Modern Approaches on Material Science

DOI: 10.32474/MAMS.2023.05.000211

ISSN: 2641-6921

Research Article

Trip-Aided Bainitic Ferrite or Carbide-Free Bainite (CFB) Steel: a Revisit

Gopal Sanyal*

[1]*Mechanical Metallurgy Division, Materials Group, India*

***Corresponding author:** Gopal Sanyal, Mechanical Metallurgy Division, Materials Group, BARC, Trombe, Mumbai, India

Received: 📅 August 11, 2023 **Published:** 📅 August 14, 2023

Abstract

Trip-aided Bainitic Ferrite (TBF) or Carbide-Free Bainite (CFB) is a special kind of steel offering superior combination of strength, toughness, and ductility due to transformation-induced plasticity (TRIP) effect. The current work involves critical review of this category of steel so as to present a brief state-of-the-art concept about such steels considering their alloy chemistry with a relevant discussion about role of each element, importance of their thermomechanical processing in conjunction with microstructural evolution, leading to corresponding mechanical response, and current challenges.

Keywords: Bainite; bainitic ferrite; TRIP steel; phase transformation

Introduction

TRIP-Aided Bainitic Ferrite (TBF) and Carbide-Free Bainite (CFB) are metaphors of the identical rating steels. Few establishments categorize them also as Dual Phase – High Ductility (DP-HD, or DH) steels. [1] On one hand, their processing route results in an ultra-fine bainitic ferrite grain size, leading to superior strength. On the other, the austenite in microstructure permits for a ‘transformation induced plasticity’ (TRIP) effect, causing heightened ductility with yet an elevated strength level Figure 1. [2] Martensitic transformation persuaded by local stress has the upshot of releasing stress concentrations, raising strain hardening rate, and endorsing uniform deformation, with resultant enhancements in strength, toughness, and ductility. TRIP-assisted steels of this type are thus recognized as ‘continuously annealed steels,’ as the intended microstructure can be obtained employing a multifaceted heat treatment by few seconds during the dealing out of the steel strip. Their microstructure composes of allotriomorphic ferrite as the foremost phase assorted with an overall 30-40% of bainite, martensite and carbon-enriched retained austenite [3].

Composition

A typical TBF steel contains about 0.1-0.2% C, ~1.5% Mn, as major alloying elements by weight in addition to either Si or Al (~1.5 wt.%). The extent of trace elements such as Nb and N and impurities such as S and P is critically limited. Table 1 is to list a few important TBF steels with detailed composition [1, 4-8].

Effects of each alloying element

Carbon is limited to no more than 0.2% to minimize carbide formation and attainment of desired strength with favouring retention of austenite at low temperature. This practice favours better weldability and corrosion resistance. Mn is added for retention of sufficient austenite to affect the desired TRIP effect. Si averts cementite (Fe_3C) precipitation, so the carbon released by bainite supplements the retained austenite. Instead of Si, Al is also beneficial in supressing Fe_3C formation (steel 3 of Table 1). There is no trouble in obtaining the desired microstructure but aluminium in solution does not underwrite to the ferrite’s strength. That is why, aluminium-bearing steels are weaker than silicon-bearing counterparts [9] The strength of the Al-containing TRIP steels can be raised with no compromise in formability by enhancing the normal carbon concentration and optimising the heat treatment [10] Efforts have been endeavoured to advance the attributes of these alloys by microalloying with Nb. Nb in solid solution appears to surge the amount of retained austenite [11] Yet, for the case of isothermally transformed TRIP steel, fine NBCs precipitates reported to exist within the bainitic ferrite for highest isothermal transformation temperature (475°C), has been found to contribute subtly for strengthening of the steel [12] Purposeful accompaniments of N to TRIP-assisted steels cause precipitation of fine AlN in g. The nitrides limit the advance of a grains during following inter-critical annealing. Hence, presence of a mass fraction of Alan of just 4×10−4 decreases the a grain diameter by a factor of two, since about 4 to 2 µm, with a resultant surge in the strength and ductility [13].

