



University of Novi Sad  
Faculty of Technical Sciences

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**39. SAVETOVANJE PROIZVODNOG MAŠINSTVA SRBIJE  
- SPMS 2023 -**

**39<sup>th</sup> INTERNATIONAL CONFERENCE ON PRODUCTION  
ENGINEERING OF SERBIA  
- ICPE 2023 -**

# **ZBORNİK RADOVA PROCEEDINGS**



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Novi Sad, 26-27 October 2023

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON PRODUCTION ENGINEERING OF  
SERBIA - ICPE 2023  
Novi Sad 2023

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*Publisher:* **UNIVERSITY OF NOVI SAD, FACULTY OF TECHNICAL SCIENCES  
DEPARTMENT OF PRODUCTION ENGINEERING  
DEPARTMENT OF INDUSTRIAL ENGINEERING AND ENGINEERING  
MANAGEMENT  
21000 NOVI SAD, Trg Dositeja Obradovica 6, SERBIA**

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*Organization of this Conference was approved by Educational-scientific Council of Faculty of Technical Sciences in Novi Sad*

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*Technical treatment and design:* Milana ILIĆ MIĆUNOVIĆ  
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*Printing by:* FTN, Graphic Centre  
GRID, Novi Sad

*CIP classification:*

CIP - Каталогизacija y publikaciji  
Библиотека Матице српске, Нови Сад

621.7/.9(082)

CABETOBAHJE производног машинства Србије (39 ; 2023 ; Нови Сад)  
Zbornik radova = Proceedings / 39. Savetovanje proizvodnog mašinstva Srbije,  
SPMS 2023 - 39th International Conference of Production Engineering, ICPE 2023,  
26-27. October 2023, Novi Sad. - Novi Sad : Faculty of Technical Sciences, 2023  
(Novi Sad : GRID). - XXV, 391 str. :ilustr. ; 24 cm  
Dostupno i na: <http://spms.fink.rs/abstract.html> . - Radovi na srp. i engl. jeziku. -  
Tekst štampan dvostubačno. - Tiraž 60. - Str. X-XI: Predgovor ; Foreword / Miodrag  
Hadžistević. - Bibliografija uz svaki rad.

ISBN 978-86-6022-610-7

a) Производно машинство – Зборници

COBISS.SR-ID 127854345

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*Financing of the Proceedings was sponsored by the Ministry of Education, Science and Technological Development of the Republic of Serbia.*

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Society of Production  
Engineering

**SPMS 2023**

39. Savetovanje proizvodnog mašinstva Srbije

**ICPES 2023**

39<sup>th</sup> International Conference on Production Engineering of  
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Faculty of Technical  
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Novi Sad, Serbia, 26. – 27. October 2023

## REVIEW OF THE FIRST GENERATION OF THE ADVANCED HIGH-STRENGTH STEELS (AHSS) AND THEIR MANUFACTURING PROCEDURES

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**Abstract:** *The objective of this paper was to present the first generation of 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. The first generation, to which this paper relates, includes the DP (Dual-Phase), CP (Complex-Phase), TRIP (Transformation Induced Plasticity) and martensitic steels. Besides implementation of materials with higher strength, lower mass of structures could be achieved by application of materials of a lower density (e.g., aluminum 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 application of lightweight materials, primarily with processing (low machineability, 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, heat treatment, strength, quenching, annealing, tempering.

### 1. 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 fulfill the mentioned requirements. In the transportation industry, the change that effectively provides for these requirements to be met is actually

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. The high strength of these steels is a result of 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.

## 2. REVIEW OF THE GENERAL CHARACTERISTICS OF THE AHSSs OF THE FIRST GENERATION

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 2.1 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, [1].

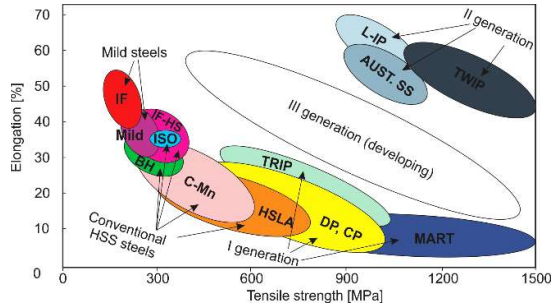


Figure 2.1 Mechanical characteristics of the advanced high strength steels

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

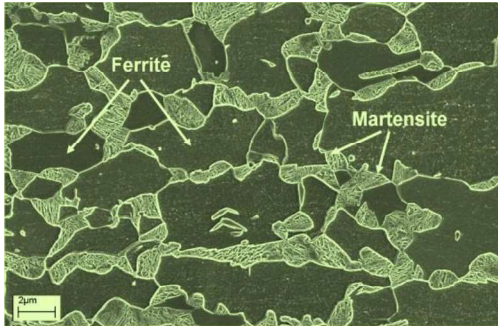
Due to the favorable relationship between the strength and plasticity, the DP steels have the greatest application in the automotive industry. The tensile strength value ranges from 420 to 1030 MPa, and the elongation from 5 to 28 %. The chemical composition of some of the DP steels is shown in table 2.1, while their mechanical properties are shown in table 2.2. 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 [1, 2]. An example of microstructure of the DP steel is shown in Figure 2.2.

