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VARIOUS STEEL SHEET APPLICATIONS FOR AUTOMOTIVE

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Abstract

The biggest concerns that the automotive industry face today are those related to the environment and safety. In terms of the environment, reducing green house gases to prevent global warming is an urgent issue. In order to reduce CO_2 emissions, Toyota has developed and is aggressively selling hybrid vehicles, while at the same time, actively proceeding with fuel cell vehicle development. As for the internal combustion engine vehicle, various fuel consumption improvement techniques have been employed, such as those related to engine efficiency, combustion, transmission efficiency, and weight reduction. Reducing vehicle weight has proven to be a highly effective method for reducing CO_2 emissions, thereby, reducing the weight of sheet steel parts, which account for approximately fifty percent of the vehicle.

At the same time, in terms of safety, collision prevention and passenger protection are important. New body structure designs and materials have been studied to increase body crash performance under actual conditions. Advanced high strength steel application has been identified as one of the most important methods for managing both environment and safety concerns.

In this presentation, the application status of high strength steels will be reviewed. These steels include 440, 590, and 980 MPa sheet steel and hot stamped material for body structure parts, bake hardenable 340 MPa sheet for closure panels, and hot rolled 590 and 780 MPa steel for truck frame and chassis parts. Also, high strength sheet steel application concerns and future expectations will be discussed.

Introduction

The biggest concerns that the automotive industry face in the early twenty first century are related to environment and safety. In terms of the environment, reducing green house gases to prevent global warming is an urgent issue. In order to reduce CO_2 emissions, Toyota has developed and is aggressively selling hybrid vehicles, while at the same time, actively proceeding with fuel cell vehicle development. As for the internal combustion engine vehicle, various fuel consumption improvement techniques have been employed, such as those related to engine efficiency, combustion, transmission efficiency, and weight reduction. Reducing vehicle weight has proven to be a highly effective method for reducing CO_2 emissions, thereby, reducing the weight of sheet steel parts, which account for approximately fifty percent of the vehicle.

Simultaneously, the safety- concerns involving collision prevention and passenger protection are important. New body structure designs and materials have been studied to increase body crash performance. Advanced high strength steel applications have been identified as one of the most important methods for managing both environmental and safety concerns. High strength steels, along with other various steels for automotive, will be reviewed.

Required Properties for Automotive Steel Sheet

In the past, the primary attributes required from automotive sheet steels were identified as strength and corrosion resistance. These properties were necessary to meet basic automotive performance needs, as well as requirements for mass production stampability, weldability and paintability. Over the years, steel sheet grades have been successfully developed and have evolved to meet changing performance and production needs. For example, coated steel sheet applications were accelerated by US automotive OEMs putting forward "ten years no perforation and five years no cosmetic corrosion" targets in the mid 1980's. Currently, hot-dip galvannealed (GA) coated steel sheet is applied to approximately eighty percent of the body-in-white. The expectations for automotive sheet steels continue to change with customers changing needs.

In recent years ACEA announced their self-imposed plan to control average CO_2 gas discharge volumes to less than 140g/km by 2008. Also, in Japan, a fuel efficiency improvement plan for gasoline vehicles, which would require an approximate twenty percent improvement by 2010 versus actual 1995 results, was drafted. It states that more than eighty percent of a vehicle's CO_2 discharge occurs during operation. Reducing vehicle weight is one method for reducing CO_2 discharge volumes for a running vehicle. Figure 1 shows the relationship between vehicle weight and fuel efficiency. It can be seen that 100 kg of weight reduction in both internal combustion engine and hybrid vehicles correspond to approximately one km/l fuel efficiency improvement.

