

(19)



Europäisches
Patentamt
European
Patent Office
Office européen
des brevets



(11)

EP 2 423 344 A2

(12)

EUROPEAN PATENT APPLICATION

published in accordance with Art. 153(4) EPC

(43) Date of publication:

29.02.2012 Bulletin 2012/09

(51) Int Cl.:

C22C 38/00 ^(2006.01)**C21D 8/06** ^(2006.01)**B21B 1/16** ^(2006.01)(21) Application number: **10767329.5**

(86) International application number:

PCT/KR2010/002568(22) Date of filing: **23.04.2010**

(87) International publication number:

WO 2010/123315 (28.10.2010 Gazette 2010/43)

(84) Designated Contracting States:

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

(30) Priority: **23.04.2009 KR 20090035699**(71) Applicant: **Posco****Pohang****Kyungsangbook-do 790-300 (KR)**

(72) Inventors:

- **KIM, Dong-Hyun**

Pohang**Kyungsangbook-do 790-360 (KR)**

- **LEE, You-Hwan**

Pohang**Kyungsangbook-do 790-360 (KR)**

- **LEE, Sang-Yoon**

Pohang**Kyungsangbook-do 790-360 (KR)**

- **CHO, Hyung-Keun**

Pohang**Kyungsangbook-do 790-360 (KR)**(74) Representative: **Zech, Stefan Markus****Meissner, Bolte & Partner GbR****Postfach 86 06 24****81633 München (DE)**

(54) **HIGH STRENGTH, HIGH TOUGHNESS STEEL WIRE ROD, AND METHOD FOR MANUFACTURING SAME**

(57) Provided are a high-strength, high-toughness steel wire rod and a method of manufacturing the same. The steel wire rod of the present invention has a composition including 0.07 wt% to 0.14 wt% of aluminum (Al) and nitrogen (N) wherein Al:N (where Al and N denote

wt% of each element) is in a range of 15:1 to 25:1. Since a steel wire rod having sufficient strength and toughness improvement effects can be obtained with a simple alloy component, a steel wire rod capable of allowing processing such as cold forging to be performed without an additional heat treatment may be provided.

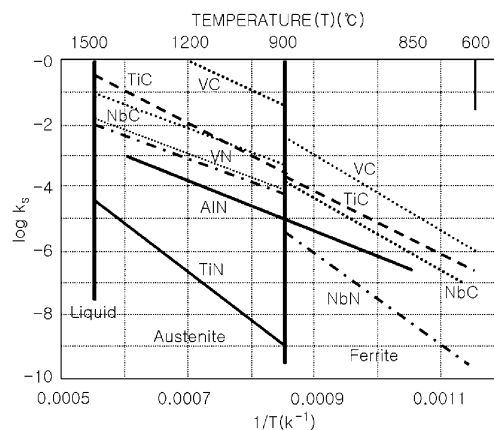


FIG. 1

EP 2 423 344 A2

Description

[Technical Field]

[0001] The present invention relates to a high-strength, high-toughness steel wire rod and a method of manufacturing the same, and more particularly, to a high-strength, high-toughness steel wire rod as a steel wire rod used for applications such as cold forging, which can be manufactured by a simple method in comparison to a typical non-tempered steel wire rod, as well as using less alloying elements and having high dimensional accuracy in comparison to a tempered steel wire rod generated by a typical heat treatment process.

[Background Art]

[0002] A steel used in a wire rod requiring high strength and toughness, especially a steel wire rod for cold forging, such as an S45C rod having a cold strength of 700 MPa or more, is a steel requiring ductility and toughness necessary for processing as well as requiring high strength in terms of the strength of a final component. That is, since a wire rod needs to be processed into the shape of a final product, the wire rod needs to have sufficient ductility and toughness in order not to be broken during processing. After being processed into components, the wire rod needs to contribute to the lightening of an apparatus in which the components are used, e.g., an automobile, by having sufficient strength.

[0003] However, in general, material strength and toughness are characteristics that are difficult to be made compatible with each other, and a phenomenon in which toughness decreases while the strength improves is generally seen. Therefore, as an example of a typical method, when a wire rod for cold forging is manufactured, spheroidizing annealing is first performed in order to secure the toughness and ductility of the wire rod, and then processing for obtaining a desired component shape is performed. Thereafter, quenching and annealing treatments are performed in order to obtain the strength in the component. A steel (a wire rod) manufactured by the process is referred to as a "tempered steel", and as a manufacturing method thereof, a process was suggested in which rolling and quenching are performed on a steel wire rod and an elongated steel wire rod is obtained by processing martensites transformed by the process while being maintained within a temperature range of 500°C to 600°C.

[0004] However, there is a limitation in that manufacturing costs may increase because a large amount of alloying elements must be added to improve hardenability as well as performing additional processes such as quenching and tempering in order for a steel to have sufficient strength through quenching and annealing treatments. In addition, the dimensional accuracy of a component deteriorated due to thermal stress induced in the component through a quenching process. Also, the investment cost for manufacturing facilities increased, and it was difficult to overcome limitations with respect to cooling rates and rolling load increases when the steel wire rod was manufactured through the method.

[0005] A non-tempered steel, in which a temper heat treatment is not performed, was provided in order to resolve the limitations generated in the tempered steel. The term "non-tempered steel" denotes a steel in which a desired level of strength may be obtained without performing one or more of the spheroidizing annealing or quenching and tempering heat treatments. However, since processing is generally performed in a state of satisfying the strength required for a final product, high deformation resistance is generated during the processing of a steel wire rod. Therefore, in many cases, a non-tempered steel is used for components requiring relatively small workability, such as a stud or a U-bolt.

[0006] One method of providing the non-tempered steel may be generating a microstructure having high strength and toughness in a steel by controlling the composition of alloying elements and a cooling pattern thereof. In the method, a microstructure having high strength and toughness is selected from among the internal microstructures of the steel and an alloy component and a cooling pattern that are appropriate for the microstructure are introduced. For example, an alloy component, in which a content of C, undesirable for toughness, is decreased and the mixture of elements such as Cr and Mo is performed, is introduced as an appropriate alloy component. A steel produced through the alloy component is rolled, and then microstructures are transformed into ferrites + pearlites by performing controlled cooling. When the method is successful, the strength and toughness of the microstructure may be secured up to a certain level. However, when the method is used, the effect of reductions in manufacturing costs due to the omission of a heat treatment is offset because a large amount of alloying elements are added and it is impossible to obtain sufficient strength because a ferrite fraction is low and the microstructure is coarse. There is also a limitation in that the toughness of the microstructure is insufficient to be used for severe processing due to the generation of coarse pearlites.

[0007] Also, although a great deal of research into non-tempered steels has been conducted to date, in terms of a cost reduction through the omission of a heat treatment, the non-tempered steel manufactured by the method is undesirable when forging is performed to achieve complex shaping of a component in order to reduce the number of components in addition to the recent lightening and strengthening of vehicles. Therefore, in order to resolve such limitations, a material, which does not break and may sufficiently secure the strength of a final product even in the case processing introducing greater deformation is performed, is in demand.