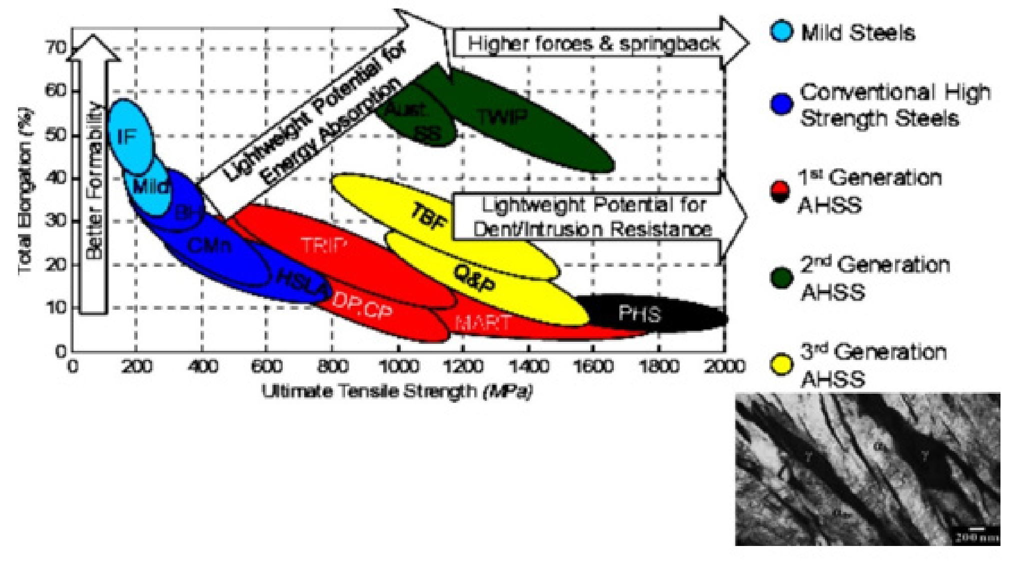

Figure 1: Steel banana curve, showing TBF steel amongst several different grades and classes with (inset) typical microstructure of a TBF steel [2].

Table 1: Chemical composition of a few notable TBF steel [1,4-8].

Steel	Alloying elements/impurities (wt. %)								Reference/Remarks
	C	Mn	Si	Al	N	Nb	S	P	
1	0.12	1.5	1.5	0.045	0.0035	-	-	-	[1]
2	0.16	1.3	0.38	0.03	0.0065	-	-	-	[1] Low-Si
3	0.11	1.55	0.06	1.5	0.0017	-	-	-	[1] High-Al
4	0.19	1.59	1.63	0.036	0.0109	-	-	0.013	[4]
5	0.2	1.55	1.5	-	-	-	-	-	[5]
6	0.2	1.55	1.5	-	-	0.039	-	-	[5]
7	0.233	1.54	1.365	0.08	-	-	0.004	0.007	[6]
8	0.14	1.66	1.94	0.05	-	-	0.015	0.008	[7]
9	0.13	1.42	1.5	2.22	-	-	0.009	0.013	[8] High-Al, High-Si

Thermomechanical processing

During thermomechanical processing (TMP) of TRIP-aided steels, the bainite reaction is stifled when the austenite is sternly distorted, due to the commencement of mechanical stabilisation (Figure 2) [14-15] That is why, TMP does not amass the equivalent reimbursements as in ferrite-pearlite steels. The consequence is embroidered by the fact that the allotriomorphic ferrite conversion is fast-tracked. The greater volume portion of allotriomorphic ferrite leaves a smaller amount of austenite obtainable for the bainite transition. [16] It also favours a larger amelioration of the remaining austenite with carbon, thus dropping the quantity of attainable bainite. An extra upshot is to lessen the sum of crystallographic variants of bainite that form in apiece austenite crystal. Variants are

