



## REVIEW OF THE ADVANCED HIGH-STRENGTH STEELS USED IN AUTOMOTIVE INDUSTRY

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Received in December 2023

Accepted in December 2023

### RESEARCH ARTICLE

**ABSTRACT:** The objective of this paper was to present Advanced High-Strength Steels (AHSS) and their manufacturing processes, as well as to emphasize their complexity. The AHSSs were created as a solution to reduce the weight of parts and structures in transportation industries (automotive, airplane and truck industry). Regarding the development of the AHSSs, it was divided in three generation. Besides implementation of materials with higher strength, lower mass of structures could be achieved by application of materials of a lower density (e.g., aluminium and titanium). Application of the lightweight materials directly results in lowering the structures' mass, and it positively affects energy efficiency, preservation of the environment and lowering the pollution levels. However, there are still numerous problems and disadvantages, related to the application of lightweight materials, primarily with processing (low machinability, deformability, as well as weldability). Besides the processing problems, mentioned materials have higher prices than steel; therefore, development of new steel grades, as well as development of new methods for realizing the higher strength was initiated. It is already well known from the literature that by implementing the selected heat treatment procedures (varying the heating and cooling regimes), the steel properties could be altered. It was thus concluded that combination of the heat treatment and plastic deformation in steel production can result in increasing the steel strength, while simultaneously keeping the good deformability and even weldability.

**KEY WORDS:** AHSS, quenching, annealing, heat treatment, tempering

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## **PREGLED NAPREDNIH ČELIKA POVIŠENE JAČINE KORIŠĆENIH U AUTOMOBILSKOJ INDUSTRIJI**

**REZIME:** Cilj ovog rada je da prikaže napredne čelike povišene jačine, načine njihovog dobijanja, kao i da ukaže na složenost pojedinih proizvodnih postupaka. Nastali su kao težnja da se smanji masa konstrukcija i delova koji se koriste u transportnoj industriji. Iz ugla razvoja, mogu se podeliti u tri grupe. Masa konstrukcija se osim upotrebom jačih materijala može smanjiti i primenom materijala koji imaju manju gustinu (npr. Al ili Ti). Upotreba lakih materijala direktno utiče na smanjenje mase i pozitivno deluje na povećanje energetske efikasnosti i prirodne sredine. Uprkos brojnim prednostima, postoje i nedostaci koji ograničavaju primenu ovih materijala. Ovi nedostaci su primarno vezani za proizvodne procese (smanjena obradivost rezanjem i deformisanjem, loša zavarljivost i sl.). Pomenuti laki metali, Al i Ti, osim pomenutih nedostataka imaju i visoku cenu u odnosu na čelike, te se njihovo polje primene dodatno sužava. Zbog svega gore navedenog započet je razvoj čelika povišene jačine kao i novih kombinacija mehanizama ojačanja koji dovode do porasta jačine čelika. Iz literature je poznato da se termičkom obradom može uticati na svojstva čelika, a u kombinaciji sa obradom deformisanjem na visokim temperaturama, uspevaju da se dobiju visoke vrednosti jačine i da se zadrži adekvatna plastičnost, a na nekim mestima čak i zavarljivost.

*AHSS, quenching, annealing, heat treatment, tempering*

**KLJUČNE REČI:** *AHSS, kaljenje, žarenje, termička obrada, otpuštanje*

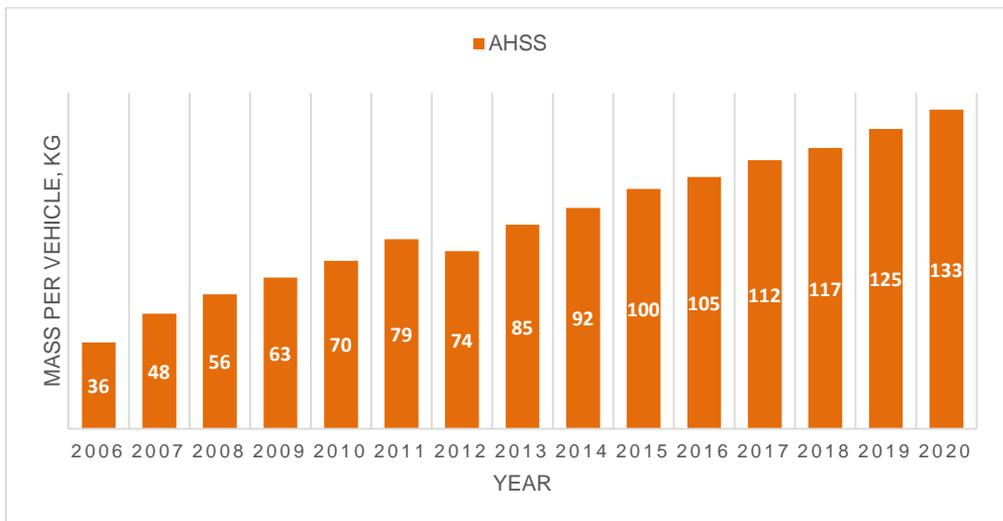
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# REVIEW OF ADVANCED HIGH-STRENGTH STEELS AND THEIR MANUFACTURING PROCEDURES

*Djordje Ivković, Dragan Adamović, Dušan Arsić, Nada Ratković, Andjela Mitrović, Ružica Nikolić*

## INTRODUCTION

As the trends in modern industry are increasingly oriented towards the preservation of natural resources, increasing energy efficiency, reducing the harmful gases emission, as well as the carbon footprint, it is necessary to make adequate changes to fulfil the mentioned requirements. In the transportation industry, the change that effectively provides for these requirements to be met is related to reducing the mass of the steel structures. By using the composite or light-weight materials (Al, Ti and their alloys) that have the lower density and/or higher strength than steels, the mass of the structure can be significantly reduced. At the expense of the smaller mass, obtained by use of these materials, the production process is made more difficult due to their poor machinability by cutting and deforming, as well as poor weldability of the composite and light-weight materials, which all result in the price increase of the final product. To keep the processing method as simple as possible and the products' price as low as possible, development of the special high-strength steels started in the last decades of the 20th century. Compared to the classic steels, the new materials have significantly higher strength, with their machinability by cutting and deforming, as well as weldability, being at the required level [1]. The high strength of these steels is a result of the application of the complex thermal (heat), thermomechanical and mechanical processing procedures. Thus, the high strength allows the dimensions of the cross-sections of parts to be smaller; subsequently the amount of material used and the weight of structures became smaller. Regarding the industry of vehicle production, amount of AHSS used in vehicle body production increases each year (Figure 1). Nowadays, HSS are used in vehicles not only for body parts but for even more reliable components of the cars [2].