[0008] As a method satisfying the demand, a method recently suggested may include the grain refinement of a material.

That is, strength and toughness, as somewhat contradictory demands, may be satisfied at the same time because the strength and toughness may be improved in comparison to typical levels when the grains of a material are refined.

[0009] An example of the method may be a method of refining austenite grains by decreasing a C content and adding a trace amount of Ti. That is, in the method, the content of C that increases the deformation resistance of a material is decreased and the reduction of strength due to the decrease in the C content is compensated by the grain refinement. The method adopts a method of refining grains by promoting a so-called "pinning effect", in which austenite grains are pinned by Ti-based precipitates (e.g., nitrides or carbonitrides) through the addition of Ti. The reason for this is that the strength and toughness of a material may improve when the grains thereof are refined and thus, the material may be easily processed without having a breakage, even with the same deformation resistance and strain applied thereto.

[0010] Elements showing behavior similar to Ti may be Nb, V, and the like. These elements also form precipitates such as carbides or carbonitrides and may perform a role in refining the grains of a material.

[0011] However, these elements have limitations in that insufficient effects are obtained therefrom in comparison to the purpose of the addition as described below. That is, these elements have very high melting temperatures of 1350°C or more as shown in FIG. 1, such that these elements do not completely melt during the reheating of a slab, or a temperature of precipitate formation is, in most cases, limited to 900°C or less, as well as the driving force for precipitation is being relatively weak. In general, rolling is performed in a temperature range of 850°C to 1050°C, and precipitation in a narrow temperature range is not effective because continuous precipitation of the precipitates in the rolling temperature range is desirable for grain refinement.

[Disclosure]

[Technical Problem]

[0012] An aspect of the present invention provides a steel wire rod having a simple component system effective for grain refinement due to the formation of precipitates in a wide temperature range and a method of manufacturing the steel wire rod.

[Technical Solution]

[0013] According to an aspect of the present invention, there is provided a steel wire rod having a composition including: aluminum (Al) in a range of about 0.07 wt% to about 0.14 wt%; and nitrogen (N), wherein Al:N (where Al and N denote a wt% of each element) is in a range of about 15:1 to about 25:1.

[0014] At this time, a sum of Ti, Nb, and V contents may be about 0.01 wt% or less.

[0015] Also, the steel wire rod of the present invention may further include about 0.15 wt% to about 0.3 wt% of carbon (C), about 0.05 wt% to about 0.15 wt% of silicon (Si), about 1.0 wt% to about 3.0 wt% of manganese (Mn), about 0.02 wt% or less of phosphorous (P), or about 0.02 wt% or less of sulfur (S).

[0016] Fine AlN-based nanoprecipitates having a size of about 130 nm or less may be formed in the steel wire rod.

[0017] Also, the steel wire rod may have a microstructure including ferrites having an area fraction of between about 50% and about 70% and pearlites having an area fraction of between about 30% and about 50%.

[0018] Further, the steel wire rod may have a tensile strength range of about 600 MPa to about 700 MPa and an elongation range of about 20% to about 30%.

[0019] According to another aspect of the present invention, there is provided a method of manufacturing a steel wire rod including: finishing rolling a steel having the composition in a temperature range of about 850°C to about 1050°C; and cooling the steel at a cooling rate of about 5 °C/s or less.

[0020] At this time, a composition of the steel may further include about 0.15 wt% to about 0.3 wt% of C, about 0.05 wt% to about 0.15 wt% of Si, about 1.0 wt% to about 3.0 wt% of Mn, about 0.02 wt% or less of P, or about 0.02 wt% or less of S.

[Advantageous Effects]

[0021] According to the present invention, a steel wire rod capable of allowing processing such as cold forging to be performed thereupon without an additional heat treatment may be provided because a steel wire rod having sufficient strength and toughness improvement effects can be obtained with a simple alloy component.

[Description of Drawings]

[0022] The above and other aspects, features and other advantages of the present invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

[0023] FIG. 1 is a graph showing the formation temperature and equilibrium constant of precipitates that may be generated in a steel;

[0024] FIG. 2 is optical micrographs showing the internal microstructure of each type of steels manufactured according to the Example of the present invention;

[0025] FIG. 3 is a graph comparing impact toughness for each sample manufactured according to the Example of the present invention;

[0026] FIG. 4 is a graph comparing a grain size of austenite for each sample manufactured according to the Example of the present invention;

[0027] FIG. 5 is transmission electron micrographs of the wire rod manufactured according to the Inventive Example of the present invention;

[0028] FIG. 6 is four transmission electron micrographs for confirming the precipitate distribution in the wire rod manufactured according to Inventive Example of the present invention;

[0029] FIG. 7 is optical micrographs showing internal microstructures when the wire rod manufactured according to Inventive Example of the present invention is drawn and manufactured into components; and

[0030] FIG. 8 is a graph showing the results of grain size and room-temperature impact toughness variations according to the changes of Al/N.

[Best Mode]

[0031] Hereinafter, the present invention is described in detail.

[0032] The inventors of the present invention understood the limitations of the related art and conducted in-depth research in order to overcome the technical limitations of the related art. As a result, when aluminum (Al) is added in a larger quantity than a typical input range, Al forms precipitates in a majority of rolling temperatures. Therefore, pinning sites are continuously provided during rolling as well as providing nucleation sites for a new microstructure.

[0033] Austenite grains are refined when the process is performed, and thus, a final microstructure such as ferrites or pearlites transformed from the microstructure has a grain size smaller than a typical microstructure. Therefore, the process is effective in improving the strength and toughness of a steel.

[0034] In the present invention, a content of Al is limited to 0.07 wt% to 0.14 wt% in order to obtain the favorable effect. The Al content is larger than the Al content typically added for deoxidation and is a desirable range for forming Al-based precipitates (in particular, nitrides) in a steel. Therefore, in order to form sufficient nitrides, Al may be added to 0.07 wt% or more, to 0.075 wt% or more, and for example, to 0.08 wt% or more. However, when the Al content is too high, a ratio of oxide-based precipitates increases and the size of the precipitates becomes large, such that it is not only difficult for Al to contribute to grain refinement, but rather Al deteriorates fatigue characteristics of a steel wire rod. Therefore, an upper limit of the Al content is determined as 0.14 wt%.

[0035] At this time, since the added Al forms fine precipitates having a nanosize by mainly reacting with nitrogen, a quantitative ratio between the contents of Al and nitrogen may exist in order to thermodynamically form nitrides easily. If the nitrogen content is insufficient, the nitrides are not formed even though a large amount of Al is added and there may be a concern that a generated amount of oxides may become relatively too large. On the other hand, when the nitrogen content is too high, there may be concerns that corner cracks may be formed or a nozzle clogging phenomenon may be generated during casting. In consideration of the, a ratio of Al:N (where Al and N denote wt% of each element) may be in a range of 15:1 to 25:1. The content of nitrogen may be in any possible range in the steel as long as it satisfies the condition. However, the content of nitrogen, for example, may be 0.0035 to 0.008 wt%.