Citation: Gopal Sanyal*. Trip-Aided Bainitic Ferrite or Carbide-Free Bainite (CFB) Steel: a Revisit. Mod App Matrl Sci 5(3)- 2023. MAMS. MS.ID.000211. DOI: 10.32474/MAMS.2023.05.000211

preferred by the remaining stresses and dislocation arrangements left in the distorted austenite grain morphology which thereafter transmutes to bainite. This phenomenon has been vibrantly verified in TRIP steels using orientation imaging microscopy (OIM) [17] The bainitic structure that forms since deformed austenite is observed to be far further set and restricted in crystallographic variants than that since undeformed austenite. This should partake significances on the mechanical properties, but they are not yet studied well. Deformation presents misorientations in the austenite, which are congenital by discrete plates of bainite. It has been exhibited that in a bainite plate that is about 10 μm long, the misorientation between the two ends can be as large as 8° when the bainite breeds from austenite that has been permanently deformed by 80% strain. [18] The defects accountable for this misorientation must result in a consolidation of the bainite plates.

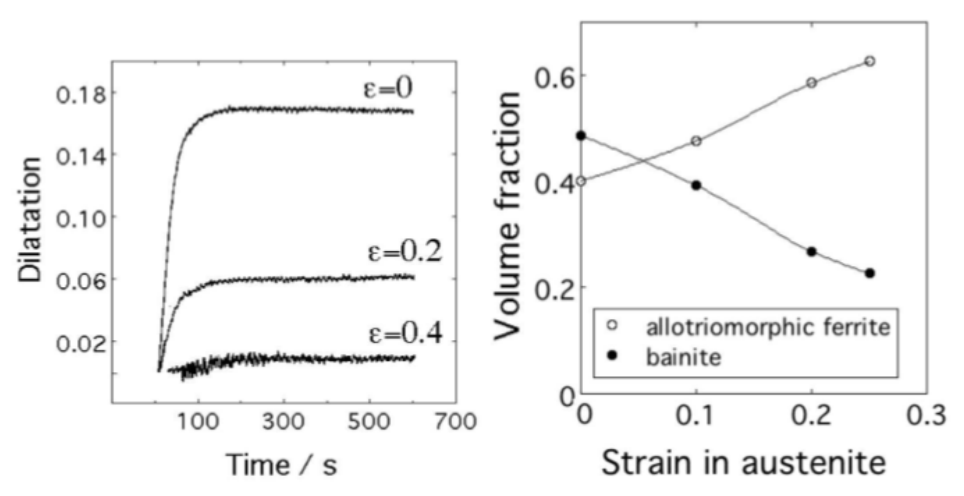

Figure 2: (a) Mechanical stabilisation of bainite transition in a TRIP steel as a function of plastic strain, ϵ, in g. The dilatation is a quantification of the portion of bainite that develops, and the time is at the temperature where bainite forms [13] and (b) The increase in amount of allotriomorphic a is when g is plastically strained, causing a decrease in the segment of bainite [14].

Microstructure evolution

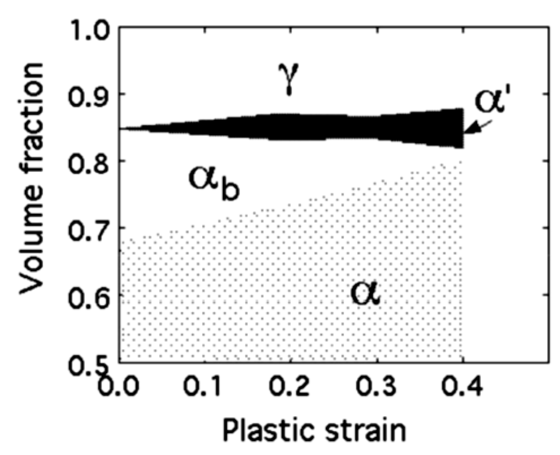

Figure 3: The influence of strain on the development of microstructure in TRIP-assisted steels [1]