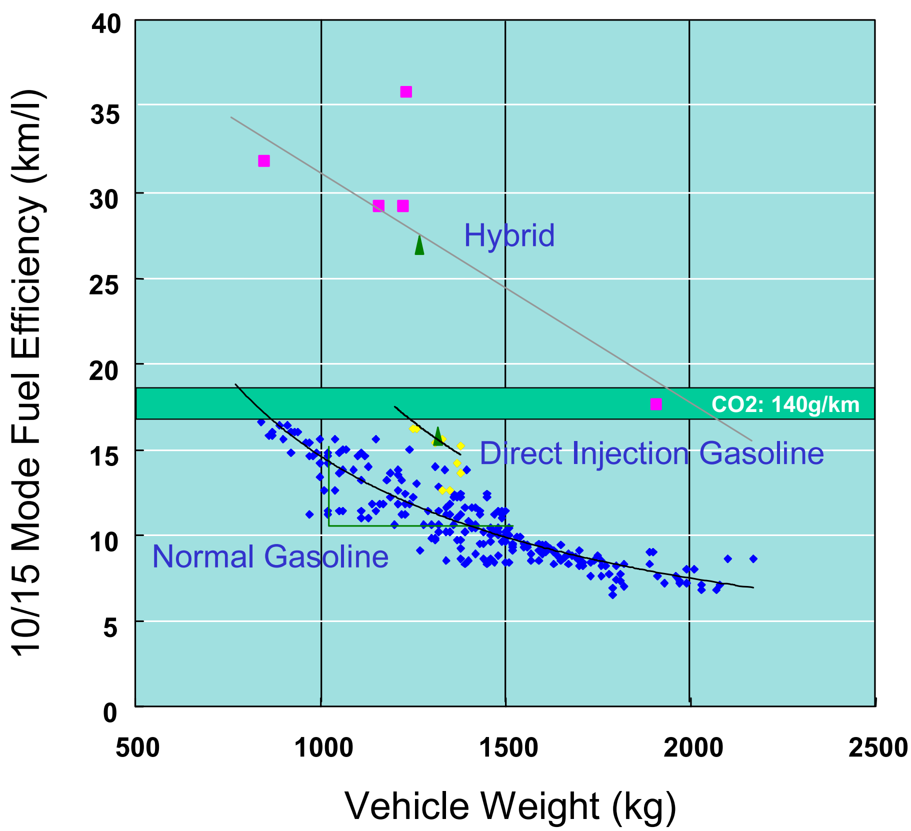

Figure 1. Relationship between vehicle weight and fuel efficiency.

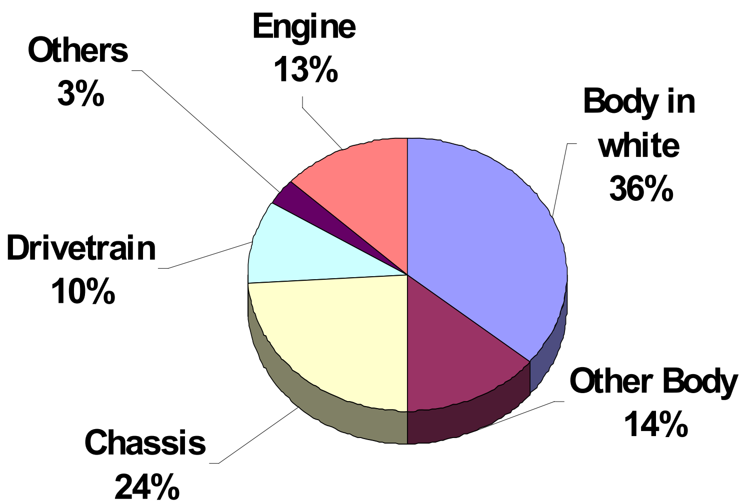

Figure 2. Weight ratio of each vehicle part.

Figure 2 shows the weight ratio of each part of the vehicle. The body-in-white, along with other body parts, accounts for approximately half of an entire vehicle's weight. When including chassis parts, the ratio becomes approximately 3/4 of total vehicle weight. Therefore, a focus upon weight reduction in body and chassis parts is highly effective for improving fuel efficiency and reducing CO_2. High strength steel application is placed as one of the leading methods for reducing weight.

In the case of the body-in-white, closure outer panels require tension stiffness and dent resistance. Inner structural parts require stiffness and crash performance characteristics. On the other hand, chassis parts, such as the suspension control arm, require fatigue strength, as well as part stiffness and crash performance. Although the required properties are different from part to part, the application of high strength steel is effective to reduce weight and increase crash performance by enhancing static and dynamic strength. Table I shows the required property for various vehicle components [1].

Table I. Required component properties.