*Figure 1. Amount of AHSS steel used in vehicle body production [1]*

## 2. REVIEW OF THE GENERAL CHARACTERISTICS OF THE AHSS

### 2.1 The first generation AHSS

Sheets of tensile strength higher than 500 MPa belong to a group of the so-called high-strength steels (HSS). They possess a complex microstructure, which is usually composed of ferrite, bainite, martensite and residual austenite. The first generation AHSSs includes the Dual Phase steels (DP), Complex Phase steels (CP), Transformation Induced Plasticity steels (TRIP) and the martensitic steels. These steels were created as a result of the need for materials of a greater strength as compared to the classic steels. As with other steel materials, the rule applies here that as the strength increases, the plasticity decreases. From figure 2 one can conclude that the TRIP steels have the lowest strength but the highest plasticity, while for the martensitic steels the situation is quite opposite. They have the highest strength, but the lowest plasticity, [3].

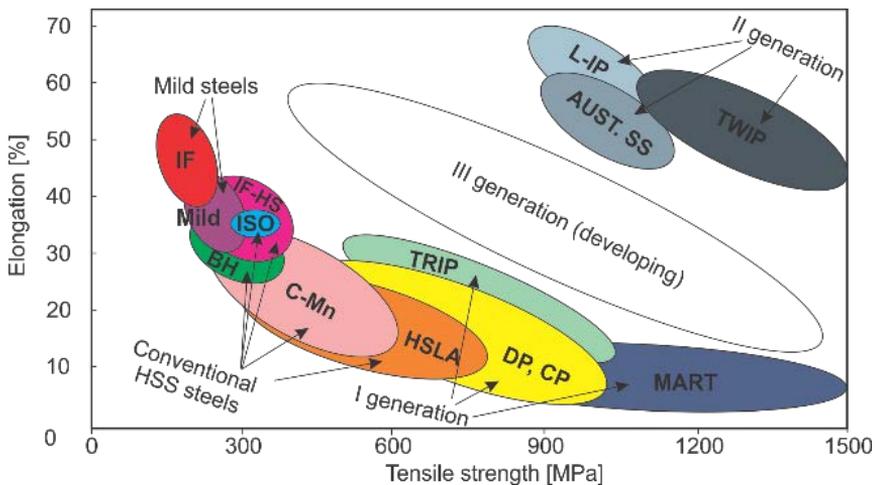


Figure 2. Mechanical characteristics of the advanced high strength steels [3]

#### 2.1.1 The DP (Dual-phase) steels

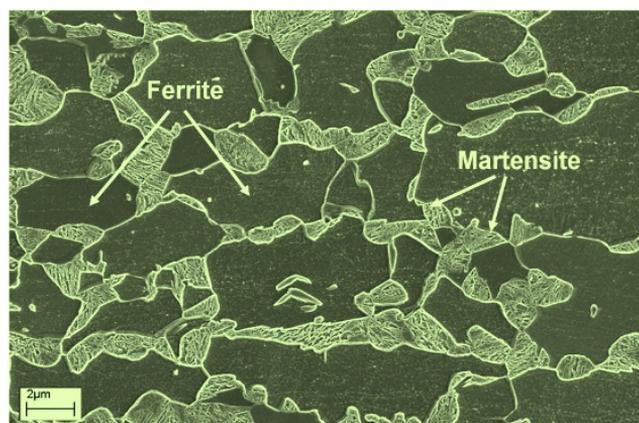
Due to the favorable relationship between the strength and plasticity, the DP steels have the greatest application in the automotive industry. The tensile strength value ranges from 420 to 1030 MPa, and the elongation from 5 to 28 %. The chemical composition of some of the DP steels is shown in table 1, while their mechanical properties are shown in table 2. The microstructure of the DP steel is made of a ferritic matrix containing martensite. The maximum share of martensite is 40 % and the steels' mechanical characteristics depend on it [3, 4]. An example of microstructure of the DP steel is shown in Figure 3.

Table 1. Chemical composition of certain DP steels' classes, wt% [4]

Designation according to EN 10336:2006	max C	max Si	max Mn	max P	max S	Al	max Cu	max B	max Ti+Nb	max Cr + Mo
HCT490X	0.14	0.5	1.8	0.05	0.01	0.01-1.5	0.2	0.005	0.15	1.0
HCT780X	0.18	0.8	2.5	0.05	0.01	0.015-1.0	0.2	0.005	0.15	1.4
HCT1180G2	0.23	1.0	2.9	0.05	0.01	0.015-1.0	0.2	0.005	0.15	1.0

**Table 2.** Mechanical characteristics of certain DP steels' classes [4]

Designation according to EN 10336:2006	$R_{p0.2}$ , MPa	$R_m$ , MPa	$A_{80}$ , %
HCT490X	290-380	490-600	24
HCT780X	440-550	780-900	14
HCT1180G2	900-1100	1180-1350	5

**Figure 3.** Ferritic-martensitic microstructure of the DP steels [4]

### 2.1.2 The CP (Complex Phase) steels

These steels were so named due to their microstructure, which contains several different structural phases. The chemical composition of these steels is similar to composition of the DP steels. They are characterized by the high strength, while their plasticity is very low. They are the most widely used for production of columns and beams, as well as other simpler parts in the automotive industry [5].

