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HOT-ROLLED STEEL SHEET AND ASSOCIATED PRODUCTION METHOD

The invention primarily concerns hot-rolled steel sheet.

The invention further concerns methods enabling such steel sheet to be produced.

The need to reduce the weight of automotive vehicles and increase safety have led to the production of high-strength steels.

Historically, the development of these steels was begun with the addition of alloying elements primarily to obtain precipitation hardening.

Subsequently, "dual phase" steels were proposed which contain martensite in a ferritic matrix in order to obtain structural hardening.

In order to obtain higher levels of strength combined with suitability for deformation, "TRIP" (Transformation Induced Plasticity) steels were developed the microstructure whereof is composed of a ferritic matrix composed of bainite and residual austenite, which under the effect of deformation, such as during a stamping operation for example, is transformed into martensite.

Finally, to achieve mechanical strength greater than 800 MPa, multi-phase steels with a majority bainite structure have been proposed. These steels are used in industry, and in particular in the automobile industry, to manufacture structural components.

This type of steel is described in the publication EP 2 020 451. To obtain an elongation at break greater than 10% as well as mechanical strength greater than 800 MPa, the steels described in this publication, in addition to the known presence of carbon, contain manganese and silicon, molybdenum and vanadium. The microstructure of these steels essentially contains upper bainite (at least 80%) as well as lower bainite, martensite and residual austenite.

However, the fabrication of these steels is expensive because of the presence of molybdenum and vanadium.

The invention therefore seeks to make available a sheet, the fabrication costs of which are less than the fabrication costs of the sheet described in EP 2 020 451.

Moreover, certain automobile parts, e.g., bumper beams and suspension arms, are fabricated by shaping operations that combine different modes of deformation. Certain microstructural characteristics of the steel can turn out to be well suited to one mode of deformation but less well suited to another. Certain portions of the parts must have high yield strength, while others must exhibit good suitability for the shaping of a cut edge.

This latter property is evaluated as follows: after a hole has been cut into a sheet, a tapered tool is used to expand the edges of this hole. It is during this operation that premature damage can be observed in the vicinity of the edges of the hole during the expansion, whereby this damage begins in the second-phase particles or at the interfaces between the different microstructural components in the steel.

As described in standard ISO 16630:2009, the hole expansion method consists of measuring the initial diameter Di of the hole before stamping, then the final diameter Df of the hole after stamping, determined when through-cracks are observed in the thickness of the sheet on the edges of the hole. The hole expansion ability Ac% is determined according to the following formula: $Ac\% = 100\text{x}\,\frac{(Df-Di)}{Di}$. Ac is therefore used to quantify the ability of a sheet to withstand stamping at the level of a cut orifice. According to this method, the initial diameter is 10 mm.

Under these conditions, an object of the invention is to make available a steel sheet, the hole expansion ratio Ac% of which is greater than or equal to 50%, for a thickness range likely to be obtained by hot rolling, i.e. from 1.5 to 4 mm.

Moreover, the invention deals with an uncoated or electro-galvanised or galvanised steel sheet. The composition and the mechanical characteristics of the steel must be compatible with the stresses and thermal cycles of the continuous hot dip galvanising processes.

An object of the invention is also a method for the fabrication of a steel sheet that does not require significant rolling forces, which makes it possible to fabricate the steel in a wide range of thicknesses.

An additional object of the invention is to make available a steel sheet which has little sensitivity to the problems of springback encountered during cold stamping operations. For this purpose, the yield stress Re must not be greater than 840 MPa. The yield stress must be not less than or equal to 690 MPa to satisfy the weight-reduction requirements.

An additional object of the invention is a steel sheet that can be easily welded using conventional assembly methods.

Finally, an additional object of the invention is a hot rolled steel sheet with economical fabrication costs, having simultaneously a yield stress greater than 690 MPa and less than or equal to 840 MPa, mechanical strength between 780 MPa and 950 MPa, elongation at break greater than 10% and a hole expansion ratio Ac % greater than or equal to 50%. Yield stress greater than 690 MPa is understood as a yield stress that is strictly greater than 690 MPa.

To that end, the invention proposes a hot rolled steel sheet, the chemical composition of which is as follows, with the contents being expressed in percent by weight:

$0.040\% \leq C \leq 0.065\%$

$1.4\% \leq Mn \leq 1.9\%$

$0.1\% \leq Si \leq 0.55\%$

$0.095\% \leq Ti \leq 0.145\%$

$0.025\% \leq Nb \leq 0.045\%$

$0.005\% \leq Al \leq 0.1\%$

$0.002\% \leq N \leq 0.007\%$

$S \leq 0.004\%$

$P < 0.020\%$

optionally

$Cr \leq 0.7\%$

$Cu \leq 0.1\%$

$Ni \leq 0,25\%$

$B \leq 0.003\%$

$Ca \leq 0.005\%$

$Mg \leq 0.005\%$

the remainder consisting of iron and unavoidable processing impurities,

the microstructure of which contains granular bainite, ferrite, cementite in a surface percentage less than 1.5%, and carbonitrides of titanium and niobium, and

the ratio between the grain size DL measured parallel to the rolling direction and the grain size D_N measured perpendicular to the rolling direction is less than or equal to 1.4.

The sheet claimed by the invention can also have the following optional characteristics, considered individually or in combination:

- the ratio between the grain size DL measured parallel to the direction of rolling and the grain size D_N measured perpendicular to the direction of rolling is less than or equal to 1.3.
- according to a first aspect of the invention, the chemical composition is as follows, whereby the contents are expressed in percent by weight:

$0.045\% \leq C \leq 0.065\%$

$1.6\% \leq Mn \leq 1.9\%$

$0.1\% \leq Si \leq 0.55\%$

$0.095\% \leq Ti \leq 0.125\%$

$0.025\% \leq Nb \leq 0.045\%$

$0.01\% \leq Al \leq 0.1\%$

$0.002\% \leq N \leq 0.007\%$

$S \leq 0.004\%$

$P < 0.020\%$

optionally

$Cu \leq 0.1\%$

$Ni \leq 0.25\%$

$B \leq 0.003\%$

$Ca \leq 0.005\%$

$Mg \leq 0.005\%$

said composition not comprising chrome.