[0036] Further, micro-alloying elements such as Nb, V, and Ti, which are generally added for grain refinement, are not substantially added in the present invention. However, since these elements are mixed in the steel through various routes and inevitably exist without being completely removed during steelmaking processes, the sum of the contents thereof may be 0.01 wt% or less, and for example, may be 0.005 wt% or less. The reason for this is that physical properties of the steel may deteriorate when these elements are added.

[0037] That is, according to the research results of the inventors of the present invention, TiN precipitates by first reacting nitrogen in a molten steel with Ti when Ti is added together, under a condition in which Al exists in the content range. Therefore, the effect of grain refinement intended in the present invention is difficult to obtain because the generation of AlN precipitates is prevented. Also, corner cracks are promoted during casting when Nb is added together with Al, and precipitates may be coarse when a large amount of Al is added as in the present invention. Further, it is difficult to obtain the effect of grain refinement because of coarse V(C,N) first precipitates formed when V is added.

[0038] Contents of other elements are not particularly limited except for the contents of Al, Nb, V, or Ti. That is, since a major characteristic of the present invention is to refine grains by forming fine precipitates through the addition of a large amount of Al, the addition or exclusion of other components that do not affect grain refinement may be easily performed by a person skilled in the art. Therefore, the types and ranges thereof do not have to be particularly limited.

[0039] However, since one of the major applications of the high-strength, high-toughness steel intended to be provided

in the present invention is for cold forging, a steel component system for obtaining more desirable effects by combining the component conditions is suggested as a steel for cold forging below.

[0040] C: 0.15 to 0.3 wt%

[0041] C is an element essentially added to secure the strength of steel. C may be included at 0.15 wt% or more in order to obtain sufficient strength and C may be limited to 0.3 wt% or less in order to secure sufficient toughness. In particular, a content of C may be limited to a range of 0.15 wt% to 0.3 wt%, in consideration of the component characteristics of the steel suggested in the present invention that has a relatively high Mn content in comparison to a typical steel wire rod for cold forging which will be described later.

[0042] Si: 0.05 wt% to 0.15 wt%

[0043] Si has an effect of strengthening the strength of a matrix by dissolving in ferrites. A content of Si may be 0.05 wt% in order to obtain a solid solution strengthening effect by means of Si. However, when the Si content is too high, workability and toughness may deteriorate because work hardening is rather excessive during a cold forging process. Therefore, Si may be controlled to 0.15 wt% or less.

[0044] Mn: 1.0 wt% to 3.0 wt%

[0045] Mn is an alloying element that increases the strength of steel, affects impact properties, improves rolling properties, and reduces brittleness. In particular, according to an exemplary embodiment of the present invention, a composition of the steel wire rod is designed to compensate the reduction of strength with Mn instead of reducing C for securing toughness. Therefore, Mn may be added to 1.0 wt% or more. However, Mn may be limited to 3.0 wt% or less because a work hardening phenomenon is severe when the Mn content is too high.

[0046] P: 0.02 wt% or less

[0047] P may be controlled to 0.02 wt% or less because P segregates at grain boundaries and becomes a cause of toughness degradation. P may be controlled to 0.01 wt% or less if the control of P is possible during refining.

[0048] S: 0.02 wt% or less

[0049] S may be controlled as much as possible because S as a low-melting point element combines with Mn to decrease toughness and adversely affects the characteristics of a high-strength wire rod. However, an upper limit thereof is limited to 0.02 wt% in consideration of the load during a refining process.

[0050] That is, a composition of the wire rod of the present invention, for example, may include a component system in which each element is controlled in ranges of 0.15 to 0.3 wt% of C, 0.05 to 0.15 wt% of Si, 1.0 to 3.0 wt% of Mn, 0.02 wt% or less of P, 0.02 wt% or less of S, in addition to the composition in which Al and N contents are controlled in the ranges and Nb, V, and Ti are substantially not added. That is, a high-strength, high-toughness wire rod may be obtained by means of the simple component system.

[0051] Different from a component system as typically suggested in which a large amount of alloying elements are added, the component system of the present invention is a very simple component system, in which an appropriate condition of the effective formation of Al precipitates is suggested such that only a few elements are additionally added without the addition of expensive alloying elements. Therefore, alloy costs will be lower as well as an effect in which a difficult task such as controlling of the components during steel making processes is not necessary being obtained.

[0052] Also, the steel wire rod having the composition of the present invention may include fine grains without being subjected to a typical complex controlled rolling process for providing non-tempered steel by forming a large amount of fine Al-based precipitates therein.

[0053] That is, fine AlN-based nanoprecipitates having a size of 130 nm or less are formed in the steel wire rod having the composition during rolling and cooling processes. Since the formation temperature of such precipitates is over a range of about 850°C to 1050°C as shown in FIG. 1, the precipitates are finely dispersed and distributed in the steel wire rod during performing a typical rolling (rolling is typically performed in the temperature range), and thus, act to greatly refine internal grains. The smaller the size of the nanoprecipitates is, the more the nanoprecipitates are dispersed, and thus, are more effective for preventing grain growth. Therefore, a lower limit of the size of the Al-based precipitates does not have to be particularly limited. However, it may be confirmed that the size of the precipitates is 10 nm or more when the nitride forming condition is used. In particular, it may be confirmed that precipitates having a size range of 10 nm to 60 nm occupy about 20% to 30% among the total precipitates by area, precipitates having a size range of more than 60 nm to 80 nm occupy about 40% to 50% by area, and precipitates having a size of more than 80 nm occupy the remainder.

[0054] When the precipitates are formed under the condition, rolling is performed, and the steel wire rod is slowly cooled for subsequent cold rolling, a microstructure composed of 15 μm to 40 μm (e.g., 15 μm to 20 μm) of fine ferrites and 20 μm to 55 μm (e.g., 20 μm to 25 μm) of fine pearlites may be obtained in the steel wire rod. The area fraction of the ferrites among the microstructure may be in a range of about 50% to 70% and the area fraction of the pearlites may be in a range of about 30% to 50% for securing sufficient cold forgeability. The wire rod with the favorable microstructure of the present invention has a tensile strength range of about 600 MPa to 700 MPa and an elongation range of about 20% to 30% as well as having an impact toughness of about 140 joules or more (130 joules or more for a drawn wire rod) without being subjected to a spheroidizing heat treatment. Also, a drawn wire rod, which is obtained by drawing the

wire rod at a reduction ratio range of 15% to 40%, i.e., a reduction ratio range during typical drawing, may have a tensile strength range of 800 MPa to 950 MPa and an elongation range of 15% to 25%.

[0055] The steel wire rod of the present invention may be easily manufactured by anyone skilled in the art and thus, the manufacturing method thereof does not have to be particularly limited. Since fine Al-based precipitates may precipitate in a wide temperature range as the characteristics of the steel wire rod of the present invention, an applicable range of rolling temperature is wide. Therefore, a cooling rate may be varied and applied according to the properties of a microstructure required for the application of the steel wire rod.

