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(54) A method for processing a steel product, and product produced using said method

(57) The invention relates to a method for processing a steel product, in which the steel product is passed between a set of rotating rolls of a rolling mill stand in order to roll the steel product. According to the invention, the rolls of the rolling mill stand have different peripheral velocities such that one roll is a faster moving roll and the other roll is a slower moving roll, and the peripheral velocity of the faster moving roll is at least 5% higher and at most 100% higher than that of the slower moving roll, and the thickness of the steel product is reduced by at most 15% per pass, and the rolling takes place at a maximum temperature of 1350°C.

The invention also relates to a steel product produced using the method, and to the use of this steel product.

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Description

[0001] The invention relates to a method for processing a steel product, in which the steel product is passed between a set of rotating rolls of a rolling mill stand. This rolling mill stand may be part of a rolling mill device consisting of one or more rolling mill stands.

[0002] Rolling is a very standard operation for imparting desired dimensions and properties to metal in general and steel in particular. Apart from obtaining the desired final geometry of the steel product, rolling also results in an improvement to the structure as a result of the metallurgical processes taking place during and after the rolling.

[0003] However, the conventional rolling, which for wide products is usually considered to be a plane strain compression process, results in a considerable change in thickness, which in some cases is undesirable or impossible. For example, in heavy construction it is necessary to have steel plate with a thickness of 60 to 150 mm for, inter alia, the production of off-shore platforms or bridges. Since cast steel slabs currently have a maximum thickness of less than 400 mm, the change in thickness caused by the rolling to 150 mm would only amount to approximately 60%. Each pass through a conventional rolling mill stand usually results in a change in thickness of 10 to 30%.

[0004] The casting of slabs sometimes results in the formation of porosity in the slab, a characteristic which is inherent to the casting process. This porosity is closed up by the pressure applied as a result of the slabs being rolled a sufficient number of times. However, if it is necessary to form a plate with a very high thickness, the rolling only closes up the pores in the outermost layers of the slab, and not those in the core of the material. However, the pores in the core of the material are highly disadvantageous for the mechanical properties of the material, in particular for the toughness properties of the plate. Also, grain refinement only occurs in the outermost layers of the plate. To close up the pores by the application of pressure and to achieve grain refinement even in the core of the plate, the degree of rolling through the thick slab therefore has to be high, whereas the combination of starting thickness of the slab and final thickness of the steel product do often not allow a large thickness reduction.

[0005] It is possible to introduce a large equivalent strain into a product without imposing a large thickness reduction under laboratory conditions using small samples with the Equal Channel Angular Extrusion (ECAE) method in which extreme shear strains are applied without changing the specimen's dimension. In ECAE a billet is extruded through a die with two channels of equal cross-section that meet at an angle. Under ideal circumstances the billet is sheared on crossing the plane of intersection of the channels by an amount determined by the angle between the two channels. Since the cross section does not change during the process, it can be repeated thereby accumulating strain. However, this laboratory technique cannot be used for industrial production of steel products because of the very high process forces required, and the impossibility to up-scale this process for flat products of conventional dimensions.

[0006] It is an object of the invention to provide a method for introducing a large equivalent strain into the steel product without imposing an equivalent reduction in thickness of the product.

[0007] It is also an object of the invention to provide a method for processing a steel product which allows the properties of the product produced thereby to be improved.

[0008] Yet another object of the invention is to provide a method for processing a steel product which results in grain refinement in the product which is thereby produced.

[0009] Yet another object of the invention is to provide a method for processing continuously cast steel by means of which the properties of the slab or strip are improved.

[0010] It is another object of the invention to provide a method for processing a continuously cast steel slab or strip with which it is possible to close up pores in the cast material.

[0011] It is also an object of the invention to provide a steel product with improved mechanical properties which is produced with the aid of this method.

[0012] In the context of this invention, steel should be considered to comprise all ferrous alloys for example ultra-low carbon steels, low-carbon steels, medium to high carbon steels, electrical steels, and stainless steels. A steel product in the context of this invention comprises ingots, slabs, blooms, billets, bar, rod, strip and profiled sections.

[0013] One or more of these objects are achieved by a method for processing a continuously cast steel product, in which the steel is passed between a set of rotating rolls of a rolling mill stand in order to roll the steel product, wherein the rolls of the rolling mill stand have different peripheral velocities such that one roll is a faster moving roll and the other roll is a slower moving roll, wherein the peripheral velocity of the faster moving roll is at least 5% and at most 100% higher that that of the slower moving roll, wherein the thickness of the steel product is reduced by at most 15% for each pass, and wherein that the rolling takes place at a maximum temperature of 1350°C.