- according to the first aspect of the invention, the composition of the steel is as follows, whereby the contents are expressed in percent by weight:

$0.1\% \leq Si \leq 0.3\%$

- according to a second aspect of the invention, the chemical composition is as follows, whereby the contents are expressed in percent by weight:

$0.040\% \leq C \leq 0.065\%$

$1.4\% \leq Mn \leq 1.9\%$

$0.1\% \leq Si \leq 0.4\%$

$0.095\% \leq Ti \leq 0.145\%$

$0.025\% \leq Nb \leq 0.045\%$

$0.01\% \leq Al \leq 0.1\%$

$0.002\% \leq N \leq 0.007\%$

$0.2\% \leq Cr \leq 0.7\%$

$S \leq 0.004\%$

P < 0.020%

optionally

Cu ≤ 0.1%

Ni ≤ 0.25%

B ≤ 0.003%

Ca ≤ 0.005%

Mg ≤ 0.005%

- when the composition of the steel includes chromium, the chromium content is as follows: 0.4% ≤ Cr ≤ 0.6%

- the surface percentage of the granular bainite is between 80% and 95% and the surface percentage of the ferrite is less than 20%.

- The density of titanium nitrides having an average size greater than 6 μm is less than or equal to 3/mm^2.

- The composition of the steel contains, in percent by weight:

0.0005% ≤ Ca ≤ 0.005%

- The composition of the steel contains, in percent by weight:

0.0005% ≤ Mg ≤ 0.005%

The invention further relates to a method for the production of the sheet described above.

Said method is characterised in that a steel is obtained in the form of liquid metal having the following composition, whereby the contents are expressed in percent by weight:

0.040% ≤ C ≤ 0.065%

1.4% ≤ Mn ≤ 1.9%

0.1% ≤ Si ≤ 0.55%

0.095% ≤ Ti ≤ 0.145%

0.025% ≤ Nb ≤ 0.045%

0.005% ≤ Al ≤ 0.1%

0.002% ≤ N ≤ 0.007%

S ≤ 0.004%

P < 0.020

optionally

Cr ≤ 0.7%

Cu ≤ 0.1%

Ni ≤ 0.25%

B ≤ 0.003%

Mg ≤ 0.005%

the remainder consisting of iron and unavoidable impurities,

and in that a vacuum treatment or SiCa treatment is performed; in the latter case the composition further comprises the following, expressed in percent

0.0005% ≤ Ca ≤ 0.005%,

in that the quantities of titanium [Ti] and nitrogen [N] dissolved in the liquid metal satisfy the relation %[Ti] %[N]<6.10^{-4}%^{2},

in that the steel is cast to obtain a cast semi-finished product, and that said semi-finished product is optionally reheated to a temperature between 1160° C. and 1300° C., then in that said cast semi-finished product is hot rolled with an end-of-rolling temperature between 880°C and 930°C, the rate of reduction of the penultimate pass being less than 0.25, the rate of the last pass being less than 0.15, the sum of the two rates of reduction being less than 0.37, the start-of-rolling temperature of the penultimate pass being less than 960°C, so as to obtain a hot rolled product, then

in that said hot-rolled product is cooled at a rate of between 50 and 150° C/s to obtain a hot-rolled steel sheet, and in that said sheet is coiled at a temperature between 470 and 625° C.

Said method can also comprise, according to a first aspect of the invention, the following optional characteristics, considered individually or in combination:

- the composition of the steel is as follows, with the contents being expressed in percent by weight:

$0.045\% \leq C \leq 0.065\%$

$1.6\% \leq Mn \leq 1.9\%$

$0.1\% \leq Si \leq 0.3\%$

$0.025\% \leq Nb \leq 0.045\%$

$0.095\% \leq Ti \leq 0.125\%$

$0.01\% \leq Al \leq 0.1\%$

$0.002\% \leq N \leq 0.007\%$

$S \leq 0.004\%$

$P < 0.020\%$

optionally

$Cu \leq 0.1\%$

$Ni \leq 0.25\%$

$B \leq 0.003\%$

$Mg \leq 0.005\%$

said composition not comprising chromium.

- if the composition does not include chromium, the sheet is coiled at a temperature between 515 and strictly 620° C.
- the sheet is coiled at a temperature between 515 and 560° C., said sheet is pickled, then the pickled sheet is heated to a temperature of between 600°C and 750°C, then the heated pickled sheet is cooled at a rate of between 5 and 20°C/s,

and the sheet thus obtained is coated with zinc in a suitable zinc bath.

The method can also comprise, according to a second aspect of the invention, the following optional characteristics, considered individually or in combination:

- the composition of the steel is as follows, with the contents being expressed in percent by weight:

$0.040\% \leq C \leq 0.065\%$

$1.4\% \leq Mn \leq 1.9\%$

$0.1\% \leq Si \leq 0.4\%$

$0.095\% \leq Ti \leq 0.145\%$

$0.025\% \leq Nb \leq 0.045\%$

$0.005\% \leq Al \leq 0.1\%$

$0.002\% \leq N \leq 0.007\%$

0.2% ≤ Cr ≤ 0.7%

S ≤ 0.004%

P < 0.020

optionally

Cu ≤ 0.1%

Ni ≤ 0.25%

B ≤ 0.003%

Ca ≤ 0.005%

Mg ≤ 0.005%

and said sheet is coiled at a temperature of between 470°C and 580°C.

- the composition of the steel is as follows, whereby the contents are expressed in percent by weight:

0.4% ≤ Cr ≤ 0.6%

- when the sum of the contents of Mn, Si and Cr is less than 2.35%, the sheet is coiled at a temperature between 520° C and 580° C.

Other characteristics and advantages of the invention are described below by way of example and with reference to the single accompanying figure which illustrates the curve of the hole expansion ratio Ac % as a function of the equiaxial character of the grains, which is observed on a polished and etched surface.

According to the invention, the carbon content by weight is between 0.040% and 0.065%. A carbon content in this range makes it possible to obtain simultaneously a high elongation at break and mechanical strength greater than 780 MPa. For a higher carbon content, in particular above 0.095%, the suitability for welding tends to decrease (Table 1).

In addition, the maximum carbon content by weight is set at 0.065% which makes it possible to ensure the complete transformation of austenite to granular bainite and thereby avoids the formation of martensite and austenite and the accompanying formation of hard second phases that limit the hole expansion ability. This maximum content therefore makes it possible to achieve a hole expansion ratio Ac % greater than or equal to 50%.

According to the invention, the manganese content by weight is between 1.4% and 1.9%. When present in these quantities, the manganese contributes to the strength of the sheet and limits the formation of a central segregation band. It contributes to obtaining a hole expansion ratio Ac % greater than or equal to 50%.

An aluminium content by weight between 0.005% and 0.1% makes it possible to ensure the de-oxidation of the steel during its fabrication.

According to the invention, the chemical composition of the hot-rolled steel sheet also includes titanium and niobium. These two elements in particular give the steel the desired strength, the necessary hardening and the specified hole expansion ratio Ac % These two elements each give the sheet the specific properties of strength, hardness and hole expansion ratio. It has been discovered in the context of this invention that these two elements must be present in specific content levels in the composition of the steel.

