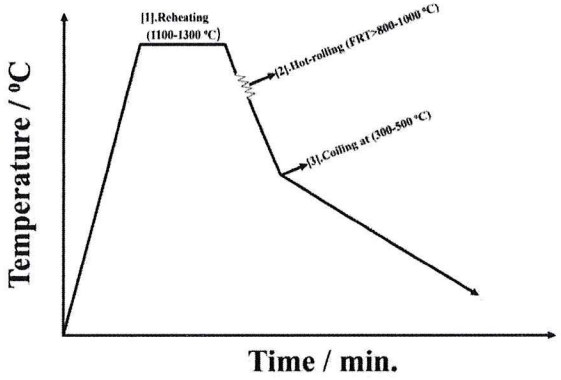


Figure 1

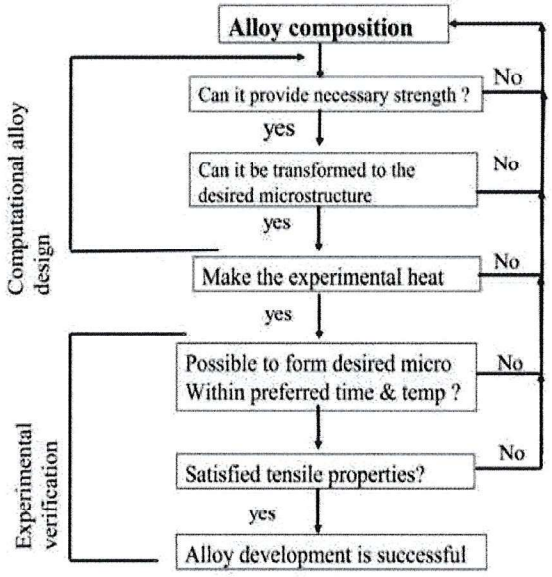


Figure 2

Dated 05th day of **September, 2023**

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

Dean
Sponsored Research & Industrial Consultancy
Indian Institute of Technology Roorkee
Roorkee-247667 (INDIA)

(Applicant)

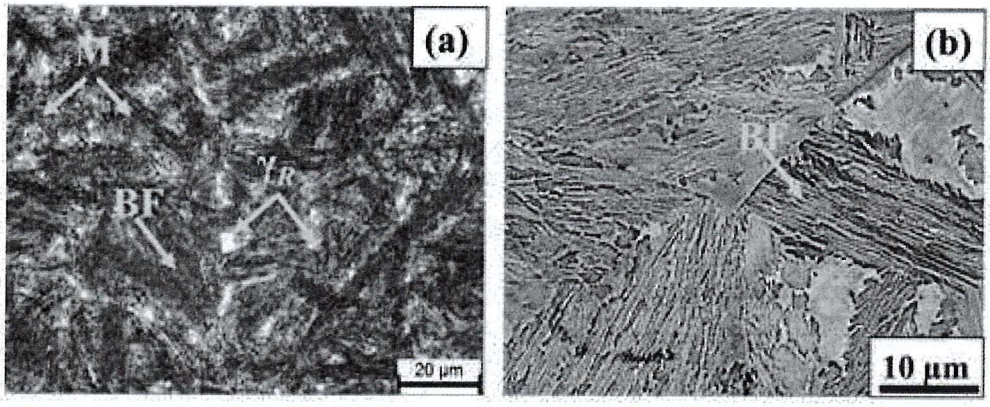


Figure 3

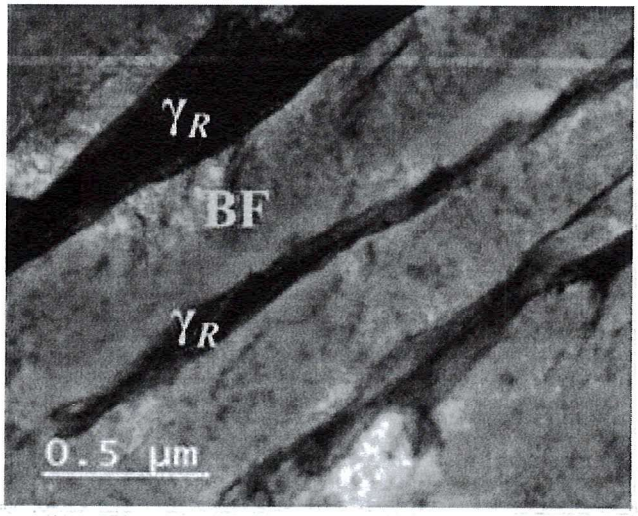


Figure 4

Dated 05th day of **September, 2023**

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

Dean
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Roorkee-247667 (INDIA)

(Applicant)