			Main Part	Required Property				
				Part Stiffness $\propto E \cdot t$	Tension Stiffness $\propto E \cdot t^3$	Anti Dent $\propto \sigma_y \cdot t^2$	Fatigue Strength $\propto \sigma_B \cdot t$	Impact Strength $\propto \sigma_y^{0.6} t^2$
Body	Exposed		Hood, Door, Luggage		○	○		
Body	Unexposed	Panel	Floor, Dash	○				○
Body	Unexposed	Structural	Side Member, Roof Rail	○			○	○
Body	Frame			○			○	○
Chassis			Suspension Arm	○			○	○
Others			Seat Frame	○			○	○
Others			Bumper R/F Door Impact Beam					○

Various Steel Sheet Application Status

Various steel sheet application for body-in-white

Various strength grades from mild 270 MPa to 980 MPa high strength along with heat treatable type grades are being applied to the body-in-white. 270 MPa mild grade steel is used for body side outer panels, closure inner panels, floor panels, and so forth. The body side outer panel is typically a difficult to form part, so a grade with excellent friction performance, in addition to high elongation and high r-value, is needed. Therefore, steel with a high lubricant film such as pre-phosphate on GA coated steel is desirable.

Figure 3 shows the parts where high strength grades are applied. Among exposed panels, such as hoods, doors and luggage outer panels, 340 MPa bake hardenable (BH) steel is commonly used. BH steels feature a yield strength increase during the e-coat baking process. Using this alloy enables enhancement of a panel's dent resistance while maintaining formability. Currently, 340 MPa BH steel alloys consist of ultra low carbon with Ti and/or Nb additions to control the amount of free carbon.

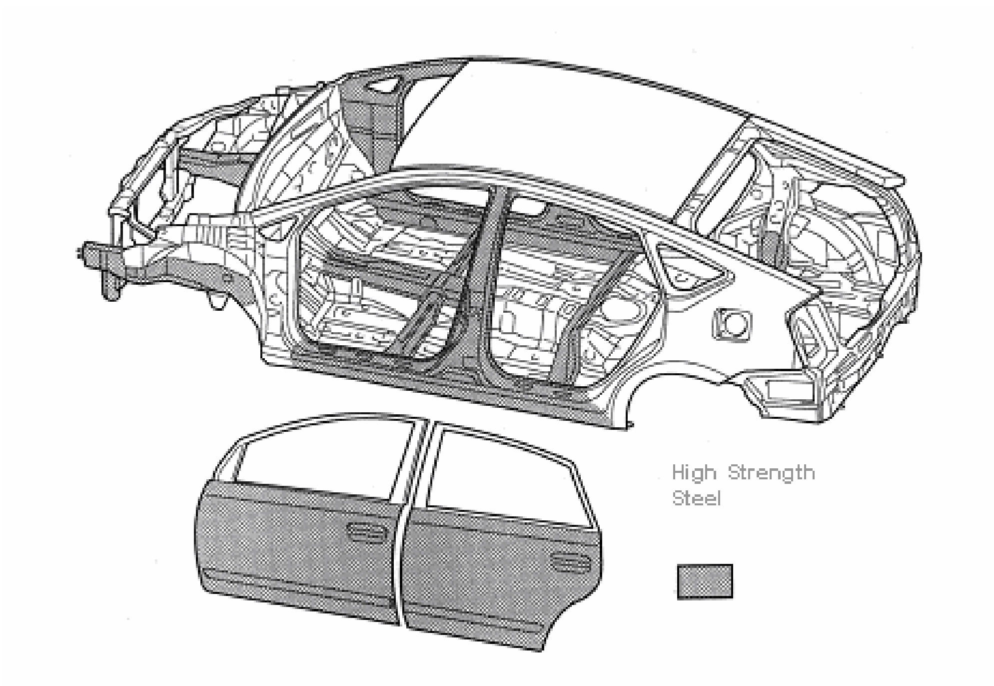

Figure 3. High strength steel application parts for the body-in-white.

