# APPLICATION OF HIGH-STRENGTH STEELS IN VEHICLE DESIGN

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**Abstract**

High-strength steels are the materials, which could fulfill the requirements for mass reduction, improve energy efficiency, reduced fuel consumption of modern automotive industry without compromising in safety and affordability. This kind of materials are relatively new for automotive applications. The lightweight capability of high-strength steels resulted from theirs microstructure, obtained through combinations of micro alloying elements and highly controlled production processes. Due to advanced properties, especially very beneficial combination of strength and ductility, high-strength steels must be considered differently from the conventional steels, which they replaced during design process of new vehicles. This fact is the basis hypothesis for this paper. The research shown in the paper is done by relevant literature survey related to this area. The results presented in the relevant literature were analyzed and put into relationship with modern demands in vehicle design. The aim of this paper is to identify the aspects of high-strength steels application in automotive industry and to highlight of perspectives of this application. The conclusion of the paper is that high-strength steels provide lightweight and environment friendly capability in vehicle design with sustainable prices, remained reliability and even improved safety. The global conclusion of the paper is that steels, especially high-strength steels are favourable material for vehicle applications.

## 1 Introduction

Modern demands, which are founded at vehicle design in present automotive industry, encourage develop and usage of new, advanced, materials whose properties and behaviour in real exploitation conditions are not completely identified. Usage of those materials, despite significant benefits, induced large and potentially dangerous problems. The necessity for using the advanced materials with suitable properties requested the obligation for testing those materials, especially to sensitivity for stress concentration. The controls of raw and prefabricated materials, so as their processing technology, come to the focus of testing concerns. The listed tendencies in design, at the area of automotive industry, cause the improvement of existing technologies, so as the development and differentiation of new, advanced methods of elements' joints realizations. In addition, the analyses of demands which are founded in vehicle design, at automotive industry, show that modern cars have, beside the primary function as transport vehicle, numerous and very different functions. On the other hand, they have to fulfill very strict requirements, which are fundamentally different. The estimated requirements and criterions often have complex system of interactions [1, 2, 3 and 4]. Technology of joining by welding allows high level of flexibility during the process of design in relation to other joining methodologies. Selections of material in the area of automotive industry design, altogether with identification of adequate joining methodology, represent one of the most important procedures in this process [5, 6 and 7]. The principle of archiving the real properties of products in present automotive industry is presented illustratively at Fig. 1.

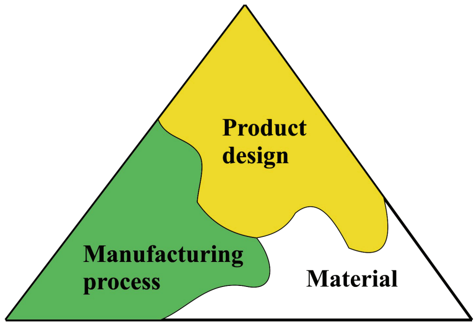


**Fig. 1. The principle of archiving the real products properties**

## 2 High-strength low-alloy steels

High-strength steels were developed and produced in order to ensure the improvements of the mechanical characteristics and to conform the resistance to corrosion in relation to conventional carbon steels. Those steels are not considered as alloyed steels in conventional meaner because, primarily, they have to provide specific mechanical characteristic without determined chemical composition. Chemical compositions of those steels can even vary by thickness in order that variations in chemical composition provide uniformity of mechanical characteristics [8 and 9].

Common usage and development of these steels are linked to seventh decade of the 20th century and to the beginnings of commercial production of iron alloys, especially ferroniobium. Significant improvements of mechanical characteristics resulted in summary mass reductions and increasing of load capacities of the vehicles with elements made of those steels. In addition, the chemical compositions of those steels provide higher flexibilities of thermo-mechanical processing.