The effect of transformation from plastically deformed austenite, on the overall development of microstructure in TRIP-assisted steels can pictorially summarised in Figure 3. [1,19] Papaefthymiou et al. observed that the application of plastic deformation in the inter-critical temperature regime has a strong impact on the formed microstructure throughout a standard heat treatment sequence on a TRIP steel. They elaborated this dependence with the help of phase maps. The decomposition of g during supercooling since the inter-critical temperature is boosted, leading to the g becoming minor in quantity and steadier. Succeeding bainite creation is thus sluggish and to a condensed level. Lesser expanses of bainite are linked with greater amounts of retained g, resulting in easier martensite development during quenching to ambiance.

Mechanical Properties

It is tough to attain decent formability at strength heights in surplus of 900MPa when the microstructure is that of normal TRIP-assisted steels, i.e., comprising of a combination of allotriomorphic a, bainite and g. The shortcoming may be evaded by eradicating the allotriomorphic a to attain only bainitic a and retained g. This not just only upsurges the strength but by turning the microstructure more even, imparts decent stretch-flange ability as quantified in hole expansion tests [20] Supplementary enhancements are accomplished by guaranteeing that majority of the g is in the shape of films instead of blocks that simply convert into martensite. [21] The blend of formability and strength realized in fully bainitic TRIP steels is valuable in manufacturing machineries e.g., the arms of automobile suspension arrangements. 'Quench and partitioning steels' are usually formed by cooling the steel to a temperature underneath MS such that a portion of martensite is attained, and then heating to let some of the extra carbon in the martensite to divide into the retained g. Such practice can deliver an UTS of even more than 1650 MPa with a total elongation of 19%, due to mixed microstructure. However, such heat treatment may be too sophisticated for mass production [22] Many reports involving split Hopkinson bar tests suggest no compromise in ductility of TRIP steels when tested at higher strain rates. (Figure 4) [23-25] Empirically it has been suggested that yield anisotropy is reduced in such steels when tested at high strain rates [26] Pre-strain has been reported to increases the high-cycle fatigue limit in rotating beam tests carried out on smooth samples (Figure 5) [27].

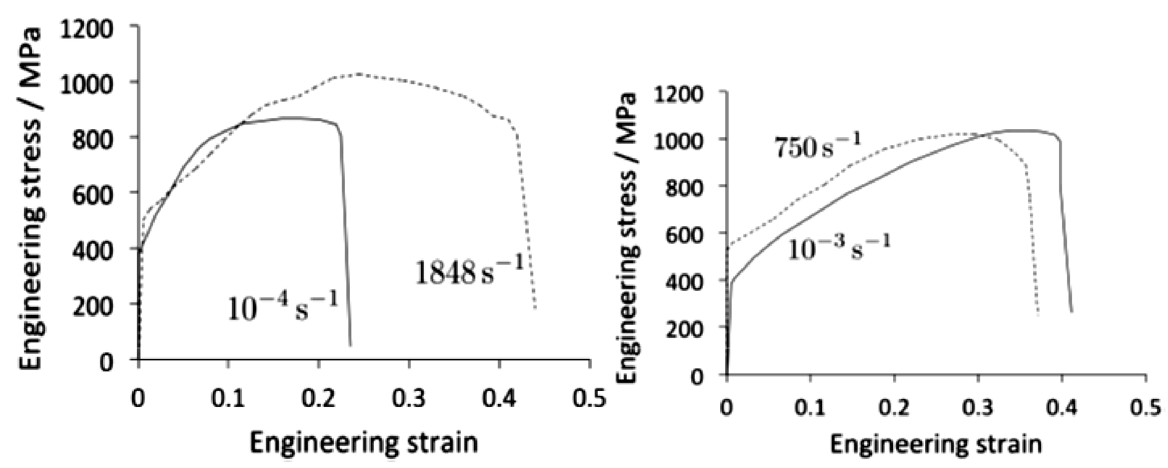

Figure 4: Strain-rate dependence of the tensile properties of TRIP-assisted steels (a) Fe-0.21C-1.78Mn-1.53Si wt% steel [24] and (b) Fe-0.2C-0.4[Si, CR, Mo]-2.9[Al, Mn] wt% steel [25].