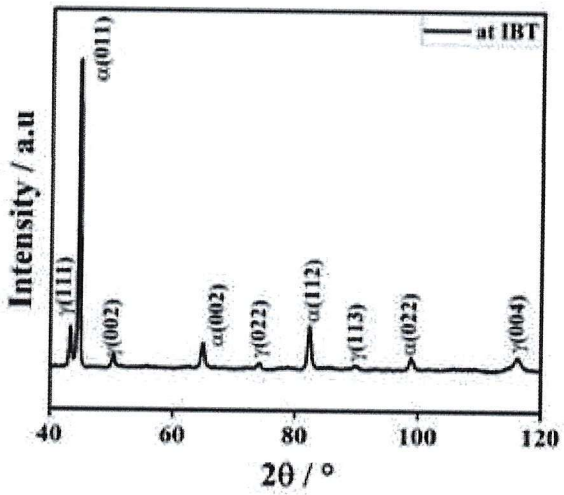


Figure 5

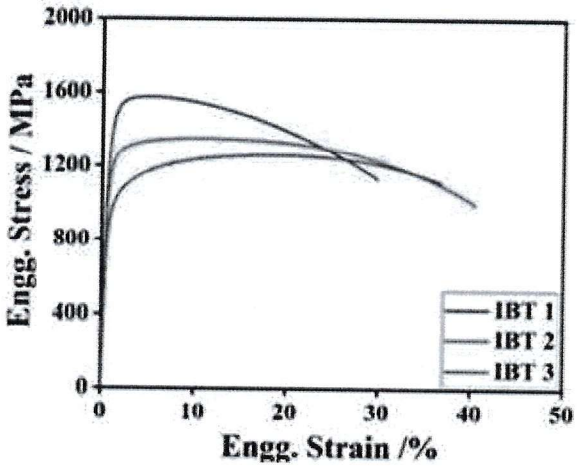


Figure 6

Dated 05th day of **September, 2023**

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FORM 2

THE PATENTS ACT, 1970

(39 of 1970)

&

The Patent Rules, 2003

COMPLETE SPECIFICATION

(See sections 10 & rule 13)

1. TITLE OF THE INVENTION

A HOT-ROLLED CONTINUOUSLY COOLED BAINITIC STEEL COMPOSITION AND ITS METHOD OF PREPARATION

2. APPLICANT (S)

NAME	NATIONALITY	ADDRESS
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE	IN	Roorkee- 247667, Uttarakhand, India.

3. PREAMBLE TO THE DESCRIPTION

COMPLETE SPECIFICATION

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

FIELD OF INVENTION:

[001] The present invention relates to the field of steel composition. The present invention in particular relates to a hot-rolled continuously cooled bainitic steel composition and its method of preparation.

DESCRIPTION OF THE RELATED ART:

[002] Automotive parts are required to satisfy two inconsistent necessities, viz. ease of forming and strength but in recent years a third requirement of improvement in fuel consumption is also bestowed upon automobiles in view of global environment concerns. Thus, now automotive parts must be made of material having high formability in order that to fit in the criteria of ease of fit in the intricate automobile assembly and at same time have to improve strength for vehicle crashworthiness and durability while reducing weight of vehicle to improve fuel efficiency.

[003] Therefore, intense Research and development endeavors are put in to reduce the amount of material utilized in car by increasing the strength of material. Conversely, an increase in strength of steel sheets decreases formability, and thus development of materials having both high strength and high formability is necessitated.

[004] Earlier research and developments in the field of high strength and high formability steel sheets have resulted in several methods for producing high strength and high formability steel sheets, some of which are enumerated herein for conclusive appreciation of the present invention:

[005] Reference may be made to the following:

[006] IN Publication No. 202217062521 relates to a steel plate according to the present invention has a chemical composition, in

terms of mass%, of C: 0.03-0.25%, Si: 0.1-2.0%, Mn: 1.0-3.0%, P: 0.200% or less, S: 0.0500% or less, Al: 0.01-1.00%, N: 0.0100% or less, and Ti: 0.01-0.25%, with the remainder being Fe and impurities. The metal structure includes, in terms of a surface area percentage, ferrite: 50-85%, with the remainder being one or more selected from martensite, bainite, and retained austenite. The cumulative intensity of ?-fibers exceeds 4.0 times in terms of a random intensity ratio, and an average KAM value is 1.30° or less in crystal grains having a crystal orientation of within 10° from a ?-fiber.

[007] Low C content and guaranteed tensile strength (700 MPa) is too low. Presence of low carbon tempered martensite and polygonal ferrite is said to be the responsible microstructures. Their processing route is hot rolling, cold-rolling followed by annealing, which may also be subjected to hot-dip galvanizing or plating and must be targeted for producing lower strength steel.

[008] The present invention is hot rolling followed by runout table cooling and coiling operations for producing strong bainitic plates and sufficient amount of retained austenite (RA) to achieve ultra-high strength and ductility.

[009] IN Publication No. 202227066755 discloses a new bainitic steel to be used for manufacturing a drill component, such as a drill rod, or in any other components wherein such steels are useful. The present disclosure further relates to a drill component comprising the bainitic steel. The bainitic steel comprises the following composition in weight %: C 0.33 to 0.40; Si 0.60 to 1.45; Mn 0.25 to = 0.80; P = 0.03; S = 0.03; Cr 1.00 to 1.50; Ni 0.10 to 0.60; Mo 0.40 to 0.80; N = 0.020; Al = 0.05; balance Fe and unavoidable impurities.