The chemical composition as well as mechanical properties of some CP steels are shown in tables 3 and 4, respectively. As an example, the CP 800 steel microstructure is shown in Figure 4. It contains 42 % ferrite, 40 % bainite, 13 % martensite and 5 % residual austenite, [3, 5].

**Table 3.** Chemical composition of certain CP steels' classes, wt%, [5]

Designation according to EN 10346:2009	max C	max Si	max Mn	max P	max S	Al	max Cu	max B	max Ti + Nb	max Cr+Mo
HCT600C	0.1	0.4	1,6	-	-	-	-	-	-	-
HCT780C	0.18	1.0	2.5	0.05	0.01	0.15-1.0	0.2	0.005	0.15	1.0
HCT980C	0.23	1.0	2.7	0.05	0.01	0.015-1.0	0.2	0.005	0.15	1.0

**Table 4** Mechanical characteristics of certain CP steels' classes, [5]

Designation according to EN 10336:2006	$R_{p0.2}$ , MPa	$R_m$ , MPa	$A_{80}$ , %
HCT600C	360-440	600-700	19
HCT780C	570-720	780-920	10
HCT980C	780-950	980-1140	6

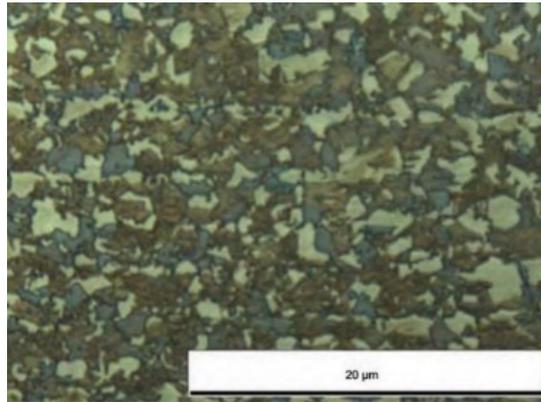


Figure 4. Microstructure of the CP800 steel [5]

### 2.1.3 The TRIP (Transformation Induced Plasticity) steels

Steels of this class contain carbon in the range of 0.1 to 0.4 % and alloying elements, such as Si, Al, Ti, Ni and V. Depending on the chemical composition of these steels, their strength ranges from 500 to 1050 MPa, and elongation from 12 to 32 %. Due to the good ratio of strength and plasticity, they are intended for the manufacturing the complex parts of automobile structures. The chemical composition and mechanical characteristics of some of the TRIP steels are presented in tables 5 and 6, respectively, [3,6].

The microstructure of the TRIP steels is complex. It basically consists of a ferrite-bainite matrix containing 5 to 20 % of the residual austenite. Thanks to this microstructure, these steels have good deformability properties. The share of ferrite in the ferrite-bainite matrix has the greatest impact on mechanical properties of these steels, [3, 6]. Figure 5 shows an example of the TRIP steel's microstructure.

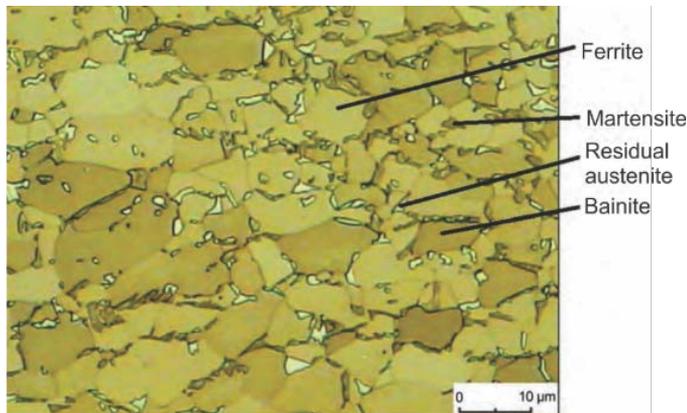


Figure 5. Example of TRIP steel microstructure [3]

A special feature of the TRIP steels is the increase in strength during deformation since the residual austenite is transformed into martensite [6]. That is why these steels are primarily used for production of the car body parts that are the most often exposed to deformation during a collision. The increase in strength of the parts during their deformation directly affects the increase in the safety of passengers in the car [3, 6].

**Table 5.** Chemical composition of the TRIP steels, wt%, [7, 8]

Designation according to EN 10346:2009	max C	max Si	max Mn	max P	max S	Al	max Cu	max B	max Ti + Nb	max Cr+ Mo
HCT690T	0.24	2.0	2.2	0.05	0.01	0.015-2.0	0.2	0.005	0.2	0.6
HCT780T	0.25	2.2	2.5	0.05	0.01	0.015-2.0	0.2	0.005	0.2	0.6

**Table 6.** Mechanical characteristics of the TRIP steels [7, 8]

Designation according to EN 10346:2009	$R_{p0.2}$ , MPa	$R_m$ , MPa	$A_{80}$ , %
HCT690T	40-520	690-800	24
HCT780T	450-570	780-910	21

### 2.1.4 Martensitic steels

These steels were developed due to the need for steels with extremely high values of tensile strength. Their microstructure contains predominantly martensite, due to which the tensile strength of these steels is within range 720 to 1680 MPa, and the elongation is within range 3 to 15 %. The chemical composition and mechanical characteristics of some martensitic steels are shown in tables 7 and 8, respectively. Due to those exceptionally high mechanical properties, these steels are often subjected to tempering prior to forming, or the forming is done with preheating, and the forming itself is done in a tool that is cooled by the flowing water. In this way, the molded part obtains the martensitic structure, which comes as a result of the contact between the material in the initial state and the working surfaces of the tool [3, 9].