Titanium is more particularly present in the steel in a quantity between 0.095% and 0.145% by weight. Above 0.095%, the mechanical strength of 780 MPA is not achieved and below 0.145% there are risks of the precipitation of coarse titanium nitrides which can cause premature damage during the expansion of the hole. In fact, when nitrides larger than 6 μm are present, it has been found that they are one of the majority causes of cleavage from the matrix during the cutting and stamping steps.

In addition, the invention teaches that the nitrogen content by weight is between 0.002% and 0.007%. The nitrogen content must be below 0.007% to avoid a premature precipitation of nitrides in the liquid metal. Although the nitrogen content can be extremely low, its limit value is set at 0.002% so that the fabrication can be carried out under satisfactory economic conditions.

The niobium content by weight in the composition of the steel is between 0.025% and 0.045% and preferably between 0.025% and 0.035%. When present in a percent by weight greater than 0.025%, niobium hardens effectively via the formation of very fine carbonitrides. However, above a content of 0.045% by weight, the recrystallisation of the austenite is retarded. The structure then contains a significant fraction of elongated grains, as a result of which it is no longer possible to achieve the specified hole expansion rate Ac %.

The combined addition of titanium and niobium in the specific proportions indicated above makes it possible to achieve optimal properties of hardening and expansion ability of the hole.

Thus the steel claimed by the invention does not include the expensive addition of molybdenum.

Optionally, the composition can include chromium in a quantity less than or equal to 0.7% to improve the surface quality, most particularly in a content between 0.4 and 0.6%. According to one aspect of the invention, however, the presence of chromium is not absolutely necessary, which has the advantage of eliminating expensive additions. According to another aspect of the invention, the addition of chromium in a quantity between 0.2% and 0.7%, preferably between 0.4 and 0.6%, makes it possible to coil the steel at lower temperatures, as described in greater detail below.

The composition can also include the optional presence of copper in a quantity of up to 0.1% and/or nickel in a quantity of up to 0.25%.

To improve the surface quality, the composition can also optionally include boron in a quantity less than or equal to 0.003% and preferably between 0.0015 and 0.0025%.

According to the invention, silicon is present in the chemical composition of the sheet in a content between 0.1% and 0.55% by weight.

The silicon retards the precipitation of the cementite. In the quantities defined according to the invention, the cementite precipitates in very small quantities, e.g., in a surface percentage less than 1.5% and in a very fine form. This finer morphology of the cementite makes it possible to obtain a high hole expansion ability, e.g. greater than or equal to 50%.

The sulphur content of the steel claimed by the invention is less than 0.004% to limit the formation of sulphides, in particular manganese sulphides.

The low levels of sulphur and nitrogen in the composition of the sheet are beneficial in terms of the hole expansion ability.

The phosphorus content of the steel claimed by the invention is less than 0.020% to promote the hole expansion ability and weldability.

It can also be specified that the composition of the steel includes the presence of calcium in a percentage by weight of less than or equal to 0.005%, preferably between 0.0005% and 0.005% and/or the presence of magnesium in a percentage by weight less than or equal to 0.005%, preferably between 0.0005 and 0.005%.

These two elements make it possible to form fine oxides or oxysulphides of calcium and magnesium. These oxides or oxysulphides act as nucleants for a subsequent very fine precipitation of titanium nitrides/carbonitrides. The reduction in the size of the carbonitrides therefore makes it possible to achieve an improved hole expansion ability. The microstructure of the sheet according to the invention contains granular bainite.

Granular bainite is distinguished from upper and lower bainite. The definition of granular bainite can be found in the article entitled *Characterization and Quantification of Complex Bainitic Microstructures in High and Ultra-High Strength Steels—Materials Science Forum Volume 500-501, pages 387-394; November 2005.*

According to this article, the granular bainite that composes the microstructure of the sheet according to the invention is defined as having a significant proportion of highly disoriented adjacent grains and an irregular morphology of the grains.

According to the invention, cementite is present in low quantities, limited to a surface percentage not exceeding 1.5%. The damage that occurs between the bainite matrix and the cementite which is significantly harder is therefore limited. This low content of cementite originates in particular from the addition of the silicon used and makes it possible to obtain a steel sheet with a hole expansion ratio Ac % greater than or equal to 50%.

The sheets can contain up to 20% ferrite in surface percentage.

Finally, according to the invention, the sheet also contains carbonitrides of titanium and niobium.

The sheet claimed by the invention is free of martensite and austenite, which makes it possible to prevent the presence of hard second phases, the effect of which would be to limit the hole expansion ratio Ac %. The microstructure of the sheet of the invention contains principally granular bainite and possibly ferrite and cementite in the proportions determined and indicated above. The sheet is precipitation hardened and is characterised by the absence of the hard second phases mentioned above.

Reference is made to figure 1 which illustrates the relationship between the ratio between the grain size D_L measured parallel to the rolling direction and the grain size D_N measured perpendicular to the rolling direction and the hole expansion ratio Ac.

The ratio D_L/D_N is determined as follows: The microstructure is observed on a cut section that has been polished and etched using a reagent which is known in itself, by optical microscopy at magnifications ranging from approximately 500 to 1500× over a surface which comprises a statistically representative population of grains. Image analysis software, which is known in itself, such as, for example, EBSD (Electron Back Scattered Diffraction) cartography, is used to determine the average grain sizes measured parallel (D_L) and perpendicular (D_N) to the rolling direction. The ratio D_L/D_N therefore characterises the average elongation of the grains in the rolling direction, which is also called the equiaxial character.

As illustrated in figure 1, the inventors have shown that there is a relationship between the hole expansion ratio Ac % and the ratio D_L/D_N. The straight line plotted in figure 1 indicates the lower envelope of the experimental results and makes it possible to determine, at the level of the expansion of a given hole, the value of the ratio D_L/D_N that must not be exceeded to achieve this given level. It has therefore been shown that to obtain a coefficient Ac greater than or equal to 50%, the ratio D_L/D_N must be less than or equal to 1.4, which means that the grains must be relatively equiaxial. To obtain a hole expansion ratio Ac % greater than 65 or equal to 100%, the ratio D_L/D_N must be respectively less than or equal to 1.3 or 1.1.

Moreover, the surface percentage of the granular bainite is between 80% and 95% and the surface percentage of the ferrite is less than 20%.

To obtain a surface percentage of cementite of less than 1.5%, the silicon content is between 0.1 and 0.55% by weight.

Tables 1, 2A, 2B and 2C below illustrate the influence of the chemical composition and the fabrication conditions of a hot-rolled steel sheet on the microstructure and the mechanical strength, the elongation at break, the hole expansion ratio Ac % and the ratio D_L/D_N.
All these steel compositions have a phosphorus content less than 0.020% by weight.