[010] Low Mn, higher Cr content makes it different from present invention. Their processing method includes after reheating, the bars were heat treated between (600°C to 850°C) and holding for more than 3 hours.

[011] IN Publication No. 202217031541 relates to a heat treated cold rolled steel sheet having a composition comprising of the following elements, 0.1%=Carbon=0.25%, 2.15%= Manganese=3.0%,1%=Silicon=0.8%, 0.1%=Aluminum=0.9%, 0.05%=Chromium=0.5%, 0%= Phosphorus=0.09%, 0%=Sulfur=0.09%, 0%=Nitrogen=0.09%, 2.4%=C + Mn=3%, 0%=Niobium=0.1%, 0% =Titanium=0.1%,0%=Vanadium=0.1%,0%=Molybdenum=1%, 0%= Nickel=1%, 0%=Calcium = 0.005%, 0% = Boron = 0.01%, 0% = Cerium = 0.1%, 0% = Magnesium ? 0.05%,0% = Zirconium? 0.05% the remainder being composed of iron and unavoidable impurities, the microstructure of said steel sheet comprising, 20% to 70% Martensite, 5 to 60% of Inter-critical Ferrite, 5 to 30% of Transformed Ferrite, 8% to 20% of Residual Austenite and 1 to 20% Bainite, wherein the cumulated amount of Inter-critical and Transformed Ferrite is between 15% and 65%. Low C content (0.1-0.25 wt%), low Si (<0.8-1.0 wt%), high Mn (2.15-3.0 wt%), presence of high martensite content (> 20%), low bainite content (below 20%), and lower extent of guaranteed yield strength (>600 MPa) tensile strength (>950 MPa), elongation (14 %). This provides cold-rolled steel sheets.

[012] IN Publication No. 202217033497 relates to a hot rolled steel sheet having a composition comprising, by weight percent: C: 0.10 - 0.25 %, Mn: 3.5 - 5.0 %, Si: 0.80 - 1.60 %, B: 0.0003 - 0.004 %, S = 0.010 %, P = 0.020 %, N = 0.008 % the remainder of the composition

being iron and unavoidable impurities resulting from the smelting, and having a microstructure consisting of, in surface fraction: between 50% and 80% of lath bainite, lower than 30% of granular bainite, the rest being martensite, martensite- austenite islands and austenite films, and having less than 20% of martensite and M-A islands having the multiplication of the maximum length Lmax of the grain by the maximum width Wmax of the grain higher than 1 μm2.

[013] The alloying contents are different than our steel. Their steel is a different one having different chemical composition than ours; the said steel contains lower C, high Mn and no Cr. The method has higher coiling temperature and they performed welding of hot-rolled steel sheet.

[014] IN Publication No. 202117034792 relates to a chemical composition containing, in mass%, 0.02-0.20% of C, 0.01-1.50% of Si, 0.10-3.00% of Mn, not more than 0.10% of P, not more than 0.010% of S, 0.005-0.100% of Al, 0.02-0.20% of Ti, 0.001-0.010% of N, 0-0.50% of Cu, 0-0.50% of Ni, 0-1.00% of Cr, 0-0.40% of Mo, 0-0.060% of Nb, 0-1.00% of V, 0-0.0100% of B, 0-0.0050% of Ca, and not more than 0.0100% of O, the remaining portion being Fe and impurities, and has a metal structure in which, in area %, ferrite accounts for 60-80% thereof and the total of ferrite and bainite is not less than 90%, wherein the average of grain sizes of the ferrite and the bainite is not more than 7.0 μm, the standard deviation of the grain sizes is not more than 2.0 μm, and the standard deviation of the sizes of Ti carbonitride is not more than 10 nm. This has low C and low guaranteed tensile strength (>830 MPa). The processing has two steps of cooling after FRT which were not adopted in our study. After coiling, the welding of steel sheet is performed.

[015] IN Publication No. 202217022913 relates to a prescribed chemical composition, and, by area%, the composition of the metal is 80.0% or more bainite, 10.0% or less ferrite and 10.0% or less residual composition, wherein, setting the axis as the <110> direction in the bainite, the total density of the length L7 of grain boundaries in which the crystal orientation difference is 7° and length L68 of the grain boundaries in which the crystal orientation difference is 68° is 0.35-0.60 μm/μm2, and the tensile strength is greater than or equal than 780 MPa. This has low C content. They have mentioned about the presence of polygonal ferrite upto 10%. They also have mentioned that there will the presence of tempered martensite, cementite and pearlite upto 10%. All these microstructural constituents (polygonal ferrite, cementite, tempered martensite, pearlite etc.), are not used in present invention. Low value of tensile strength (980 MPa) and elongation (14%). Higher coiling temperature after FRT (finish rolling temperature) and possibility of subjecting to hot-dip galvannealing, hot-dip galvanizing or hot-dip aluminium plating in accordance with a standard method made this a different product from ours.