**Table 7** Chemical composition of certain martensitic steels' classes, wt%, [9]

Designation according to VDA 239-100	max C	max Si	max Mn	max P	max S	Al	max Cu	max B	max Ti + Nb	max Cr+ Mo
CR1030Y130T-MS	0.28	1.0	2.0	0.02	0.025	$\geq 0.010$	0.2	0.01	0.15	1
CR1220Y1500T-MS	0.28	1	2	0.02	0.025	$\geq 0.010$	0.2	0.01	0.15	1
CR1350Y1700T-MS	0.35	1	3	0.02	0.025	$\geq 0.010$	0.2	0.01	0.15	1

**Table 8** Mechanical characteristics of certain martensitic steels' classes [9]

Designation according to VDA 239-100	$R_{p0.2}$ , MPa	$R_m$ , MPa	$A_{80}$ , %
CR1030Y130T-MS	1030-1330	1300-1550	3
CR1220Y1500T-MS	1220-1520	1500-1750	3

As emphasized at the beginning, these steels' microstructure is composed of a martensitic matrix containing small shares of ferrite and bainite. The martensitic steel CR1220Y1500T-MS microstructure is presented in figure 6.

## 2.2 The second generation AHSS

As it was shown, the first generation AHSS possesses great strength, but elongation and plasticity are low, especially for martensitic steels. Due to the lower plasticity, deformation rates during forming procedures such as bending and deep drawing are reduced and the risk of crack appearance is increased. In automotive industries, parts often have complex design and to produce such parts, greater plasticity is required, and researchers began developing the second generation AHSS.

Design of the second generation of AHSS is based on austenitic microstructure, which offers greater plasticity and formability in comparison to the first generation, but strength levels are not drastically reduced, [3]. The second generation of the AHSS includes the TWIP (TWinning Induced Plasticity) steels, L-IP (Lightweight Induced Plasticity) steels and austenitic stainless steels.

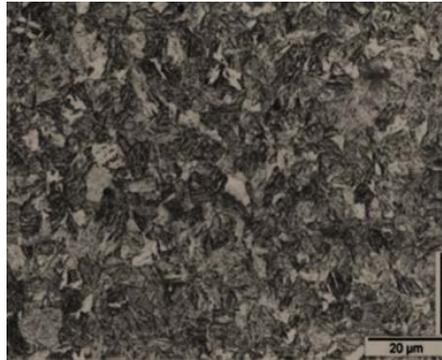


Figure 6. Microstructure example of the martensitic steels [3]

### 2.2.1 The TWIP (TWinning Induced Plasticity) steels

The TWIP steels have austenitic microstructure, which is retained at room temperatures due to high Mn content (22 % to 30 %). Besides Mn, the TWIP steels also contain fair amount of Al (maximum 10 %), as well as Si (maximum 3 %). Tendency to create twins in microstructure allows for the great strength to be achieved. Austenitic microstructure allows for elongation values to range from 60 to 90 % and their tensile strength exceeds 1000 MPa. The high strength results from austenitic microstructure ability to form twins, which are blocking movement of dislocation, thus increasing strength. [3, 10, 11].

The chemical composition and mechanical properties of some TWIP steels are shown in tables 9 and 10, respectively, and a microstructure example is given in figure 7.

**Table 9.** Chemical composition of some TWIP steels, wt%, [2, 9]

Designation according to BS	Mn	Si	Al	C
Fe -15Mn-4Si-2Al	16.2	4.0	1.8	0.2
Fe-20Mn-3Si-3Al	20.1	2.8	2.9	0.4
Fe-25-Mn-4Si-2Al	25.5	3.9	1.8	0.3
Fe-30Mn-4Si-2Al	28.7	4.0	2.0	0.2
Fe-30Mn-2Si-4Al	30.6	2.0	3.9	0.1

**Table 10.** Mechanical properties of some TRIP steels [2, 9]

Designation according to BS	$R_{p0.2}$ , MPa	$R_m$ , MPa	A, %
Fe -15Mn-4Si-2Al	190	1080	39
Fe-20Mn-3Si-3Al	300	840	82
Fe-25-Mn-4Si-2Al	280	770	69
Fe-30Mn-4Si-2Al	220	770	75
Fe-30Mn-2Si-4Al	210	570	83

### 2.2.2 The L-IP (Lightweight Induced Plasticity) steels

This steel group is still in development. Up to now, it is known that their strength ranges between 1000 to 1100 MPa, and elongation values reach up to 80 %. Application of this steel group could be found in automotive industry for producing parts with complex geometry, due to their good plasticity values [3].

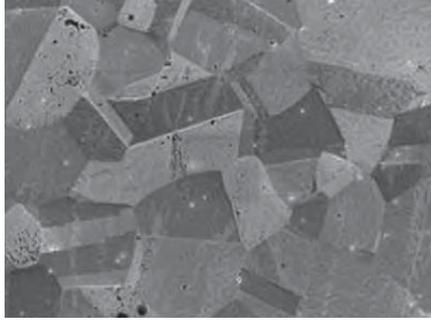


Figure 7. Microstructure of annealed Fe-30Mn steel [3]

### 2.2.3 Austenitic stainless steels

Austenitic stainless steels contain more than 12 % of Cr dissolved in solid solution, thus they are resistant to corrosion. This steel group besides Cr contains high values of Ni (max 35 %), which allows austenite to be stable at room temperatures. Addition of Ni drastically increases production costs due to its high price. Yield stress values range from 200 to 400 MPa, tensile strength values from 900 to 1200 MPa, and elongation values from 40 to 45 %. In comparison to other steels, they have good strength and formability with addition of corrosion resistance, so they can be used in more aggressive environment, [3]. The chemical composition and mechanical properties of some austenitic stainless steels are shown in tables 11 and 12, respectively, and microstructure example is given in figure 8.