[0056] In particular, when the application of the steel wire rod of the present invention is for cold forging, it is not necessary to perform controlled rolling on steel in a narrow temperature range and cooling in a cooling rate having a controlled range as in a typical case. Even in the case rolling is performed in a temperature range of 850°C to 1050°C, a typical temperature range of rolling, and cooling is performed thereafter at a cooling rate range of 0.1 °C/s to 5 °C/s which is frequently used for manufacturing a typical steel wire rod for cold forging, a steel wire rod in which sufficient fine grains are formed may be obtained.

[0057] Since precipitates are formed in a wide temperature range, i.e., 850°C to 1050°C, in the present invention, grain boundary effects due to the precipitates may be sufficiently obtained when the finishing rolling temperature is in the temperature range. Therefore, the finishing rolling temperature may be selected as the temperature range.

[0058] With respect to the steel wire rod for cold rolling, since it is favorable to have a microstructure consisting of ferrites and pearlites in order for the wire rod not to have too large deformation resistance, slow cooling may be performed at a cooling rate of 5 °C/s or less to a temperature of Ar₁ or less. Undesirable results may be obtained when a typical steel wire rod is slowly cooled because the size of grains becomes too large. On the other hand, with respect to the steel wire rod of the present invention, fine grains may be formed even though slow cooling is performed within the range because a large amount of fine precipitates is dispersed and distributed therein. However, when the cooling is performed at an excessively slow cooling rate, a separate facility may be required. Therefore, the cooling rate may be 0.1 °C/s or more.

[Mode for Invention]

[0059] Hereinafter, the present invention is described in more detail according to the attached drawings and Example which will be described later. However, it has to be noted that the following Example only exemplifies the present invention and does not limit the scope of the present invention. Therefore, the scope of the present invention is defined by the appended claims and the details reasonably inferred therefrom.

[0060] (Example)

[0061] In order to understand the effect of precipitates exist in samples, austenite grain sizes (AGS) and impact toughnesses at 950°C were compared when C, Si, Mn, P, and S were respectively controlled to 0.25 wt%, 0.15 wt%, 2.0 wt%, 0.015 wt%, and 0.0016 wt%, and the contents of Ti, Nb, V, Al, and N were changed as described in Table 1 below. In order to imitate rolling conditions, a solid solution treatment was performed on the samples by heating at 1180°C, and then 0.6 (n?) of strain was exerted thereon at a strain rate of 10/s at 950°C. Thereafter, the samples were rapidly cooled to room temperature in order to confirm the austenite grain sizes. The results obtained therefrom are presented in Table 1.

[0062]

[Table 1]

Sample	Ti	Nb	V	Al	N	AGS (μm)	V-notch (J)	U-notch (J)	Remark
Sample 1	-	-	-	-	0.004	32.6	140.34	156.45	Comparative standard target
Sample 2	-	-	-	0.04	0.004	15.8	165.89	180.63	Al/N ratio = 10
Sample 3	-	-	-	0.08	0.004	12.4	169.62	213.72	Al/N ratio = 20
Sample 4	0.015	-	-	-	0.004	17.1	160.3	175.89	Low Ti(C,N)
Sample 5	0.030	-	-	-	0.004	18.3	79.48	130.22	High Ti(C,N)
Sample 6	-	0.03	-	-	0.004	32.6	93.49	132.13	Low Nb(C,N)
Sample 7	-	0.06	-	-	0.004	23.8	156.8	160.5	High Nb(C,N)
Sample 8	0.015	0.03	-	-	0.004	28.1	139.9	166.97	Combined addition of Ti and Nb

(continued)

Sample	Ti	Nb	V	Al	N	AGS (μm)	V-notch (J)	U-notch (J)	Remark
Sample 9	-	-	0.05	-	0.004	20.6	103.65	177.15	Low V(C,N)
Sample 10	-	-	0.1	-	0.004	18.7	30.86	67.96	High V(C,N)

[0063] As shown in Table 1 and FIG. 2, it may be understood that in the case of sample 3, in which only aluminum and nitrogen were added and Nb, V, and Ti were not added as in the present invention, the austenite grain size (AGS) at 950°C was about 12.4 μm which was very small in comparison to the other samples. When the grain size at 950°C was small, microstructures such as ferrites and pearlites generated in the fine austenites also have a fine grain size.

[0064] Also, as shown in Table 1 and FIG. 3, it may be understood that the impact toughness (V-notch, U-notch) of the sample 3 having a small austenite grain size was best.

[0065] Samples having the same composition as the samples described in Table 1 were solid solution treated at 1180°C, and then 0.6 of strain was exerted thereon at a strain rate of 10/s at 800°C, 850°C, 900°C, and 950°C, respectively. Thereafter, the samples were rapidly cooled, and the austenite grain sizes thereof were compared and presented in FIG. 4. As shown in FIG. 4, it may be understood that fine grain sizes were obtained at all temperature conditions in the case of sample 3 corresponding to the condition of the present invention.

[0066] When the strain was exerted at 800°C, which does not correspond to the rolling temperature of a typical steel wire rod for cold forging, the austenite grain sizes were 30 μm or more in all cases. This indirectly suggests that rolling may be performed at a temperature of 850°C or more in order to obtain fine grains.

[0067] Transmission electron micrographs obtained from the steel manufactured with a condition of the sample 3 in Table 1 were shown in FIG. 5. As shown in FIG. 5, it may be confirmed that cubic AlN having a size of about 130 nm or less was finely and uniformly precipitated therein.

[0068] Also, in order to investigate the size distribution of the fine precipitates, transmission electron micrographs showing the distribution of the precipitates were obtained from four locations of the sample 3 including the result of FIG. 5, and then the size distribution of each precipitate was obtained. The results thereof are presented in FIG. 6. It was confirmed from the results that an area fraction of precipitates having a size range of 10 nm to 60 nm was 29.2%, an area fraction of precipitates having a size range of more than 60 nm to 80 nm was 48.6%, and an area fraction of precipitates having a size range of more than 80 nm to 130 nm was 22.2%. The scales in FIG. 6 represent 0.2 μm .

[0069] Further, optical micrographs of the samples, in which the steel manufactured with the condition of the sample 3 was drawn and then subjected to cold processing, were shown in FIG. 7. As shown in FIG. 7, it may be confirmed in the samples that a content of fine ferrites having a size range of 15 μm to 20 μm was in a range of about 65% to 70% and a content of pearlites having a size range of 20 μm to 25 μm was in a range of about 30% to 35%. According to the measurement results of the impact values of the samples, it may be confirmed that the samples had high V-notch and U-notch impact value ranges of 55 joules to 60 joules and 150 joules to 190 joules, respectively. Therefore, it may be confirmed that a non-tempered steel wire rod having sufficient workability may be manufactured when the composition of the steel wire rod is controlled and rolling is performed according to the conditions of the present invention.