These tables also provide information on the fabrication cost of the sheet, the ease of fabrication of the hot-rolled steel sheet in a thickness range from 1.5 to 4 millimetres, and the weldability of the sheet.

The coiling temperatures of the hot-rolled and cooled steel sheet are indicated for all the examples presented in these tables as well as for certain counterexamples.

These tables also indicate the more or less significant presence of "M-A" compounds, i.e. "Martensite-residual Austenite". Due to their intrinsic hardness (martensite) or their ability to form martensite under the influence of deformation (residual austenite), the presence of these compounds which combine martensite and residual austenite in variable proportions is detrimental for obtaining high values of the hole expansion ratios.

All the compositions and processing conditions of the sheet claimed by the invention are such that the density of TiN with an average size greater than or equal to 6 μm is less than or equal to $3/mm^2$.

Table 1 specifically relates to examples in which the composition of the steel does not include chromium.

Counterexample 1 corresponds to a sheet described in publication EP 2 020 451. In this sheet, as explained above, the presence of vanadium and molybdenum results in excessive costs.

Counterexample 2 shows that in the absence of molybdenum and in the presence of vanadium, the sheet obtained has a maximum tensile strength which is too low.

This maximum tensile strength Rm can be increased by adding carbon and niobium (counterexample 3), but in this case the hole expansion ratio is insufficient.

In counterexample 4, a niobium content of 0.03% and a low titanium content once again result in a maximum tensile strength which is too low.

Counterexamples 2, 3 and 4 also have an excessive presence of the M-A compounds defined above.

In counterexamples 5 and 6, the niobium and titanium contents are high. It can be noted that with (counterexample 5) or without (counterexample 6) molybdenum, the hole expansion ratio is insufficient and the ratio D_L/D_N is too high. In addition, for counterexample 5, high contents of niobium and molybdenum cause problems of dimensional feasibility.

Finally, counterexample 7 differs from counterexample 3 in that the composition does not include vanadium and includes a high carbon content. In this case, the result is insufficient weldability, a detrimental proportion of "M-A" compounds as well as an insufficient yield stress and hole expansion ratio.

Examples 1 to 3 are included within the framework of the invention for a silicon content between 0.1% and 0.55%.

Due to the absence of hardening elements (Mo in particular) and the limited niobium content, the steels claimed by the invention can be used for easy fabrication by hot rolling in a wide range of thicknesses.

Tables 2A, 2B and 2C relate specifically to compositions that include chromium in content levels between 0.2 and 0.7%.

The coiling temperatures of the hot rolled and cooled steel sheets are 500°C and 550°C.

In counterexamples A and B, the manganese content is 1.296%. For these two counterexamples, it has been found that whether the coiling temperature is 500°C or 550°C, the sheet does not have the required properties, in particular in terms of the maximum tensile strength.

In counterexamples C and D, the silicon content is 0.6%. For these two counterexamples, it has been found that whether the coiling temperature is 500°C or 550°C, the sheet does not have the required properties, in particular on account of numerous "M-A" compounds.

The other results presented in Tables 2A, 2B and 2C are classified according to the increasing sum of the added contents of manganese, silicon and chromium.

Tests performed with a composition that is within the framework of the invention for a sum of the contents of Mn, Si and Cr of less than 2.35 and a coiling temperature of 500°C produced unsatisfactory results, in particular in terms of maximum tensile strength.

When the sum of the contents of Mn, Si and Cr is greater than 2.35, the properties of the sheet obtained are satisfactory whether the coiling temperature is 500°C or 550°C.

Table 1

	Chemical composition (in %)										
	C	Mn	Si	Al	S	Cr	Mo	Nb	Ti	V	N
Counterexample 1	0.078	1.801	0.22	0.03	0.003	0.408	0.307	-	-	0.154	0.007
Counterexample 2	0.095	2.054	0.21	0.035	0.002	0.399	-	-	-	0.162	0.003
Counterexample 3	0.129	2.087	0.304	0.038	0.001	0.402	-	0.031	-	0.184	0.004
Counterexample 4	0.06	2.011	0.502	0.04	0.003	0.514	-	0.03	0.023	-	0.004
Counterexample 5	0.05	1.88	0.227	0.035	0.003	-	0.145	0.087	0.09	-	0.006
Counterexample 6	0.057	1.626	0.206	0.033	0.002	-	-	0.069	0.086	-	0.005
Counterexample 7	0.095	1.943	0.483	0.04	0.003	0.505	-	0.028	0.021	-	0.005
Example 1 *	0.05	1.7	0.2	0.033	0.002	-	-	0.04	0.105	-	0.005
Example 2 **	0.049	1.64	0.215	0.032	0.003	-	-	0.041	0.112	-	0.004
Example 3 ***	0.064	1.779	0.521	0.05	0.001	-	-	0.031	0.104	-	0.006

	Analytic cost	Thickness feasibility	Weldability	Fraction of MA islands	Yield stress Re (Mpa)	Maximum tensile strength Rm (Mpa)	Total elongation at break	Hole expansion (ISO method)	Grain elongation ratio DL/DN		
Counterexample 1	●	○	○	○	780	867	19	64	ND		
Counterexample 2	◎	○	◎	◎	698	758	13.4	ND	ND	●	Poor
Counterexample 3	◎	○	◎	●	769	847	16.8	33.3	ND	○	Average
Counterexample 4	○	○	○	◎	624	738	18.1	ND	ND	◎	Good
Counterexample 5	●	●	○	○	836	878	13.4	45	1.8	ND	not determined
Counterexample 6	○	◎	○	○	813.5	820	13.5	43.1	1.44		
Counterexample 7	○	○	◎	●	688	966	12.8	21.8	ND		
Example 1 *	○	○	○	○	816.5	821	14.8	66.5	1.35	* Coiling temp.: 560 °C	
Example 2 **	○	○	○	○	816	824	14.4	78	ND	** Coiling temp.: 500 °C	
Example 3 ***	○	○	○	○	776	934	16.9	53	ND	*** Coiling temp.: 578 °C	

Table 2A

	Chemical composition (in %)									
	C	Mn	Si	Al	S	Cr	Nb	Ti	N	Mn+Si+Cr
Counterexample A *	0.049	1.298	0.209	0.03	<0.001	0.616	0.033	0.102	0.004	-
Counterexample B **	0.049	1.296	0.209	0.03	<0.001	0.616	0.033	0.102	0.004	-
Counterexample C *	0.065	1.6	0.8	0.045	<0.001	0.6	0.03	0.125	0.004	-
Counterexample D **	0.065	1.6	0.8	0.045	<0.001	0.6	0.03	0.125	0.004	-
Example 1 *	0.048	1.492	0.206	0.031	<0.001	0.612	0.031	0.1	0.004	2.31
Example 2 *	0.048	1.501	0.207	0.031	<0.001	0.614	0.032	0.1	0.005	2.322
Example 3 **	0.056	1.78	0.207	0.038	0.002	0.405	0.03	0.108	0.005	2.392
Example 4 *	0.045	1.78	0.4	0.038	0.002	0.22	0.03	0.122	0.004	2.4
Example 5 **	0.045	1.78	0.4	0.038	0.002	0.22	0.03	0.122	0.004	2.4