[016] IN Publication No. 202217033501 relates to a hot rolled and annealed steel sheet having a composition comprising, by weight percent: C: 0.1 - 0.25 %, Mn: 3.00 - 5.00 %, Si: 0.80 - 1.60 %, B: 0.0003 - 0.004 %, S = 0.010 %, P = 0.020 %, N = 0.008 % the remainder of the composition being iron and unavoidable impurities resulting from the smelting, and having a microstructure consisting of, in surface fraction: more than 20% of recrystallized ferrite, the balance being non-recrystallized ferrite, more than 15% of said recrystallized ferrite having grain size larger than 5 μm and a density of carbides at grain boundary of recrystallized ferrite less than 5 carbides per 10 μm of grain boundary length.

[017] It has low C, higher Mn and considering Cr, Al as optional element. This does not disclose anything about presence of bainite, retained austenite and martensite. The Vickers hardness is lower than us. In this pickling is done after coiling to remove oxidation.

[018] IN Publication No. 202137006880 Provides a high-strength hot-rolled coated steel sheet having a TS of 980 MPa or more, excellent bulging formability and stretch flange formability, and excellent coatability. The high-strength hot-rolled coated steel sheet includes a steel sheet having a chemical composition containing, by mass%, C: 0.03% to 0.09%, Si: 0.01% to 1.60%, Mn: 2.20% to 3.60%, P: 0.100% or less, S: 0.0100% or less, Ti: 0.05% to 0.18%, B: 0.0005% to 0.0050%, Al: 0.005% to 0.40%, N: 0.010% or less, and a balance of Fe and inevitable impurities, in which a CSM value expressed by the equation 33.8[%C] [%Mni + 12.4[%Si]/[%Mn] is 3.3 to 12.0, and a steel microstructure containing bainite in an amount of 85% or more in terms of area fraction and martensite in an amount of 2.0% or more and 15.0% or less in terms of area fraction and includes a coating layer or an alloyed coating layer on a surface of the steel sheet. This has low C content, high Mn and N addition. Guaranteed minimum strength is low 980 MPa and no information regarding the presence of retained austenite. This is a coated steel.

[019] Publication No. JPH0967619 relates to a high strength hot rolled steel plate excellent in workability and corrosion resistance by subjecting a continuously cast slab of low carbon steel, free from segregation and having a specific composition, to hot rolling, cooling and coiling under respectively specified temp. Conditions. A low carbon steel, which has a composition containing, by weight, 0.02-0.08% C, <2.0% Mn, <1.5% Si, 0.05-0.1% P, <0.005% S, 0.10-0.60% Cu, 0.05-0.60% Ni, and <0.06% Cr or further containing specific

small amounts of Mo, Nb, and Ti, is cast into a slab by a continuous casting method, and the unsolidified part with high Mn and P contents in the central part of the slab is removed by, e.g. pushing it upward, by which a segregation-free continuously cast slab is prepared. This slab is finish-hot-rolled in a temp. Range between Ar3 and (Ar3 +100 deg.C) and the resultant plate is cooled without delay at >=50 deg.C/sec cooling rate and successively coiled in a bainitic transformation region of 300 to 500 deg.C, not higher than (550-1000P) deg.C (where P represents the content of P in the steel plate). This has Low C content and Cr anoumt very low.

[020] Publication No. JPH09170017 relates to a high strength steel improved in crack propagation resistance. A continuously cast slab, having a composition containing 0.30-0.80% C, 0.05-0.40% Si, <=0.50% Mn, 1.00-3.00% Cr, 0.40-1.00% Mo, 0.01-0.40% V, 0.005-0.02% N, <=0.010% P, <=0.006% S, 0.010-0.10% acid soluble Al, and 0-0.10% Ti and/or 0-0.20% Nb, is hot-rolled and formed into bainitic structure. The resultant steel plate, in which the average grain size of carbides is regulated to >=1μm, is austenitized at 850-1100 deg.C and then cooled rapidly down to a temp. not higher than the martensite formation temp. and tempered at 200-600 deg.C or cooled rapidly down to a temp. between 200 deg.C and the martensite formation temp. and held in this temp. region for 10-90min. Prior to the austenitizing treatment, annealing and cold rolling can be repeatedly applied. This has low amount of Si, Mn and the higher content of Cr, Mo and N is present. Also, the carbides is present.

