A Review on the development of 3rd generation advanced-high strength steels (HSS)

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Abstract: ***Conventional-high strength steels (HSS) are an integral part of the automotive bodies for many years by the automotive industries due to their high strength. The 1st-generation advanced HSS with ferrite in the microstructure provides high strength than the conventional-HSS but failed to give sufficient toughness. The 2nd-generation advanced HSS enhances the toughness of the advanced-HSS. But the presence of more alloying elements cost the 1st- and 2nd-generation advanced-HSS. With less amount alloying elements, the 3rd-generation advanced-HSS give better strength and toughness than the 1st- and 2nd-generation advanced-HSS at a low cost. The 3rd-generation advanced-HSS generates multiphase microstructure (ferrite, martensite, retained austenite, bainite).***

Keywords**: 1st-generation advanced-HSS, 2nd-generation advanced-HSS, 3rd-generation advanced-HSS, ductility, multi-phase microstructure**

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I. INTRODUCTION

Initially, the classification of steel is on three types according to their microstructure and tensile strength. The first type is a low carbon and conventional type of high strength steel (HSS), the second type is the development of the 1st-generation advanced-HSS, and the third type is the 2nd-generation advanced-HSS. The interstitial free and traditional mild steel are under low strength steel. The conventional-HSS consists of C and Mn containing steel, bake hardening, and high strength low alloy steels. Advanced-HSS are lightweight and more fuel-efficient without compromising passenger safety [1]. High strength, ductility, and high formability are also the properties of advanced-HSS. Selective chemical composition and complex microstructure require less material, which reduces the vehicle's weight. With the addition of different alloying elements or heat treatment techniques or using thermo-mechanical processing routes, advanced-HSS achieves these properties [2, 3].

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II. STEEL GENERATION

A. Mild Steel

Mild steel is generally known as low carbon steel as it contains less amount of carbon (0.05% to 0.25%) by weight. Mild steel is ductile, machinable, and weldable. It has a maximum tensile strength of 440MPa. This steel is suitable for forming operations and has low corrosion resistance in an acidic environment.

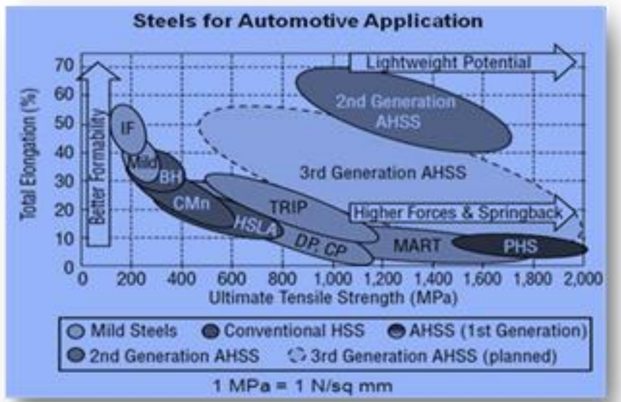

Fig.1 The tensile strength of each generation of AHSS on the horizontal axis and the elongation is on the vertical axis [4].

B. Interstitial free (IF)

IF steels are the deep-drawing steels, having outstanding ductility, formability, and high work hardening rates with low strength. Low strength limits its use in automotive bodies. Quenching and partitioning techniques further improve the properties of the IF steels [5, 6].

C. Bake hardenable (BH)

BH steels contain a simple ferritic microstructure but, solid-solution strengthening gives strength to this steel. Special heat treatment techniques help to keep the carbon in the solution. This heat treatment method increases the yield strength of this steel by maintaining its formability [7].

D. High strength low alloy (HSLA) steels

The addition of alloying elements like titanium, vanadium, niobium, etc., improves the HSLA-steel properties by forming stable carbides, nitrides, or carbo-nitrides [8]. These steels provide high mechanical properties such as strength, toughness, high formability, and weldability. These steels also have a high rate of corrosion-resistance properties [9, 10].

III. 1ST-GENERATION ADVANCED-HSS

The addition of alloying elements into the mild steel develops the HSLA-steels. These steels are of high strength, but they have a low rate of elongation. By further modification, HSLA-steels are changing into the 1st generation advanced-HSS like dual-phase steel (DP-steel), complex Phase steel (CP-steel), transformation induced plasticity steel (TRIP-steel), and martensitic steels [11, 12].

A. DP- Steel

The mechanical properties of DP-steels can modify by changing the grain size, morphology, and volume fraction of martensite. DP-steels are having a microstructure of ferrite and martensite, which possess high specific strength. These steels usually have high ultimate tensile strength (UTS) (due to the martensite). The application of different heat treatment methods helps to give these properties [13, 14].

B. CP-Steel

The microstructure of complex phase steels consists of a ferrite/bainite matrix. It contains a small amount of martensite, pearlite, and retained austenite. CP-steels show high formability, high yield strength with higher fatigue strength. Alloying elements like titanium, vanadium, or niobium modify the properties by precipitation strengthening [15].