Inner structural parts, such as members and reinforcements, have utilized solid solution hardening type 440 MPa high strength steel for a long time. Recently, in order to meet the latest collision safety ratings, such as those for front and side impact, 590 MPa and 980 MPa high strength steels are being applied. Application of these grades is increasing for components such as front side member, front pillar, center pillar, rocker, and roof side. Comparing 590 MPa with 440 MPa high strength steels, 590 MPa has poorer formability due to higher yield strength and lower elongation, as well as higher spring back and warping due to higher yield and tensile strengths. There are mainly three types of 590 MPa high strength steel grades; 1) precipitation type, 2) dual phase type (DP), and 3) retained austenite type (TRIP). DP steel typically has a lower yield strength and higher elongation compared to precipitation-hardened steel. TRIP steel has an even higher elongation than that of DP steel. DP and TRIP steels with lower yield strength and higher elongation levels can effectively address formability concerns. However, the lower yield strength, a feature of DP and TRIP steels, is not effective for maintaining the dimensional accuracy of stampings. Despite this concern, DP grades are the most popular among the high strength steel types, primarily due to their worldwide availability. In order to minimize the dimensional accuracy concerns of 590 MPa high strength steel, several countermeasures can be applied including simplification of part shapes to allow for easy stamping (Figure 4) [2], accurately predicting spring back and warp volume for improved die design, and clarification of basic stamping conditions.

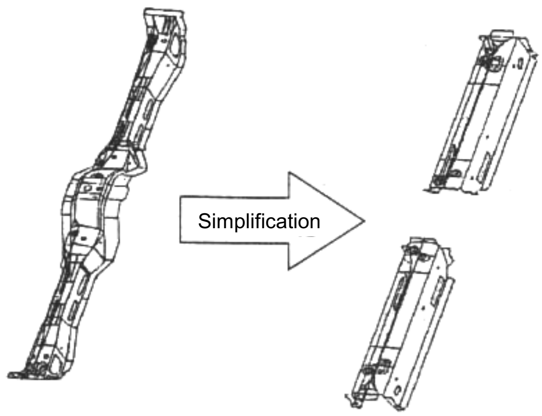

Figure 4. Simplification of part shape to apply high strength steel (floor cross member).

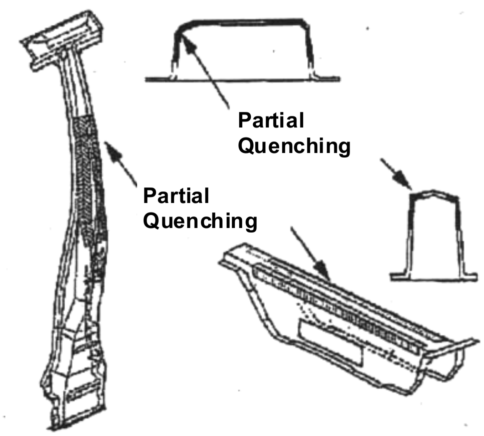

Figure 5. Example of high frequency induction heating and quenching application (B-pillar reinforcement and floor cross member).

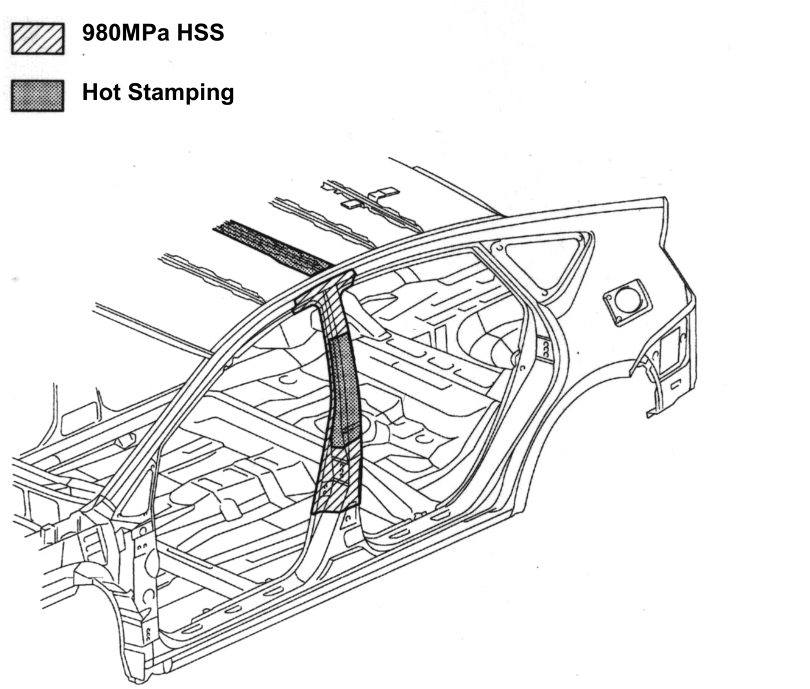

Figure 6. Example of hot stamping application.