[0070] In order to confirm whether sufficient strength and toughness may be obtained when the steel having the condition was manufactured by an actual wire rod rolling process, a billet having the composition of sample 3 which satisfied the desirable composition conditions of the present invention was manufactured as a wire rod. In order to manufacture the wire rod, the billet was heated at 1150°C, rough rolling and finishing rolling were respectively finished at 910°C and 1050°C, and sizing rolling was performed at 1035°C. The rolled wire rod was cooled at a rate of 0.5 °C/s, and then wound at 835°C. The wire rod was cooled to 500°C at a cooling rate of 0.5 °C/s, and then a wire rod having a diameter of 18 mm was manufactured by air cooling (Inventive Example 1). Characteristics are evaluated on a drawn wire rod obtained by performing drawing with a reduction ratio of 28.2% with respect to the wire rod (Inventive Example 2).

[0071] Also, characteristics are also evaluated on a wire rod (Comparative Example 1) and a drawn wire rod (Comparative Example 2) respectively obtained by using the same methods as Inventive Examples 1 and 2 and adding 0.015 wt% of Ti instead of Al and a wire rod (Comparative Example 3) and a drawn wire rod (Comparative Example 4) respectively obtained by using the same methods as Inventive Examples 1 and 2 and adding 0.01 wt% of V instead of Al, wherein the contents of C, Si, Mn, P, S, and N are the same as Inventive Example 1. The results thereof are presented in Table 2.

[0072]

[Table 2]

Category	YS (MPa)	TS (MPa)	El (%)	R.A. (%)	U-notch (J)	V-notch (J)
Inventive Example 1	378	658	24.0	61.4	150.7	135

(continued)

Category	YS (MPa)	TS (MPa)	El (%)	R.A. (%)	U-notch (J)	V-notch (J)
Inventive Example 2	757	835	18.4	60.3	143	98
Comparative Example 1	320	580	19.2	55.7	120.3	100.1
Comparative Example 2	702	789	15.5	53.1	97.7	83.1
Comparative Example 3	333	592	18.9	57.2	121.7	103.1
Comparative Example 4	711	797	16.2	56.6	95.1	80.7

[0073] As shown in Table 2, with respect to Inventive Examples of the present invention, 658 MPa or more of tensile strength was obtained in the wire rod and about 835 MPa or more of improved tensile strength was obtained after drawing. However, with respect to Comparative Examples, tensile strengths of the wire rods were 580 MPa (Comparative Example 1) and 592 MPa (Comparative Example 3) which were 60 MPa or more lower than that of Inventive Example 1, and tensile strengths were only about 789 MPa (Comparative Example 2) and 797 MPa (Comparative Example 4) even after drawing which were about 40 MPa lower than that of Inventive Example 2.

[0074] Also, an elongation value representing the workability of a non-tempered steel wire rod with respect to Inventive Example 1, i.e., the Inventive Example of a wire rod, had a high value approaching 24%, but elongation values of Comparative Examples 1 and 3, in which grain refinements are promoted by adding Ti, V or the like, were respectively 19.2% and 18.9%, about 5% lower than that of Inventive Example 1. Such differences were continuously maintained even after drawing, and Inventive Example 2 had an elongation value of 2% or more higher than those of Comparative Examples 2 and 4. Therefore, it may be understood that both strength and workability are improved when a large amount of Al is added as well as increasing a ratio of Al:N to about 20:1.

[0075] It may also be understood that reduction of area (R.A.) values with respect to Inventive Examples of the present invention were about 3% to 6% higher than those of the Comparative Examples.

[0076] Further, it may be confirmed that U-notch and V-notch impact toughness values of Inventive Examples, which are indicators of toughness, are 25 joules or more higher than those of the Comparative Examples. Thus, it may be confirmed that the steel wire rod manufactured according to the present invention also had a high level of toughness.

[0077] Therefore, it may be confirmed that the steel wire rod manufactured according to the conditions of the present invention may be used in applications requiring high strength and high toughness such as a wire rod for cold forging.

[0078] In order to review the effect of an Al/N ratio on grain size and room temperature impact values, the grain size and impact value (V-notch test) were investigated by varying the Al/N ratio by changing only a content of N while other conditions remained the same as those of the sample 3, and the results thereof are presented in FIG. 8. In FIG. 8, units of grain size and the toughness value were μm and joules, respectively. As shown in FIG. 8, the room temperature impact value (i.e., impact absorption energy) was a low value of 110 joules or less when the Al/N ratio was 5, but the impact value rapidly increased when the Al/N ratio was 10 or more. Also, the impact value rapidly decreased at an Al/N ratio of more than 25 and the impact value when the Al/N ratio was 30 became similar to the impact value when the Al/N ratio was 5. Therefore, it may be understood that the Al/N ratio may be in a range of 10 to 25 when the impact value is considered. However, it was confirmed that when the Al/N ratio was 10, the grain size was 35 μm or more and the effect of grain refinement was somewhat poor as well as having the high occurrence of corner cracks during casting. Therefore, it may be confirmed that the Al/N ratio may be in a range of 15 to 25.

[0079] While the present invention has been shown and described in connection with the exemplary embodiments, it will be apparent to those skilled in the art that modifications and variations can be made without departing from the spirit and scope of the invention as defined by the appended claims.

Claims

1. A high-strength, high-toughness steel wire rod comprising:

aluminum (Al) in a range of about 0.07 wt% to about 0.14 wt%; and
nitrogen (N),

wherein Al:N (where Al and N denote a wt% of each element) is in a range of about 15:1 to about 25:1.

2. The high-strength, high-toughness steel wire rod of claim 1, wherein a sum of Ti, Nb, and V contents is about 0.01 wt% or less.

EP 2 423 344 A2

3. The high-strength, high-toughness steel wire rod of claim 1 or 2, further comprising about 0.15 wt% to about 0.3 wt% of carbon (C), about 0.05 wt% to about 0.15 wt% of silicon (Si), about 1.0 wt% to about 3.0 wt% of manganese (Mn), about 0.02 wt% or less of phosphorous (P), or about 0.02 wt% or less of sulfur (S).

4. The high-strength, high-toughness steel wire rod of claim 1 or 2, wherein fine AlN-based nanoprecipitates having a size of about 130 nm or less are formed in the steel wire rod.

5. The high-strength, high-toughness steel wire rod of claim 1 or 2, wherein the steel wire rod has a microstructure comprising ferrites having an area fraction of between about 50% and about 70% and pearlites having an area fraction of between about 30% and about 50%.

6. The high-strength, high-toughness steel wire rod of claim 1 or 2, wherein the steel wire rod has a tensile strength range of about 600 MPa to about 700 MPa and an elongation range of about 20% to about 30%.

7. A method of manufacturing a high-strength, high-toughness steel wire rod comprising:

finishing rolling a steel having a composition of claim 1 or 2 in a temperature range of about 850°C to about 1050°C; and
cooling the steel at a cooling rate of about 5 °C/s or less.

8. The method of claim 7, wherein the steel further comprises about 0.15 wt% to about 0.3 wt% of C, about 0.05 wt% to about 0.15 wt% of Si, about 1.0 wt% to about 3.0 wt% of Mn, about 0.02 wt% or less of P, or about 0.02 wt% or less of S.