Table 2.1 Chemical composition of certain DP steels' classes, [2]

Notation 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 2.2** Mechanical characteristics of certain DP steels' classes, [2]

Notation 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 2.2** Ferritic-martensitic microstructure of the DP steels, [3]

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 [4].

As an example, the CP 800 steel microstructure is shown in Figure 2.3. It contains 42 % ferrite, 40 % bainite, 13 % martensite and 5 % residual austenite, [1, 4].

## 2.2 The CP (Complex Phase) steels

These steels were so named due to their microstructure, which contains several

**Table 2.3** Chemical composition of certain CP steels' classes, [4]

Notation 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 2.4** Mechanical characteristics of certain CP steels' classes, [4]

Notation 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

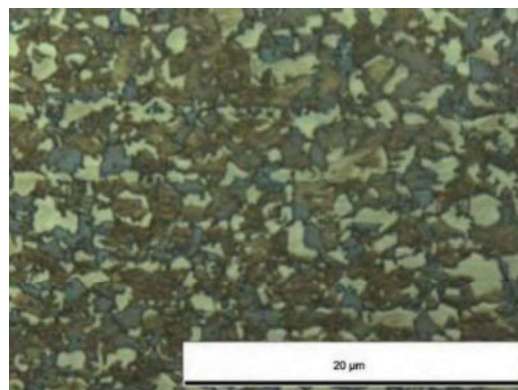
### 2.3 The transformation induced plasticity (TRIP) steels

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 2.4 and 2.5, respectively, [1,4].

The microstructure of the TRIP steels is complex. It basically consists of a ferrite-bainite matrix containing 5 to 20 % 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, [1, 5].

**Table 2.4** Chemical composition of the TRIP steels, [5]

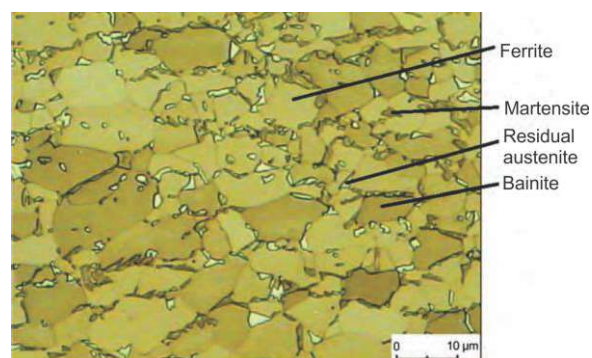
Notation according to EN 10346:2009	max %C	max %Si	max %Mn	max %P	max %S	%Al	max %Cu	max %B	max %Ti + %Nb	max %Cr+ %Mo
HCT690T	0.24	2.0	2.2	0.05	0.01	0.015-2.0	0.2	0.005	0.2	0.6
HCT780T	0.25	2.2	2.5	0.05	0.01	0.015-2.0	0.2	0.005	0.2	0.6



**Figure 2.3** Microstructure of the CP800 steel, [1]

Figure 2.4 shows an example of the TRIP steel's microstructure.

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 [1, 5].



**Figure 2.4.** Microstructure of TRIP steels [1]

**Table 2.5** Mechanical characteristics of the TRIP steels, [5]

Notation 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

## 2.4 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 2.6 and 2.7, 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 [1, 7].

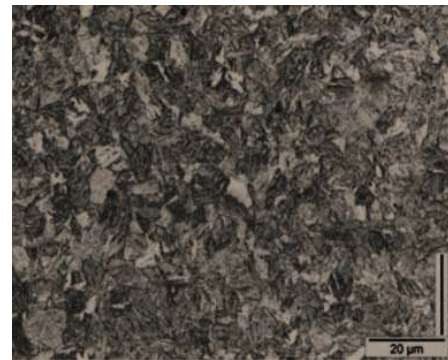
**Table 2.6** Chemical composition of certain martensitic steels' classes, [7]

Notation 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 2.7** Mechanical characteristics of certain martensitic steels' classes, [7]

Notation 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 2.5.

**Figure 2.5** Microstructure of the martensitic steels, [1]

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

#### 3.1 Thermal and thermomechanical processes for obtaining the 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, [1].

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, [1].

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 3.1 shows the thermal cycle for obtaining the cold-rolled DP steel, [1].

Obtaining the hot-rolled DP steel 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 3.2, [1].