The structures of low-alloy steels, after the processing are typically fine grain and consisted of ferrite (α) grains with small dimensions and with shape homogeneity. In addition, the small amount of cementite is present in microstructures of those steels, so as fine dispersed particles of carbon nitride, which can be identify only by electron microscope [8, 10 and 11]. During the final rolling process, the favourable conditions for creation of the large numbers of referent locations within the distinct formation of α metal grains. The density of those locations in the structures of steels is consequence of production processing and the level of material deformation. The effects of regeneration of deformed microstructure are present, such as recuperation and recristalization. By those phenomena, the deformed microstructure turns into undeformed that resulted in decline of dislocation density in microstructure. During production process of steels, the different phenomena, with opposite consecutive processes, are induced. Those phenomena cause increase, so as decrease of dislocation density. The recristalization process is suppressed by decrease of speed of grains' nucleuses formation and by the reduction of movement of metal grains and sub grains boundaries. The recristalization process is consequence of the presence of alloying elements' atoms in solid soluble of steels and it is induced by continual rolling with short break periods, when the effect of niobium is dominant. In addition, recristalization process is induced as the consequence of precipitation during reversible rolling with longer break periods, when the dominant process is separation of carbon nitride.

High-strength low-alloy steels are selected on the bases of minimal required mechanical properties, while the producers determine its chemical compositions [9, 10 and 11]. According to American Society of Materials, the high-strength low-alloy steels are classified in six different grades:

- Corrosion resistant steel grade enclosed the steels with higher resistant to atmospheric corrosion or higher resistant to corrosion at highly potentate chemical environments.

This steel grade, beside other alloying elements, contains small amounts of cupper and phosphor for improving corrosion resistance [9, 10 and 11].

- Low-alloy ferrite–pearlite steel grade contain very small amounts of elements that are forming carbides or carbon nitride, such as niobium, vanadium and titanium for the aims of precipitation reinforcement and control of transformation temperatures [9, 10 and 11].
- Rolled pearlite steel grade enclosed carbon-manganese steel that contain small amount of other alloying elements due to reach higher strength, toughness and formability, so as improve weldability [9, 10 and 11].
- Acyclic ferrite steel grade (low carbon bainite) has less than 0,05% carbon content and provides very useful properties: high yield stress limit, good weldability and formability with high toughness [9, 10 and 11].
- Dual-phase steel grade enclosed steels that have microstructure with martensite dispersed in ferrite matrices. This type of microstructure provides good combination of plasticity and high tension strength [9, 10 and 11].
- Steels with controlled shape of inclusions are classified into steel grade that have inclusions of sulphide with shape variation from elongated to globular, which are formed by the presents of calcium, zirconium, titanium or lanthanides in small amounts. This grade of high-strength steel is characterized by improved plasticity and toughness trough the material thickness [9, 10 and 11].

The presented classification of high-strength steels is not strict because many steel grades showed characteristic that are common for different grades or even the same with steels from different grades. Shares of different steels grades for forming of average car body in present automotive industry are shown at Fig.2. [5].