C. TRIP-steels

TRIP-steels have a carbon percentage of 0.20-0.25% ferrite and martensite in the microstructure, along with a lesser amount of retained austenite. These steels give high strength, formability, impact resistance, and toughness. During plastic deformation, the austenite part of the TRIP steel changes into the martensite. It increases the elongation. It produces some bainite at an intermediate temperature [16 - 18].

D. Martensitic steels

Martensitic steels are possessing high strength and toughness with high corrosion resistance. It consists of a matrix with a higher amount of martensite, with a lesser amount of ferrite and bainite. The addition of carbon with 11 to 17% chromium forms martensitic stainless steel. It strengthens austenite and improves the weldability of the steel [19, 20].

E. Press Hardening Steels (PHS)

Press hardening steels with B, C, and Mn as alloying elements, providing ultra-high strength[21]. M. Abbasi et al. observed that for boron-alloyed steel, flow strength and the rate of work hardening decreases, and hardness increases as the deformation temperature increases at the time of the isothermal transformation process [22].

F. Limitations of 1st-generation advanced-HSS

For 1st-generation advanced-HSS material, strength is high, but it fails to give the required elongation. The 1st-generation advanced-HSS is consists of only ferritic microstructure rather than multiphase microstructure. Therefore, the development of 2nd-generation advanced-HSS takes place to meet the requirements of the automotive industry.

IV. 2ND-GENERATION ADVANCED-HSS

The 2nd generation advanced-HSS are generally stainless steel and twin induced plasticity or TWIP steel. The addition of alloying elements enhances the strength and elongation because of the high cost and low weldability of these steels, which do not meet the automotive industry requirements [23, 24].

A. Twinning induced plasticity steels

In TWIP steels, the manganese percentage is between 17 to 24%, due to which this steel is fully austenitic at room temperatures. It is a 2nd generation steel where the tensile strength of the steel ranges from 600–100MPa with high toughness and stretchability. For TWIP steel (>15%Mn), when the steel is under deformation, it generates twins. These twins strengthen the steel and make the steel fully austenitic structure. The elongation of these steels is more than 50 % [25, 26]. In TWIP steels, the rate of strain hardening depends on the stacking fault energy (SFE). SFE regulates the deformation behavior of the TWIP steel. By lowering the SFE, ductility enhances. Alloying element addition helps to increase the twinning behavior of TWIP steel. For pure twining steel, SFE should be more than 20 mg/m2. By adding aluminum into the TWIP steel SFE, increases.

B. Stainless steels

Austenitic stainless steel (ASS) exhibits high strength, elongation, and a high work-hardening capacity. During cold working, Austenite is not stable in the ASS. It can partly transform into martensite, which provides high strength to the steel.

C. Limitations of 2nd-generation advanced-HSS

These steels provide high strength and high formability, which is necessary for automotive body parts. The addition of the alloying of elements increases the cost, and its delayed cracking fracture limits its use in the automobile body parts [27].

V. 3RD-GENERATION ADVANCED-HSS

The 3rd generation advanced-HSS consists of a multiphase microstructure as martensite, austenite, and bainite. Austenite helps to enhance the work hardening capacity of the 3rd generation advanced-HSS[28]. The thermo-mechanical treatment controls the stability of austenite. The 3rd generation advanced-HSS possess a combination of high strength and elongation while reducing the weight. Recently, quenching-partitioning steel (Q and P steels) and TRIP aided bainitic ferrite steel [29] developed under the 3rd generation advanced-HSS. These steels consist of fine-grain ferrite, carbide free bainite, martensite, and retained austenite.

A. Q and P steels

Q and P steels contain austenite with a carbon partitioning between martensite and retained austenite. In the quenching stage, initially, austenite quenching occurs below the starting temperature of martensite. In the partitioning stage, the remaining austenite with carbon gets stabilized at room temperature [30]. Q and P steels possess good tensile strength and toughness along with lightweight and high corrosion resistance. These properties of the Q and P steels make them acceptable for automotive body parts. The addition of alloying elements further modifies the properties of this steel [31, 32].

B. TRIP aided bainitic ferrite steel

TRIP-aided bainitic ferrite steels provide good mechanical properties. The presence of these properties makes them favorable for the automotive industry. The addition of silicon gives carbide-free bainite and metastable-retained austenite during heat treatment, which further enhances the mechanical properties of this steel [33, 34].

C. Nano steel

Nowadays, researchers are trying to develop steels with nanocrystalline structures by applying different processing methods and advanced heat treatment techniques. For this steel, the grain size of austenite is in the nanometer range. High strength, toughness, lightweight, and high corrosion resistance make this steel more suitable for automotive bodies [35].

CONCLUSIONS

According to the growth and development of the advanced-HSS steels (1st, 2nd, and recently the 3rd generation), it is clear that these steels meet all the requirements for the automotive body parts which need the automotive industry. These steels provide high strength, toughness, light weight, and high corrosion resistance. Hence these steels are widely used as an economical choice for the automotive industry.

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