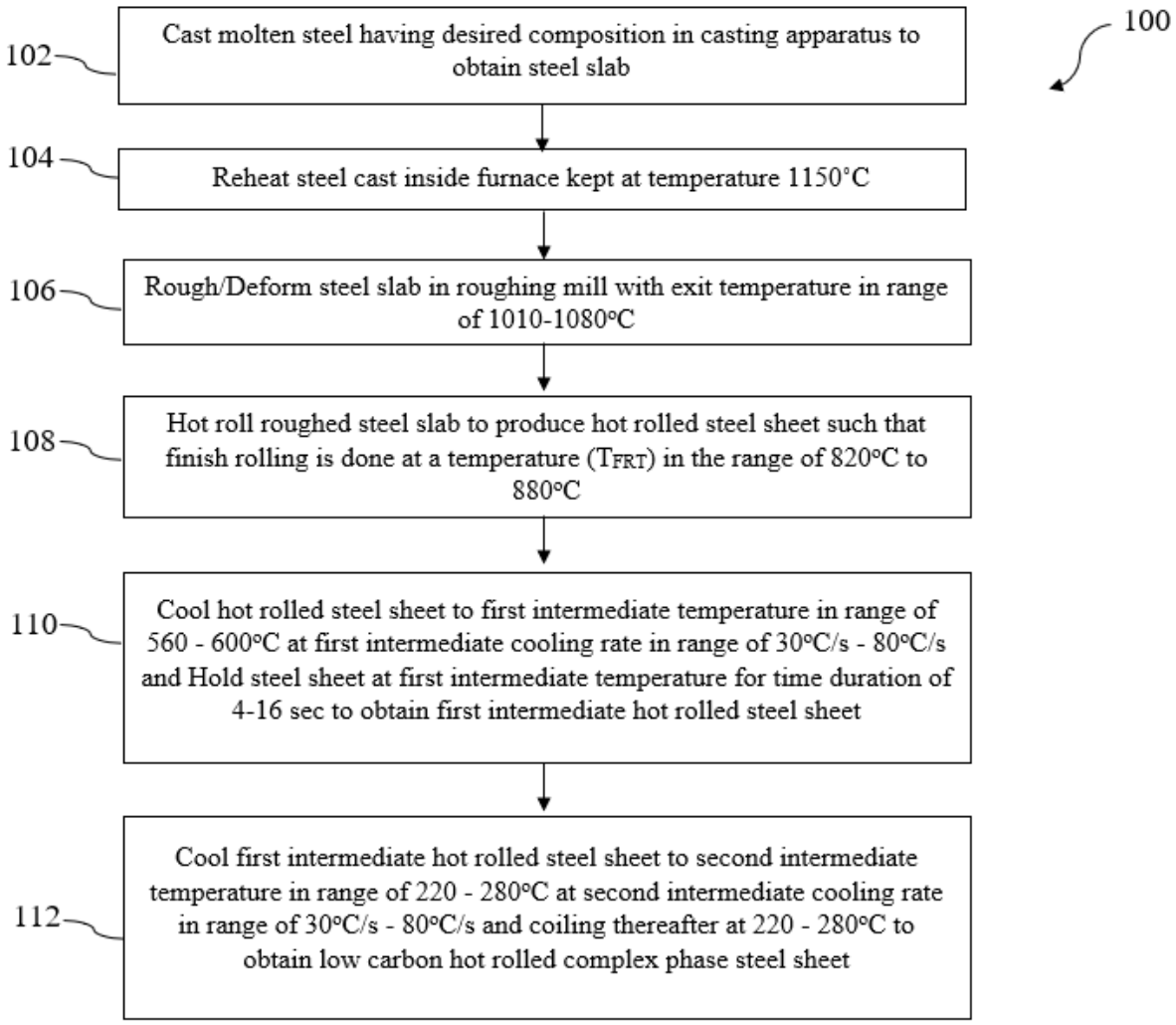


Figure 1

Gopinath Arenur Shankararaj
IN/PA 1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT

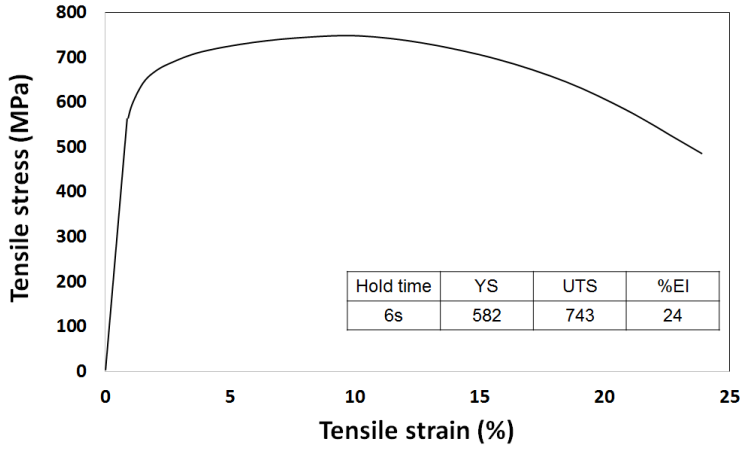


Figure 2a

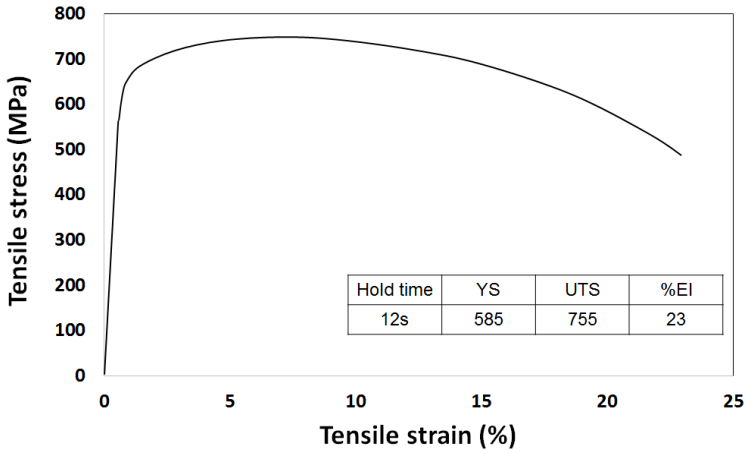


Figure 2b

Gopinath Arenur Shankararaj
IN/PA 1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT

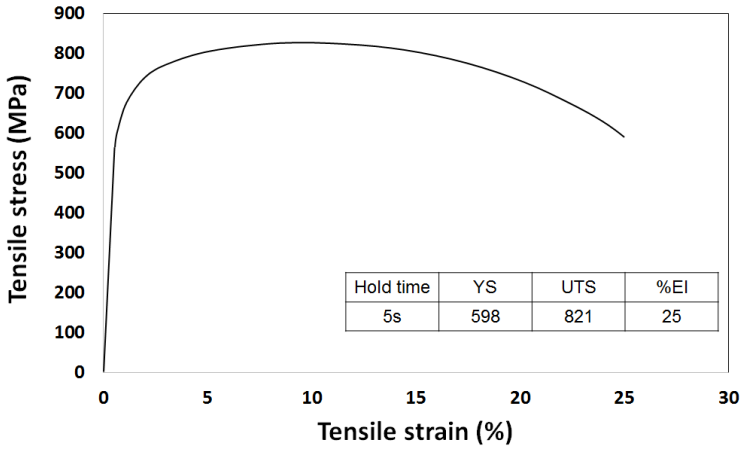


Figure 2c

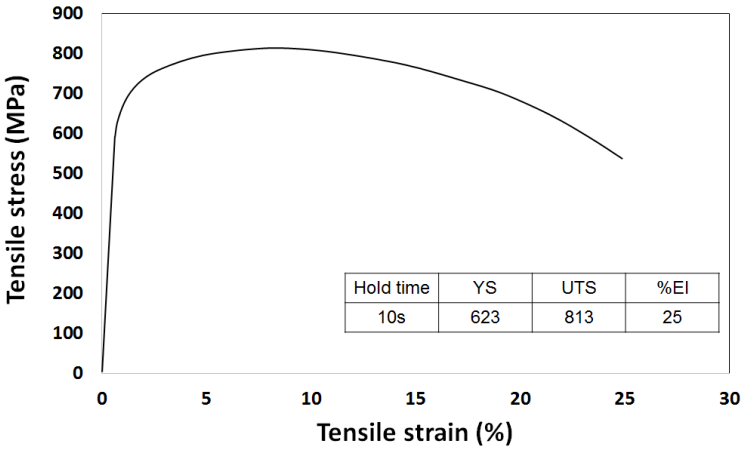


Figure 2d

Gopinath Arenur Shankararaj
IN/PA 1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT

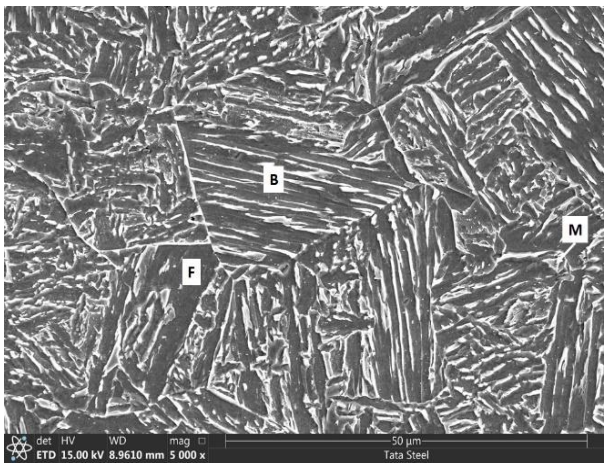


Figure 3a

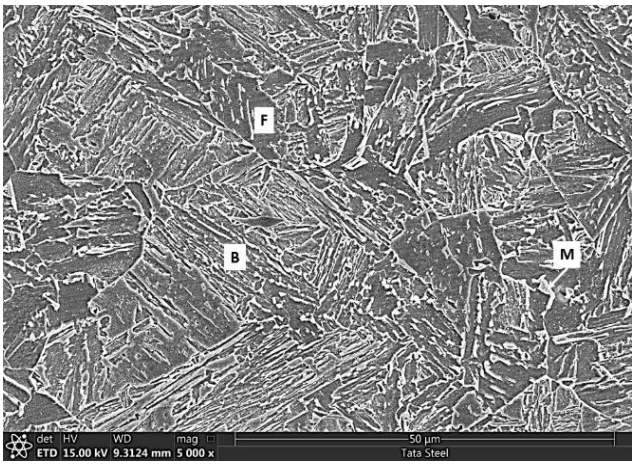


Figure 3b

Gopinath Arenur Shankararaj
IN/PA 1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT

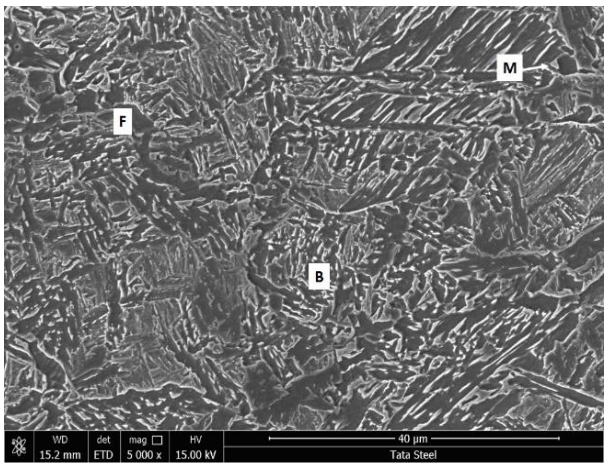


Figure 3c

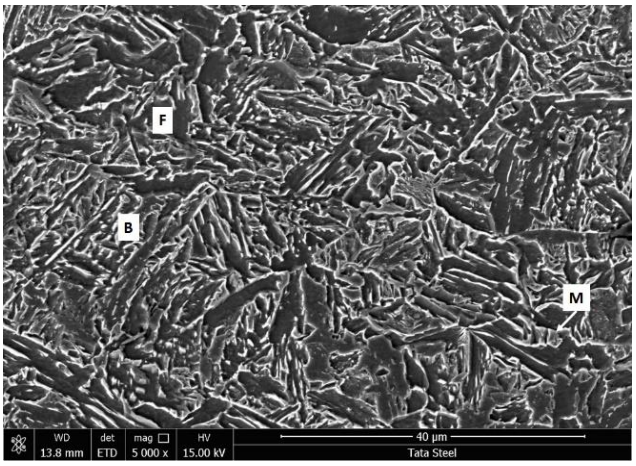


Figure 3d

Gopinath Arenur Shankararaj
IN/PA 1852
OF K&S PARTNERS
AGENT FOR THE APPLICANT

FORM 2

THE PATENT ACT, 1970

(39 of 1970)

&

THE PATENT RULES, 2003

COMPLETE SPECIFICATION

(See Section 10, Rule 13)

METHOD OF MANUFACTURING LOW CARBON HOT ROLLED COMPLEX PHASE STEEL

APPLICANT:

TATA STEEL LIMITED, an Indian company at: JAMSHEDPUR, JHARKHAND, INDIA - 831001

Nationality - INDIA

The following specification particularly describes the nature of the invention and the manner in which it is to be performed.

FIELD OF INVENTION

[0001] The present invention relates to a low carbon hot rolled complex phase steel sheet or strip having thickness ranging from 2.0 mm to 6.0 mm, and more particularly to the method of manufacturing the low carbon hot rolled complex phase steel sheet or strip with excellent tensile ductility at room temperature.

BACKGROUND

[0002] Low carbon hot rolled steel strips are extensively used for the manufacturing of structural components of automobiles. Hot rolled low carbon steel strips with microstructures containing two or more phases, commonly known as advanced high strength steels, are widely used in making various structural components of vehicles. One very common example is dual phase (DP) steel having a microstructure comprising ferrite and martensite. While the presence of martensite accounts for the adequate strength, the ferrite, being the soft phase, ensures appreciable ductility. Some important features of dual phase steel grades are:

- Strengthening through phase transformation
- Appreciable strength without heavy alloying
- Smooth stress-strain plot, without yield point elongation phenomenon, ensuring good formability etc.

[0003] On the other hand, the microstructures of complex phase (CP) steels, in general, comprise at least 3 phases. Bainite being the major phase in this case, the other phases are ferrite and martensite. Apart from that, the higher strength variants of CP steel family may also contain retained austenite and precipitates such as carbides and carbonitrides. However, these steels utilize costly alloy additions such as Cr, Ni, Mo to provide the necessary strength and ductility increasing the overall cost of manufacture, which is undesirable.

[0004] The present disclosure is directed to overcome one or more limitations stated above or any other limitation associated with the prior arts.

OBJECTIVE OF INVENTION

[0005] It is an object of the invention to solve the problems of the prior art and to provide new steel developed with leaner chemistry by excluding or reducing Ni, Mo, Co like expensive alloying elements to achieve the required properties by exploiting the existing hot rolling facilities in the integrated steel plants to get desired microstructure.

[0006] Another objective of the present invention is to develop a low carbon hot rolled complex phase steel that can be made into steel strips, sheets, and blanks, having tensile strength in the range of 700 – 850 MPa and having microstructure consisting of bainite, ferrite and martensite.

[0007] Another objective of present invention is to provide a new easier manufacturing method combining thermomechanical, hot rolling and heat treatment processes for the proposed chemical composition.

[0008] It is yet another objective of the present invention, to provide the low carbon hot rolled complex phase steel comprising the following composition expressed in weight %: C < 0.11, Mn: 1.0-2.0, S < 0.006, P < 0.02, Si: 0.20-0.80, Al: 0.02-0.06, Nb: 0.00-0.06, Cr: 0.10-0.90, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities.

SUMMARY OF INVENTION

[0009] This summary is provided to introduce concepts related to a low carbon hot rolled complex phase steel, and a method of manufacturing the low carbon hot rolled complex phase steel sheet or strip. The concepts are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

[0010] In one aspect of the present invention, a method for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm is provided. The method (100) comprises casting molten steel having a composition expressed in weight %: C < 0.11, Mn – 1.0-2.0, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-0.06, Nb – 0.00-0.06, Cr – 0.10-0.90, N (ppm) <

80, and the balance being Iron (Fe) and unavoidable impurities to obtain a steel slab. The method also comprises reheating the steel slab to a temperature greater than 1150^{o}C. The method further comprises roughing the steel slab in roughing mill with exit temperature in the range of 1010-1080^{o}C. The method comprises hot rolling the roughed steel slab to produce a steel sheet such that finish rolling is done at a temperature (T_{FRT}). T_{FRT} varies in the range 820^{o}C to 880^{o}C. The method also comprises cooling the hot rolled steel to a first intermediate temperature in the range of 560 - 600^{o}C at a first intermediate cooling rate in the range of 30^{o}C/s - 80^{o}C/s to obtain first intermediate hot rolled steel. The first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 4-16 sec. The method further comprises cooling the first intermediate hot rolled steel to a second intermediate temperature in the range of 220 - 280^{o}C at a second intermediate cooling rate in the range of 30^{o}C/s - 80^{o}C/s and coiling thereafter to obtain low carbon hot rolled complex phase steel sheet. The low carbon hot rolled complex phase steel sheet comprises a microstructure of 5-20% ferrite, 5-20% martensite and about 60-90% bainite. The low carbon hot rolled complex phase steel exhibits an ultimate tensile strength in the range of 700 - 850 MPa.