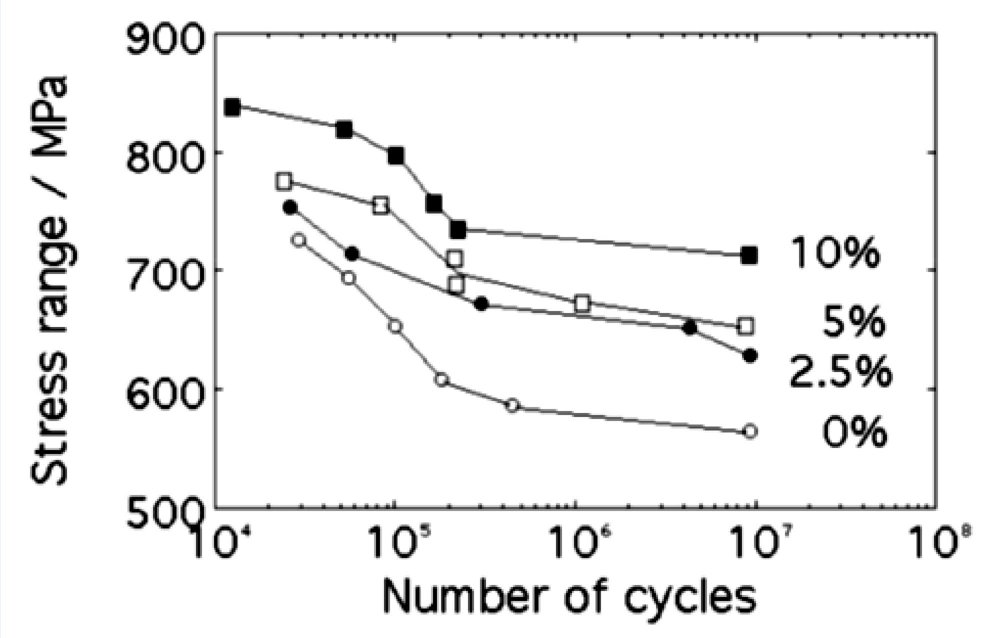

Figure 5: S-N curves for a TRIP-assisted steel with prior deformation as indicated [1,27].

Citation: Gopal Sanyal*. Trip-Aided Bainitic Ferrite or Carbide-Free Bainite (CFB) Steel: a Revisit. Mod App Matrl Sci 5(3)- 2023. MAMS. MS.ID.000211. DOI: 10.32474/MAMS.2023.05.000211

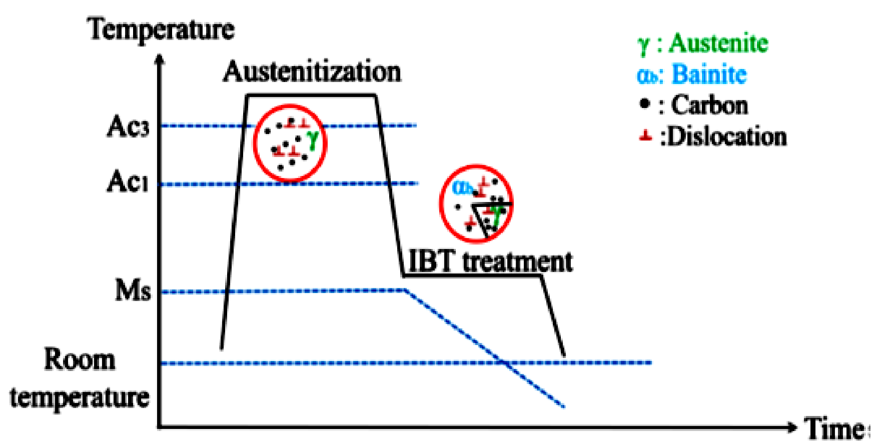

Figure 6: General heat treatment procedure employed on carbide-free bainitic (CFB) steel [29].