**Table 11.** Chemical composition of some austenitic stainless steels, wt%, [12]

Designation according to EN 10088.2	max C	maxN	max Mn	max Si	Cr	max Ni
X8CrNiS18-9	0.15	-	2.0	1.0	17-19	8-10
X5CrNi18-10	0.07	0.1	2.0	0.75	17.5-19.5	8-10.5
X8CrNi25-21	0.25	-	2.0	1.5	24-26	19.22
X5CrNiMo17-12-2	0.08	0.1	2.0	0.75	16-18	10-14

**Table 12** Mechanical properties of some austenitic stainless steels [12]

Designation according to EN 10088.2	$R_{p0.2}$ , MPa	$R_m$ , MPa	$A_{50}$ , %
X8CrNiS18-9	300	650	45
X5CrNi18-10	205	515	40
X8CrNi25-21	205	515	40
X5CrNiMo17-12-2	205	515	40

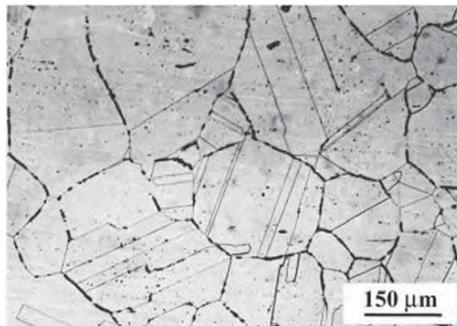


Figure 8. Microstructure example of austenite stainless steel [3]

## 2.3 The third generation AHSS

As the second generation AHSS is based on austenite microstructure, those steels contain high values of Cr and Ni to allow austenite to be stable at room temperature. The addition of mentioned components drastically increases price of steel, thus greatest disadvantage of second generation AHSS is their high price. Developing cheaper steels with similar properties represents the key for wider application of AHSS, [12].

Development of third generation AHSS is based on the goal to achieve similar plasticity of second generation AHSS, but with significantly lower price. The third generation AHSS includes Q&P (Quenching and Partitioning) steels, Medium Mn steels and Trip Aided Bainitic Ferrite (TBF) steels.

### 2.3.1 The Q&P (Quenching and Partitioning) steels

These steels typically contain C (0.1 - 0.3 %), Si and/or Al (1 - 2 %) as well as Mn (1.5 - 3 %). The yield stress values range from 600 to 1150 MPa, tensile strength from 980 to 1300 MPa and elongation from 8 - 22 %. One can conclude that strength values are higher than of the second-generation steels, with reduced formability. However, it needs to be emphasized that the price of the third-generation steels is significantly lower. Mechanical properties of some Q&P steels are given in table 13. Steels from this group are often used to produce parts of vehicle chassis such as B-pillars, [14].

**Table 13** Mechanical properties of some Q&P steels [15]

Designation of steel	$R_{p0.2}$ , MPa	$R_m$ , MPa	A, %
QP980	698	1057	20
QP1180	990	1188	16

The microstructure of these steels is composed of austenite (5 - 12 %), ferrite (20 - 40 %) and martensite (50 - 80 %). As the ratio of mentioned phases changes, the steel's properties vary accordingly. Example of a microstructure is presented in figure 9.

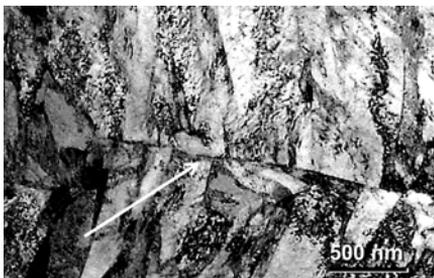


Figure 9. Microstructure of Q&P steel [16]

### 2.3.2 The medium Mn steels

This steel group has fine grain ferritic-austenitic microstructure. Percentage of austenite in microstructure can vary from 20 to 40 %, based on required properties and chemical composition. Typical for this steel group is that they contain C (0.05 - 0.4 %), Si (1- 3 %) and Mn (3 - 12 %). The yield stress values range from 400 to 1150 MPa, tensile strength from 780 to 1350 MPa and elongation ranges from 15 to 60 %. A microstructure example is given in figure 10, [14].

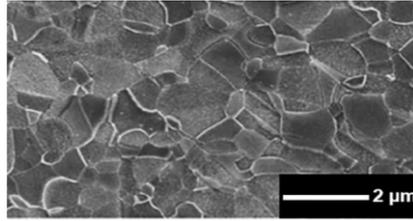


Figure 10. Microstructure of Medium Mn steel [17]

### 2.3.3 The TBF (Trip Aided Bainitic Ferrite) steels

The TBF steels are similar to Q&P steels and the first grades of this group were produced in Japan. The yield stress value is around 790 MPa, tensile strength around 1240 MPa, and elongation 16.5 %. These steels are alloyed with Mn, Al, Nb and Cr and their microstructure is composed of bainite, ferrite and austenite. The share of austenite has the great effect on plasticity and can be controlled through the carbon content. [18].

The chemical composition and mechanical properties of some TBF steels are given in tables 14 and 15, respectively. The microstructure of TBF steels is shown on figure 11.