	Analytical cost	Thickness feasibility	Weldability	Fraction of MA islands	Yield stress Re (Mpa)	Maximum tensile strength Rm (Mpa)	Total elongation at break	Hole expansion (ISO method)
Counterexample A *	○	○	○	○	725	779	8	72
Counterexample B **	○	○	○	○	725	799	16.3	100
Counterexample C *	○	○	○	◎	856	897	17.2	41
Counterexample D **	○	○	○	◎	789	848	16.3	55
Example 1 *	○	○	○	○	900	823	16.3	57
Example 2 *	○	○	○	○	760	863	16.3	55
Example 3 **	○	○	○	○	751	796	16.1	58
Example 4 *	○	○	○	○	776	830	16.8	67
Example 5 **	○	○	○	○	753	786	15.4	72

●	Poor
◎	Average
○	Good
ND	Not determined

* Coiling temp.: 550 °C

** Coiling temp.: 500 °C

Table 2B

	Chemical composition (in %)									
	C	Mn	Si	Al	S	Cr	Nb	Ti	N	Mn+Si+Cr
Example 6 *	0.043	1.77	0.4	0.036	0.02	0.293	0.03	0.121	0.004	2.463
Example 7 **	0.043	1.77	0.4	0.036	0.02	0.293	0.03	0.121	0.004	2.463
Example 8 *	0.054	1.68	0.2	0.025	0.002	0.628	0.032	0.107	0.005	2.508
Example 9 **	0.054	1.68	0.2	0.025	0.002	0.628	0.032	0.107	0.005	2.508
Example 10 **	0.057	1.77	0.345	0.036	0.002	0.404	0.03	0.108	0.005	2.519
Example 11 *	0.055	1.77	0.347	0.033	0.002	0.404	0.03	0.108	0.005	2.521
Example 12 *	0.045	1.89	0.208	0.041	<0.003	0.63	0.03	0.12	0.005	2.528
Example 13 **	0.045	1.89	0.208	0.041	<0.003	0.63	0.03	0.12	0.005	2.528

	Analytical cost	Thickness feasibility	Weldability	Fraction of MA islands	Yield stress Re (Mpa)	Maximum tensile strength Rm (Mpa)	Total elongation at break	Hole expansion (ISO method)
Example 6 *	○	○	○	○	763	839	16.8	67
Example 7 **	○	○	○	○	739	783	14.9	58
Example 8 *	○	○	○	○	764	827	17.7	51
Example 9 **	○	○	○	○	741	794	13.8	87
Example 10 **	○	○	○	○	762	809	14.6	64
Example 11 *	○	○	○	○	ND	825	15	53
Example 12 *	○	○	○	○	785	826	16.6	72
Example 13 **	○	○	○	○	741	793	15.2	82

●	Poor
◎	Average
○	Good
ND	Not determined

* Coiling temp.: 550 °C

** Coiling temp.: 500 °C

Table 2C

	Chemical composition (in %)									
	C	Mn	Si	Al	S	Cr	Nb	Ti	N	Mn+Si+Cr
Example 14 *	0.045	1.76	0.4	0.035	0.002	0.393	0.03	0.12	0.004	2.553
Example 15 **	0.045	1.76	0.4	0.035	0.003	0.393	0.03	0.12	0.004	2.553
Example 16 **	0.055	1.6	0.4	0.045	<0.001	0.6	0.03	0.125	0.004	2.6
Example 17 *	0.045	1.696	0.293	0.039	<0.003	0.63	0.03	0.121	0.005	2.619
Example 18 **	0.045	1.696	0.293	0.039	<0.003	0.63	0.03	0.121	0.005	2.619
Example 19 **	0.053	1.8	0.199	0.022	0.002	0.626	0.032	0.106	0.006	2.625
Example 20 **	0.053	1.8	0.344	0.022	0.002	0.627	0.032	0.106	0.006	2.771

	Analytical cost	Thickness feasibility	Weldability	Fraction of MA islands	Yield stress Re (Mpa)	Maximum tensile strength Rm (Mpa)	Total elongation at break	Hole expansion (ISO method)		
Example 14 *	○	○	○	○	786	838	15.5	75		
Example 15 **	○	○	○	○	754	799	14	69	●	Poor
Example 16 **	○	○	○	○	803	840	15.6	72	◎	Average
Example 17 *	○	○	○	○	824	864	14.2	62	○	Good
Example 18 **	○	○	○	○	768	811	15	71	ND	Not determined
Example 19 **	○	○	○	○	741	811	15.9	68	* Coiling temp.: 550 °C	

The fabrication method for a steel sheet defined above and having a content of silicon by weight between 0.1% and 0.55% includes the following steps:

A liquid steel is obtained having the composition indicated below, the contents being expressed in weight:

$0.040\% \leq C \leq 0.065\%$

$1.4\% \leq Mn \leq 1.9\%$

$0.1\% \leq Si \leq 0.55\%$

$0.095\% \leq Ti \leq 0.145\%$

$0.025\% \leq Nb \leq 0.045\%$

$0.01\% \leq Al \leq 0.1\%$

$0.002\% \leq N \leq 0.007\%$

$S \leq 0.004\%$

$P < 0.020\%$ and optionally:

$Cr \leq 0.7\%$

$Cu \leq 0.1\%$

$Ni \leq 0.25\%$

$B \leq 0.003\%$

$Mg \leq 0.005\%$

the rest being composed of iron and inevitable impurities,

Titanium [Ti] is added to the liquid metal containing dissolved nitrogen [N] such that the quantities of titanium [Ti] and [N] dissolved in the liquid metal satisfy the expression $\%[Ti]\ \%\ [N]<6.10^{-4}\%^2$.

The liquid metal is subjected to either a vacuum treatment or a silicon-calcium (SiCa) treatment, in which case the specified composition also contains calcium by weight such that $0.0005\% \leqq Ca \leqq 0.005\%$.

Under these conditions, the titanium nitrides do not precipitate prematurely in the form of large particles in the liquid metal, which would have the effect of reducing the hole expansion ability. The precipitation of the titanium occurs at a lower temperature in the form of uniformly distributed carbonitrides. This fine precipitation contributes to the hardening and refining of the microstructure.