[0011] In an embodiment, the low carbon hot rolled complex phase steel comprises the composition expressed in weight %: C – 0.078, Mn –1.45, Si –0.42, Al – 0.05, Nb – 0.02, Cr – 0.51, and the balance being Iron (Fe) and unavoidable impurities. The carbon equivalent (Ceq) expressed by formula CE = (C) + (Mn+Si)/6 + (Cu+Ni)/15 + (Cr+Mo+V+Nb)/5 is 0.496, wherein each symbol in brackets represents the content (mass%) of the corresponding element.

[0012] In an embodiment, the first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 6 sec.

[0013] In an embodiment, the obtained low carbon hot rolled complex phase steel exhibits a yield strength (YS) of 582 MPa, ultimate tensile strength (UTS) of 743 MPa, %Elongation – 24 and yield ratio (YS/UTS) of 0.78.

[0014] In an embodiment, the first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 12 sec.

[0015] In an embodiment, the obtained low carbon hot rolled complex phase steel exhibits a yield strength (YS) of 585 MPa, ultimate tensile strength (UTS) of 755 MPa, %Elongation – 23 and yield ratio (YS/UTS) of 0.77.

[0016] In an embodiment, the low carbon hot rolled complex phase steel comprises the composition expressed in weight %: C – 0.094, Mn –1.58, Si –0.32, Al – 0.06, Nb – 0.035, Cr – 0.58, and the balance being Iron (Fe) and unavoidable impurities, wherein the carbon equivalent (Ceq) expressed by formula CE = (C) + (Mn+Si)/6 + (Cu+Ni)/15 + (Cr+Mo+V+Nb)/5 is 0.534, wherein each symbol in brackets represents the content (mass%) of the corresponding element.

[0017] In an embodiment, the first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 5 sec.

[0018] In an embodiment, the obtained low carbon hot rolled complex phase steel exhibits a yield strength (YS) of 598 MPa, ultimate tensile strength (UTS) of 821 MPa, %Elongation – 25 and yield ratio (YS/UTS) of 0.728.

[0019] In an embodiment, the first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 10 sec.

[0020] In an embodiment, the obtained low carbon hot rolled complex phase steel exhibits a yield strength (YS) of 623 MPa, ultimate tensile strength (UTS) of 813 MPa, %Elongation – 25 and yield ratio (YS/UTS) of 0.77.

[0021] In another aspect of the present invention, a low carbon hot rolled complex phase steel comprising the following composition expressed in weight %: Carbon (C): < 0.11%, Manganese (Mn): 1.0% - 2.0%, Chromium (Cr): 0.1-0.9%, Silicon (Si): 0.2%-0.8%, Sulphur (S): <0.006%, Phosphorus (P): < 0.02%, Niobium (Ni): < 0.06%, Aluminium (Al): 0.02-0.06%, Nitrogen (N) < 80 ppm, and the remaining being substantially iron and incidental impurities. The low carbon hot rolled complex phase steel sheet comprises a microstructure of 5-20% ferrite, 5-20% martensite and about 60-90% bainite.

[0022] In an embodiment, the low carbon hot rolled complex phase steel as claimed in the claim 12, wherein the low carbon hot rolled complex phase steel comprises C < 0.09, Mn – 1.0-1.8, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-

0.06, Nb – 0.00-0.05, Cr – 0.10-0.80, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities.

[0023] In an embodiment, the low carbon hot rolled complex phase steel exhibits yield strength (YS) in the range of 480-550 MPa, ultimate tensile strength (UTS) in the range of 740-780 MPa and minimum %Elongation – 15.

[0024] In an embodiment, the low carbon hot rolled complex phase steel comprises the composition expressed in weight %: C < 0.11, Mn – 1.2-2.0, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-0.06, Nb – 0.00-0.06, Cr – 0.10-0.90, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities.

[0025] In an embodiment, the low carbon hot rolled complex phase steel exhibits yield strength (YS) in the range of 560-660 MPa, ultimate tensile strength (UTS) in the range of 780-850 MPa and minimum %Elongation – 13.

[0026] In an embodiment, the Mn content in the low carbon hot rolled complex phase steel promotes solid solution strengthening and stabilizes austenite.

[0027] In an embodiment, the Cr content in in the low carbon hot rolled complex phase steel improves hardenability of the steel and facilitate in the formation of bainite and martensite.

[0028] In an embodiment, the Nb content in the low carbon hot rolled complex phase steel is used for maintaining strength at room temperature and raising T_{nr} temperature.

[0029] In an embodiment, a component produced from the low carbon hot rolled complex phase steel is provided. The component is used in structural as well as automotive applications.