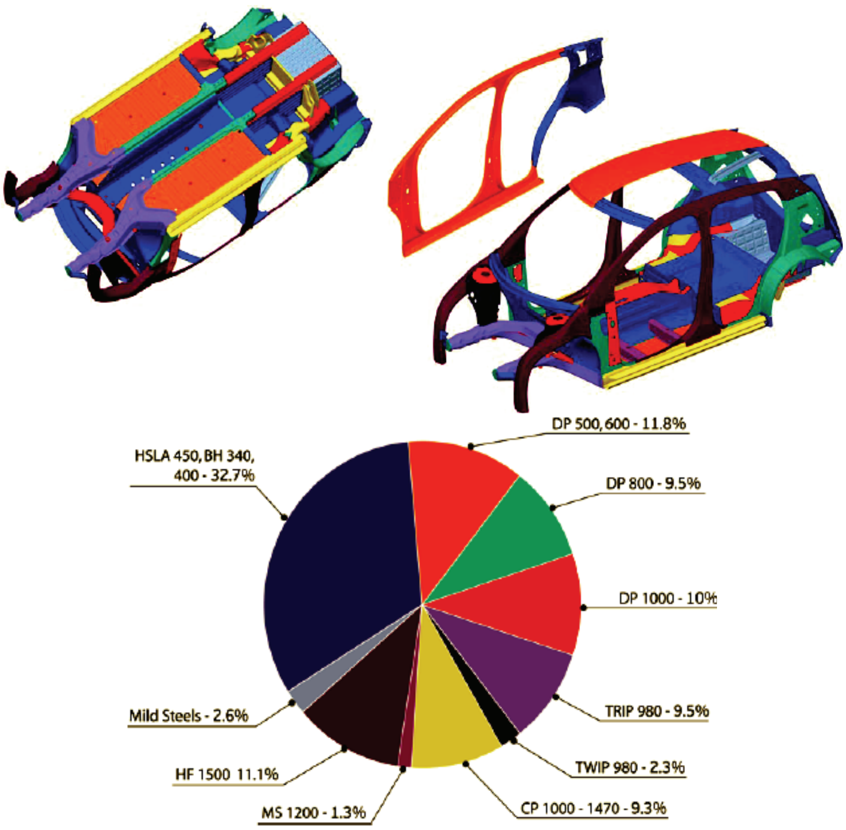


**Fig. 2. Shares of different steel grades for forming of average car body**

The effects of alloying elements in high-strength steels are very complex. The mechanical characteristics of high-strength steels are the result of many influential factors and they are not simple consequence of presents of alloying elements. High stress on yield limit is the result of fine grain microstructure of those steels and it is obtained by controlled rolling process at high temperatures with precipitation reinforcement due to present of niobium, vanadium and titanium. There are, also, different micro alloyed ferrite–pearlite steel grades such as vanadium, niobium, niobium-molybdenum, vanadium-niobium, vanadium-nitrogen, titanium, niobium-titanium and vanadium-titanium steel grades [8, 9, 10 and 11].

# 3 Joining Methodologies

In the area of present automotive industry, one of the most critical factors in safety and reliability analysis are the element joints zones. Design of element joints zones represents the most complex procedure in the process of the car project development. The zones of elements joints are the zones with high level of stress concentrations and the zones with high level of characteristics heterogeneity at the whole vehicle' structure. In present automotive industry, different joining methodologies are used. Welding joints provide material continuity at the joint zones. Stress concentrations at vehicles' structures, as complex phenomena, can be analysed from large number of very different aspects. For example, it can be considered locally and structurally, in relation to dimension level of analysis. Different from other joining methods that required holes in the joining zone, the flow of stress lines at welded joints are beneficial. It is obvious that, from the aspect of stress concentration, this joining method is preferable in relation to other joining methods, which induced higher variations of stress lines. Availability of welding technology, altogether with other aspects of this technology application, conditioned that this technology become dominant joining method in present automotive industry in cause were rejoin is not necessary. As consequence of applied technology of welding in the zones of the welds and in the heat affected zones the residual stresses are induced. Adequate welding technology represents the condition for providing required mechanical characteristics of welded joints zones and by that, the condition for proper joining. The literature survey that considered welding of high-strength low-alloyed steels showed that existing references are not satisfactory clear and precise. Using of those steels, for forming the elements in automotive industry, is valid only if adequate joining methodology is provided. Intensive development of new steel grades must be followed with progress in welding procedures. Relatively high level of embrittlement that is the result of improved mechanical characteristics make this steel grade very sensitive to heat effects of welding in relation to conventional carbon and carbon-manganese steels. In relation to heat cycle of welding, the different transformations in microstructures are induced and those transformations lead to decrease in hardness and embrittlement in heat affected zone [11, 12 and 13].