[0014] As a result of the rolls being provided with a different peripheral velocity, shearing occurs in the steel product and has been found to occur throughout the entire thickness of the product. It has been found that this requires a velocity difference of at least 5%. The shearing leads to pores in the continuously cast material being closed up to a considerable extent. This does not require a major change in thickness, but rather a change in thickness of at most 15% can suffice. Preferably this thickness reduction is at most 8% and more preferable at most 5%. This is particularly advantageous in the processing of those steel products where the dimensions of the steel product at the start of the process do not allow a singificant reduction in the thickness direction, because the thickness is substantially retained.

[0015] In addition, it is important that the rolling according to the invention can result in a grain refinement which occurs throughout the entire thickness of the rolled material, which is advantageous for the mechanical properties of the slab or strip. Inter alia, the strength of the material increases. The beneficial effects of smaller grain sizes are commonly known.

[0016] The rolling is preferably carried out at an elevated temperature. However, the maximum temperature is limited to 1350°C because the formation of low melting oxides on the surface of the steel product to be produced has to be avoided. The elevated temperature makes the rolling run more smoothly.

[0017] It is also expected that the processing according to the invention will result in a rolled sheet with less lateral spread.

[0018] The peripheral velocity of the faster moving roll is preferably at most 50% higher and more preferably at most 20% higher than that of the slower moving roll. If there is a high difference in velocity, there is a considerable risk of slipping between the rolls and the steel product, which would result in uneven shearing.

[0019] According to an advantageous embodiment, the rolling mill is designed in such a manner that the rolls have different diameters. This makes it possible to obtain the desired difference in peripheral velocity.

[0020] According to another advantageous embodiment, the rolls have a different rotational speed. This too makes it possible to obtain the desired difference in rotational speed.

[0021] It is also possible for these latter two measures to be combined, i.e. rolls with different diameters and different rotational speeds in order to obtain the desired difference in peripheral velocity of the rolls.

[0022] According to an advantageous embodiment of the method, the steel product is introduced between the rolls at an angle of between 5 and 45° with respect to the perpendicular to the plane through the center axes of the rolls. Introducing the steel product between the rolls at an angle makes it easier for the rolls to grip the steel product, with the result that the change in thickness can be kept as low as possible. Experiments have also shown that after rolling the steel product has an improved straightness if it is introduced at an angle between the rolls. The steel product is preferably fed in at an angle of between 10 and 25°, and more preferably at angle of between 15 and 25°, since with such an angle the steel product comes out of the rolling mill with a good level of straightness. It should be noted that the latter effect is also dependent on the reduction in the size of the steel product, the type of steel product and the alloy and the temperature.

[0023] For this purpose, after the rolling has been carried out for the first time, the processing operating is preferably repeated one or more times. For example, sufficiently good grain refinement is obtained by carrying out the processing operating according to the invention three times. However, the number of times that the processing operation has to be carried out depends on the thickness of the steel product, the difference in peripheral velocity of the rolls and the desired grain refinement. It is desirable for the steel product to be introduced between the rolls at an angle of between 5 and 45°, preferably between 10 and 25° and more preferably between 15 and 25° during each processing operation.

[0024] If the processing operation according to the invention is repeated a number of times, according to an advantageous embodiment the steel product can be passed through the rolling mill stand in opposite directions for each pass. The steel product then changes direction after each rolling operation and is always passed through the same rolling mill stand. In this case, the rolls have to rotate in opposite directions for each pass. In this case too, it is desirable for the steel product in each case to be introduced at an angle between the rolls.

[0025] According to another advantageous embodiment, the steel product is successively passed through two or more rolling mill stands. This method is suitable primarily for strip material, which in this way can undergo the desired processing operation very quickly.

[0026] According to a preferred embodiment of the invention the rolling is carried out on a steel product of which at least a skin layer has a substantially austenitic structure, and preferably on a steel product having a substantially austenitic structure throughout. Typical minimum temperatures range from 900 °C for an ultra low carbon steel to 800-870 °C for a low carbon steel (depending on the chemical composition of course) to about 723 °C for a steel with 0.8 %C. In all cases the maximum temperature is 1350 °C. In case of rolling an austenitic stainless steel, the rolling always takes place on an austenitic structure.