[0030] Other features and aspects of this disclosure will be apparent from the following description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] Figure 1 illustrates a flowchart of a method of manufacturing a low carbon hot rolled complex phase steel, according to an embodiment of the present invention;

[0032] Figure 2a illustrates a graphical representation of stress versus elongation, obtained during tensile test of low carbon hot rolled complex phase steel having composition of Steel 1(holding time 6 sec);

[0033] Figure 2b illustrates a graphical representation of stress versus elongation, obtained during tensile test of low carbon hot rolled complex phase steel having composition of Steel 1(holding time 12 sec);

[0034] Figure 2c illustrates a graphical representation of stress versus elongation, obtained during tensile test of low carbon hot rolled complex phase steel having composition of Steel 2(holding time 5 sec);

[0035] Figure 2d illustrates a graphical representation of stress versus elongation, obtained during tensile test of low carbon hot rolled complex phase steel having composition of Steel 2(holding time 10 sec);

[0036] Figure 3a illustrates a SEM image of the low carbon hot rolled complex phase steel having composition of Steel 1(holding time 6 sec);

[0037] Figure 3b illustrates a SEM image of the low carbon hot rolled complex phase steel having composition of Steel 1(holding time 12 sec);

[0038] Figure 3c illustrates a SEM image of the low carbon hot rolled complex phase steel having composition of Steel 2(holding time 5 sec); and

[0039] Figure 3d illustrates a SEM image of the low carbon hot rolled complex phase steel having composition of Steel 2(holding time 10 sec).

[0040] The drawings referred to in this description are not to be understood as being drawn to scale except if specifically noted, and such drawings are only exemplary in nature.

DETAILED DESCRIPTION

[0041] The detailed description of various exemplary embodiments of the disclosure is described herein with reference to the accompanying drawings. It should be noted that the embodiments are described herein in such details as to clearly communicate the disclosure. However, the amount of details provided herein is not intended to limit the anticipated variations of embodiments; on the

contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present disclosure as defined by the appended claims.

[0042] It is also to be understood that various arrangements may be devised that, although not explicitly described or shown herein, embody the principles of the present disclosure. Moreover, all statements herein reciting principles, aspects, and embodiments of the present disclosure, as well as specific examples, are intended to encompass equivalents thereof.

[0043] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of example embodiments. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises", "comprising", "includes" and/or "including," when used herein, specify the presence of stated features, integers, steps, operations, elements and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components and/or groups thereof.

[0044] It should also be noted that in some alternative implementations, the functions/acts noted may occur out of the order noted in the figures. For example, two figures shown in succession may, in fact, be executed concurrently or may sometimes be executed in the reverse order, depending upon the functionality/acts involved.

[0045] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which example embodiments belong. It will be further understood that terms, e.g., those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0046] The present disclosure provides a method (100) of manufacturing low carbon hot rolled complex phase steel that may be used to produce components for

automobile applications. The low carbon hot rolled complex phase steel comprises the following composition expressed in weight %: C < 0.11, Mn – 1.0-2.0, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-0.06, Nb – 0.00-0.06, Cr – 0.10-0.90, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities. The low carbon hot rolled complex phase steel comprises a structure including a bainitic phase, ferrite phase, and martensite phase. In an embodiment, the low carbon hot rolled complex phase steel comprises a microstructure of 5-20% ferrite, 5-20% martensite and about 60-90% bainite. The low carbon hot rolled complex phase steel exhibits an ultimate tensile strength in the range of 700 - 850 MPa and a minimum %Elongation – 13.

[0047] In one embodiment, the low carbon hot rolled complex phase steel comprises C < 0.09, Mn – 1.0-1.8, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-0.06, Nb – 0.00-0.05, Cr – 0.10-0.80, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities. The low carbon hot rolled complex phase steel exhibits yield strength (YS) in the range of 480-550 MPa, ultimate tensile strength (UTS) in the range of 740-780 MPa and minimum %Elongation – 15.

[0048] In another embodiment, the low carbon hot rolled complex phase steel comprises the composition expressed in weight %: C < 0.11, Mn – 1.2-2.0, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-0.06, Nb – 0.00-0.06, Cr – 0.10-0.90, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities. The low carbon hot rolled complex phase steel exhibits yield strength (YS) in the range of 560-660 MPa, ultimate tensile strength (UTS) in the range of 780-850 MPa and minimum %Elongation – 13.

[0049] Referring to Figure 1, an exemplary thermo-mechanical method (100) of manufacturing the low carbon hot rolled complex phase steel strip, sheet or blank is illustrated. Each step shown in figure 1 represents one or more process, method or subroutine steps carried out in the method. Furthermore, the order of blocks is illustrative only and the blocks can change in accordance with the present disclosure. Additional blocks can be added, or fewer blocks can be utilized, without departing from this disclosure. The method (100) for manufacturing the low carbon hot rolled complex phase steel strip, sheet or blank begins at step (102). At step

(102), molten steel having composition expressed in weight %: C < 0.11, Mn – 1.0-2.0, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-0.06, Nb – 0.00-0.06, Cr – 0.10-0.90, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities is cast in a casting apparatus to obtain a steel slab.

[0050] At step (104), the steel slab (cast ingots) is reheated inside a furnace kept at a temperature of greater than 1150˚C. In one example, the furnace is an induction air melting furnace. In the preferred embodiment, the steel slab is reheated to a temperature in the range of 1150 - 1280 ^{o}C.

[0051] At step (106), the heated steel slab obtained in the step (104) is rolled/deformed in the roughing mill with exit temperature in the range of 1010-1080^{o}C.

[0052] At step (108), the roughed steel slab obtained in step (106) is subjected to a second hot working process such as hot rolling process such that finish rolling is done at a temperature (T_{FRT}) to obtain a hot rolled steel strip. T_{FRT} varies in the range 820^{o}C to 880^{o}C. The hot rolling process may be carried out by passing the steel through a pair of rolls and rolling may be carried out for at least five times to reduce the thickness of the steel to required size in the range of 2-6 mm. In an embodiment, the hot rolling process is performed by passing the steel through a pair of rolls and rolling is carried out for at least 5 times.