Post-deformation microstructures

Two austenite morphologies can be engaged afterward transition to bainite: film austenite, dispersed amid discrete bainitic ferrite's subunits, and bristly austenite chunks, situated between non-parallel bainite sheaves. [28] Blockish austenite is structurally not stable and transmutes to martensite with little exterior loads, and thus does not have much influence on the plasticity of TBF steels. Hereafter, blockish austenite must be reduced or, preferably, eliminated, to guarantee high strength and ductility of TBF steels. [28] Very fine grained TBF steels are made by complete austenization, trailed by holding at constant temperature, (Figure 6). [29] A scheme involving many stages for low temperature bainitic transition has been technologically advanced to polish the structure and advance the strength-ductility balance. [30] The steel strip is primarily soaked at 300 °C for 1.5 hour to let fractional alteration of austenite happen, then rapidly shifted to one more furnace at 250 °C for 24 hours and lastly soaked at 200 °C for 72 hours. [30] The bulky austenite thus increasingly transforms into superfine bainite morphology. Two processes are in control for fine-tuning of bainite grain: primarily, a bigger driving force of bainitic transition at lesser temperature accelerates formation of sizable embryo of bainite; secondly, thus the carbon migrated to austenite all through the isothermal soaking course, austenite is steadier to hinder boundary migration, which limits the growing of bainite subunits [30].

Challenges

There are a few blockades still constraining additional progress of CFB steels. The knowhow of bainitic transition stays still debatable [31] Two diverse opinions regarding bainitic transformation mechanism have been stated: (a) diffusion-controlled transformation [32] where growing of bainitic sheaf is attained by a migration "ledge" and inertia of the transition is encouraged by the solute drag effect at the drifting austenite/bainitic ferrite boundary, and (b) a diffusion-less transition [33] where bainitic ferrite is developed by a displacive machinery analogous to martensitic transformation. The bainitic conversion stops while the Gibbs free energy of bainitic ferrite and austenite becomes equal. The supplementary question is the comparatively sluggish pace of bainitic alteration, restraining the manufacturing interest. Addition of Al and Co is looked upon as a decent option to hasten the bainitic transition since they upsurge the motive vigour for bainitic transition and make available a grain fine-tuning upshot [34] The transition spell is reduced from 240 to 24 hours or, even 8 hours by adding 1.6 wt.% Co or 1.6 wt.% Co plus 1 wt.% Al [34] The alteration can be more augmented by grain size refinement. [34] Finer austenite grains possess a greater boundary concentration, working as greater nucleation spots for bainitic ferrite and quickening the birth of bainite [34].

Conclusions

TBF or CFB steels have been critically reviewed. The steels offer superior combination of strength and ductility due to finer grain structure and ability to impart TRIP effect due to presence of reasonable amount of retained austenite along with fine and even distribution of bainitic ferrite and martensite. Typically, Mn and Si/Al @ 1.5 wt.% are added as alloying element in this kind of steels. This prearrangement is obtained since development of stepwise heat treatment route favouring transformation of austenite into finer bainitic ferrite. Though the potentially obtainable mechanical properties (typically UTS: 1600 MPa with ductility 20%) are excellent for lightweight automobile applications, processing of such steel is till date still expensive and thus industrial interest for such steel is still not up to the mark. More scientific investigation is thus necessary for overcoming such drawbacks to find the steel commercially successful.

References

1. Bhadeshia, Harshad Kumar Dharamshi Hansraj (2019) Bainite in steels: theory and practice. CRC press.
2. Billur, Eren, Semih Karabulut, İmren Öztürk Yilmaz, Samet Erzincanlioğlu Hafize et al; (2018) Mechanical Properties of Trip Aided Bainitic Ferrite TBF Steels in Production and Service Conditions. Hittite Journal of Science and Engineering 5(3): 231-237.