Characteristic of formed zones at joints of the elements, made of high-strength steels, in automotive industry can be degraded, generally, in three manners [12 and 13]. Firstly, it is in case of using high energy of welding or when temperature of preheating is higher then allowed. Secondly, it is in case when energy level of welding or temperature of preheating is low and under the allowed limits. Thirdly, it is when the heat cycle of welding is related to heat cycle that induces segregation of some elements at the binderies of metal grains and forced degradation of toughness [12, 13 and 14]. With the improvement in mechanical characteristics, the diapason of allowed welding parameters is reduced and, by that, the risks of using welding parameters that are out of limits are higher. This fact must be considered properly, especially in case of high-strength low-alloy steel application in automotive industry.

# 4 Application characteristic of high-strength steels in vehicle design

The high-strength low-alloy steels with bainite or ferrite–pearlite microstructure are used for production of car bodies, shafts, elements of engines and so on. The high-strength steels with yield limit of 600 MPa are used for specific zones of car bodies [15]. For the analysis of application characteristics of high-strength steels in automotive industry, the example of car body presented at Fig. 3. are considered.

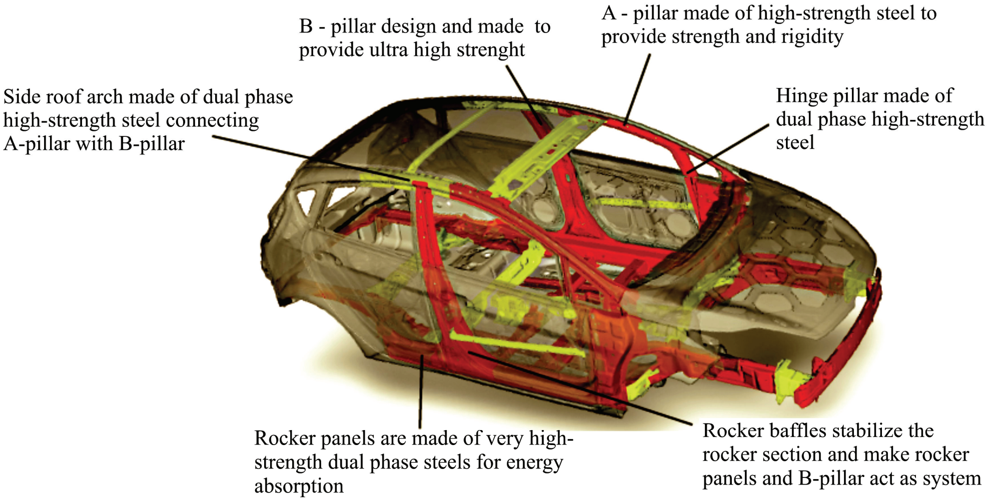


**Fig. 3. Materials of specific zones of car body.**

Specific elements of car body are made of high-strength and high-strength low-alloyed steels in order to archive required strength and rigidity of car body with simultaneous reduction in its mass. By the aims of material selection and forming of those specific zones (Fig.3.), the beneficial mechanical properties are provided. Those zones represent the zones of energy absorption in case of collision and they improve passive safety of vehicles. Mechanical properties of selected materials provide decrease of dimensions of those specific zones and by that, increase of flexibility in car body design. Furthermore, the mass reduction makes ability the reduction of fuel consumption and further reduction of pollutant gases emissions. All this, reduced the complete ecological impact of production and exploitation of vehicles. Aggressive reduction of vehicles' mass by the application of high-strength steels and its design optimizations highlights the new tendencies in car design. In modern automotive industry, high concerns are put on passive safety. Behaviour of vehicle structure at collisions are analysed, firstly, by numerical simulations and then experimentally tested [3, 15 and 16]. The major influential factors for behaviour of vehicle structure in collision are the characteristic and mechanical properties of specific zones made of high-strength low-alloy steels presented at Fig.4.