[0053] At step (110), the hot rolled steel strip obtained in step (108) is cooled to a first intermediate temperature in the range of 560 - 600^{o}C at a first intermediate cooling rate in the range of 30^{o}C/s - 80^{o}C/s. Thereafter the steel strip or sheet is held at the first intermediate temperature for a time duration of 4-16 sec to obtain first intermediate hot rolled steel sheet.

[0054] At step (112), the first intermediate hot rolled steel sheet is cooled to a second intermediate temperature in the range of 220 - 280^{o}C at a second intermediate cooling rate in the range of 30^{o}C/s - 80^{o}C/s and coiling thereafter at 220 - 280^{o}C to obtain low carbon hot rolled complex phase steel sheet having thickness in the range of 2 mm to 6 mm. The obtained low carbon hot rolled complex phase steel sheet comprises a microstructure of 5-20% ferrite, 5-20% martensite and about 60-90% bainite. The obtained low carbon hot rolled complex

phase steel sheet or strip exhibits ultimate tensile strength ranging from about 700 MPa to 850 MPa, and minimum %elongation of 13%.

[0055] Austenite pancaking is achieved by substantial deformation of austenite below Tnr temperature. To ensure required amount of deformation under Tnr, it is important to raise the Tnr by suitable alloying additions. Nb is considered the most common and effective alloying element for this purpose. Addition of Mn facilitates stabilization of austenite, particularly in a situation when C content is maintained below 0.1% to ensure a low carbon equivalent (CE). Addition of Cr slows down the transformation, which facilitates the formation of hard phases like martensite and bainite more conveniently under industrial conditions, which otherwise would have required extremely high cooling rates. A higher austenitization temperature is required to ensure complete dissolution of micro-alloying elements, mainly Nb.

[0056] The hot deformation schedule should ensure a substantial amount of deformation (about 50%) under Tnr. Immediately after finish rolling, there should be a rapid drop of temperature, to restrict grain growth. This is first stage of cooling, during which some amount of ferrite forms in the microstructure, and the temperature drops just below the bainitic transformation temperature.

[0057] Holding at this temperature for certain time duration is required for the completion of bainitic transformation. The time length of this intermediate holding determines the bainite fraction in the microstructure. After the intermediate holding, another rapid cooling treatment (second stage cooling) transforms the remaining austenite into martensite.

[0058] The method (100) of the present disclosure includes melting, casting, heat treatment, thermomechanical hot-rolled routes, which are simple. Slab drop-out temperature, finish rolling temperature, 2 step cooling rates after finish rolling, intermediate holding temperature and time, and coiling temperature, all have significant effects on final mechanical properties.

[0059] Following portions of the present disclosure provides details about the proportion of each element in a composition of the low carbon hot rolled complex phase steel and their role in enhancing properties.

[0060] Carbon (C) may be used in the range of about 0.0 to 0.11 wt.%: Amount of Carbon is so selected such that it is just sufficient for generating bainite and martensite on cooling.

[0061] Sulphur (S) may be used in the range of about < 0.006 wt.%, & Phosphorus (P) may be used in the range of about < 0.02 wt.%: Amounts of Sulphur and phosphorus are kept as low as possible.

[0062] Manganese (Mn): 1.0 to 2.0 wt.%: Manganese promotes solid solution strengthening and stabilizes austenite. However, excessive amount of Mn is not recommended as it can deteriorate weldability of the steel.

[0063] Chromium (Cr) may be used in the range of about 0.1 to 0.9 wt.%. Chromium (Cr) addition can substantially increase the strength and hardenability of the steel and facilitate the formation of bainite and martensite.

[0064] Niobium (Nb) may be used below 0.06 wt.%. Niobium (Nb) content is used for (a) maintaining strength at room temperature, (b) raising T_{nr} temperature, etc. The addition of Nb should be optimum, as excessive addition will increase the strength and cost of the material.

[0065] The chemical composition of the proposed alloys, and their carbon equivalent (CE) values are shown in Table 1.

Element (wt. %)	**C**	**Mn**	**Si**	**Cr**	**Al**	**Nb**	**Fe**	**CE**
Steel 1	0.078	1.45	0.42	0.51	0.05	0.02	Bal.	0.496
Steel 2	0.094	1.58	0.32	0.58	0.06	0.035	Bal.	0.534

Table -1: Chemical composition, and carbon equivalent (CE) of Steel 1 & 2

[0066] The carbon equivalent (Ceq) is expressed by formula CE = (C) + (Mn+Si)/6 + (Cu+Ni)/15 + (Cr+Mo+V+Nb)/5, wherein each symbol in brackets represents the content (mass%) of the corresponding element.

[0067] To investigate the properties of the steels, experiments were carried out for specific compositions which are reported in Table 1 of low carbon hot rolled

complex phase steel formed by using the method (100) of the present disclosure. Tensile specimens were prepared according to ASTM E8 specification, applicable for specimens with thickness 6 mm or less, and gauge length 25 mm. XRD samples were prepared by following standard methods. SEM and TEM samples were prepared by following standard methods.

[0068] Different samples of the low carbon hot rolled complex phase steel were prepared by utilizing the compositions as mentioned in table 1 and by varying the holding times at the first intermediate temperature followed during the method (100). Standard metallography techniques were followed to prepare the samples for different mechanical properties measurements. The measured properties for the steel samples are depicted in Table 2.

