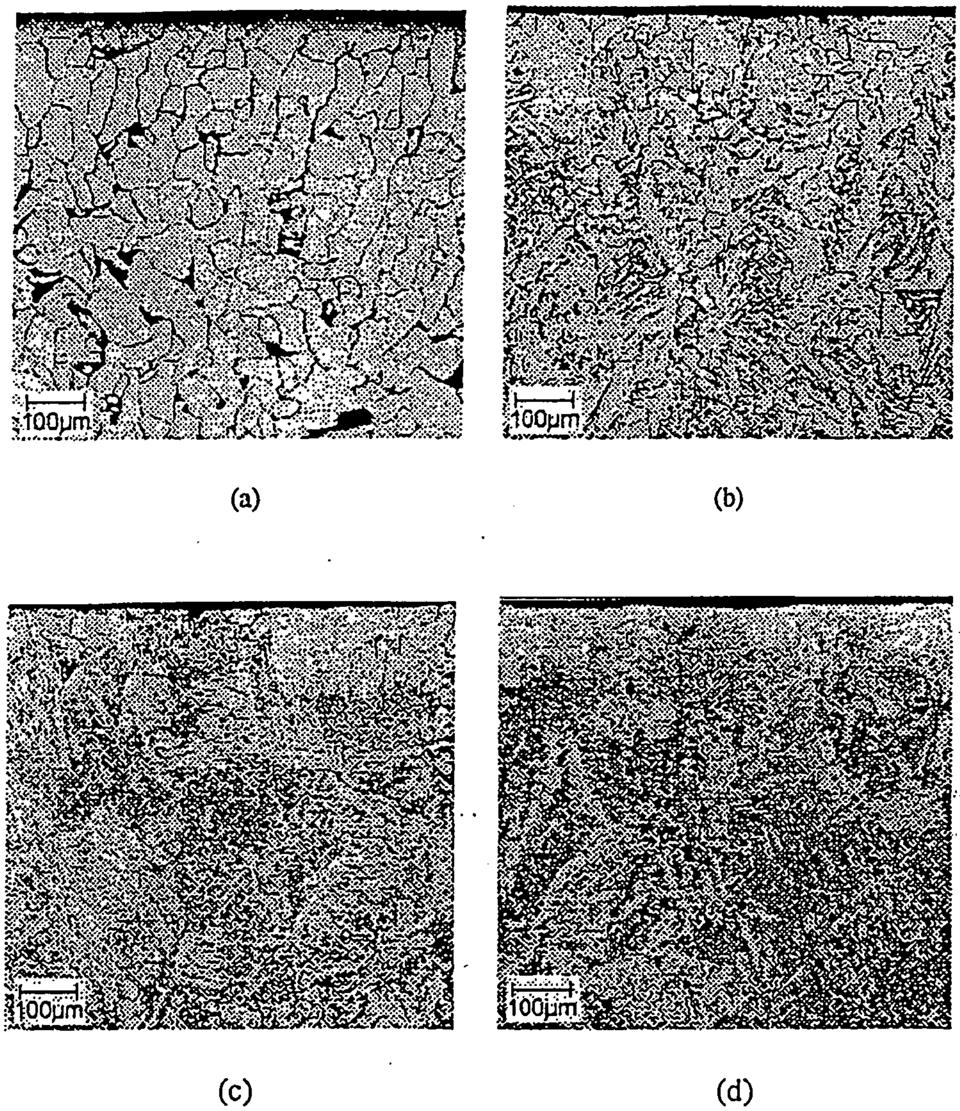

FIGURE 3

REFERENCES CITED IN THE DESCRIPTION

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