[0027] According to a second preferred embodiment the rolling is carried out on a steel product of which at least a skin layer has a substantially austenitic-ferritic two-phase structure, and preferably on a steel product having a substantially austenitic-ferritic two-phase structure throughout. Typical temperatures range for a low carbon steel from 723 °C ending at 800-870 °C. The temperature range decreases with increasing carbon contents to reduce to an eutectoid point of about 723 °C for a steel with 0.8 %C.

[0028] According to a third preferred embodiment the rolling is carried out on a steel product of which at least a skin layer has a substantially ferritic structure, and preferably on a steel product having a substantially ferritic structure throughout. For a low carbon steel with a carbon content higher than 0.02% the maximum temnperature is about 723 °C, whereas for steels with lower carbon contents such as ultra low carbon steels the maximum temperature is about 850 °C. It should be noted here that these temperature boundaries for the ferritic, ferritic-austenitic and austenitic region depend on the composition of the steel and on the thermomechanical history of the steel. The phase transformation is not instantaneous once a critical temperature is exceeded and therefore a transforming steel may have a skin layer of a different phase compared to the centre layer of the steel product.

[0029] According to a further advantageous embodiment of the invention the rolling is performed at temperatures between 0 °C and 720°C. This comprises not only the cold rolling of the ferritic steel product, but also the advantageous rolling of steel with a martensitic structure or the austenitic stainless steel structure.

[0030] It is possible for the method to be preceded or followed by a rolling operation which is carried out using a rolling mill in which the rolls have substantially identical peripheral velocities. In this way, by way of example, an accurately desired thickness or smoothness can be imparted to the product.

[0031] According to another advantageous embodiment, a steel product is produced according to a method comprising the steps of:

- continuous casting of a steel strand;
- optionally heating and/or temperature homogenising the steel strand between a casting machine and a rolling device;
- optionally rolling the steel product in one or more rolling mill stands of the rolling device with rolls having substantially identical peripheral velocities;
- optionally accelerated cooling after the last rolling step;
- optionally cutting the steel product into slabs or coils before or after rolling;
- optionally coiling the steel product
- cooling the steel product

[0032] The most commonly used method to produce steel slabs is by continuous casting of a steel strand and cutting it into steel slabs with a thickness of between 200 and 400 mm. After casting, these slabs are usually allowed to cool down to ambient temperatures before being introduced in the furnaces of a hot strip mill. In some cases the slabs can be introduced into the furnace while it is still warm or hot from casting (respectively so-called "hot-charging" or "direct-charging").

[0033] The thickness of the continuously cast strand is preferably below 150 mm, more preferably below 100 mm and even more preferably below 80 mm for thin slab casting.

[0034] The cast strand may be cut after casting by means of a cutting device. The thus obtained slabs may be stored for later processing and allowed to cool down or they may be processed immediately. In the former case the slabs may require reheating prior to rolling, in the latter case the slabs may require to be homogenised in temperature. After finish rolling the rolled product may be cooled using accelerated cooling and optionally coiled. After the final processing step the steel product cools or is cooled to ambient temperatures. In case the cast strand is not cut into slabs, but processed immediately by continuous, endless or semi-endless rolling, the rolled product will be cut in a later stage of the rolling process e.g. before the optional coiler. It will be obvious that the rolling according to the invention may take place anywhere between the casting step and the final cooling step, or even thereafter.

[0035] Prior to coiling the steel product may be subjected to accelerated cooling. After the final processing step the steel product cools or is cooled to ambient temperatures.

[0036] According to another embodiment of the invention the thickness of the continuously cast strand is preferably below 20 mm, more preferably below 10 mm and even more preferably below 5 mm.

[0037] The cast strand having a cast microstructure may be cut after casting by means of a cutting device. The thus obtained slabs may be stored for later processing and allowed to cool down or they may be processed immediately. In the former case the slabs may require reheating prior to rolling, or they may be used as final product. In the latter case the slabs may require to be homogenised in temperature. One drawback of the strip-cast steel products is that the end product still largely has the cast microstructure, since the strip has scarcely been rolled. Consequently, the mechanical properties of the end products are relatively poor, and consequently the use of the end products is limited and do not meet the standards of the products obtained through the conventional thick slab or even the more recent thin slab route. During the rolling process according to the invention the microstructure is transformed from a casting structure to a wrought microstructure without substantial reduction in thickness thereby improving the final properties of the steel product significantly. After finish rolling the rolled product may be cooled using accelerated cooling and optionally coiled. After the final processing step the steel product cools or is cooled to ambient temperatures. In case the cast strand is not cut into slabs, but processed immediately by continuous, endless or semi-endless rolling, the rolled product will be cut in a later stage of the rolling process e.g. before the optional coiler. After finish rolling the rolled product may be cooled using accelerated cooling. After the final processing step the steel product cools or is cooled to ambient temperatures. Again, it will be obvious that the rolling according to the invention may take place anywhere between the casting step and the final cooling step, or even thereafter.