Citation: Gopal Sanyal*. Trip-Aided Bainitic Ferrite or Carbide-Free Bainite (CFB) Steel: a Revisit. Mod App Matrl Sci 5(3)- 2023. MAMS. MS.ID.000211. DOI: 10.32474/MAMS.2023.05.000211

3. Pereloma, Elena, David V, Edmonds (2012) eds. Phase transformations in steels: fundamentals and diffusion-controlled transformations. Elsevier.
4. Streicher Clarke AM, Speer JG, Matlock DK, Williamson DL, DeCoomanBC, et al. (2005) Analysis of lattice parameter changes following deformation of a 0.19 C-1.63 Si-1.59 Mn transformation-induced plasticity sheet steel.Metallurgical and Materials Transactions A 36: 907-918.
5. Pereloma, Elena V, Timokhina IB, Peter D, Hodgson (1999) Transformation behaviour in thermomechanically processed C–Mn–Si TRIP steels with and without Nb. Materials Science and Engineering A 2: 448-452.
6. Li, Zhuang, Di Wu, Rong Hu (2006) Austempering of hot rolled Si-Mn TRIP steels Journal of Iron and Steel Research International 5: 41-46.
7. Itami, Atsushi, Manabu Takahashi, Kosaku Ushioda (1995) Plastic stability of retained austenite in the cold-rolled 0.14% C-1.9% Si-1.7% Mn sheet steel. Isij International 35(9): 1121-1127.
8. Jacques, Pascal, Quentin Furnémont, Anne Mertens, Francis Delannay, et al. (2001) On the sources of work hardening in multiphase steels assisted by transformation-induced plasticity. Philosophical Magazine A 81(7): 1789-1812.
9. Girault, Etienne, Anne Mertens, Pascal Jacques, Yvan Houbaert (2001) Comparison of the effects of silicon and aluminium on the tensile behaviour of multiphase TRIP-assisted steels. Scripta materialia 44(6): 885-892.
10. De Meyer, Marijke, Vanderschueren DCBCD, De Cooman BC (1999) The influence of the substitution of Si by Al on the properties of cold rolled C-Mn-Si TRIP steels. ISIJ international 39(8): 813-822.
11. Hanzaki, Zarei A, Hodgson PD, Yue S (1995) The influence of bainite on retained austenite characteristics in Si-Mn TRIP steels. ISIJ international 35(1): 79-85.
12. Sugimoto, Koh Ichi, Toshiki Muramatsu, Tomohiko Hojo, Shun Ichi Hashimoto, et al. (2005) Ultra-high-strength C-Si-Mn-Nb-Mo TRIP-aided sheet steels. In Materials Science and Technology 2005 Conference 15-24.
13. Baik, Seung Chul, Sung Ho Park, Ohjoon Kwon, Dong Ik Kim, et al. (2006) Effects of nitrogen on the mechanical properties of cold rolled TRIP-aided steel sheets. ISIJ international 46(4): 599-605.
14. Luo, Haiwen, Lie Zhao, Suzelotte O, Kruijver, et al. (2003) Effect of intercritical deformation on bainite formation in Al-containing TRIP steel. ISIJ international 43(8) : 1219-1227.
15. Basuki, Arif, Etienne Aernoudt (1999) Effect of deformation in the intercritical area on the grain refinement of retained austenite of 0.4 C trip steel.Scripta Materialia 40(9): 1003-1008.
16. Ryu H B, Speer JG, Wise JP (2002) Effect of thermomechanical processing on the retained austenite content in a Si-Mn transformation-induced-plasticity steel. Metallurgical and Materials Transactions A 33: 2811-2816.
17. Girault, Etienne, Stéphane Godet, Patrice Jacques, Ph Bocher, et al. (2001) Effect of hot-rolling in the austenitic region on the formation of isothermal bainite in a 0.4 C-1.5 Si-1.4 Mn steel. Le Journal de Physique IV (11) PR8: 8-217.