Mechanical Properties	**Steel 1 (6 Sec)**	**Steel 1 (12 Sec)**	**Steel 2 (5 Sec)**	**Steel 2 (10 Sec)**
Yield Strength (MPa)	528	585	598	623
Ultimate Tensile Strength (MPa)	743	755	821	813
Total elongation (%)	24	23	25	25
YR (YS/UTS)	0.78	0.77	0.728	0.77

Table 2: Variation in mechanical properties with varying composition and holding time.

[0069] Figures 2a to 2d illustrate the tensile results of the obtained low carbon hot rolled complex phase steel having compositions reported in Table 1 and by varying the holding times at the first intermediate temperature followed during the method (100). The mechanical properties are very remarkable considering the leaner chemistry of the current steels; ranging from 700 – 850 MPa UTS, accompanied with min 13% of elongation.

[0070] Figures 3a to 3d illustrate SEM images of the obtained low carbon hot rolled complex phase steel having compositions reported in Table 1 and by varying the holding times at the first intermediate temperature followed during the method

(100). From the figures it can be observed that the developed steels exhibits microstructure having bainite, ferrite and martensite. The major strength and ductility of the steels is coming from the phase mixture of bainite, ferrite and martensite. This also shows that there is a considerably large process window of intermediate holding time. This is also corroborated by the micrographs shown in Figures 3a, 3b, 3c, and 3d.

[0071] The present invention provides low carbon hot rolled complex phase steel and the method (100) of manufacturing the low carbon hot rolled complex phase steel having higher strength with bare minimum addition of alloying elements. The low carbon hot rolled complex phase steels makes an important contribution towards the cost effective, futuristic, and strategic light weight application of steel with greater factor of safety. A superior factor of safety may be obtained by achieving the sharp increase of yield strength with reasonable ductility, specifically required for the automotive and structural applications. The thermomechanical / hot-rolling process is quite simple and does not require huge energy consumption. Therefore, the method (100) of the present disclosure aids in reducing energy consumption and thus a cost-effective steel manufacturing process. Further, the method (100) provides a new steel developed with leaner chemistry by excluding or reducing Ni, Mo, Co like expensive alloying elements to achieve the required properties by exploiting the existing hot rolling facilities in the integrated steel plants to get desired microstructure.

[0072] The method (100) may employ additional processes such as grinding to remove scaling and to make both surfaces parallel to each other, without limiting the scope of the invention.

[0073] It should be understood that the experiments are carried out for particular compositions of the low carbon hot rolled complex phase steel reported in Table 1 and the results brought out are reported in Table 2. However, this composition should not be construed as a limitation to the present disclosure as it could be extended to other compositions of the low carbon hot rolled complex phase steel strip, as well.

[0074] Furthermore, the terminology used herein is for describing embodiments only and is not intended to be limiting of the present disclosure. It will be appreciated that several of the above-disclosed and other features and functions, or alternatives thereof, may be combined into other systems or applications. Various presently unforeseen or unanticipated alternatives, modifications, variations, or improvements therein may subsequently be made by those skilled in the art without departing from the scope of the present disclosure as encompassed by the following claims.

[0075] The claims, as originally presented and as they may be amended, encompass variations, alternatives, modifications, improvements, equivalents, and substantial equivalents of the embodiments and teachings disclosed herein, including those that are presently unforeseen or unappreciated, and that, for example, may arise from applicants/patentees and others.

[0076] While the foregoing describes various embodiments of the invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof. The scope of the invention is determined by the claims that follow. The invention is not limited to the described embodiments, versions, or examples,

which are included to enable a person having ordinary skill in the art to make and use the invention when combined with information and knowledge available to the person having ordinary skill in the art.

We Claim:

1. A method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm, the method (100) comprising:

casting molten steel having a composition expressed in weight %: C < 0.11, Mn – 1.0-2.0, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-0.06, Nb – 0.00-0.06, Cr – 0.10-0.90, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities to obtain a steel slab;

reheating the steel slab to a temperature greater than 1150^{o}C;

roughing the steel slab in roughing mill with exit temperature in the range of 1010-1080^{o}C;

hot rolling the roughed steel slab to produce a steel sheet such that finish rolling is done at a temperature (T_{FRT}), wherein T_{FRT} varies in the range of 820^{o}C to 880^{o}C;

cooling the hot rolled steel to a first intermediate temperature in the range of 560 - 600^{o}C at a first intermediate cooling rate in the range of 30^{o}C/s - 80^{o}C/s to obtain first intermediate hot rolled steel, wherein the first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 4-16 sec;

cooling the first intermediate hot rolled steel to a second intermediate temperature in the range of 220 - 280^{o}C at a second intermediate cooling rate in the range of 30^{o}C/s - 80^{o}C/s and coiling thereafter to obtain low carbon hot rolled complex phase steel sheet, wherein the low carbon hot rolled complex phase

steel sheet comprises a microstructure of 5-20% ferrite, 5-20% martensite and about 60-90% bainite, wherein the low carbon hot rolled complex phase steel exhibits an ultimate tensile strength in the range of 700 - 850 MPa.

2. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm as claimed in the claim 1, wherein the low carbon hot rolled complex phase steel comprises the composition expressed in weight %: C – 0.078, Mn –1.45, Si – 0.42, Al – 0.05, Nb – 0.02, Cr – 0.51, and the balance being Iron (Fe) and unavoidable impurities, wherein the carbon equivalent (Ceq) expressed by formula CE = (C) + (Mn+Si)/6 + (Cu+Ni)/15 + (Cr+Mo+V+Nb)/5 is 0.496, wherein each symbol in brackets represents the content (mass%) of the corresponding element.
3. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm as claimed in the claim 2, wherein the first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 6 sec.
4. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm as claimed in the claim 2, wherein the obtained low carbon hot rolled complex phase steel exhibits a yield strength (YS) of 582 MPa, ultimate tensile strength (UTS) of 743 MPa, %Elongation – 24 and yield ratio (YS/UTS) of 0.78.
5. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range

of 2 mm to 6 mm as claimed in the claim 2, wherein the first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 12 sec.

6. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm as claimed in the claim 2, wherein the obtained low carbon hot rolled complex phase steel exhibits a yield strength (YS) of 585 MPa, ultimate tensile strength (UTS) of 755 MPa, %Elongation – 23 and yield ratio (YS/UTS) of 0.77.
7. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm as claimed in the claim 1, wherein the low carbon hot rolled complex phase steel comprises the composition expressed in weight %: C – 0.094, Mn –1.58, Si – 0.32, Al – 0.06, Nb – 0.035, Cr – 0.58, and the balance being Iron (Fe) and unavoidable impurities, wherein the carbon equivalent (Ceq) expressed by formula CE = (C) + (Mn+Si)/6 + (Cu+Ni)/15 + (Cr+Mo+V+Nb)/5 is 0.534, wherein each symbol in brackets represents the content (mass%) of the corresponding element.
8. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm as claimed in the claim 7, wherein the first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 5 sec.
9. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm as claimed in the claim 8, wherein the obtained

low carbon hot rolled complex phase steel exhibits a yield strength (YS) of 598 MPa, ultimate tensile strength (UTS) of 821 MPa, %Elongation – 25 and yield ratio (YS/UTS) of 0.728.

10. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm as claimed in the claim 7, wherein the first intermediate hot rolled steel is held at first intermediate temperature for a time duration of 10 sec.

11. The method (100) for manufacturing low carbon hot rolled complex phase steel sheet or strip having thickness in the range of 2 mm to 6 mm as claimed in the claim 10, wherein the obtained low carbon hot rolled complex phase steel exhibits a yield strength (YS) of 623 MPa, ultimate tensile strength (UTS) of 813 MPa, %Elongation – 25 and yield ratio (YS/UTS) of 0.77.

12. A low carbon hot rolled complex phase steel comprising the following composition expressed in weight %:

Carbon (C): < 0.11%,

Manganese (Mn): 1.0% - 2.0%,

Chromium (Cr): 0.1-0.9%,

Silicon (Si): 0.2%-0.8%,

Sulphur (S): <0.006%

Phosphorus (P): < 0.02%

Niobium (Ni): < 0.06%,

Aluminium (Al): 0.02-0.06%,

Nitrogen (N) < 80 ppm, and the remaining being substantially iron and incidental impurities, wherein the low carbon hot rolled complex phase steel sheet comprises a

microstructure of 5-20% ferrite, 5-20% martensite and about 60-90% bainite.

13. The low carbon hot rolled complex phase steel as claimed in the claim 12, wherein the low carbon hot rolled complex phase steel comprises C < 0.09, Mn – 1.0-1.8, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-0.06, Nb – 0.00-0.05, Cr – 0.10-0.80, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities.

14. The low carbon hot rolled complex phase steel as claimed in the claim 13, wherein the low carbon hot rolled complex phase steel exhibits yield strength (YS) in the range of 480-550 MPa, ultimate tensile strength (UTS) in the range of 740-780 MPa and minimum %Elongation – 15.

15. The low carbon hot rolled complex phase steel as claimed in the claim 12, wherein the low carbon hot rolled complex phase steel comprises the composition expressed in weight %: C < 0.11, Mn – 1.2-2.0, S < 0.006, P < 0.02, Si – 0.20-0.80, Al – 0.02-0.06, Nb – 0.00-0.06, Cr – 0.10-0.90, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities.

16. The low carbon hot rolled complex phase steel as claimed in the claim 15, wherein the low carbon hot rolled complex phase steel exhibits yield strength (YS) in the range of 560-660 MPa, ultimate tensile strength (UTS) in the range of 780-850 MPa and minimum %Elongation – 13.

17. The low carbon hot rolled complex phase steel as claimed in the claims 12, 13 and 15, wherein the Mn content in the low carbon hot rolled complex phase steel promotes solid solution strengthening and stabilizes austenite.

18. The low carbon hot rolled complex phase steel as claimed in the claims 12, 13 and 15, wherein the Cr content in the low carbon hot rolled complex phase steel improves hardenability of the steel and facilitate in the formation of bainite and martensite.

19. The low carbon hot rolled complex phase steel as claimed in the claims 12, 13 and 15, wherein the Nb content in the low carbon hot rolled complex phase steel is used for maintaining strength at room temperature and raising T_{nr} temperature.

20. A component produced from the low carbon hot rolled complex phase steel as claimed in the claims 1 to 19, wherein the component is used in automobile applications.

Dated this 7th day of February 2022



GOPINATH ARENUR SHANKARARAJ
Of K&S Partners

IN/PA 1852

AGENT FOR THE APPLICANT

ABSTRACT

METHOD OF MANUFACTURING LOW CARBON HOT ROLLED COMPLEX PHASE STEEL

The present invention relates to a method (100) for manufacturing low carbon hot rolled complex phase steel. The low carbon hot rolled complex phase steel comprises the following composition expressed in weight %: C < 0.11, Mn: 1.0-2.0, S < 0.006, P < 0.02, Si: 0.20-0.80, Al: 0.02-0.06, Nb: 0.00-0.06, Cr: 0.10-0.90, N (ppm) < 80, and the balance being Iron (Fe) and unavoidable impurities. The low carbon hot rolled complex phase steel sheet comprises a microstructure of 5-20% ferrite, 5-20% martensite and about 60-90% bainite. The low carbon hot rolled complex phase steel exhibits an ultimate tensile strength in the range of 700 - 850 MPa and minimum % Elongation – 13%.

<To be published with Figure 1>