[0038] A further advantage is obtained if the steel product to be processed according to the previous two embodiments is a stainless steel.

[0039] In the context of this invention, stainless steel comprises both ferritic, austenitic-ferritic duplex steels and austenitic stainless steels. These steels are commonly applied in application where the corrosion resistance of unalloyed or low-alloy steel is inadequate. The combination of corrosion resistance, high strength and good ductility usually associated with the duplex stainless steels results in applications where the formability of ferritic and austenitic stainless steels is inadequate. Typical examples of a ferritic stainless steels according to EN 10088 (1995) are X2CrNi12- 1.4003 (410) X6Cr14 - 1.4016 (430), and of austenitic stainless steels are X5CrNiMo17-12-2 1.4401 (316) X5CrNi18-10 - 1.4301 (304). These steels are typically used as general-purpose stainless steels in plate, strip, semi-, bar, rod and applied as construction steels for buildings, pipelines, kitchenware, components in pumps and valves etc.

[0040] The thickness of the slab or strip is preferably reduced by at most 15% for each pass, and preferably by at most 8% and more preferably by at most 5% for each pass. Since the shearing and therefore the grain refinement are brought about by the difference in peripheral velocity between the rolls, the reduction in thickness of the material is not required to obtain grain refinement. The reduction in thickness is required primarily in order to enable the rolls to grip the material. This only requires a slight change in thickness, which is advantageous in the case of thin continuously cast steel slab, strip cast material and strip material. The smaller the reduction, the thicker the slab or strip remains after each pass. The possible applications of continuously cast slabs and strip material increase as a result. With the aid of the method according to the invention, better mechanical properties can be imparted to the steel product, without the need for a substantial reduction in thickness. Since the method according to the invention can be used to impart better properties to an already relatively thin steel product, it is to be expected that thicker continuously cast plate and strip material, now with better mechanical properties, will also find industrial applications.

[0041] In the production of high strength steel strip microalloyed with one or more of the elements Nb, V, Ti or B (these steelgrades are usually called HSLA-steels (high strength, low alloy)), in a hot strip mill acording to the well-known principles of thermomechanical rolling it is a problem to produce strip with a higher thickness. The continuously cast slabs that are used to start the rolling process with usually have a fixed thickness of between 200 and 350 mm, for example 225 mm. The rolling mills also usually are divided in a roughing section where the slab is rolled down in a number of passes, for example 5 passes, to a chosen thickness of, for example, 36 mm. This so-called transfer bar thickness is usually a fixed thickness within a given hot strip mill and the deviations from this fixed value are minimal. Deviations from this value by increasing its value usually results in rolling forces or torques in the finishing mill which exceed operational limits, thereby causing risks to the rolling mill or resulting in unacceptable changes in the shape and profile of the product. Decreasing the thickness of the transfer bar usually results in rolling forces or torques in the roughing mill which exceed operational limits. However, the fixed value of the transfer bar also causes a problem because it results in different values of reduction for a thick strip of for example 18 mm and a thin strip of for example 4 mm. In the first case the total reduction in the finishing mill is 50%, in the second case it is 89%. This has large repercussions on the development of the microstructure of the steel during and after hot-rolling because the thermo-mechanical conditions are quite different which results in different recrystallisation of the deformed austenite and different precipitation kinetics of micro-alloying elements. Consequently also the phase transformation during cooling after rolling is affected. In an advantageous embodiment of the invention the degree of deformation of the steel product can be increased without the need to increase the transfer bar thickness, or the degree of deformation can be kept unchanged while the final thickness of the steel product is increased.