18. Godet, Stéphane, Glez JC, Yan He JJ, Jonas, et al. (2004) Grain-scale characterization of transformation textures. Journal of applied crystallography 37(3): 417-425.
19. Papaefthymiou S, Bleck W, Kruijver S, SietsmaJ, Zhao L, et al. (2004) Influence of intercortical deformation on microstructure of TRIP steels containing Al. Materials Science and Technology, London, UK 20(2): 201-206.
20. Sugimoto, Koh ichi, Tsutomu Iida, Jyunya Sakaguchi, Takahiro Kashima, et al. (2000) Retained austenite characteristics and tensile properties in a TRIP type bainitic sheet steel. ISIJ international 40(9): 902-908.
21. Bhadeshia HKDH, Edmonds DV (1983) Bainite in silicon new steels composition–property approach Part 1 Metal Science 9: 411-419.
22. Gao, Guhui, Han Zhang, Zhunli Tan, Wenbo Liu, et al. (2013) A carbide-free bainite/martensite/austenite triplex steel with enhanced mechanical properties treated by a novel quenching–partitioning–tempering process. Materials Science and Engineering A 165-169.
23. Sun, Xin, Ayoub Soulami, Kyoo Sil Choi, O. Guzman, W Chen (2012) Effects of sample geometry and loading rate on tensile ductility of TRIP800 steel. Materials Science and Engineering p. 1-7.
24. Van Slycken, Joost, Patricia Verleysen, Joris Degrieck, Ludovic Samek (2006) High-strain-rate behavior of low-alloy multiphase aluminium-and silicon-based transformation-induced plasticity steels. Metallurgical and Materials Transactions A 37: 1527-1539.
25. Curtze SVT, Kuokkala M, Hokka, Peura P (2009) Deformation behavior of TRIP and DP steels in tension at different temperatures over a wide range of strain rates. Materials Science and Engineering 1: 124-131.
26. Jeehyang H, Hoon Huh, Chang Soo Lee (2013) Effect of strain rate on plastic anisotropy of advanced high strength steel Sheets. International Journal of Plasticity 44: 23-46.
27. Song, Sung-Moo, Koh-Ichi Sugimoto, Shinsuke Kandaka (2003) Effects of Prestraining on High-Cycle Fatigue Strength of High-Strength Low Alloy TRIP-Aided Steels. Journal of the Society of Materials Science 3: 223-229.
28. Garcia-Mateo, Carlos FG, Caballero Thomas Sourmail, Kunt (2012) Tensile behaviour of a nanocrystalline bainitic steel containing 3 wt% silicon. Materials Science and Engineering pp. 185-192.
29. Caballero FGH, Bhadeshia KJA, Mawella DG, Jone (2022) Very strong low temperature bainite Materials science and technology 3: 279-284.
30. Wang XL, Wu F, Hu L, Wan XL (2014) Multi-step isothermal bainitic transformation in medium-carbon steel. Scripta Materialia 74: 56-59.
31. Fielding LCD (2013) The bainite controversy. Materials Science and Technology 4: 383-399.
32. Reynolds WT, Hartfield, Aaronson HI (1990) An investigation of the generality of incomplete transformation to bainite in Fe-CX alloys Metallurgical Transactions A 21: 1479-1491.
33. Bhadeshia, Harshad Kumar Dharamshi Hansraj, Christian JW (1990) Bainite in steels Metallurgical transactions A 21: 767-797.
34. Gjostein NA, Domian HI, Aaronson, Eichen E(1966) Relative interfacial energies in Fe- C alloys. Acta Metallurgica 12: 1637-1644.

Citation: Gopal Sanyal*. Trip-Aided Bainitic Ferrite or Carbide-Free Bainite (CFB) Steel: a Revisit. Mod App Matrl Sci 5(3)- 2023. MAMS. MS.ID.000211. DOI: 10.32474/MAMS.2023.05.000211

DOI: 10.32474/MAMS.2023.05.000211