THIRD GENERATION OF ADVANCED HIGH STRENGTH SHEET STEELS FOR THE AUTOMOTIVE SECTOR: A LITERATURE REVIEW

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Abstract
The modern vehicles demand a better fuel economy, decrease in ozone harming substance outflows, and superior safety requirements led to new developments of steel grades with higher strength and good formability. Third generation of advanced high strength steels are the next stage for the automotive companies in steel sheets development. The principal concept of third generation of AHSS is to reap the mechanical properties benefits from first and second generation of AHSS at cost neither too high nor too low. This literature review summarizes the results achieved in a previous paper of the Third Generation of Advanced High Strength Sheet steels literature published by D. Krizan et al. Where we intend to focus on, the recent developments and future trends of the third generation of advanced high strength sheet steels (3-GEN AHSSs) including quenching and partitioning (Q&P), TRIP bainitic ferrite (TBF), medium manganese, density reduced TRIP (δ-TRIP) and nano steels for the modern automotive industry, with emphasis on their main characteristics, processing, and applications.

Keywords: *AHSS, mechanical properties, automotive industry, microstructure*

1. Introduction

Steel has superior mechanical, physical, chemical, and thermal properties compared to many other materials. These features make steels the best candidate for many applications. Due to the changeability in strength levels and extraordinary flexibility regarding formability, steel is considered as the ideal material for the automotive sector. Its application is not restricted only in vehicle bodies, but many other parts like engine, chassis, and wheels, etc. are produced from steels. The weight reduction; enhanced fuel efficiency, elevated safety precautions, and increasing comfort requirements led to new development of steel grades with higher strength and good formability, what gave to the automotive designers more opportunities to optimize the component geometry and to meet the growing desire of consumer [1].

A serious improvement has been achieved in the past several years of development for high-strength steels, where new grades of Advanced High Strength Steel (AHSS) with an extraordinary strength-ductility combination have been developed resulting from carefully controlled cooling and heating processes.

The current review builds on a previous paper of the Third Generation of Advanced High Strength Sheet steels literature published by D. Krizan et al. Where The main properties, the metallurgical background and the main processing routes of the recent developments and future trends of the third generation of advanced high strength sheet steels (3-GEN AHSSs) were discussed.

2. AHSS families

There are in excess of 3500 various types of steel with different properties, as indicated by the World Steel Association. Steel is composed of iron and carbon ranges from 0.0 to 2.06%, with less than 1% of impurities and additional alloying elements such as Manganese, Silicon, Phosphorus, Sulphur, and Oxygen.

Therefore, we can classify steels in the automotive sector with different methods. There are three principal groups, which are Low Strength Steels, Conventional High Strength Steels and Advanced High Strength Steels (AHSS). Also, new AHSS grades have been developed for example: X-AHSS (Extra Advanced High Strength Steels) and U-AHSS (Ultra Advanced High Strength Steels), and various types of so-called 3-GEN AHSS steels. In Figure 1, the relationship between the ultimate tensile strength (UTS) and the total elongation (TE) is shown for various generations of high strength steels [2].