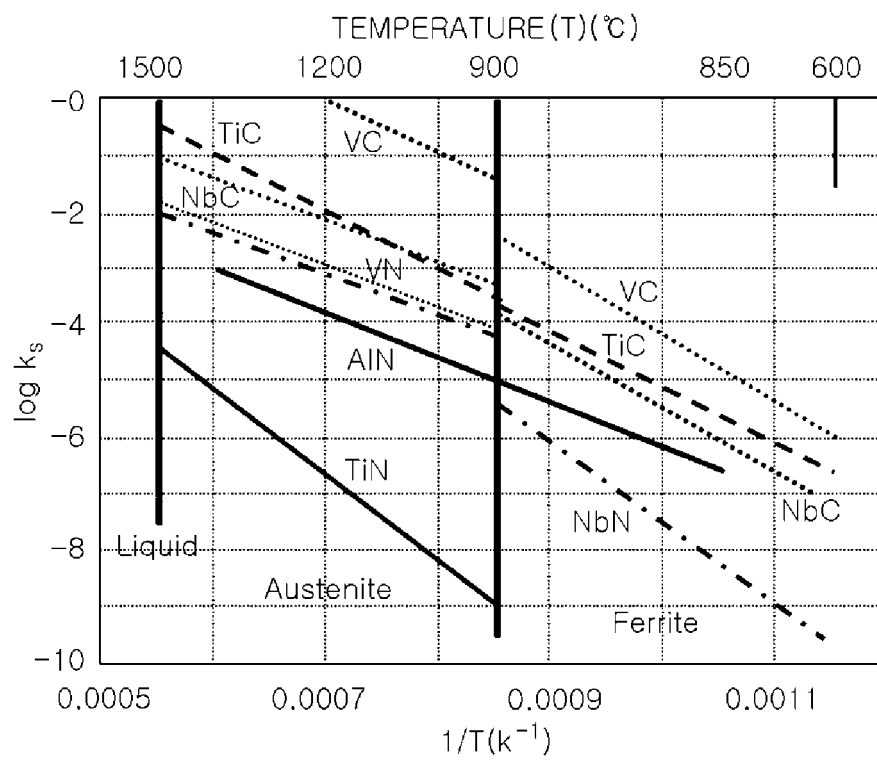


FIG. 1

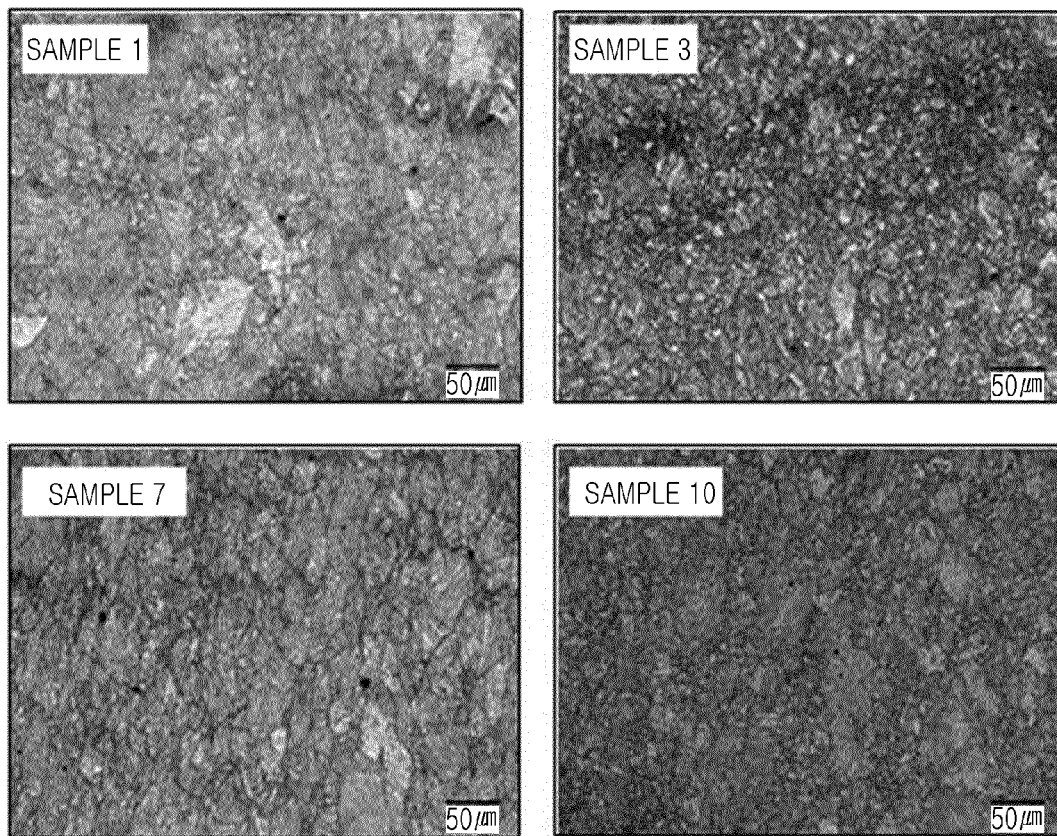


FIG. 2

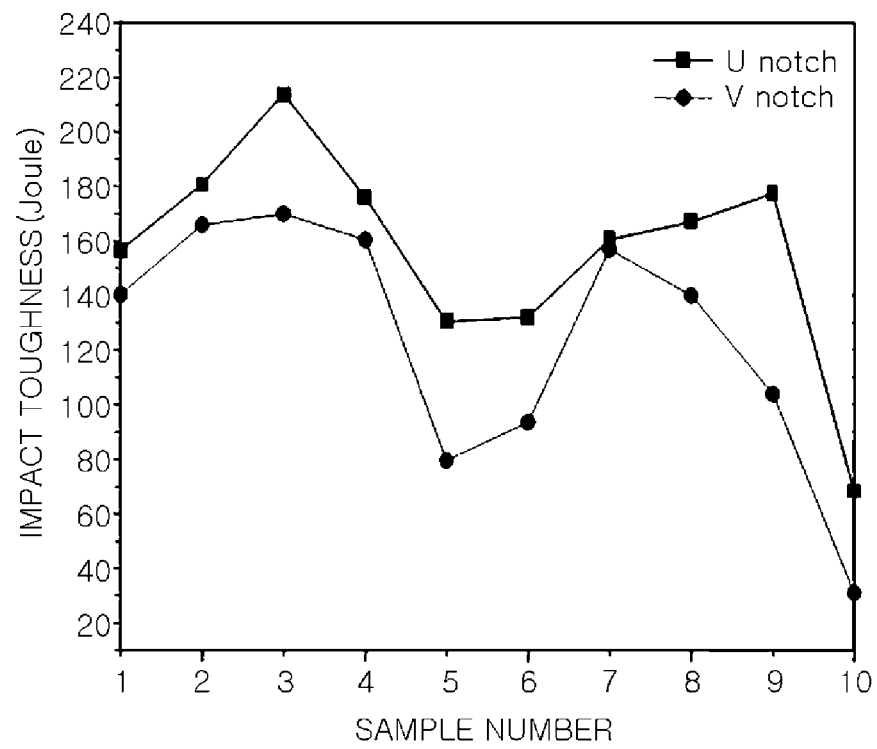