**Table 14.** Chemical composition of some TBF steels, wt%, [19]

Designation according to VDA 239-100	max C	max Si	max Mn	max P	max S	Al	max Cu	max B	mac Ti + Nb	max Cr+ Mo
CR330Y590T-DH	0.15	0.8	2.5	0.05	0.01	0.015-1.0	0.2	0.005	0.15	1.4
CR440Y780T-DH	0.18	0.8	2.5	0.05	0.01	0.015-1.0	0.2	0.005	0.15	1.4
CR700Y980T-DH	0.23	1.8	2.9	0.05	0.01	0.015-1.0	0.2	0.005	0.15	1.4

**Table 15.** Mechanical properties of some TBF steels, [20]

Designation according to VDA 239-100	$R_{p0.2}$ , MPa	$R_m$ , MPa	$A_{80}$ , %
CR330Y590T-DH	330-440	590-700	26
CR440Y780T-DH	440-550	780-900	18
CR700Y980T-DH	700-850	980-1130	13

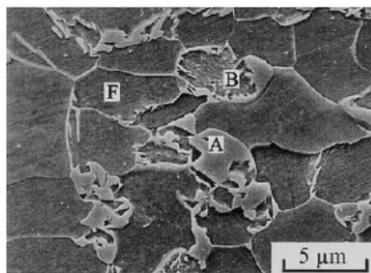


Figure 11. Microstructure example of TBF steel [3]

## 3. REVIEW OF PROCEDURES FOR OBTAINING THE THIN SHEETS OF INCREASED STRENGTH STEELS

### 3.1 Thermal and thermomechanical processes for obtaining the first generation AHSS

#### 3.1.1 DP steels

The name of these steels indicates that there are two phases in their microstructure. That structure consists of a ferrite matrix in which martensite particles are wedged. The

maximum share of martensite in the microstructure of these steels is 40 %, and with that share increase in the microstructure, the strength and hardness increase, as well, [3].

The production of the cold-rolled DP steels is primarily based on the heating and heating-through of the previously obtained cold-rolled steel strips of the appropriate chemical composition, to a temperature in the interval between  $A_{c1}$  and  $A_{c3}$ . In this temperature interval, the microstructure of the steel consists of ferrite and austenite. With an increase in the heating temperature (approaching the critical temperature  $A_{c3}$ ), the proportion of austenite increases, as well as the amount of carbon that can be dissolved in the austenite. To limit the share of martensite to 40 %, the maximum heating and heating-through temperature of these steels should be 800 °C, [3].

The heating-through is followed by cooling, where the cooling rate is higher than the critical one. In that way, the austenite with dissolved carbon forms martensite particles, which are distributed in the ferrite matrix. Figure 12 shows the thermal cycle for obtaining the cold-rolled DP steel, [3]. This first assumes that the appropriate semi-finished product from the ironworks is heated to a temperature between 1180 and 1250 °C, when it is rolled. After obtaining a strip of appropriate thickness, it is slowly cooled to a temperature between  $A_{c1}$  and  $A_{c3}$ , to obtain a mixture of ferrite and austenite in the microstructure. This is followed by the rapid cooling from that range, which results in the two-phase microstructure. The schematics of this procedure is presented in Figure 13, [2].

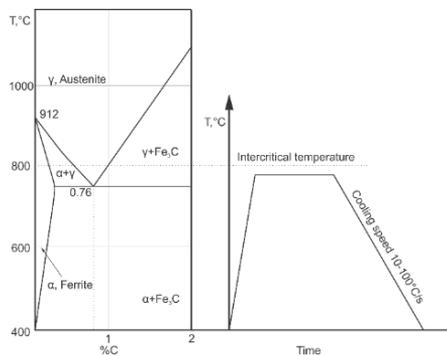


Figure 12. Thermal cycle for obtaining the cold-rolled DP steels [1]

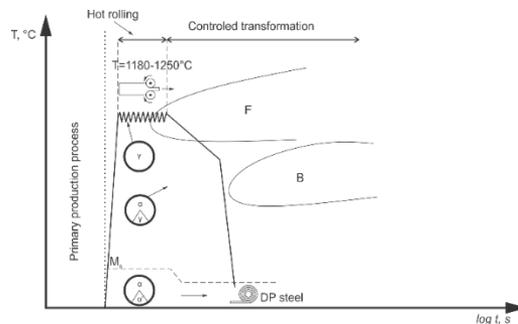


Figure 13. Schematics of producing the hot-rolled DP steels [2]

### 3.1.2 CP steels

The CP steels have an interphase microstructure. It consists of a ferrite-bainite matrix in which there are small shares of martensite, residual austenite and pearlite. Obtaining these steels implies that the starting semi-finished product is first heated to the high-austenitic temperature region, where the carbon content is 0.2 %. After the heating, the steel is cooled

down to a temperature between 900 and 800 °C, when it is rolled. After the rolling, the part is heated-through for 60 s, during which the ferrite-austenitic structure is obtained, and the carbon content increases to 0.4 %. The heating-through is then followed by the slow cooling to a temperature of 450 °C, where the steel is isothermally held for 90 s, which results in formation of a small share of bainite, and the carbon share increases to 1.2 %. After the isothermal holding, the thin strips are wound and then cooled to a room temperature. The thermal process of obtaining these steels is shown in Figure 14, [3].

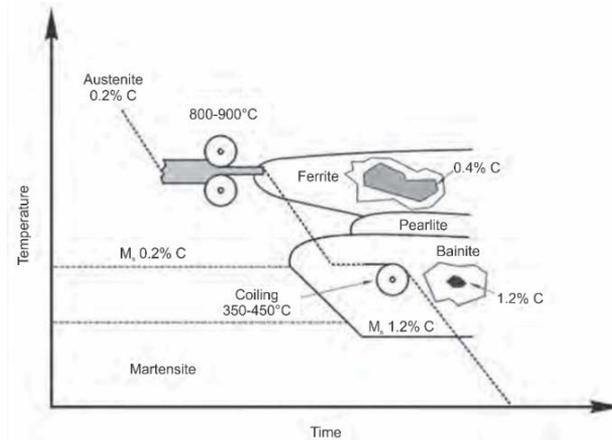


Figure 14. Thermomechanical process of obtaining the CP steels [3]

### 3.1.3 TRIP steels

The microstructure of these steels is also the interphase one. It is formed from a ferrite matrix in which the residual austenite and bainite are wedged. The process starts with rolling in the austenitic region, followed by cooling to 800 °C. At this temperature, the steel is heated-through for 60 s, which is followed by rapid cooling to 450 °C, where the steel is held isothermally for 90 s. This isothermal holding results in formation of a certain amount of bainite in the ferrite matrix. After the holding at 450 °C, the steel is wound to a coil and cooled to ambient temperature. The comparison of procedures for obtaining the DP and TRIP steel is schematically shown in Figure 15, [3].