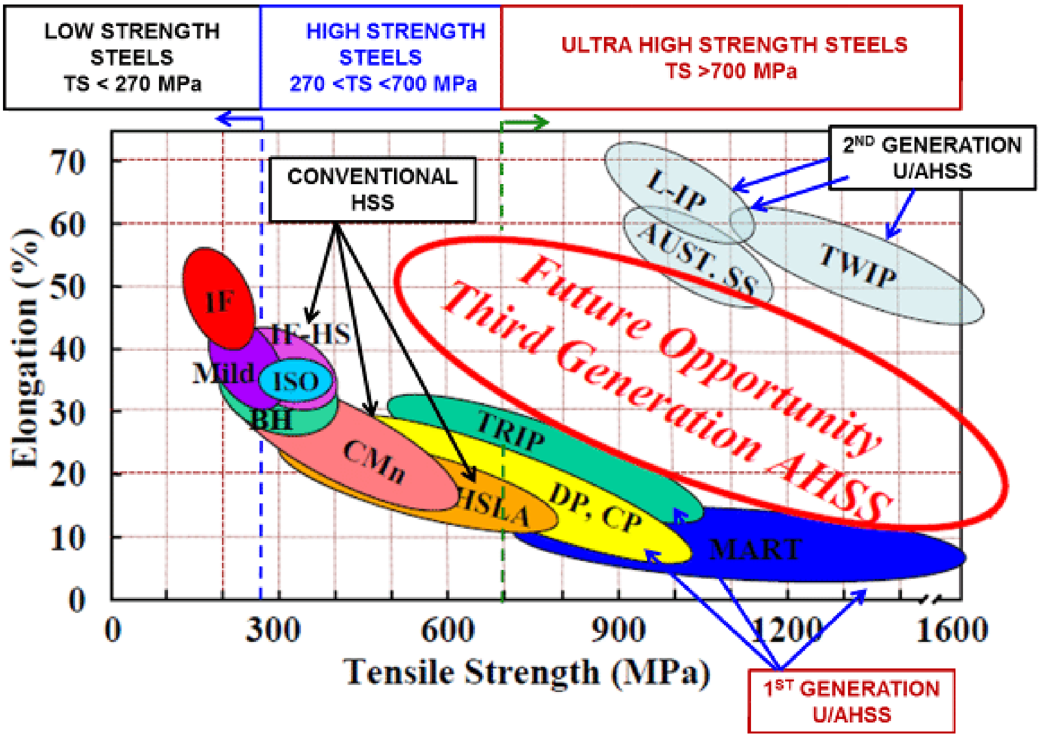

Figure 1. *Various automotive steels and their corresponding elongations and tensile strengths [2]*

One of the classification methods present the strength of the steel. In general, steels with 270 MPa tensile strength or less are named as “Low Strength steels” while steels with tensile strength in between 270 and 700 MPa are denoted as "HSS"; and steels with 700 MPa tensile strength and above are called as "AHSS", where in most cases, the term AHSS is preferred instead of XHSS and UHSS differentiation [3]. However, it is worth mentioning that there are some problems in this classification system with the on-going development of the many new grades for each type of steel. Therefore, some type of steel can have strength grades that encompass two or more strength ranges.

3. Third Generation AHSS Development

Lately, several cooperation and programs have been made between steel companies and research institutes to developing 3-GEN AHSS with superior mechanical properties in between the first and second generation AHSS. Where recent researches are focusing on improving the mechanical properties of the third generation in order to conquer the first and second generation AHSS disadvantages, by different methods such as improvement in processing routes, minimizing the alloying elements, strain aging, grain refinement and transformation induced plasticity (TRIP) or twinning induced plasticity (TWIP) effects [3].

The 3-GEN AHSS have complex microstructures consisting of ferrite, martensite, bainite and significant amounts of metastable (or retained) austenite. Where, the multi-phase constituents increased ductility (e.g., ferrite), strength (e.g., martensite or bainitic) and enhance the strain hardening (e.g., austenite). A few types have been developed in recent times, two of them are in production and have already been incorporated in the modern car body structures: TRIP-aided Bainitic Ferrite (TBF) steels and Quench-and-Partitioning (Q&P) steels, whereas, the others are still under development and not yet commercially available: Medium-Mn steels, density reduced TRIP steels (δ-TRIP), Nano steel [4].

3.1. TBF Steels

TBF steels have received a wide interest because of their unique combination of high strength-formability and can be produced at relatively low costs. These steels are essentially bainitic ferrite matrix with metastable retained austenite inclusions. TBF chemical composition is containing (0.15 wt% C), (1.5 wt% Si), (1.5 wt% Mn), in addition to alloy modifications comprises Al, Nb and Cr content [5]. TBF steels produced by hot and cold rolling processes [6]. Hot rolling is generally carried out at temperatures where the steel is supposed to be fully austenitic. After that, the material is cooled down at which the austenite transforms to bainite. These steels have a high level of silicon concentration in order to avoid any precipitation of carbide particles during bainitic transformation that may deteriorate the toughness also ensure the austenite stabilization by enhancing the carbon content [7]. Essentially, the low carbon with small addition of alloying content ensure good weldability without the need for any additional heat treatments [8]. Tensile strength level for TBF steels is usually above 980 MPa. For its unique and excellent properties, TBF steel can be applied to various structural automobile components, especially the applications that require high localized strain realization such as seat frames or center pillar reinforcements [9].