[021] Publication No. JPH11117039 relates to produce a high tensile strength hot rolled steel plate excellent in punch stretch formability, shape freezability, and stretch-flange formability and haying

superior multiple press formability, under the process conditions capable of setting over a wide range. Solution: A steel stock, having a composition consisting of, by weight, 0.010-0.10% C, 0.50-1.50% Si, 0.50-2.00% Mn, 0.01-0.15% P, <=0.005% S, 0.001-0.005% N, one or >=2 kinds among 0.005-0.03% Ti, 0.005-0.03% V, and 0.01-0.06% Nb, and the balance Fe with inevitable impurities, is used. The steel stock is held at 900-1300 deg.C for <=3600 sec and continuously hot rolled at 780-980 deg.C finish rolling finishing temp. Then, within 1 sec after the completion of rolling, the resultant steel plate is cooled at (50 to 200) deg.C/sec cooling rate and successively coiled at 300-650 deg.C. In this way, a structure, consisting of 80-97%, by volume, of ferritic phase of <=10 μm average particle diameter and the balance low temp. transformation phase composed essentially of bainitic phase, can be provided. It has very low C content (0.010-0.10 wt%), high amount of ferrite (80-97%). Targeted tensile strength of this steel is very low (540 to 590 Mpa). The coiling temperature (470°C) is higher after finish rolling and holding time at winding temperature not mentioned.

[022] Publication No. US2020181750 relates to a method for producing a high-strength steel sheet having high ductility, formability and weldability includes providing a cold-rolled sheet, with a composition containing: 0.15% ≤C≤0.23%, 1.4% ≤Mn≤2.6%, 0.6% ≤Si≤1.3%, with C+Si/10≤0.30%, 0.4% ≤Al≤1.0%, with Al≥6(C+Mn/10)−2.5%, 0.010% ≤Nb≤0.035%, 0.1% ≤Mo≤0.5%, annealing the sheet at 860°C-900° C. To obtain a structure consisting of at least 90% austenite and at least 2% inter-critical ferrite, quenching to a temperature between Ms-10° C. and Ms-60° C. at a rate Vc higher than 30° C./s, heating to a temperature PT between 410° C. and 470° C. for 60 s to 130 s, hot-dip coating the sheet, and cooling to room temperature. The microstructure

includes 45% to 68% of martensite, consisting of 85% to 95% partitioned martensite having a C content of at most 0.45%, and fresh martensite; 10% to 15% retained austenite; 2% to 10% inter-critical ferrite; 20% to 30% lower bainite. It has low C content, and Cr is absent. Low value of yield and ultimate strength (800 MPa & 1180 MPa) and total elongation (13%) are lower. Presence of inter-critical ferrite (2%), a very high amount of martensite (45% to 68%) and low amount of bainite (20% to 30%) make this steel different. Annealing the cold-rolled steel sheet these are not adopted in present. It also includes plating with Zn which were not adopted in our invention.

[023] IN Publication No. 201931004464 discloses a method for producing high strength-hot rolled steel sheet. The process starts from casting a steel slab of a defined composition. Then, heating, the steel slab to a first predetermined temperature for a first predetermined time. The steel slab is then subjected to a hot working, to produce a steel sheet. The hot working includes deforming, the steel slab in a first hot working process, at a second predetermined temperature and deforming, the steel slab in a second hot working process, at a third predetermined temperature. After hot working, the steel sheet is cooled at a predetermined cooling rate. The method further includes coiling, the steel sheet, at a fourth predetermined temperature to obtain the high-strength hot rolled steel sheet. The hot-rolled steel sheet comprises primarily a single-phase bainitic ferrite microstructure. Thus, the steel sheet exhibits high-strength along with excellent stretch flange ability and high ductility. This has low C, Si content, and absence of Cr. Lower assured tensile strength (590 MPa) makes this steel different than ours. They have used two step of hot working; this was not adopted in our study. The process is hot rolling followed by runout table

cooling and coiling operations for producing strong bainitic plates and sufficient amount of retained austenite (RA) to achieve ultra high strength and ductility.

[024] Publication No. US2020399727 relates to a flat product of steel with yield strength ftp 0.2 of 660 to 820 MPa, BH2 value greater than 30 MPa, a hole expansion ratio greater than 30%, and a microstructure having a first main component at a proportion of at least 50%, including one or more individual components of ferrite, tempered bainite, and tempered martensite, each with less than 5% carbides, and a second main component at a proportion of 5% to 50%, including one or more individual components of martensite, residual austenite, bainite or perlite, with the steel having a following chemical composition (in weight %): C: 0.04 to 0.12; Si: 0.03 to 0.8; Mn: 1 to 2.5: P: max. 0.08; S: max. 0.01; N: max. 0.01; Al: up to 0.1; Ni+Mo; up to 0.5; Nb: up to 0.08; Ti: up to 0.2; Nb+Ti: min, 0.03; Cr: up to 0.6; the remainder being iron including unavoidable steel-associated elements. It has low C, Si.

[025] Guaranteed value of yield strength (660-820 MPa), tensile strength (760-960 MPa) and elongation (10-12 %) are low compared to our work, presence of tempered bainite and martensite makes this a different steel from ours.

[026] Their processing route is also different. Higher coiling temperature (450-600°C) and include optionally hot dip-coating were not adopted in our study.