FIG. 3

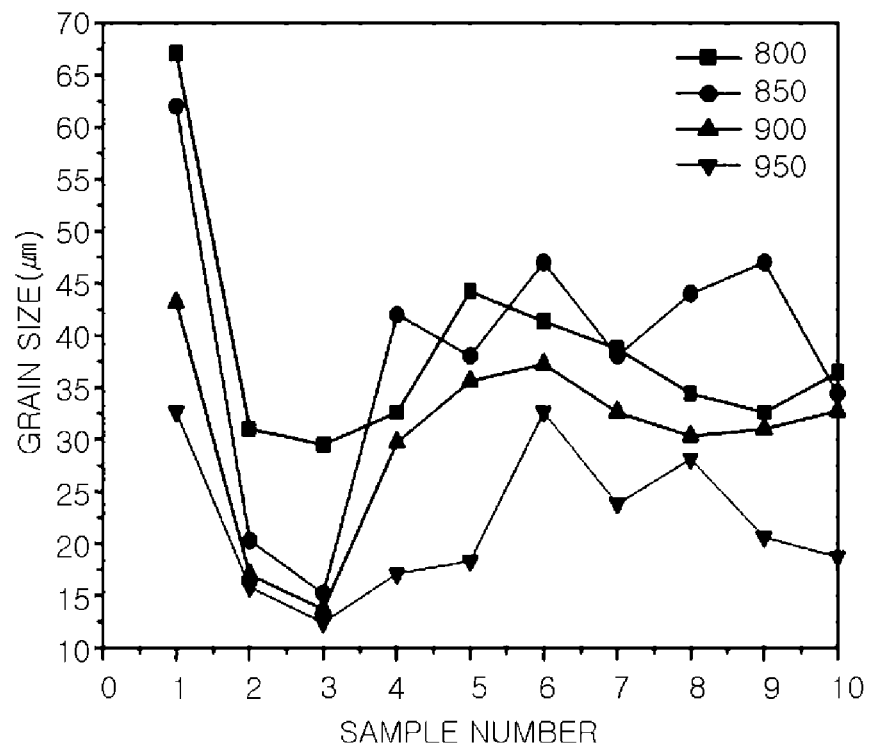


FIG. 4

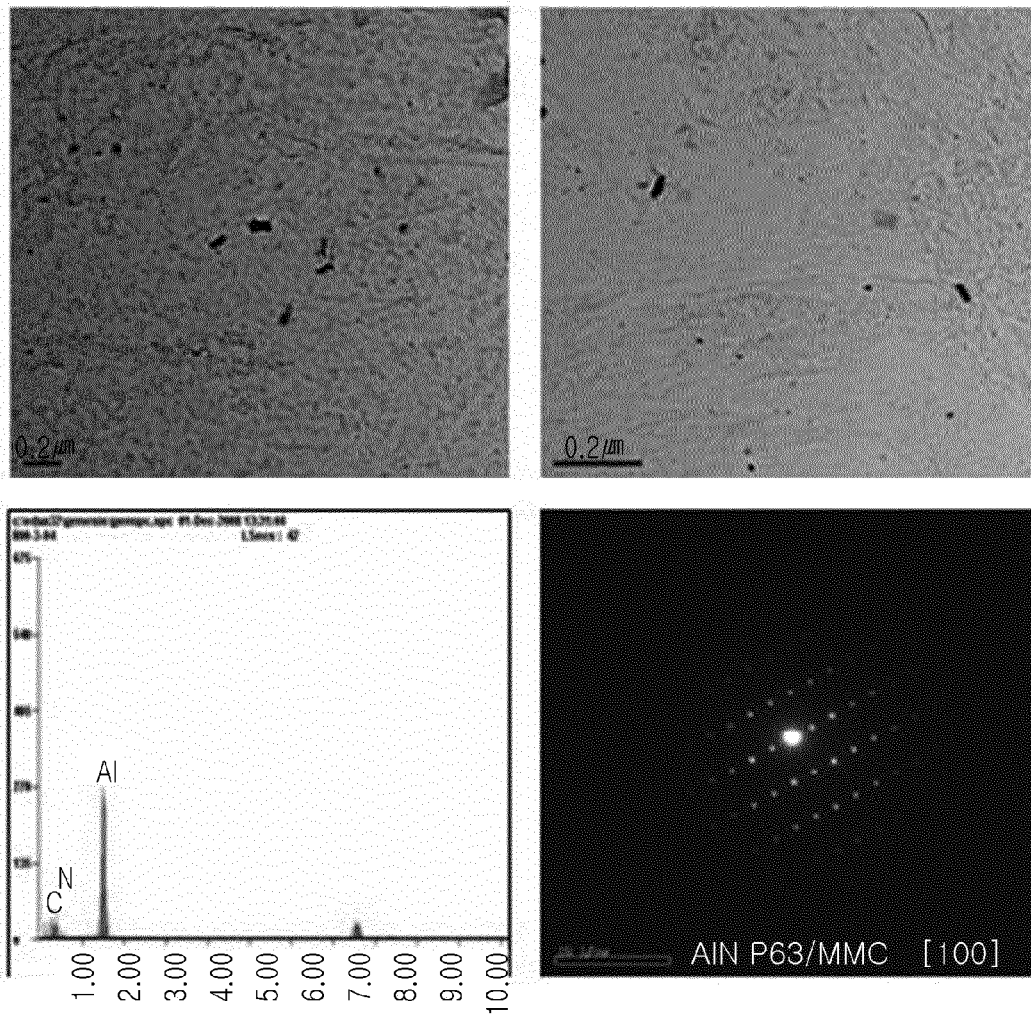


FIG. 5