3.2. "Q & P" Steels

Q & P heat treatment process has an important role to develop 3-GEN AHSS. The microstructure of Q & P steels contains (5 – 12 %) metastable retained austenite, (20 – 40 %) ferrite, (50 - 80 %) martensite and around (4%) of alloying elements (carbon, nickel, molybdenum, manganese, and silicon) [10]. These grades of steels produced through a multi-step thermal processing route (as shown in Figure 2

[11]). The first step it comes after heating the steel to full or partial austenite temperature, then quenching at martensite temperature (M_s) to have a mixture of martensite and austenite microstructure. The second step which is (called as partitioning stage), the steel soaked at the partitioning temperature (TP), in order to provide the carbon atoms for stabilizing the austenite at room temperature. Tensile strength level for Q & P steels are usually above 1180 MPa. Very similar to TBF steels, these steels could be used in various structural and safety automobile components.

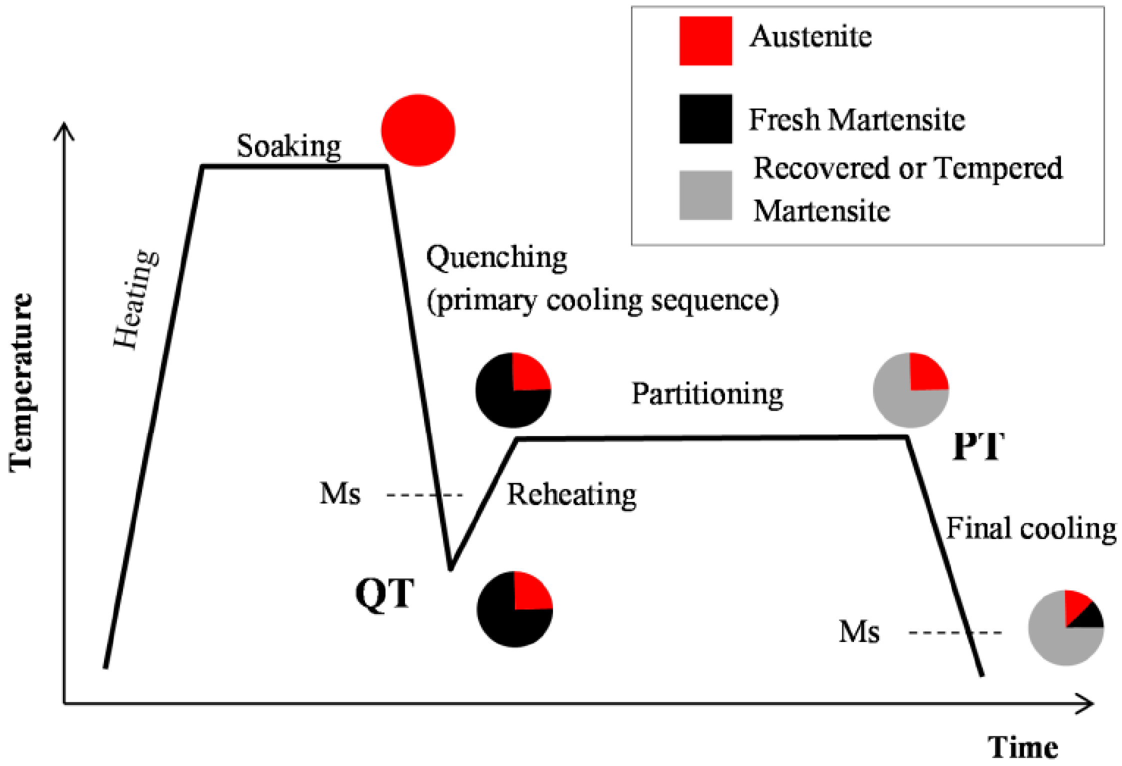

Figure 2. *Q&P processing route [11]*

3.3. Medium-Mn Steels

Medium Manganese steels are further development of austenitic steel that was already applied in the 2-GEN AHSS. Their properties are suitable for the 3-GEN AHSS, they exhibit high combinations of strength (1000–1500 MPa) and ductility (31–44%) at reasonable cost [12]. These steels have a complex microstructure consisting of a nano/ultra-fine grained austenite and ferrite/martensite, with Mn content around (3–10 %), and high level of retained austenite (30 volume %) which enhanced ductility due to the higher strain hardenability as a results of the transformation-induced plasticity (TRIP) or even the twinning-induced plasticity (TWIP) effects [13]. Beside of alloying with Mn, certain amount (1-3 wt %) of Silicon and/or Aluminum and (up to 0.2 wt %) low Carbon contents are also added in order to raise precipitation hardening in the martensite matrix and improve the austenite stability, respectively [14]. Medium-Mn steels are produced via an intercritical annealing process. During annealing in the ferrite+austenite temperature region, the formation of martensite depends on the stability of austenite, through alloying of C and Mn partitioning in a smaller grain size to the intercritical austenite. Lately, many studies have been carried out to study more about medium-Mn steels through various investigation such as the influence of adjusting alloy composition, austenitisation temperature, annealing temperature, annealing time, heating rate, etc. In order to have different types of beneficial microstructures that may be commercialized in the near future.