[027] Publication No. US2020157647 relates to a steel sheet has a component composition and contains 6 to 80% of ferrite and 20 to 94% of a microstructure composed of one or two or more of upper bainite, fresh martensite, tempered martensite, lower bainite, and

retained γ, and contains 7 to 20% of retained γ, where: an area ratio (SγUB) of retained γ having a particle width of 0.18 to 0.60 μm, a particle length of 1.7 to 7.0 μm, and an aspect ratio of 5 to 15 is 0.2 to 5%; and a total area ratio (SγBlock) of fresh martensite having an equivalent circle diameter of 1.5 to 15 μm and an aspect ratio of 3 or less and/or retained γ particles having an equivalent circle diameter of 1.5 to 15 μm and an aspect ratio of 3 or less it is 3% or less (including 0%). It has: Low C, High Mn content and presence of tempered martensite make its composition and microstructural different than our work. In this annealing after cold-rolling was done between Ac_1 and Ac_3, and Coiling temperature is high.

[028] Patent No. US10876184 relates to a process for making a hot rolled high strength steel (HRHSS) product including the steps of casting a steel slab having, in weight percent, C: 0.18-0.22, Mn: 1.0-2.0, Si: 0.8-1.2, Cr: 0.8-1.2, S: 0.008 max, P: 0.025 max, Al: 0.01-0.15, N: 0.005 max, Nb: 0.02-0.035, Mo: 0.08-0.12, the remainder iron (Fe) and incidental impurities, hot rolling the steel slab into strip at a finish rolling temperature (FRT) of 850-900° C., cooling the hot rolled strip at 40° C./s or more over a run out table (ROT) until the strip reaches 380-400°C, coiling the hot rolled strip, and then air cooling to room temperature has low C content, and high Cr. Their minimum guaranteed tensile strength (1000-1200MPa), yield strength (600-650 MPa) and total elongation (16-17%) are lower.

[029] Publication No. US2019093190 relates to a high-strength steel sheet exhibiting excellent ductility and stretch-flange ability, and a method for manufacturing such a high-strength steel sheet. The high-strength steel sheet has a chemical composition including specific proportions of components in which C/Mn is 0.08 to 0.20, the balance being iron and inevitable impurities, and includes

microstructures including, in terms of area fraction relative to all the microstructures, 40% to 70% total of ferrite and bainitic ferrite, 5% to 35% martensite and 5% to 30% retained austenite. The proportion of martensite (including retained austenite) adjacent to bainitic ferrite is not less than 60% of all martensite (including retained austenite). The proportion of 4.0 GPa and smaller differences in microhardness measured at 0.5 μm intervals is not less than 70%. The proportion of microstructures with 8.0 GPa or smaller microhardness is not less than 85% of all the microstructures. Their minimum guaranteed tensile strength (950 MPa). It also includes plating and galvannealing treatments.

[030] The carbon content of designed steel may vary in the range of 0.20 to 0.50 wt.%; the silicon content from 1.0 to 2.5 wt.%; and the manganese content varies from 1.0 to 3.0 wt.%. Also, the aluminium may vary from 0.01 to 1.0 wt.%, chromium from 0.1 to 1.0 wt.%; and nitrogen may vary from 0.002-0.005 maximum, respectively.

[031] Hence, there needed an improved steel composition which can provide high strength and elongation.

[032] In order to overcome above listed prior art, the present invention aims to provide a hot-rolled continuously cooled bainitic steel composition and its method of manufacturing. The present invention has the higher value of strength and elongation in comparison to the strength and elongation mentioned in the prior art. The minimum guaranteed strength for the current innovation is above 1220 MPa which has not been mentioned by any of these prior arts.

[033] It also deals with a different manufacturing method in which reheating of the steel was carried out in a temperature range of

1050-1300°C for minimum of 0-20 hrs. steel will be cast into a slab, hot rolling the slab into strip at the required finish rolling temperature (FRT) 800-1000°C up to 4-10 mm thickness. After the FRT, the cooling will be done at 1-50°C per second and the strip will be coiled at 300-500°C for 0.5 to 2 hrs. The cooling of the coil would be natural cooling leading to producing the desired microstructure containing 10-50% C-enriched austenite, 45-85% ultrafine nano-structured carbide-free bainite, and 1-10% martensite.

OBJECTS OF THE INVENTION:

[034] The principal object of the present invention is to provide a hot-rolled continuously cooled bainitic steel composition and its method of manufacturing.

[035] Another object of the present invention is to provide a bainitic steel composition to provide high strength and elongation.

[036] Yet another object of the present invention is to provide a hot-rolled continuously cooled bainitic steel composition to provide high strength and elongation a method for manufacturing the same comprising.