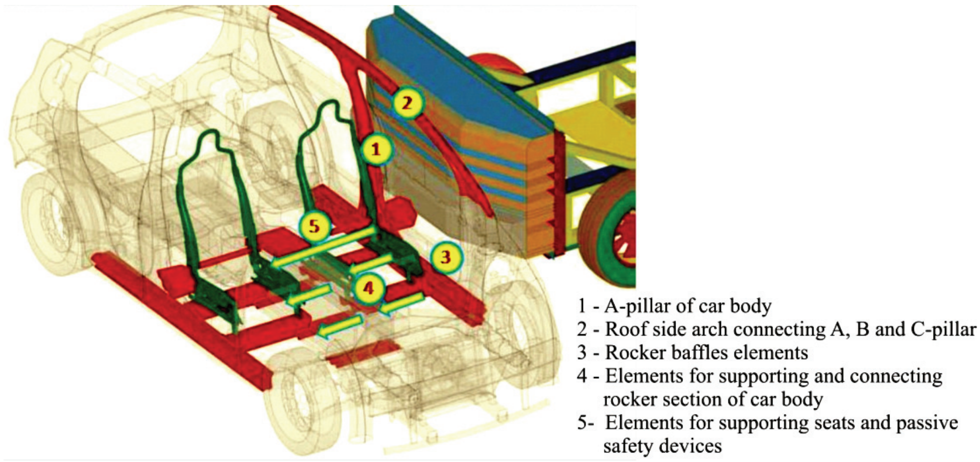


**Fig. 4. Simulation of car body structure in collision.**

The principle of energy efficient design in automotive industry enclosed the analysis of the complete energy used for car production and exploitation, so as the methods for its reduction.

This principle is directly connected to emission of pollutant gases during exploitation of vehicles. Considerations of energy efficiency and pollutant gases emissions in the exploitation periods of vehicles proposed the using of lightweight materials other then high-strength low-alloyed steels. However, that partial analysis has the consequence of even higher pollutant gases emission and reduced energy efficiency during the whole life of vehicles. The benefit of mass reduction with simultaneous reduction in pollutant gases emission can be archived only by application of high-strength low-alloy steels. On the other hand, from the aspects of developing the new, even efficient vehicle powertrains, the summary equivalent of carbon dioxide emissions are even more influenced by the share of its emission during production process. Only high-strength low-alloyed steels provide reduction of summary pollutant gases emission with out of safety, reliability and affordability safety compromises.

## 5 Conclusion

High-strength low-alloy steels are the materials with currently fastest growing share of usage in automotive industry. Those steels have significantly different characteristics from the characteristics of conventional steels that they replaced. Their lightweight capability is linked to specific ratio of strength and toughness to weight, as result of complex, multi phase microstructure. The shares of usage of this steels for production of cars in United States of America according to Ducker WorldWide in the year 2007 and projections for those shares of usage in year 2015 are presented at Fig. 5. [17].