3.4. δ-TRIP Steels

This grade of steels recently became popular and very promising concept for the 3-GEN AHSS for automotive application. δ-TRIP steels have showed high mechanical properties beside to the low-density characteristics. Frequently, δ-TRIP steels refer to density reduced TRIP steels due to the high aluminum addition. Their chemical composition contains (0.3 - 0.4 wt% C), (2 - 6 wt% Al), (0.2 - 0.8 wt% Si) and (0.5 - 1.6 wt% Mn) [15]. The reason of the small silicon concentration is to avoid surface quality problems by forming adherent red scales during hot rolling and bare spot defects on the sheet surface during galvanizing process [16]. Alternatively, silicon and aluminum alloys working together to avoid any precipitation of carbide particles during bainitic transformation. Also, another role for aluminum alloy is to ensure the presence of δ-ferrite during the solidification phase which is the major constituent in δ-TRIP steels microstructure [17].

These steels undergo the TRIP effect and depend on the presence of δ-ferrite which differentiates it from conventional TRIP-assisted steels. Generally, δ-TRIP steels final microstructure consisting of a mixture of bainitic ferrite, retained austenite and α- or δ-ferrite [18]. They have excellent mechanical properties with tensile strengths of around 600 to 800 MPa at elongations above 30% [19]. What made it as an excellent choice for the lightweight application in the automotive industry, especially the application that require excellent deep drawability like safety parts.

3.5. Nano Steel

Nano steel is one of the new AHSS, belongs to the 3-GEN AHSS as new class of cold formable steels, with an extraordinary strength-ductility combination obtained from their nanocrystalline structure. This novel microstructure produced through a unique chemistry and heat treatment [20]. Nano steel is mainly austenitic in the first place besides to some borides. Following the casting process a special heat treatment to refined the austenite into nanometer scale. Where, nanoscale phase enhances the strain hardening during plastic deformation. These features are required for vehicle light-weighting, because they give the possibility to produce thinner parts with higher strength at room temperature.

NanoSteel company started production of first trials of Nano steel sheet in 2012. Since that time, a modest amount of literatures has been done. In 2013, NanoSteel commissioned Design AG (EDAG), to evaluate three grades of sheet being commercialized by the company in cars body structures [21]. In this study, a vehicle body in white (BIW) comprised of NanoSteel's sheet steels is compared to the baseline 2011 Honda Accord and the Lightweight Vehicle (LWV) from NHTSA's study. The different weight results are listed in Table 1.

Table 1. *NanoSteel BIW Mass Comparison to 2011 Honda Accord and NHTSA's Lightweight Vehicle.*

Vehicle	BIW Mass (Kg)	Weight Reduction (%)
2011 Honda Accord	328.0	-
NHTSA LWV	255.2	22%
NanoSteel BIW	228.1	30%

4. Summary

The subject of this research is the recent developments in Advanced High Strength Steel (AHSS), used in the automotive industry. Among these developments, the third generation of Advanced High Strength Steels (3-GEN AHSS) are the most important ones. The main types of this new generation including quenching and partitioning (Q&P), TRIP bainitic ferrite (TBF), medium manganese, density reduced TRIP (δ-TRIP) and nano steels were overviewed.

5. Conclusion

A serious improvement has been achieved in the past several years of development for high strength steels. The advanced high strength steels (AHSS) family comprises the first and second generation are not able to satisfy all the functional performance needs for the modern vehicle's parts. The third generation (3-GEN) AHSS was created and developed in order to conquer those disadvantages. The mechanical properties of 3-GEN AHSS types close the gap between the 1-GEN and 2-GEN AHSS. A few types have been developed in recent times with an extraordinary strength-ductility combination resulting from unique controlled cooling and heating processes with carefully added alloys contents. Two of these new types are in production and have already been incorporated in the modern car body structures: TRIP-aided Bainitic Ferrite (TBF) steels and Quench-and-Partitioning (Q&P) steels. Whereas the others are still under development and not yet commercially available: Medium-Mn steels, density reduced TRIP steels (δ-TRIP), Nano steel.

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