At the same time, heat treatment technologies such as hot stamping and partial high frequency induction heating and quenching are also being applied to strengthen parts. High frequency induction heating and quenching is a technology that applies partial heat treatment to targeted portions of a part after normal press forming. This treatment results in 900 to 1200 MPa tensile strength levels using 390 or 440 MPa high strength steel [3, 4]. Hot stamping technology creates tensile strength levels approaching 1500 MPa by using simultaneous hot forming and quenching. In order to obtain the aimed strength levels with hot stamping, alloying elements, particularly carbon, are specified to a tight range. Figure 5 and 6 show examples of high frequency induction heating and quenching, and hot stamping applications.

Various steel sheet applications for chassis parts

Chassis parts' applications primarily use hot rolled steel sheet with a gauge of more than 2.0mm. Suspension control arms, typically made from 440 and 590 MPa steel sheets, have been challenged to increase strength levels to use 780 MPa steel. As a result, the highest possible weight reduction level of 15 percent has been achieved (Figure 7). In order to apply this higher strength steel to the control arm, both higher elongation and stretch flanging ability were required for stamping. Stretch flangeability refers to local elongation performance. Though it was challenging to cope with both properties, 780 MPa high strength steel with both, higher elongation and stretch flangeability was developed in cooperation with Japanese steel mills [5].

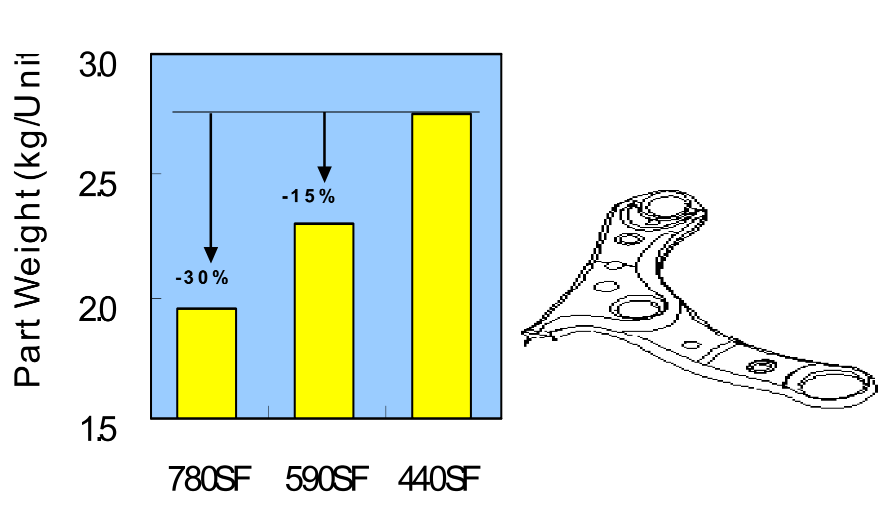

Figure 7. Weight reduction of suspension control arm by high strength steel application.

Various steel sheet applications for other parts

Other typical high strength steel part applications include the bumper reinforcement, door impact beam, seat structural frame, and truck frame.

Cold rolled 980 MPa high strength steel has been successfully applied to bumper reinforcements and seat structural frames. Depending on part shape, different forming processes are applied. Roll forming is typically used for the bumper reinforcement, while stamping is used for the seat structural frame. In the case of seat structural frames, three types of 980 MPa high strength steel are applied; 1) higher elongation type, 2) higher stretch flanging ability type, and 3) compatible type. Each is applied to meet specific part formability properties (Figure 8) [6-8]. For the truck frame, 590 and 780 MPa hot rolled high strength steels are applied (Figure 9).

Functional steel sheet grades are also finding automotive applications such as electromagnetic steel for hybrid vehicle motors and laminated steel for engine oil pans.