[0042] With profiled sections the degree of deformation is essential for the properties of the final product as well. For example, it is known that steel billets which are rolled into profiled sections, such as H-sections, often have a part which has undergone scarcely any rolling, with the result that little or no grain refinement occurs in this part. Steel billets for sections usually have a gauge between 200 and 400 mm, for example 230 mm or 310 mm. These are rolled in the slab/bloom/billet stage after reheating to a temperature of maximal 1350°C. Finish rolling occurs usually at a temperature where the steel is austenitic and flange thicknesses range from 10 to 150 mm. Non-limitative examples for typical steel grades used for these sections comprise CMn-steels and HSLA-steels. The process according to the invention allows a finer grainsize of the billet because of the larger degree of deformation in the billet, and also allows a reduction in the pore size of the billet, resulting in better fracture toughness.

[0043] Recently it has become clear from the results of basic research that properties such as strength, toughness and corrosion resistance can be improved by reducing grain size. Steels have been developed with a very fine grain size by controlling the structure of the grain. These steels not only provide higher tensile strengths compared to conventional steel, but also improved toughness, endurance and corrosion resistance. This technology has been implemented in the hot strip mill by imposing a very large thickness reduction at low rolling temperatures, as a result of which the rolling forces and torques increase to extremely high levels. However, the proposed solution for obtaining ultra fine ferrite grains relies on grain refinement by ordinary rolling (i.e. plane strain compression) at low hot rolling temperatures and requires a very powerful rolling mill. Furthermore, a strong thickness reduction is imposed to the material to attain the required levels of deformation. In the process according to the invention, a significant grain reduction can be achieved because of the accumulation of strain in the steel without substantially reducing the thickness. The average grainsize of the steel product obtained is preferably smaller than 5 μm, more preferably smaller than 2 μm and even more preferably smaller than 1 μm.

[0044] According to another embodiment of the invention the properties of complex phase steels are unexpectedly improved because of the accumulation of strain in the steel without substantially reducing the thickness. When the steel product is rolled in the austenitic state and subsequently acceleratedly cooled, the large degree of accumulated deformation allows the steel to transform to a very fine ferrite grain in combination with a very finely distributed fine-grained second phase consisting of bainite or martensite. A small amount of carbides may also be present. The ferrite content of this steel product is preferably at least 60%, more preferably at least 70% and even more preferably at least 80%. The average grainsize of the steel product obtained is preferably smaller than 5 μm, more preferably smaller than 2 μm and even more preferably smaller than 1 μm.

[0045] In conventional production of steel plates, for example of the carbon-manganese type or of the HSLA-type, the starting point is a continuously cast slab with a typical thickness between 200 and 350 mm. These slabs are reheated in a reheating furnace to a temperature between 1000 and 1350°C. After reheating these slabs are rolled to a thickness of between 30 to 200 mm, preferably 40 to 150 mm and held at temperature, for instance by shielding it against cooling. During this holding period at high temperature grain growth takes place as a result of which the final mechanical properties of the finished plate may also deteriorate. It is common knowledge that a larger grain size decreases the ductility properties and the toughness of a steel product. It is also well known that the yield strength decreases with an increase in grainsize. Consequently, grain growth during holding should be avoided. Conventionally this is done by accelerated cooling. However, the use of accelerated cooling has the disadvantage of enlarging the temperature difference between the centre part of the slab and the surface part of the slab. This temperature difference adversely affects the homogeneity of the final microstructure of the slab.

[0046] In many cases the plate receives a heat treatment during the production process. This may for example be a normalisation treatment wherein the slab is reheated into the austenite region and allowed to cool down in still air or a tempering anneal or stress relief anneal which both aim to reduce the level of internal stresses. Another example of a heat treatment is the speroidisation treatment in which elongated carbides are transformed into more or less spheroidal particles. These carbides may be iron carbides (e.g. cementite) or other metal carbides like chromium carbides. This type of annealing treatment is used often in steels with carbon contents in excess of 0.8%. Unfortunately, the majority of these heat treatments and particularly the spheroidisation treatments take a long time and frequently lead to decarburisation of the surface part of the strip thereby adversely affecting the properties.

[0047] The rolling according to the invention can also be carried out at low temperatures between 0 and 720 °C. Special benefits from the rolling can be expected when performed at low temperatures (i.e. cold rolling) because of the resulting breaking up of undesired particles. As a result of the break up of the particles the final properties of the steel product are improved. The shearing as a result of the rolling process breaks up the particles in the steel products, for example metal carbides like cementite or chromium carbides which may result in an improved toughness. The break up of the particles also affects the heat treatment response of the steel product. Different heating and cooling regimes can be employed leading to improved throughput through the heat treatment stage, e.g. a spheroidisation annealing treatment, or an improved product.