SUMMARY OF THE INVENTION:

[037] The present invention relates to a hot -rolled continuously cooled bainitic steel composition to provide high strength and elongation a method for manufacturing the same comprising: composition in wt%:C:- 0.20-0.50, Mn:- 1.0-3.0, Si:- 1.0-2.5, Cr:- 0-1.0, Al: 0.01-1.0, N: 0.005 max, Fe-balance along with some inevitable impurities. To generate the optimum microstructure of 10–50% retained austenite, 45-85% bainitic ferrite, and 1-10% martensite for delivering the essential properties, steel will be cast into a slab, hot rolling the slab into strip at the required finish rolling

temperature (FRT) 800-1000°C up to 4-10 mm thickness, winding the strip at winding temperature of 300-500°C for 0.5 to 2 hrs.

BREIF DESCRIPTION OF THE INVENTION

[038] It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered for limiting of its scope, for the invention may admit to other equally effective embodiments.

[039] Figure 1 shows schematic heat treatment cycle of the newly developed hot-rolled steel.

[040] Figure 2 shows schematic work plan of the newly developed alloy steel.

[041] Figure 3 shows microstructure of newly developed hot-rolled bainitic steel (a) Optical; (b) SEM.

[042] Figure 4 shows transmission electron microscopy microstructure showing the bainitic ferrite and retained austenite and the thickness of the bainitic plate.

[043] Figure 5 shows XRD graph of the hot-rolled steel sample shows the austenite peaks determined using the Rietveld refinement method.

[044] Figure 6 shows engineering stress v/s engineering strain diagram of three representative samples hot-rolled and continuously cooled at room temperature.

DETAILED DESCRIPTION OF THE INVENTION:

[045] The present invention provides a hot -rolled continuously cooled bainitic steel composition to provide high strength and elongation a method for manufacturing the same comprising:

composition in wt%:C:- 0.20-0.50, Mn:- 1.0-3.0, Si:- 1.0-2.5, Cr:- 0-1.0, Al: 0.01-1.0, N: 0.005 max, Fe-balance along with some inevitable impurities. To generate the optimum microstructure of 10–50% retained austenite, 45-85% bainitic ferrite, and 1-10% martensite for delivering the essential properties, steel will be cast into a slab, hot rolling the slab into strip at the required finish rolling temperature (FRT) 800-1000°C up to 4-10 mm thickness, winding the strip at winding temperature of 300-500°C for 0.5 to 2 hrs.

[046] A 40 kg batch of heat was produced within a vacuum induction furnace, following the chemical composition provided in Table 1. The resulting cast steel was then forged to a thickness of 50 mm, followed by a homogenization process within the temperature range of 1100-1300 °C for 20-48 hours after which the steel was cooled along with the furnace. All further experiments were performed with homogenized steel only. The steel will be cast into a slab, hot rolling the slab into the strip at the required finish rolling temperature (FRT) 800-1000 °C up to 3-10 mm thickness, coiling the strip at temperature of 300-500 °C for 0.5 to 2 hrs shown schematically in Fig. 1 to generate the desired microstructure which is entailed of 10–50% retained austenite, 45-85% bainitic ferrite, and 1-10% martensite. Fig. 2 shows the logic flow in the current invention through schematic representation. The first part shows the sequence in a step-by-step manner toward the finalization of composition in a theoretical manner. In contrast, the second part describes the outcome of the actual experimental works. Standard metallographic techniques like optical, scanning electron microscopy (SEM), transmission electron microscopy (TEM) and X-ray diffraction (XRD) analysis can easily discover the microstructural features. Samples for metallographic examination were cut from various surfaces of the hot-rolled strips. The samples

were polished according to the usual method and etched with 2% nital to reveal the existence of different phases as represented in Fig. 3, where Fig. 3a is the optical microscopy image etched with lepera, Fig. 3b is the Scanning electron microscopy (SEM) image etched with 2% nital.

[047] To reveal the thickness of bainitic plate use the transmission electron microscopy (TEM) image shown in Fig. 4. There were no signs of any diffusional transformation products such as ferrite, and/ cementite, and the resulting bainite is carbide-free bainite. Fig. 5 shows the XRD results of newly developed hot-rolled steel, which show a significant amount of austenite and bainitic-ferrite in the microstructure. The developed hot-rolled steel can deliver an excellent combination of tensile properties. Standard testing was conducted for hardness & tensile properties. Tensile samples were prepared following the ASTM E8 method (25 mm gauge length and 4 mm thickness) and tested in an Instron testing machine (model no. 5982). Fig. 6 reveals the engineering stress-strain diagram of newly developed hot-rolled carbide-free bainitic steel. Figure 6 shows that the newly developed steel can deliver an outstanding combination of the ultimate tensile strength (minimum UTS of 1200 MPa) and with elongation (minimum 30%). Summary of tensile test results is shown in Table 2. The thickness of the bainitic plates lies within the range of 70-200 nm.

Table 1

	C	**Si**	**Mn**	**Cr**	**Al**	**N**	**Ti**	**V**	**Nb**
Min	0.20	1.0	1.0	0.1	0.01	0.002	0.01	0.01	0.01
Max	0.50	2.5	3.0	1.0	1.0	0.004	0.5	0.45	0.04

Table 2

Hardness/VHN	YS/ MPa	UTS / MPa	Uniform Elongation / %	Total Elongation / %
335-550	**900-1150**	**1200-1550**	**10-20**	**>30**

[048] Numerous modifications and adaptations of the system of the present invention will be apparent to those skilled in the art, and thus it is intended by the appended claims to cover all such modifications and adaptations which fall within the true spirit and scope of this invention.