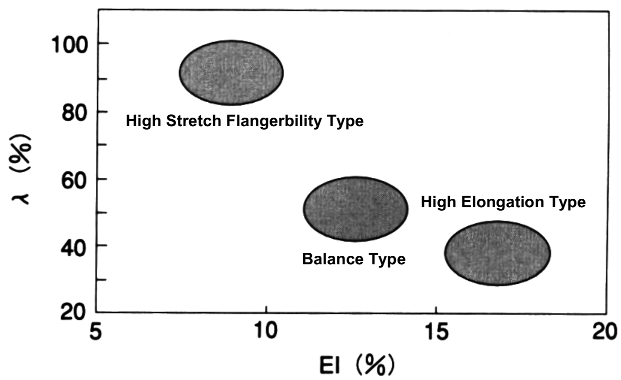

Figure 8. Elongation and stretch flanging ability balance of 980 MPa cold rolled steel.

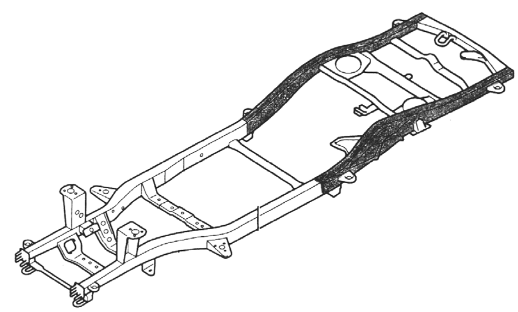

Figure 9. Example of hot rolled 780 MPa high strength steel application.

Future Steel Sheet Application

The automotive application ratio of high strength steels should be increased with higher strength grades being applied to further improve future crash performance and weight reduction efforts. Technical topics concerning further application of high strength steel are listed on Table II.

Regarding exposed panels, the application of aluminum sheet is also being considered as a method of weight reduction. In the case of a hood, weight reduction of approximately forty percent is possible by substitution of steel with aluminum. However, steel still has advantages in terms of cost, formability, etc. There is still potential to reduce weight in the outer closure panels using higher strength grades as long as the required tension stiffness and formability are ensured.

Regarding inner structural parts, there is also a possibility for further application of high strength steel even though the application approaches are different for those parts that are designed to absorb collision energy and not deform actively. For non-deformation parts, it is anticipated that material with strength levels of more than 1000 MPa will be applied. If this were the case, joining strength, delayed fracture, and brittleness would be concerns, in addition to formability and dimensional accuracy. It is known that the spot welding shear strength of grades over 590 MPa in strength does not increase in proportion to the substrate's tensile strength [9]. This is an important factor to remember when considering the application of high strength steels. It is also known that delayed fracture occurs in grades with strength higher than 1200 MPa based on fastener applications [10]. Therefore, in cases where ultra high strength steel is used, it is necessary to consider the strain introduced by stamping, the load stress of the actual part, and field salt damage. Furthermore, brittleness behavior in a cold region should also be considered.

For a part that is designed to actively deform, it is important to absorb collision energy efficiently while maintaining stable deformation properties. When higher strength steels are considered for these applications, deformation instability due to the lower elongation and toughness of the ultra high strength steels will be a concern.

On the other hand, the concern for application of higher strength steels for chassis parts is focused on fatigue strength of the arc welding area. Fatigue strength of the arc welding area does not increase in proportion to substrate strength level. Therefore, it needs to be closely considered, as well as concerns for delayed fracture and brittleness, when higher strength steels are applied

Table II. Technical concerns for high strength steel applications.

	Subject
BIW	• Formability, Dimension Accuracy • Strength of spot welded area
Chassis	• Fatigue strength of arc welded area
Common	• Delayed fracture • Brittleness

Summary

Over the years, various types of sheet steels such as coated and advanced high strength steels have been developed and applied in order to increase anti-corrosion performance and reduce vehicle weight. In the future, the importance of high strength steel is expected to increase more and more to cope with both the CO_2 reduction and increased collision safety requirements in the automotive industry. However, currently it is not always easy to efficiently use high strength steels. Steel makers and automotive OEMs should understand each of the technical barriers in the production and usage of high strength steels, and find optimized solutions for future automotive applications.

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