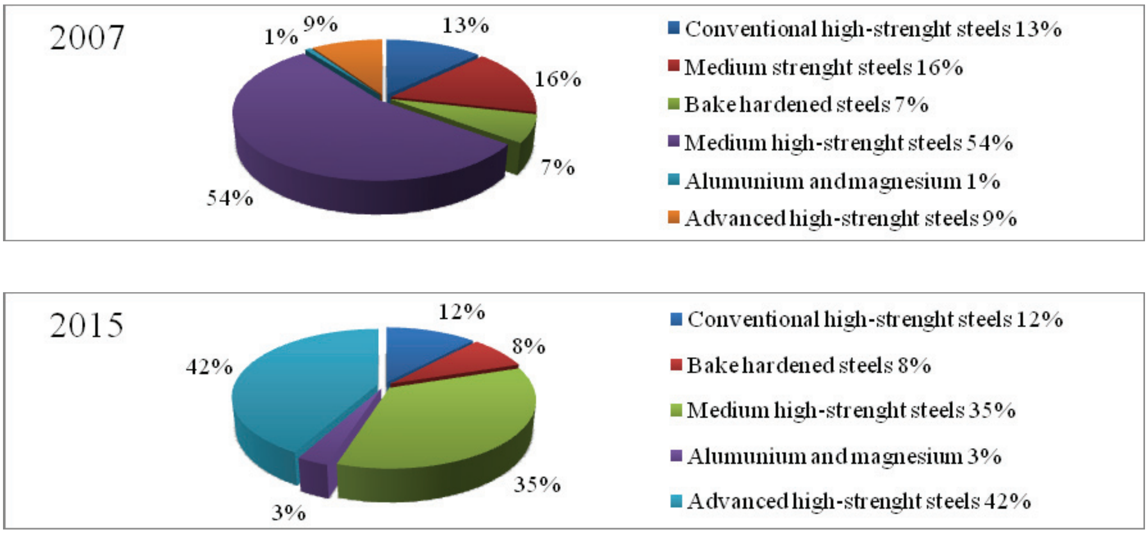


**Fig. 5. Tendencies for usage of steel grades for car body.**

Future research on this subject will be continued in order to develop new high-strength low-alloy steel grades with advanced and improved mechanical properties that are even better for application in automotive industry, as is it illustratively shown at Fig. 6. The microstructure of the second generation of high-strength low-alloy steels is, basically, austenitic at room temperatures due to high content of manganese. The step forward is done in forming technology of those steels by development of specific technology that induced the twinning of metal grains (TWIP - twinning induced plasticity). The deformation process of those steels induced the twinning of metal grains and by that, refinement of microstructure is obtained and resulted in high deformation reinforcement. The tension strength of those steels is higher than 1000 MPa with simultaneous deformation of 60%. The prices of those steels are very high due to high prices of alloying elements. The complex microstructure of those steels causes decrease of weldability. The mechanical properties of second generation of high-strength low-alloy steels overcome the requirements of automotive industry applications. The evolution of high-strength low-alloy steels is continued by development of the third generation of high-strength low-alloy steels. The intended microstructure of the third generation of high-strength low-alloy steels have to be less complex then the microstructure of the second generation, which will improve the weldability with minimal compromises in mechanical characteristics. Those intended properties of the third generation of high-strength low-alloy steels will even induced expansion of their usage in automotive industry [18 and 19].

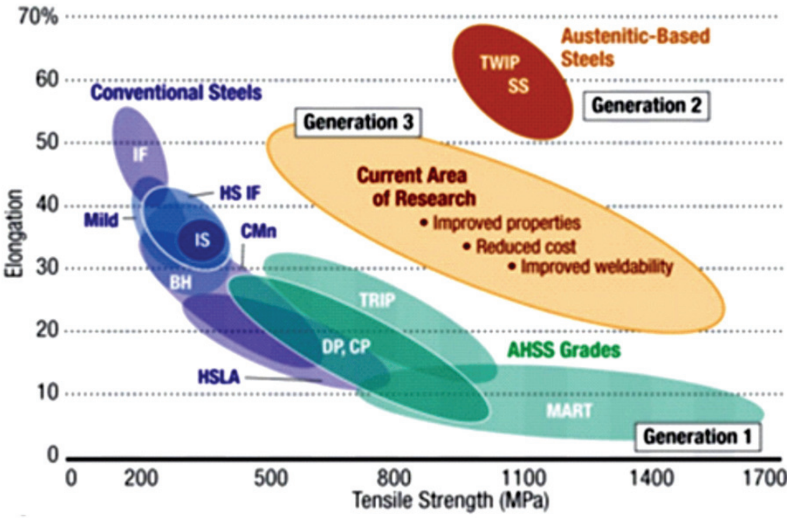


**Fig. 5. Generations of high-strength low-alloy steels**

The application of high-strength low-alloy steels in automotive industry provides many and significant advantages in vehicle design. The complete optimization of vehicle design can be done only by adequate consideration of nature and characteristics of those steels in the process of vehicle project development. Flexibility of vehicle design that has been provided by application of high-strength low-alloy steels can be archived only by adequate joining methodology in the forming of vehicle structure. Joining methodology must enclose all characteristics of materials and stress-strain states in the joints zones. The application of high-strength steels open the significant possibility in vehicle design optimizations, but, also, put some considerable problems that must be solved effectively in the process of the vehicle design.

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