[0048] It is also possible for the method according to the invention to be preceded or followed by a heat treatment of the steel product. Examples of these heat treatments are the well known normalising treatment, stress relief annealing treatment, temper annealing treatment or spheroidisation annealing treatment.

[0049] In the context of this invention, a steel product also comprises a steel where one or both steel surfaces which are to be rolled are covered with one or more layers prior to rolling according to the invention. This combination of a steel product covered on one or both surfaces with one or more layers of metal is commonly referred to as cladded plate or strip. In producing clad plate there are three options by which the covering metal is bonded to the steel substrate: explosive bonding, roll bonding and weld overlay. One of the important factors affecting the quality of clad plate is the quality of the adhesion between the substrate and the cladding layer. This is a particular problem for the clad plate which is produced by roll bonding, because in conventional rolling the stress state at the interface between the substrate and the cladding layer, or between cladding layers is compressive only. According to an advantageous embodiment, a surface of the steel product which is to be rolled is covered by one or more layers prior to rolling. The covering layer can be a metal, preferably another steel, e.g. a steel with a different composition or a stainless steel, Titanium, Nickel, Copper, Aluminium or alloys thereof. This way it is possible, for example, to produce laminated material, such as what is known as clad material for use in, for example, pipes and pipe lines, chemical plants, power plants, vessels, pressure vessels.

[0050] The invention also relates to an improved metal plate or strip which has been produced by continuous casting, preferably with the aid of the method according to the first aspect of the invention, in which the pores in the core of the plate or strip have a maximum dimension of less than 200 μm, preferably less than 100 μm, more preferably less than 20 μm and even more preferably less than 10 μm. As a result of the continuous casting, continuously cast plate and strip material always has pores which can be significantly larger than 200 μm. The standard rolling operations can only close up these pores in the core to a slight extent or cannot do so at all. The rolling operation according to the invention makes it possible to provide continuously cast plate and strip material having pores which are much smaller.

[0051] The invention also relates to an improved metal plate or strip which is produced by continuous casting, preferably with the aid of the method according to the first aspect of the invention, in which the metal plate or strip, after recrystallisation, has a substantially homogenous degree of recrystallisation over its entire thickness. The fact that the grains have all been subjected to shearing as a result of the rolling operation according to the invention, including those in the core, means that the continuously cast plate and strip material will recrystallize over the entire thickness.

[0052] The invention also relates to a steel product produced according to the invention having a thickness of preferably between 10 and 300 mm, more preferably between 20 and 160 mm, for example 60 mm, for use in for example buildings, bridges, earth moving equipment, pipe line, ship building, and off shore constructions.

[0053] The invention also relates to a steel billet produced according to the invention, for example for use as starting material for the production of a steel section, for example an H-section.

[0054] It also relates to a steel product produced according to the invention, in which the starting point is a steel ingot, and in which steel product the pores in the core of the product preferably have a maximum dimension of less than 200 μm, more preferably less than 100 μm, still more preferably less than 20 μm and even more preferably less than 10 μm as well as to a steel product produced by continuous casting and processed according to the invention, in which the pores in the core of the plate or strip have a maximum dimension of less than 200 μm, more preferably less than 100 μm, still more preferably less than 20 μm and even more preferably less than 10 μm.

[0055] The invention also relates to a steel strip produced according to the invention for use in for example parts of automobiles, transport equipment, piling, buildings, construction and to a clad steel product for use in for example pipes, chemical plants, power plants, vessels, pressure vessels and to a steel strip wherein the steel is a HSLA-steel comprising at least one of the elements niobium, titanium, vanadium or boron, or wherein the steel is an ultra low carbon steel, preferably at least partly stabilised, preferably with at least one of the elements titanium, niobium or boron.

[0056] The invention will be explained with reference to an exemplary embodiment.

[0057] Experiments were carried out using slabs of a Titanium stabilised ultra low carbon steel, carbon-manganese steels and Niobium microalloyed HSLA-steel.

[0058] The slabs were introduced at different angles varying between 5° and 45°. The temperature of the slabs when they were introduced into the rolling device was approximately 1000 °C. The two rolls were driven at a speed of 5 revolutions per minute.