The steel is then cast to obtain a cast semi-finished product. The casting is preferably done by continuous casting. The casting can very advantageously be done between counter-rotating rolls to obtain a cast semi-finished product in the form of thin slabs or thin strips. In effect, these casting methods cause a reduction in the size of the precipitates which is favourable to the hole expansion in the product obtained in the finished state.

The semi-finished product obtained is then heated to a temperature between 1160 and 1300° C. Below 1160° C, the specified mechanical tensile strength of 780 MPa is not achieved. Naturally, in the case of the direct casting of thin slabs, the stage of hot rolling the semi-finished products beginning at a temperature higher than 1160° C can be done immediately after casting, e.g., without cooling of the semi-finished product to ambient temperature, and therefore without the need to perform a reheating step. Then the cast semi-finished product is hot rolled at an end-of-rolling temperature between 880 and 930° C, the reduction rate of the penultimate pass being less than 0.25, the rate of the final pass being less than 0.15, the sum of the two reduction rates being less than 0.37, and the temperature of the start of rolling of the penultimate pass being less than 960° C, to obtain a hot rolled product.

During the final two passes, the rolling is therefore performed at a temperature below the non-recrystallisation temperature which prevents the recrystallisation of the austenite. The objective is therefore not to bring about an excessive deformation of the austenite during these final two passes.

These conditions make it possible to create the most equiaxial grain possible to satisfy the requirements relative to the hole expansion ratio Ac %.

After rolling, the hot rolled product is cooled at a rate between 50 and 150° C/s to obtain a hot rolled steel sheet. This mode of cooling is called "direct", e.g., it is performed in a single step without intermediate cooling stages.

Finally, the sheet obtained at a temperature between 470 and 625° C is coiled. This temperature is important because a coiling temperature greater than 625° C will result in a hole expansion ratio Ac % less than 50%.

In the case of the fabrication of uncoated sheet, the coiling temperature will be between 470 and 625° C so that the precipitation is as dense and as hardening as possible.

In the case of the fabrication of sheet intended to be subjected to a galvanisation operation, the coiling temperature will be between 515 and 560° C, to compensate for the additional precipitation that occurs during the reheating treatment associated with the galvanisation operation.

In this latter case, the coiled sheet will then be pickled and reheated to a temperature between 600 and 750° C. This sheet will then be cooled at a rate between 5 and 20° C/s, then coated with zinc in a suitable zinc bath.

In Table 3 below, the slab reheating temperature is varied and/or the coiling temperature for three sheets with different chemical compositions, one containing 0.215% of Si (composition A), the second 0.490% Si (composition B) and the third 0.21% Si (composition C).

All the steel sheets claimed by the invention were rolled with a reduction rate of 0.15 in the penultimate rolling pass and a reduction rate of 0.07 in the final rolling pass, the cumulative deformation of these two passes being 0.22. At the conclusion of the hot rolling, therefore, the austenite obtained is little deformed.

In the case of the steel with compositions A and B, when the coiling temperature is too high (650° C, tests A1 and B3), the hole expansion ratio Ac is significantly below 50%.

In the case of the steel with composition B, when the slab reheating temperature is only 1150° C (test B2), the specified mechanical strength of 780 MPa is not achieved.

In addition, when the composition does not contain chromium (Table 3), the coiling temperature is between 470° C. and strictly 620° C. The temperature of 620° C is excluded in accordance with test B4 in Table 3. Preference is given to a coiling temperature between 525° C and strictly 620° C.

If the composition includes chromium, the coiling temperature is preferably between 470° C and 580° C as illustrated in Tables 2A, 2B and 2C.

Other tests have also been performed on the steel containing 0.245% of Si and a small quantity of Cr at 0.0299%, the composition of which is presented in Table 4 below. The table presents the yield stress Re, the strength Rm and the elongation at break A. These tests were conducted on a slab reheated to 1240° C, hot rolled to an end-of-rolling temperature of 900° C, directly cooled at a rate of 70° C/s then coiled at a temperature between 440 and 540° C and cooled to ambient temperature. The sheet was then reheated to a temperature between 580 and 720° C before being hot-dip galvanised in a Zn bath.

For the test C1, the too low coiling temperature did not allow sufficient precipitation and hardening and the strength did not achieve 780 MPa. The same results were achieved in test C2, where the reheating temperature before galvanisation was increased without achieving the desired strength.

For test C3, the hardening was excessive and the yield stress exceeded the specified level of 840 MPa.

TABLE 3

		Test No.	Slab reheat temperature (°C)	End-of-rolling temperature (°C)	Coiling temperature (°C)	Yield stress Re (Mpa)	Maximum tensile strength Rm (Mpa)	Total elongation at break (%)	Hole expansion Ac (ISO method) (%)
Effect of reheat T	Composition B	B1	1250	900	500	768	784	16.4	93
	Composition B	B2	1150	900	500	673	703	18.1	112
Effect of coiling T	Composition A	A1	1240	900	650	824	833	15.3	34
	Composition A	A2	1240	900	560	836.5	847	14.5	50
	Composition C	C1	1250	900	500	742	774	14.8	94
	Composition B	B3	1240	900	650	821.5	833.5	15.1	47
	Composition B	B4	1240	900	620	677	887.5	14.4	46
	Composition B	B5	1250	900	500	768	784	16.4	93

	C	Mn	Si	Al	Nb	Ti	N	S	P
Composition A	0.049	1.64	0.215	0.032	0.041	0.112	0.004	0.003	0.018
Composition B	0.049	1.63	0.49	0.032	0.04	0.11	0.004	0.002	0.018
Composition C	0.051	1.66	0.21	0.006	0.04	0.116	0.002	0.002	0.015

TABLE 4

Test No.	Coiling temperature (°C)	Reheat temperature before galvanisation (°C)	Yield stress Re (Mpa)	Mechanical strength Rm (MPa)	A (%)
C1	**440**	**580**	695	**765**	12.4
C2	**440**	630	708	**774**	**8.5**
C3	**500**	720	**842**	888	12.4
C4	540	660	771	824	14

C	Si	Mn	P	S	Cr	Ni	Al	Cu	Nb	Ti	N
0.0528	0.245	1.791	0.0114	0.0015	0.0290	0.0248	0.0359	0.0295	0.0286	0.0995	0.007

MELEGEN HENGERELT ACÉLLEMEZ ÉS AHHOZ TARTOZÓ GYÁRTÁSI ELJÁRÁS

Szabadalmi igénypontok

1. Melegen hengerelt acéllemez, amely 690 MPa-t meghaladó és legfeljebb 840 MPa nagyságú folyáshatárral, 780 MPa és 950 MPa közötti szilárdsággal, 10%-nál nagyobb szakadási nyúlással és legalább 50%-os lyuktágítási aránnyal (Ac) rendelkezik, továbbá vegyi összetétele tömeg%-ban kifejezve az alábbi összetevőket tartalmazza:

0,040% ≤ C ≤ 0,065%,

1,4% ≤ Mn ≤ 1,9%,

0,1% ≤ Si ≤ 0,55%,

0,095% ≤ Ti ≤ 0,145%,

0,025% ≤ Nb ≤ 0,045%,

0,005% ≤ Al ≤ 0,1%,

0,002% ≤ N ≤ 0,007%,

S ≤ 0,004%,

P < 0,020%,

valamint adott esetben

Cr ≤ 0,7%,

Cu ≤ 0,1%,

Ni ≤ 0,25%,

B ≤ 0,003%,

Ca ≤ 0,005%,

Mg ≤ 0,005%,

ahol az összetétel fennmaradó részét vas és gyártásból fakadó elkerülhetetlen szennyeződések alkotják, továbbá a mikroszerkezetet szemcsés bénit, ferrit és 1,5%-nál kisebb felülethányadban cementit, valamint titán- és nióbium-karbonitridek képezik, ahol a 6 mikrométernél nagyobb átlagos méretű titán-nitrid sűrűsége legfeljebb $3/mm^2$, továbbá

a hengerlés irányával párhuzamosan mért D_L szemcseméret és a hengerlés irányára merőlegesen mért D_N szemcseméret hányadosa legfeljebb 1,4.

2. Az 1. igénypont szerinti acéllemez, **azzal jellemezve**, hogy a hengerlés irányával párhuzamosan mért D_L szemcseméret és a hengerlés irányára merőlegesen mért D_N szemcseméret hányadosa legfeljebb 1,3.

3. Az 1. vagy a 2. igénypont szerinti acéllemez, **azzal jellemezve**, hogy a vegyi összetétel tömeg%-ban kifejezve az alábbi összetevőket tartalmazza:

0,045% ≤ C ≤ 0,065%,

1,6% ≤ Mn ≤ 1,9%,

0,1% ≤ Si ≤ 0,55%,

0,095% ≤ Ti ≤ 0,125%,

0,025% ≤ Nb ≤ 0,045%,

0,01% ≤ Al ≤ 0,1%,

0,002% ≤ N ≤ 0,007%,

S ≤ 0,004%,

P < 0,020%,

valamint adott esetben

Cu ≤ 0,1%,

Ni ≤ 0,25%,

B ≤ 0,003%,

Ca ≤ 0,005%,

Mg ≤ 0,005%,

ahol az összetétel krómtól mentes.

4. Az előző igénypontok bármelyike szerinti acéllemez, **azzal jellemezve**, hogy az acél összetétele tömeg%-ban kifejezve az alábbi összetevőt tartalmazza:

0,1% ≤ Si ≤ 0,3%.

5. Az 1. igénypont szerinti acéllemez, **azzal jellemezve**, hogy a vegyi összetétel tömeg%-ban kifejezve az alábbi összetevőket tartalmazza:

0,040% ≤ C ≤ 0,065%,

1,4% ≤ Mn ≤ 1,9%,

0,1% ≤ Si ≤ 0,4%,

0,095% ≤ Ti ≤ 0,145%,

0,025% ≤ Nb ≤ 0,045%,

0,01% ≤ Al ≤ 0,1%,

0,002% ≤ N ≤ 0,007%,

0,2% ≤ Cr ≤ 0,7 %,

S ≤ 0,004%,

P < 0,020%,

valamint adott esetben

Cu ≤ 0,1%,

Ni ≤ 0,25%,

B ≤ 0,003%,

Ca ≤ 0,005%,

Mg ≤ 0,005%.

6. Az 1., a 2. és az 5. igénypontok bármelyike szerinti acéllemez, **azzal jellemezve**, hogy az acél összetétele tömeg%-ban kifejezve az alábbi összetevőt tartalmazza:

0,4% ≤ Cr ≤ 0,6%.

7. Az előző igénypontok bármelyike szerinti acéllemez, **azzal jellemezve**, hogy a szemcsés bénit felülethányada 80% és 95% között van, továbbá a ferrit felülethányada 20%-nál kisebb.

8. Az előző igénypontok bármelyike szerinti acéllemez, **azzal jellemezve**, hogy az acél összetétele tömeg%-ban az alábbi összetevőt tartalmazza:

0,0005% ≤ Ca ≤ 0,005%.

9. Az előző igénypontok bármelyike szerinti acéllemez, **azzal jellemezve**, hogy az acél összetétele tömeg%-ban az alábbi összetevőt tartalmazza:

0,0005% ≤ Mg ≤ 0,005%.

10. Eljárás melegen hengerelt acéllemez gyártására, amely 690 MPa-t meghaladó és legfeljebb 840 MPa nagyságú folyáshatárral, 780 MPa és 950 MPa közötti szilárdsággal és 10%-nál nagyobb szakadási nyúlással rendelkezik, **azzal jellemezve**, hogy az acélt folyékony fém formájában biztosítjuk, melynek összetétele tömeg%-ban kifejezve az alábbi összetevőket tartalmazza:

0,040% ≤ C ≤ 0,065%,
1,4% ≤ Mn ≤ 1,9%,
0,1% ≤ Si ≤ 0,55%,
0,095% ≤ Ti ≤ 0,145%,
0,025% ≤ Nb ≤ 0,045%,
0,005% ≤ Al ≤ 0,1%,
0,002% ≤ N ≤ 0,007%,
S ≤ 0,004%,
P < 0,020%,
valamint adott esetben
Cr ≤ 0,7%,
Cu ≤ 0,1%,
Ni ≤ 0,25%,
B ≤ 0,003%,
Mg ≤ 0,005%,

ahol a fennmaradó részt vas és elkerülhetetlen szennyeződések alkotják,
továbbá vákuumos vagy SiCa kezelést hajtunk végre, az utóbbi esetben az összetételben tömeg%-ban kifejezve 0,0005% ≤ Ca ≤ 0,005% is van,
továbbá a folyékony fémben oldott titán [Ti] és nitrogén [N] mennyisége kielégíti a
%[Ti] %[N] < 6.10^{-4} $\%^2$ összefüggést, továbbá az acélt öntött félkész termék előállításához formába öntjük,
a félkész terméket 1160°C és 1300°C közötti hőmérsékletre hevítjük, majd
az öntött félkész terméket 880°C és 930°C közötti hengerlésvégi hőmérsékleten meleghengerlésnek vetjük alá, ahol az utolsó előtti fokozatban az alakítás mértéke 0,25-nál kisebb, az utolsó fokozatban az alakítás mértéke 0,15-nál kisebb, a két alakítási mérték összege 0,37-nél kisebb, melegen hengerelt termék előállításához az utolsó előtti fokozat hengerléskezdeti hőmérséklete 960°C-nál kisebb,
ezután melegen hengerelt acéllemez előállításához a melegen hengerelt terméket 50 és 150 °C/s közötti sebességgel hűtjük,
továbbá a lemezt 470°C és 625°C közötti hőmérsékleten feltekercseljük.