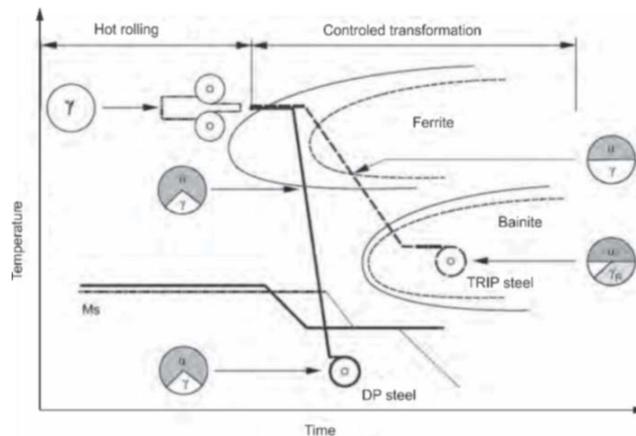


Figure 15. Comparison of production procedures of the DP and TRIP steels [2]

### 3.1.4 Martensitic steels

Steels of this kind predominantly contain martensite in microstructure. It is obtained in two ways, while both ways imply the rapid cooling of the steel from the austenite region.

The first way of obtaining such a microstructure refers to the hot-rolled steels, which are cooled down quickly, immediately after the rolling at elevated temperatures is finished, [3]. The second method implies that the previously obtained sheet metal strips are heated above the critical temperatures; they are then heated through at those temperatures and then cooled quickly, [3].

In both cases, due to heating to temperatures within the range 900 to 950 °C and rapid cooling, the final microstructure of the steel is martensite, [3]. Figure 16 shows the thermomechanical and thermal processes for obtaining these steels.

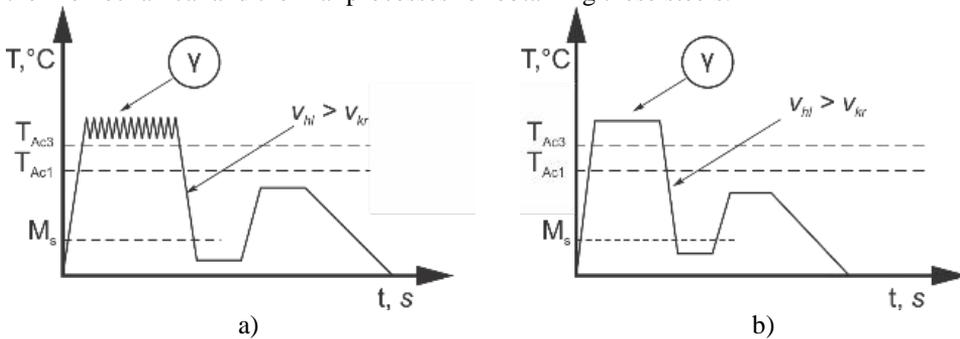


Figure 16. Thermomechanical (a) and thermal (b) procedures of obtaining the martensitic steels [3]

## 3.2 Thermal and thermomechanical processes for obtaining the second generation AHSS

### 3.2.1 TWIP steels

Typical procedure for obtaining the TWIP steels is based on appropriate thermomechanical procedure (Figure 17), which consist of the hot rolling, annealing, and quenching. the hot rolling is conducted in austenite region at 900 °C, afterwards follow the heating and annealing at 1150 °C. As annealing is finished, cooling in nitrogen gas is executed to obtain austenite. Water cooling could be conducted when martensite phase is required, [3].

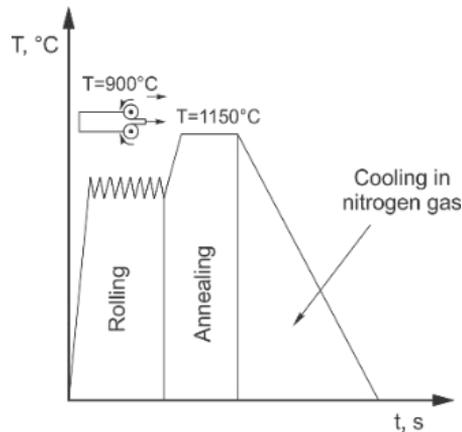


Figure 17. Example of thermomechanical procedure for TWIP steel production [2]

### 3.2.2 L-IP steels

For this steel group there is no much data available, as the fact is that they are still being developed.

### 3.2.3 Austenitic stainless steels

Steels of this group are obtained through already known procedures of continuous casting of liquid steel with proper chemical composition (Cr, Ni ...), with slight difference in the final production steps. For some austenitic stainless steels, the final step consists of the solution annealing at 1000 to 1100 °C to dissolve the formed carbides. The intense cooling is conducted from that temperature, without the phase transformation. [3]

## 3.3 Thermal and thermomechanical processes for obtaining the third generation AHSS

### 3.3.1 Q&P steels

The Q&P steels are obtained through the procedure, which consists of quenching and reheating. The quenching is done from austenite region to temperature between  $M_s$  and  $M_f$ , so that the slight amount of residual austenite is kept. After the quenching, steel is heated again to a temperature that is slightly above the  $M_s$  temperature, so that carbon, which is dissolved in residual austenite, could be partitioned into the acicular form [20, 21]. The typical heat treatment cycle is given in Figure 18.