Dated 05th day of **September, 2023**

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[5] Development and design of bainitic steel with minimum 1300 MPa UTS and minimum 20% elongation through continuous cooling; ***S. Das,*** S. Kundu, S. Sinha and A. Haldar.

[6] Development of continuously cooled bainitic steel with minimum 1200 MPa UTS and minimum 20% elongation, S. Das, Report No: R & D / 52 / 10, Report submitted to R & D Division, Tata Steel, Jamshedpur, 2010.

[7] Designing fully bainitic steel with minimum 400 VHN (~1200 MPa UTS) with minimum 20% retained austenite through continuous cooling; ***S. Das***, S. Kundu, A. Haldar; *Govt. number: 736 / KOL / 2011 / Dated 30. 05. 2011.*

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WE CLAIM:

1. A hot-rolled continuously cooled bainitic steel composition comprises carbon content of steel 0.2 to 0.50 wt.%; the silicon content 1.0 to 2.5 wt.%; and the manganese content varies 1.0 to 3.0 wt.%, aluminum from 0.01 to 1.00 wt.%, chromium from 0.1 to 1.0 wt.%, and nitrogen from 40-80 (ppm), respectively.

2. The hot-rolled continuously cooled bainitic steel composition, as claimed in claim 1, wherein the ultimate tensile strength is a minimum of 1200 MPa, whereas the yield stress is a minimum of 900 MPa and the uniform & total elongation minimum is 10% & 30%.

3. The method of preparation hot-rolled continuously cooled bainitic steel composition includes following steps:
   a) 40 kg batch of heat was produced within a vacuum induction furnace.
   b) The resulting cast steel was then forged to a thickness of 50 mm, followed by a homogenization process within the temperature range of 1100-1300 °C for 20-48 hours after which the steel was cooled along with the furnace wherein all further experiments were performed with homogenized steel only.
   c) The steel will be cast into a slab, hot rolling the slab into the strip at the required finish rolling temperature (FRT) 800-1000 °C up to 3-10 mm thickness.
   d) After the FRT, the cooling at 1-50°C per second and coiling the strip at temperature of 300-500 °C for 0.5 to 2 hrs to generate the desired microstructure.

4. The method of preparation hot-rolled continuously cooled bainitic steel composition, as claimed in claim 3, wherein final

microstructure contains 10-50% C-enriched austenite, 45-85% ultrafine nano-structured carbide-free bainite, and 1-10% martensite.

5. The hot-rolled continuously cooled bainitic steel composition, as claimed in claim 4, wherein the bainite plate thus produced has a thickness of 70-200 nm.

6. The hot-rolled continuously cooled bainitic steel composition, as claimed in claim 4, wherein the carbide-free bainitic steel produces a hardness of >350 VHN.

7. The hot-rolled continuously cooled bainitic steel composition, as claimed in claim 1, wherein the final strength of the composition steel is due to the presence of nano-sized bainite lathes and high dislocation densities and excellent ductility of steel arises due to the presence of high amount of stable retained austenite.

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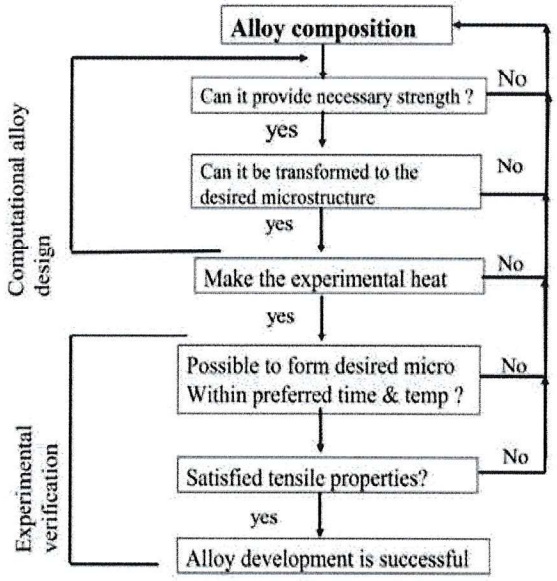
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ABSTRACT

A HOT-ROLLED CONTINUOUSLY COOLED BAINITIC STEEL COMPOSITION AND ITS METHOD OF PREPARATION

The present invention relates to a hot-rolled continuously cooled bainitic steel composition and its method of preparation. The composition comprises composition in wt%:C:- 0.20-0.50, Mn:- 1.0-3.0, Si:- 1.0-2.5, Cr:- 0-1.0, Al: 0.01-1.0, N: 0.005 max, Fe-balance along with some inevitable impurities. The composition provides high strength and elongation.

Published with Figure 2



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