11. A 10. igénypont szerinti eljárás, **azzal jellemezve**, hogy az acél összetétele tömeg%-ban kifejezve az alábbi összetevőket tartalmazza:

0,045% ≤ C ≤ 0,065%,
1,6% ≤ Mn ≤ 1,9%,

0,1% ≤ Si ≤ 0,3%,
0,095% ≤ Ti ≤ 0,125%,
0,025% ≤ Nb ≤ 0,045%,
0,01% ≤ Al ≤ 0,1%,
0,002% ≤ N ≤ 0,007%,
S ≤ 0,004%,
P < 0,020%,
valamint adott esetben
Cu ≤ 0,1%,
Ni ≤ 0,25%,
B ≤ 0,003%,
Mg ≤ 0,005%,

ahol az összetétel krómtól mentes.

12. A 11. igénypont szerinti eljárás, **azzal jellemezve**, hogy a lemezt 515°C és pontosan 620°C közötti hőmérsékleten tekercseljük fel.

13. A 10-12. igénypontok bármelyike szerinti eljárás melegen hengerelt acéllemez gyártására, **azzal jellemezve**, hogy a lemezt 515°C és 560°C közötti hőmérsékleten tekercseljük fel,
továbbá a lemezt revétlenítjük,
továbbá a revétlenített lemezt 600°C és 750°C közötti hőmérsékletre hevítjük, majd ezután a felhevített revétlenített lemezt 5 és 20 °C/s közötti sebességgel hűtjük,
továbbá az így nyert lemezt alkalmas cinkfürdőben cinkkel vonjuk be.

14. A 10. igénypont szerinti eljárás, **azzal jellemezve**, hogy az acél összetétele tömeg%-ban kifejezve az alábbi összetevőket tartalmazza:

0,040% ≤ C ≤ 0,065%,
1,4% ≤ Mn ≤ 1,9%,
0,1% ≤ Si ≤ 0,4%,
0,095% ≤ Ti ≤ 0,145%,
0,025% ≤ Nb ≤ 0,045%,
0,005% ≤ Al ≤ 0,1%,
0,002% ≤ N ≤ 0,007%,
0,2 % ≤ Cr ≤ 0,7 %,
S ≤ 0,004%,
P < 0,020%,
valamint adott esetben
Cu ≤ 0,1%,
Ni ≤ 0,25%,
B ≤ 0,003%,
Ca ≤ 0,005 %,
Mg ≤ 0,005%,

továbbá a lemezt 470°C és 580°C közötti hőmérsékleten tekercseljük fel.

15. A 10. igénypont szerinti eljárás, **azzal jellemezve**, hogy az acél összetétele tömeg%-ban kifejezve az alábbi összetevőt tartalmazza:

$0,4\% \leq Cr \leq 0,6\%$.

16. A 14. vagy a 15. igénypont szerinti eljárás, **azzal jellemezve**, hogy amennyiben a Mn, Si és Cr összetevők mennyiségének összege 2,35%-nál kisebb, a lemezt 520°C és 580°C közötti hőmérsékleten tekercseljük fel.

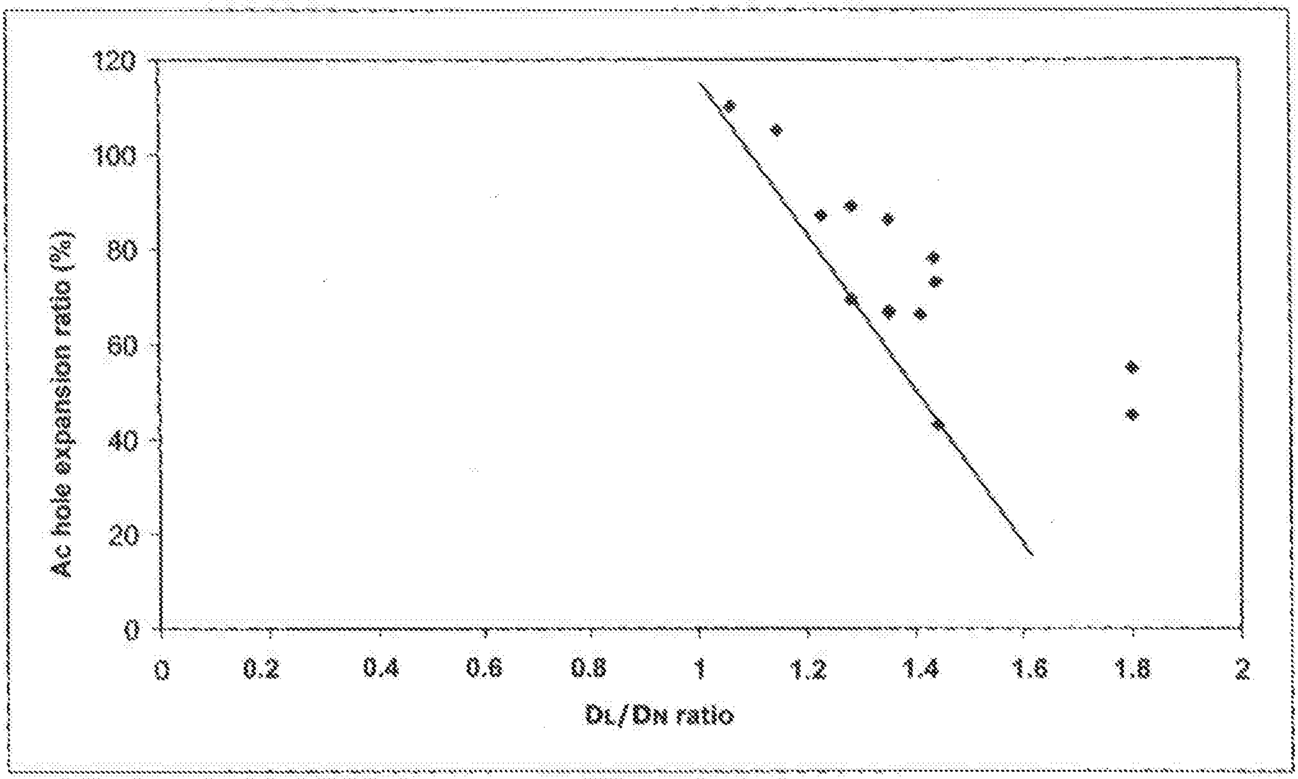

Figure 1

SZTNH-100085930