[0059] After rolling, the slabs had a certain curvature, which is highly dependent on the angle of introduction. The straightness of the slab after rolling can to a large extent be determined by the angle of introduction, in which context the optimum angle of introduction will be dependent on the degree of reduction of the slab, the type of material and alloy, and the temperature. For the slabs of steel which have been rolled in the experiment described above, an optimum introduction angle is approximately 20°.

[0060] A shear angle of 20° was measured in the steel slabs which were rolled in accordance with the experiment described above. Using this measurement and the reduction in the size of the slab, it is possible to calculate an equivalent strain in accordance with the following formula:

$$\varepsilon_{eq} = \frac{2}{\sqrt{3}} \cdot \sqrt{\left(\varepsilon_{xx}{}^{2} + \varepsilon_{yy}{}^{2}\right)}.$$

[0061] This formula is used to make it possible to present the strain in one dimension and is known from the book "Fundamentals of metal forming" by R.H. Wagoner and J.L. Chenot, John Wiley & Sons, 1997.

[0062] Therefore, in the slabs which have been rolled in accordance with the experiment, the equivalent strain is

$$\varepsilon_{eq} = \frac{2}{\sqrt{3}} \cdot \sqrt{\left(\left(\ln\left(\frac{32.5}{30.5}\right)\right)^2 + \left(\frac{1}{2}(\tan 20°)\right)^2\right)} \approx 0.25.$$

[0063] In the case of rolling with an ordinary rolling mill, shearing does not take place across the thickness of the plate and the equivalent strain is therefore only

$$\varepsilon_{eq} = \frac{2}{\sqrt{3}} \cdot \sqrt{\ln\left(\frac{32.5}{30.5}\right)^2} \approx 0.07$$

(working on the basis of a uniform strain over the entire thickness of the steel product).

[0064] Therefore, the rolling using the method according to the invention results in an equivalent strain which is three to four times higher than with conventional rolling without any difference in peripheral velocity. A high equivalent strain means less porosity in the slab, greater recrystalization and therefore greater grain refinement, and more extensive breaking up of the second-phase particles (constituent particles) in the slab. These effects are generally known to the person skilled in this field of engineering if the equivalent strain increases. Therefore, the rolling according to the invention means that the resulting properties of the material are greatly improved as a result of the use of the method according to the invention.

Claims

1. A method for processing a steel product, in which the steel product is passed between a set of rotating rolls of a rolling mill stand in order to roll the steel product, **characterized in that** the rolls of the rolling mill stand have different peripheral velocities such that one roll is a faster moving roll and the other roll is a slower moving roll, **in that** the peripheral velocity of the faster moving roll is at least 5% higher and at most 100% higher than that of the slower moving roll, **in that** the thickness of the steel product is reduced by at most 15% per pass, and **in that** the rolling takes place at a maximum temperature of 1350°C.

2. The method as claimed in claim 1, in which the thickness of the steel product is reduced by at most 8% each pass, and preferably at most 5% each pass.

3. The method as claimed in claim 1 or 2, in which the peripheral velocity of the faster moving roll is at most 50% higher and preferably at most 20% higher than that of the slower moving roll.

4. The method as claimed in one of the preceding claims, in which the rolling mill is designed in such a manner that the rolls have different diameters.

5. The method as claimed in one of the preceding claims, in which the rolls have different rotational speeds.

6. The method as claimed in one of the preceding claims, in which the steel product is introduced between the rolls at an angle of between 5 and 45° with respect to the perpendicular to the plane through the center axes of the rolls, preferably at an angle between 10 and 25° and more preferably at a angle of between 15 and 25°.

7. The method as claimed in one of the preceding claims, in which the rolling operation is repeated one or more times after the rolling has been carried out for the first time.

8. The method as claimed in claim 7, in which the steel product is passed through the rolling mill stand in opposite directions for each pass.

9. The method as claimed in claim 7, in which the steel product is successively passed through two or more rolling

mill stands.

10. The method as claimed in one of the preceding claims, in which the rolling operation as described in one of claims 1 - 9 is preceded or followed by a rolling operation which is carried out using a rolling mill in which the rolls have substantially identical peripheral velocities.

11. The method as claimed in any of the claims 1 to 10, in which the rolling is carried out on a steel product of which at least a skin layer has a substantially austenitic structure, and preferably on a steel product having a substantially austenitic structure throughout.

12. The method as claimed in any of the claims 1 to 10, in which the rolling is carried out on a steel product of which at least a skin layer has a substantially austenitic-ferritic two-phase structure, and preferably on a steel product having a substantially austenitic-ferritic two-phase structure throughout.