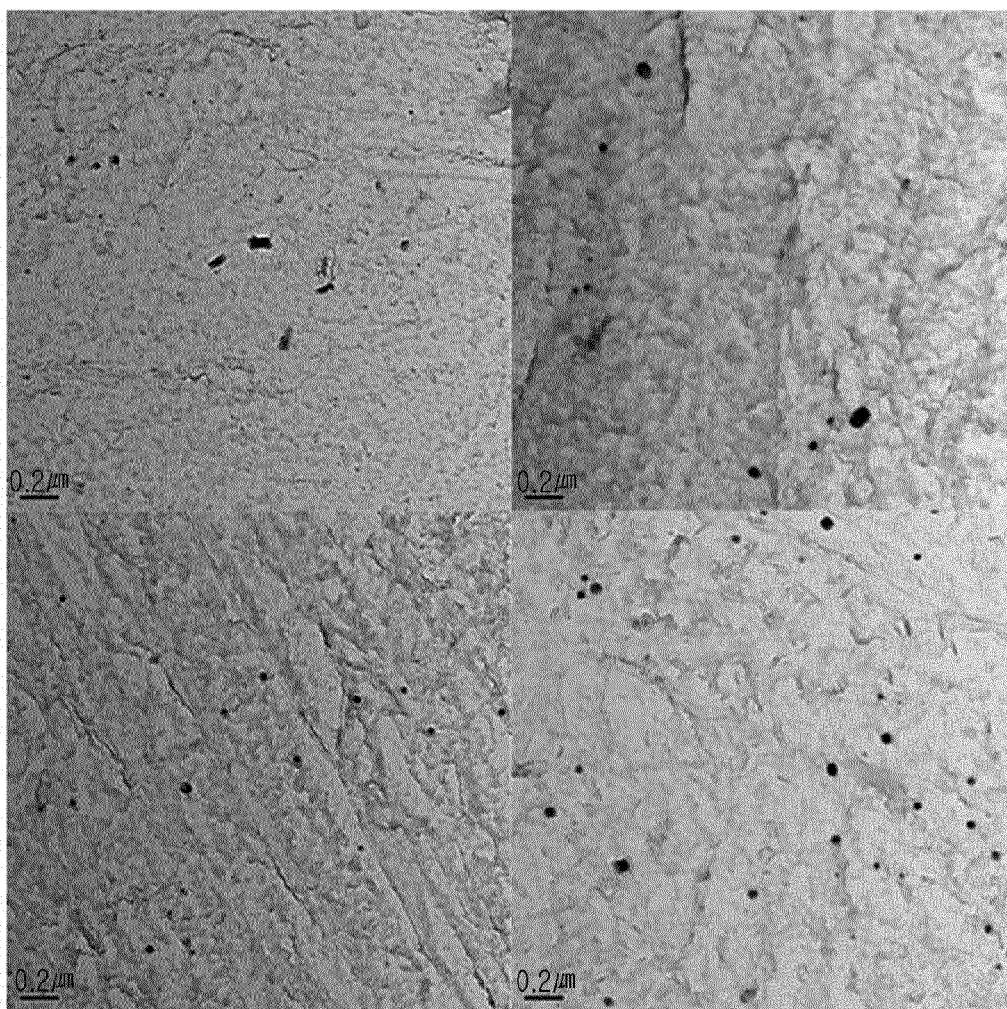


FIG. 6

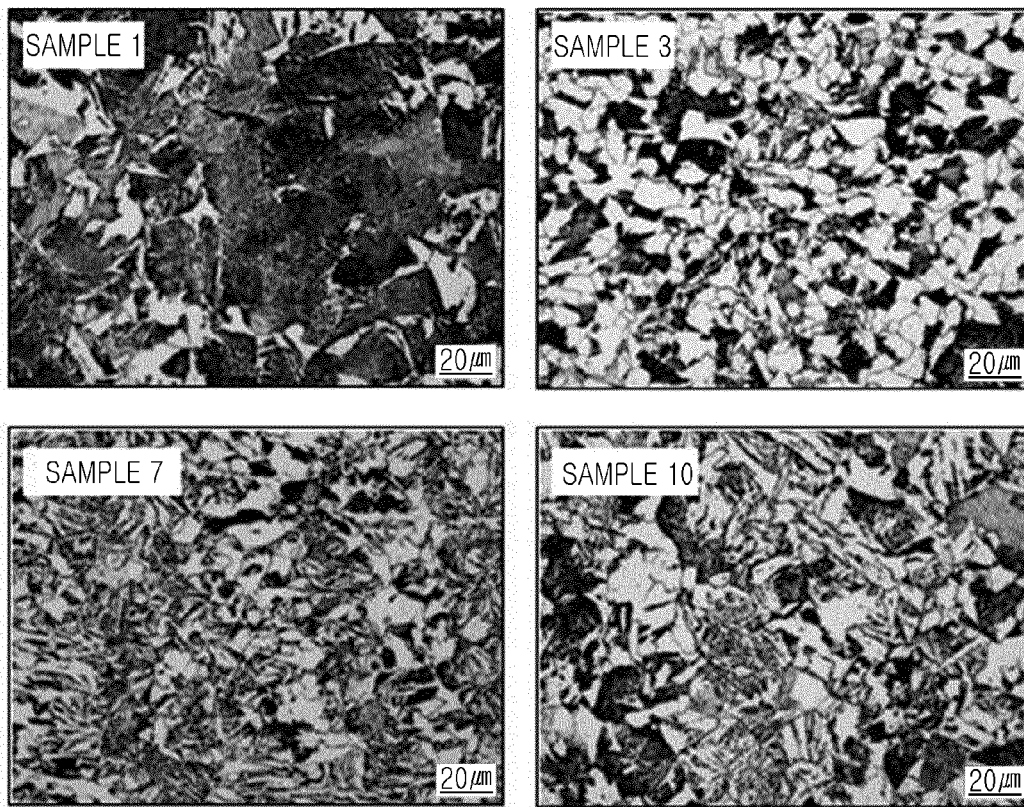


FIG. 7

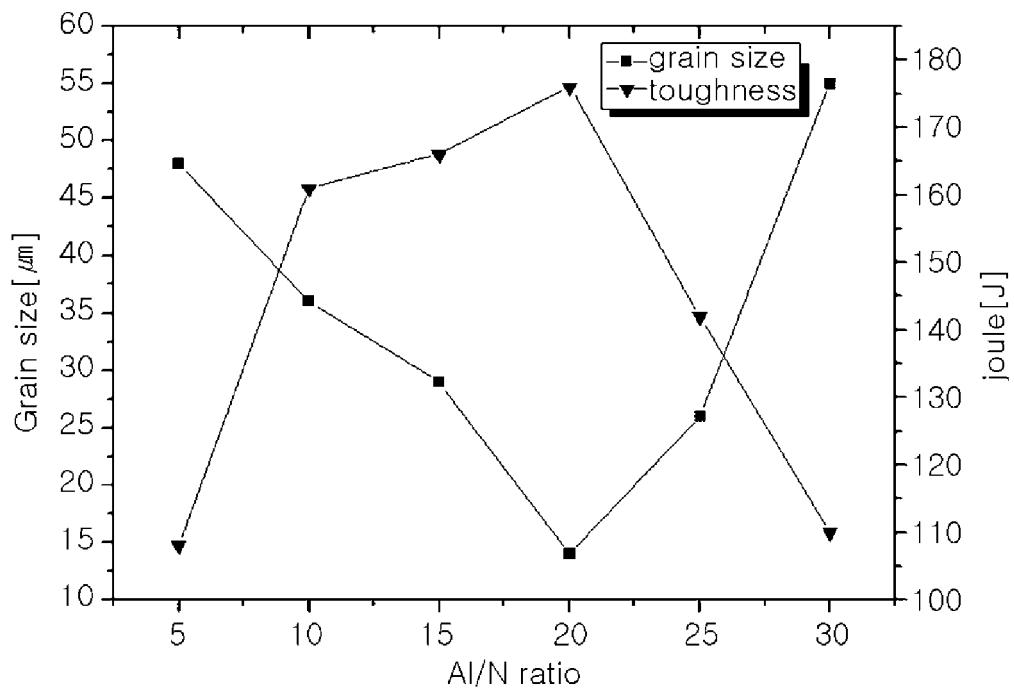


FIG. 8