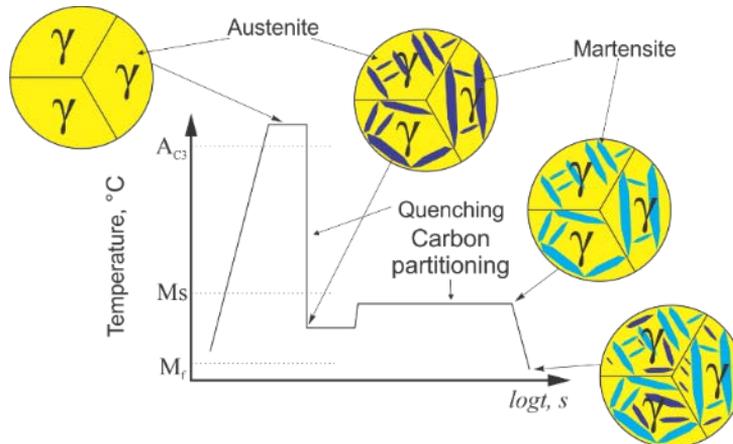


Figure 18. Thermomechanical procedure for production of Q&P steels [3]

### 3.3.2 Medium Mn steels

This steel group is produced through a special procedure (Figure 19), which begins with the hot rolling of the steel strip in austenite region. Through the initial hot rolling strips are rolled to thickness of 4 mm and temperature of the last pass needs to be higher than 800 °C. After the last pass, the strip is water cooled to room temperature. After the initial hot rolling, heating up to temperature interval from 700 to 800 °C is done and the strip is rolled down to required thickness. It needs to be emphasized that after each rolling, reheating to the mentioned temperature is required, to recover the deformed steel grains. After the final rolling, the steel strip is cooled down to room temperature and obtained steel microstructure consists of fine-grained ferrite-austenite microstructure, [22].

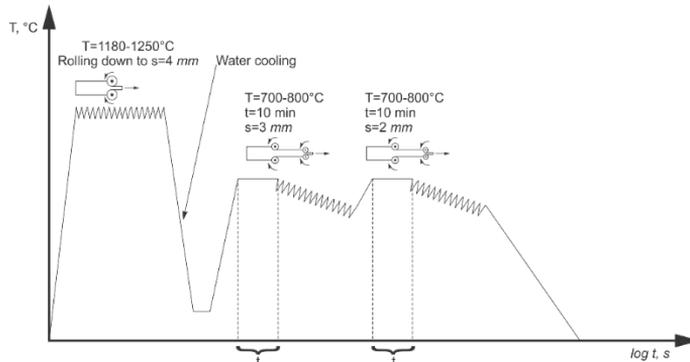


Figure 19. Example of thermomechanical procedure for producing Medium Mn steels [3]

### 3.3.3 TBF steels

The microstructure of these steels is based on a bainite matrix in which the residual austenite particles are dispersed. This structure is typically obtained through the fast cooling from austenite region to a temperature interval between  $B_s$  and  $B_f$ , and the isothermal holding on that temperature (Figure 20). The chemical composition and heat treatment parameters have the greatest influence on obtained microstructure phase shares, [23].

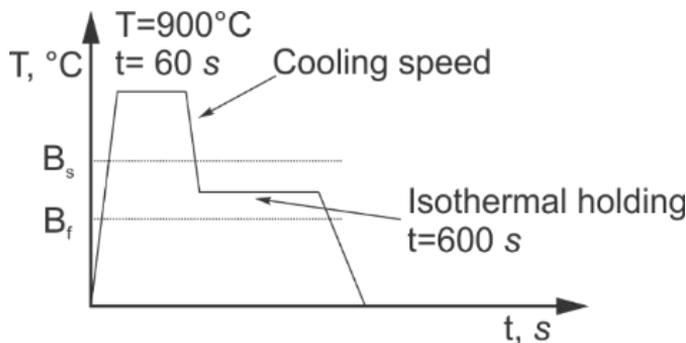


Figure 20. Example of thermal cycle for obtaining TBF steels [3]

## 4. CONCLUSIONS

Due to the increase in people's awareness of the necessity to reduce the environmental pollution, to use natural resources more rationally, development of the new steel materials, which compared to Al and Ti alloys, have a significantly higher specific mass and strength, but a lower price, better workability, and weldability (special requirements related only to cleaning and preheating of parts prior to welding), has been initiated. As an answer to this tendency, the new grades of advanced high strength steels (AHSS) have been developed. Depending on the level of development, three groups of advanced high-strength steels are distinguished. A review of all the three groups of AHSSs and some procedures for their production are presented. From the obtained data, one can conclude that all the three AHSS generations have high strength. However, deformability changes through generations.

The first generation of advanced high-strength steels has the greatest strength, but deformability is the worst among the three generations of mentioned steels.

The advanced high-strength steels of the second generation are characterized by slightly lower strength than the first-generation steels; however, they possess significantly better

deformability. Their greatest disadvantage is the very high price due to large amounts of alloying elements, especially Cr and Ni.

The third-generation steels represent the balance between the first two generations. Steels that belong to the third generation of advanced high-strength steel have good strength values (slightly below the first generation) and good deformability (slightly worse than the second generation). Their greatest advantage is the lower price as compared to the second generation, with the formability being good enough for producing the vehicle chassis parts.

*Note: The shorter version of this research was presented at “The 39th International conference on production engineering of Serbia - ICPEs 2023”, reference [24].*

## ACKNOWLEDGEMENT

The authors wish to acknowledge the financial support from the Ministry of Education and Science of the Republic of Serbia through the project Grant TR32036 and TR35024 and by the project of Operational Programme Integrated Infrastructure “Support of research and development capacities to generate advanced software tools designed to increase the resilience of economic entities against excessive volatility of the energy commodity market”, ITMS2014+ code 313011BUK9, co-funded by European Regional Development Fund.

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