13. The method as claimed in any of the claims 1 to 10, in which the rolling is carried out on a steel product of which at least a skin layer has a substantially ferritic structure, and preferably on a steel product having a substantially ferritic structure throughout.

14. The method as claimed in any of the claims 1 to 10, in which the rolling is carried out while the temperature of the steel product is higher than 0°C and lower than 720°C.

15. The method according to claim 14, in which the rolling is carried out on a steel product having a substantially martensitic structure.

16. A method for producing a steel product comprising the steps of:

- continuous casting of a steel strand;
- optionally heating and/or temperature homogenising the steel strand between a casting machine and a rolling device;
- optionally rolling the steel product in one or more rolling mill stands of the rolling device with rolls having substantially identical peripheral velocities;
- optionally accelerated cooling after the last rolling step;
- optionally cutting the steel product into slabs or coils before or after rolling;
- optionally coiling the steel product
- cooling the steel product

characterised in that between casting the strand and accelerated cooling or coiling or cooling, or after cooling, the steel product is subjected to the method of any one of the claims 1 - 10.

17. The method for producing a steel product according to claim 16 **characterised in that** the thickness of the cast strand is below 150 mm and preferably below 100 mm, even more preferably below 80 mm.

18. The method for producing a steel product according to claim 16 **characterised in that** the thickness of the cast strand is below 20 mm and preferably below 10 mm, even more preferably below 5 mm.

19. The method according to claim 16 to 18, wherein the steel product that is produced is a stainless steel product.

20. The method for producing a steel product according to claim 16 - 19 **characterised in that** the rolling is carried out on a steel product having a substantially austenitic structure, **in that** the steel is acceleratedly cooled thereafter, **in that** the steel product essentially comprises ferrite, bainite and/or martensite, and **in that** the ferrite content after cooling is preferably at least 60%, more preferably more than 70% and even more preferably more than 80%.

21. The method for producing a steel product according to claim 16 - 20 wherein the average grainsize of the steel product is smaller than 5 µm, preferably smaller than 2 µm and more preferably smaller than 1 µm.

22. The method according to any of the claims 1 - 21 wherein the steel product is subjected to a heat treatment before or after the rolling step, for example a normalising treatment, a full anneal, a stress relief anneal or a speroidisation annealing treatment.

23. The method as claimed in any of the claims 1 - 21 wherein a surface of the steel product which is to be rolled is covered by one or more layers prior to rolling.

24. The method as claimed in claim 23 wherein the covering layer is a metal, preferably another steel, e.g. a steel with a different composition or a stainless steel, Titanium, Nickel, Copper, Aluminium or alloys thereof.

25. A steel product produced according to the method of any of the preceding claims having a thickness of preferably between 10 and 300 mm, more preferably between 20 and 160 mm, for example 60 mm, for use in for example buildings, bridges, earth moving equipment, pipe line, ship building, and off shore constructions.

26. A steel product produced according to the method of any of the claims 1 - 24, in which the steel product is a steel billet.

27. A steel section, for example an H-section, **characterised in that** the steel section is produced using a billet according to claim 26.

28. A steel product produced according to the method of any of the claims 1 - 24, in which the starting point is a steel ingot, in which steel product the pores in the core of the product preferably have a maximum dimension of less than 200 µm, more preferably less than 100 µm, still more preferably less than 20 µm and even more preferably less than 10 µm.

29. A steel plate, strip or billet produced by continuous casting, using the method as claimed in one of claims 1 - 10, in which the pores in the core of the plate, strip or billet preferably have a maximum dimension of less than 200 µm, more preferably less than 100 µm, still more preferably less than 20 µm and even more preferably less than 10 µm.

30. A steel strip produced according to the method of any of the claims 16 - 21 for use in for example parts of automobiles, transport equipment, piling, buildings, construction.

31. A clad steel product produced according to claim 23 or 24 for use in for example pipes, chemical plants, power plants, vessels, pressure vessels.

32. A steel strip produced according to claim 16, 17, 18 or 21 wherein the steel is a HSLA-steel comprising at least one of the elements niobium, titanium, vanadium or boron, or wherein the steel is an ultra low carbon steel, preferably at least partly stabilised, preferably with at least one of the elements titanium, niobium or boron.

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EUROPEAN SEARCH REPORT

Application Number
EP 03 07 5546

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