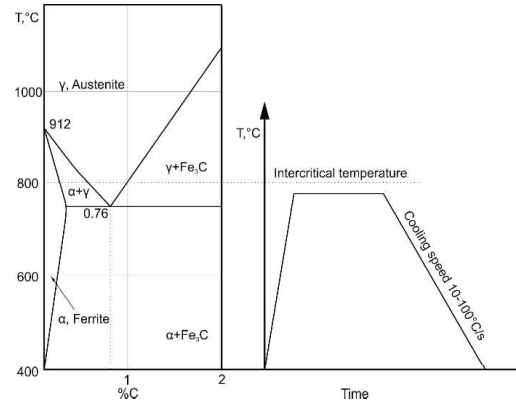


Figure 3.1 Thermal cycle for obtaining the cold-rolled DP steels

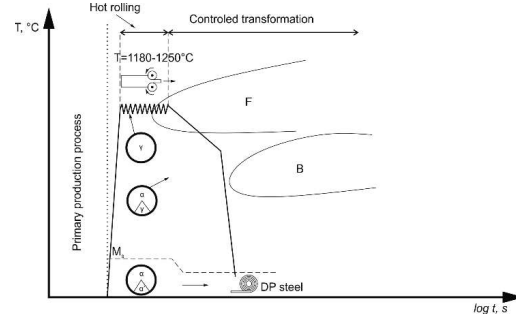
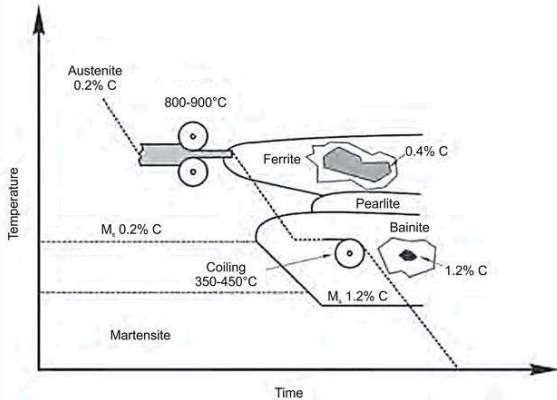


Figure 3.2 Schematics of producing the hot-rolled DP steels

#### 3.2 Thermal and thermomechanical processes for obtaining the 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 800 and 900 °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

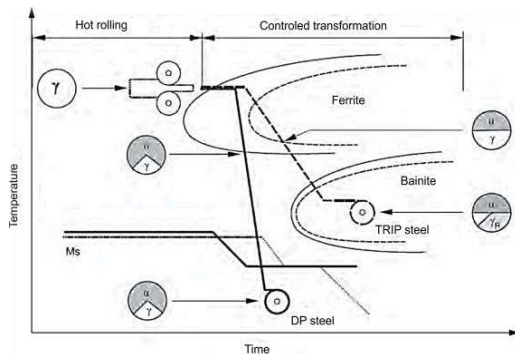
isothermal holding, the thin strips are wound and then cooled to a room temperature. The thermal process of obtaining these steels is shown in Figure 3.3, [1].



**Figure 3.3** Thermomechanical process of obtaining the CP steels

### 3.3 Thermal and thermomechanical processes for obtaining the 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 3.4, [1].



**Figure 3.4** Comparison of production procedures of the DP and TRIP steels

### 3.4 Thermal and thermomechanical processes for obtaining the martensitic steels

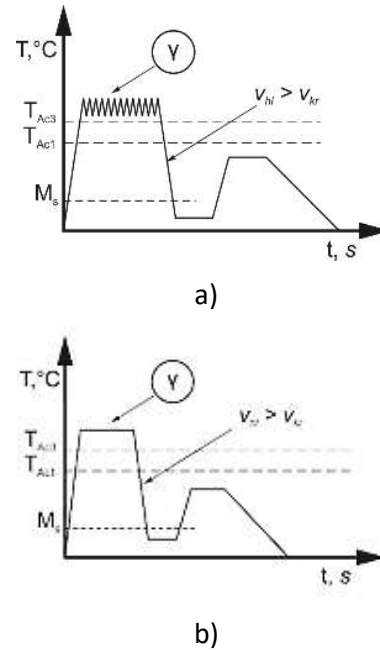
Steels of this kind predominantly contain martensite in microstructure. It is obtained in two ways, while both ways imply the rapid cooling of the steel from the austenite region.

The first way of obtaining refers to the hot-rolled steels, which are cooled down quickly, immediately after the rolling at elevated temperatures is finished, [1].

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, [1].

In both cases, due to heating to temperatures within the range 900 - 950 °C and rapid cooling, the final microstructure of the steel is martensite, [1].

Figure 3.5 shows the thermomechanical and thermal processes for obtaining these steels.



**Figure 3.5** Thermomechanical (a) and thermal (b) ways of obtaining the martensitic steels

## 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 the first generation of the AHSSs and some procedures for their production was conducted. From the presented data, one can conclude that these steels have high strength; however, simultaneously they are characterized by low deformability, which has caused numerous difficulties. This is why the development of the second generation AHSSs has begun. The advanced high-strength steels of the second generation are characterized by slightly lower strength than the first-generation steels; however, they possess the significantly better deformability.

## ACKNOWLEDGEMENT

This research was partially financially supported through the projects TR35024 and TR33015 financed by the Ministry of Science of the Republic of Serbia. Research was also partially financed by statutory research of the Czestochowa University of Technology.

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